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**MAPPING URBAN SOIL FROM ABOVE AND FROM BELOW:
SOIL SEALING, GREEN AREAS AND PARTICIPATION**

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*Un bel paesaggio una volta distrutto non torna più
(Andrea Zanzotto)*

ABSTRACT

Soil sealing is recognized as one of the main environmental issues debated in international and national Agendas. Moreover, it is considered as one of the major threat for soils, as ecosystem services drastically decrease when a natural or semi-natural surfaces are covered by artificial materials. Due to the different driving forces and impacts, soil sealing is considered a complex phenomenon. Therefore, dealing with it needs a holistic approach for a deeper understanding of the phenomenon.

In this framework, GIScience and geography give a set of integrated tools to perform a systemic analysis of soil sealing and to investigate its complex dimensions, by combining quantitative and qualitative methodologies. Hence, the thesis is articulated by developing the three main dimensions of GIScience: i) pixel, which combines spatial technologies and analyses approaches by including GIS and remote sensing techniques; ii) people, which include participation of non-expert people in spatial collection; iii) policy dimension, which investigates regulations and strategies developed to provide methodological tools and recommendations to stakeholders and policymakers.

Hence, the general objective of the thesis aims to investigate the complex phenomenon of soil sealing, focusing on its geographical dimension to achieve a more sustainable and inclusive urban management.

The specific objectives aim to: i) assess and map soil sealing at different scales of analysis by identifying and analyzing the main sources, methodologies and techniques; ii) mapping and classifying soil sealing in Padua by testing an ecological urban index; iii) mapping and assessing urban green spaces according to the property status for sustainable spatial planning; iv) investigating the phenomenon of urban agriculture in modern cities, focusing on agroecology approach and which methodologies might be used in order to adopt this practice in urban areas; v) investigating participatory mapping methodologies in support of urban sustainability analysis.

Padua was selected as a representative case study for analyzing soil sealing, in terms of magnitude of the phenomenon and of urban policies to be adopted.

Aims of the thesis were pursued and addressed in the five articles, introduced by four chapters framing the three years' research activities.

The first article "Geografia urbana e partecipazione nell'era digitale: tre esperienze a Padova tra GIScience e VGI" (2019, Bollettino della Associazione Italiana di Cartografia), addresses participatory methodologies to support urban sustainability; the second article "How to map soil sealing? A systematic review" (submitted on November 2021 to ERL) presents the state of the art on methodologies and approaches to map and assess soil sealing; the third article "Biotope Area Factor: An Ecological Urban Index to Geovisualize Soil Sealing in Padua" (2020, Sustainability) presents a methodology to map soil sealing using an urban ecological index at a detailed scale. The fourth article "Whose urban green? Mapping and classifying public and private green spaces in

Padua for supporting spatial planning policies" (2021, International Journal of Geo-Information) investigates green and agricultural areas focusing for the preservation and enhancement of these spaces. Finally, the chapter "Smart Cities and Agroecology: Urban Agriculture, Proximity Food and Urban Ecosystem Services" which appears in the book "Drones and Geographical Information Technologies in Agroecology and Organic Farming: Contributions to Technological Sovereignty" (CRC Press, in press) focuses attention on urban agriculture and its disappearance in the models and practices of smart cities.

Further applied researches both for monitoring soil sealing by using open geospatial data and technologies and to perform Ecosystem Services-based mitigation scenarios might be necessary to support a more sustainable and inclusive urban development and management.

RIASSUNTO

Nelle Agende nazionali ed internazionali, il consumo di suolo è riconosciuto come una delle principali *issue* ambientali. Il fenomeno è una delle maggiori minacce per i suoli poiché i servizi ecosistemici ad esso associati diminuiscono enormemente.

A causa della multi-fattorialità delle dinamiche soggiacenti il fenomeno e degli impatti che esso provoca, viene considerato un fenomeno complesso. Per tale motivo, si rende fondamentale adottare un approccio olistico per una sua completa comprensione.

In tale contesto, la GIScience e la geografia forniscono un insieme di strumenti in grado di sviluppare un'analisi sistemica e di integrarne le diverse dimensioni, per comprendere i processi geografici e le interazioni alle diverse scale territoriali, combinando approcci quantitativi e qualitativi.

La tesi si articola quindi sviluppando le tre dimensioni principali della GIScience: i) *pixel*, ovvero l'uso di tecnologie spaziali e approcci che includano GIS e telerilevamento; ii) *people*, ossia la partecipazione di persone non esperte nella raccolta dei dati; iii) *policies*, ovvero la dimensione normativa e delle strategie al fine di fornire strumenti e raccomandazioni a *stakeholders* e *policymakers*.

L'obiettivo generale della tesi intende indagare il fenomeno del consumo di suolo, verso una gestione urbana più sostenibile e inclusiva. Gli obiettivi specifici mirano a: i) valutare e mappare il consumo di suolo a diverse scale analizzando le principali fonti, metodologie e tecniche; ii) mappare e classificare il consumo di suolo testando un indice ecologico urbano; iii) mappare e stimare le aree verdi urbane per una pianificazione urbana sostenibile; iv) indagare il fenomeno dell'agricoltura urbana, concentrandosi sull'approccio agroecologico e su quali metodologie potrebbero essere utilizzate per adottare tale approccio nelle città; v) indagare le metodologie di mappatura partecipativa.

Padova è stata selezionata come caso di studio paradigmatico, poiché è una città fortemente interessata da questo fenomeno e sulla quale si stanno attuando politiche per uno sviluppo urbano sostenibile.

Gli obiettivi della tesi sono stati affrontati in cinque articoli, introdotti da quattro capitoli che inquadrano le attività di ricerca sviluppate nel dottorato.

Il primo articolo "Geografia urbana e partecipazione nell'era digitale: tre esperienze a Padova tra GIScience e VGI" (2019, Bollettino della Associazione Italiana di Cartografia), affronta le metodologie partecipative a supporto della sostenibilità urbana; il secondo articolo "How to map soil sealing? A systematic review" (sottomesso il 20/11/2021 a ERL) presenta lo stato dell'arte sulle metodologie per mappare e valutare il consumo di suolo; il terzo articolo "Biotope Area Factor: An Ecological Urban Index to Geovisualize Soil Sealing in Padova" (2020, Sustainability) presenta una metodologia per mappare il fenomeno utilizzando un indice ecologico urbano a scala di dettaglio. Il quarto articolo "Whose urban green? Mapping and classifying public and private green spaces in Padua for supporting spatial planning policies" (2021, International Journal of Geo-Information)

indaga le aree verdi e agricole puntando alla conservazione e valorizzazione di questi spazi. Infine, il capitolo "Smart Cities and Agroecology: Urban Agriculture, Proximity Food and Urban Ecosystem Services" presente nel libro "Drones and Geographical Information Technologies in Agroecology and Organic Farming: Contributions to Technological Sovereignty" (CRC Press, in fase di pubblicazione) focalizza l'attenzione sui temi dell'agricoltura urbana e sulla sua scomparsa nelle pratiche delle *smart cities*, dimostrando come, sia possibile valorizzare queste aree per una città inclusiva.

La presente ricerca intende rispondere ad una prima esigenza di aumentare le conoscenze geografiche sul consumo suolo. Ulteriori ricerche per monitorare il fenomeno potrebbero essere necessari per supportare una gestione urbana più sostenibile e inclusiva.

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LIST OF ORIGINAL PUBLICATIONS

The present thesis is based on the following articles:

- I. Pristeri G., Peroni F., Codato D., Pappalardo S. E., Crescini E., De Marchi M. (2019) Geografia urbana e partecipazione nell'era digitale: tre esperienze a Padova tra GIScience e VGI, *Bollettino della Associazione Italiana di Cartografia*, 166, 62-76
- II. Peroni F., Pappalardo S. E., Crescini E., Facchinelli F., Munafò M., Hodgson M., De Marchi M. How to map soil sealing? A systematic review (submitted on November 2021 to Environmental Research Letters - ERL)
- III. Peroni F., Pristeri G., Pappalardo S. E., Codato D., Masi A., De Marchi M. (2020) Biotope Area Factor: An Ecological Urban Index to Geovisualize Soil Sealing in Padua, Italy, *Sustainability*, 12 (1), 150
- IV. Pristeri G., Peroni F., Codato D., Pappalardo S. E., Crescini E., De Marchi M. (2021) Whose urban green? Mapping and classifying public and private green spaces in Padua for supporting spatial planning policies, *ISPRS Int. J. Geo-Inf.*, 10(8), 538
- V. Peroni F., Choptian J., Ledermann S. (in press) Smart Cities and Agroecology: Urban Agriculture, Proximity Food and Urban Ecosystem Services. In De Marchi M., Diantini A., Pappalardo S. (eds.): *Drones and Geographical Information Technologies in Agroecology and Organic Farming: Contributions to Technological Sovereignty*, CRC Press

The articles are referred in the text by their roman numerals.

GLOSSARY

Agroecology: the term ‘agroecology’ means either a scientific discipline, agricultural practice, and political or social movement (Wezel et al. 2009). As science it adopts an holistic and integrated approach that simultaneously applies ecological and social concepts and principles to the design and management of sustainable agriculture and food systems. It seeks to optimize the interactions between plants, animals, humans and the environment while also addressing the need for socially equitable food systems within which people can exercise choice over what they eat and how and where it is produced (FAO 2021a).

Built up areas: all areas occupied by buildings (UN-Habitat 2021).

Green Infrastructure: a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings (European Commission 2013).

Ecosystem Services: the benefits people obtain from ecosystems. These include provisioning, regulating, and cultural services that directly affect people and the supporting services needed to maintain other services (Millennium Ecosystem Assessment 2005).

Inclusive cities: the concept of inclusive cities involves a complex web of multiple spatial, social and economic factors: i) spatial inclusion: urban inclusion requires providing affordable necessities such as housing, water and sanitation. Lack of access to essential infrastructure and services is a daily struggle for many disadvantaged households; ii) social inclusion: an inclusive city needs to guarantee equal rights and participation of all, including the most marginalized. Recently, the lack of opportunities for the urban poor, and greater demand for voice from the socially excluded have exacerbated incidents of social upheaval in cities; iii) economic inclusion: creating jobs and giving urban residents the opportunity to enjoy the benefits of economic growth is a critical component of overall urban inclusion.

The spatial, social and economic dimensions of urban inclusion are tightly intertwined, and tend to reinforce each other (World Bank 2021).

Fostering cities and societies for human diversity, social inclusion, and equality is becoming an increasing priority and is key for a truly inclusive and sustainable future for all (UCLG Congress and World Summit of Local and Regional Leaders 2019).

Nature-Based Solutions: are defined as actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits (IUCN 2016).

Soil sealing: the destruction or covering of soils by buildings, constructions and layers of completely or partly impermeable artificial material (Prokop et al. 2011).

Smart cities: initiatives try to improve urban performance by using data, information and information technologies (IT) to provide more efficient services to citizens, to monitor and optimize existing infrastructure, to increase collaboration among different economic actors, and to encourage innovative business models in both the private and public sectors (Marsal-Llacuna et al. 2015).

Urban Agriculture: the growing of plants and the raising of animals for food and other uses within and around cities and towns, and related activities such as the production and delivery of inputs, processing and marketing of products (Kennard and Bamford 2020).

ACRONYMS

BAF = Biotope Area Factor

CLC = Corine Land Cover

CLMS = Copernicus Land Monitoring Service

ES = Ecosystem Services

EEA = European Environment Agency

ESA = European Space Agency

EU = European Union

GIS = Geographic Information System

GHSL = Global Human Settlement Layer

JRC = Joint Research Centre of European Commission

ISPRA = Italian Institute for Environmental Protection and Research

NDVI = Normalised Difference Vegetation Index

PPGIS = Participatory GIS

UGS = Urban Green Spaces

UHI = Urban Heat Island

UA = Urban Agriculture

UES = Urban Ecosystem Services

UN = United Nations

VGI = Volunteered Geographic Information

1. SOIL SEALING: FRAMING THE ISSUE

1.1. City population growth and urban metabolism

In the last decades, a growing number of people are moving into urban settlements from rural areas. Many advantages and opportunities are behind this choice, such as majority employment opportunities, higher wages, shorter commuting time to work, and better living facilities and services (Bhatta 2010). In addition, in urban agglomerations production, knowledge, innovation and economic growth are maximized.

Nowadays, 55% of the world's population lives in cities: Northern America is the most urbanized regions with 82% of dwellers living in urban settlements in 2018, followed by Latin America and the Caribbean (81%), Europe (EU-28) 74%, and Oceania (68%). Asia and Africa are less urbanized; these continents present almost 50% and 43% of populations living in cities respectively (United Nations et al. 2019a).

World population growth forecasts estimate that in 2050 urban population will increase to 68% and 101 countries are expected to have more than 80% of their population settle in urban areas. This growth will occur primarily in developing countries, such as India, China and Nigeria, accounting for almost 96% of urban growth (United Nations et al. 2019b).

However, according to Global Human Settlement Layer (GHSL) of the Joint Research Centre of European Commission (JRC), 75% of population (6.1 billion people) is already living in urban settlement in 2015 (Pesaresi et al. 2017). Such estimation is almost two times the population living in cities in 1975. From 1990 to 2015, Asian cities present 40% more inhabitants, followed by Africa, Latin America and the Caribbean where the urban population doubled (Alberti et al. 2019).

It is worth noting that the physical extension of urban areas is also expanding but, even if it is supposed that city size and population grow in lockstep, in reality the size of urban areas increase at a faster rate than the population (UN-Habitat 2016). The expansion of cities is on average twice as fast as urban population rise, however from 1990 to 2015 in developing countries the phenomenon is more emphasized (Seto et al. 2014). More specifically, in less developed countries urban areas increased 3.5 times in regard to urban inhabitant's growth, whereas in countries more developed, such as North America and Europe, cities raised by 1.8 fold and population increased by 1.2 fold (UN-Habitat 2016).

GHSL estimation highlights a different trend compared to those of UN-Habitat, showing that in Europe and North America settled areas have grown much more than the growth of the urban population; on the contrary, in developing countries the two dynamics showed an almost parallel trend (Melchiorri et al. 2018). For instance, in Europe built-up areas¹ within urbanized areas increased by 18%, while population growth increased by only 1.5%. In fact, from 1990 to 2015,

¹ Built up areas is defined as all areas occupied by buildings (UN-Habitat 2021)

settled areas increase of 8 million inhabitants, whereas urban areas extended of 18,500 km². In North America, the ratio of population growth to urban expansion is 1 in out of 3. Comparing data between Europe and Asia, Africa and Latin America from 1990 to 2000, it emerges that for each European inhabitant 2.2 km² were built, while for each new km² built, the population in Africa increased by 16,500 inhabitants, 13,800 in Latin America and 12,500 in Asia (Melchiorri et al. 2018). Concentration of many people in cities, the establishment of new economic activities and the expansion of built-up areas are one of the main direct and indirect drivers of remarkable pressures on urban ecosystems, both at local and regional scale. In fact, urban expansion drive to many environmental changes by land use land cover change dynamics which might be result in deforestation, impacts on hydrogeological systems, and alteration of biogeochemical cycles (Grimm et al. 2008). It is worth noting that urban growth is one of the main drivers of habitat loss and, therefore, biodiversity reduction and species extinctions (McDonald et al. 2008).

Notably, cities and urban settlements are large consumers of energy and resources. In fact, the 70% of global energy-related greenhouse gas emissions is emitted by urban systems (United Nations 2019).

Food and water demands, waste management, air, soil and water pollutants emission and production in urbanized regions are much higher than in rural regions (Folke et al. 1997; Brown 2001; Alamanos et al. 2020; Huneus et al. 2020). Moreover, most of energy resources and goods are based on “long networks” and world-wide distribution, which are generally far away the city boundary. Indeed, urban areas could be defined as heterotrophic ecosystems, mainly depending on external energy resources and Ecosystem Services (ES), many of whom come from distant areas (Collins et al. 2000). Hence, a strict and fundamental interconnection exists between urban settlements and surrounding natural and semi-natural ecosystems (Grimm et al. 2000). For example, as well explained by Raymond F. Dasmann (2002), the majority of food consumed by urban population come from global trade. The tight connection to global economy and to distant ecosystems, can guarantee the survival as well the same social reproduction of urban systems despite the massive land use land cover changes and the overexploitation of local ecosystems. In the past, or in traditional societies, the only chance of survival is based on resources provided by local ecosystems (single or contiguous ecosystems); when overexploitation of resources occurred, usually societies collapsed.

The concept of urban metabolism, introduced for the first time in 1965 by Abel Wolman, can help to better understand the complex dynamics that are intertwined within an urban ecosystem and its surroundings and can also help to understand how to develop sustainable pathways. Urban metabolism is defined as “the sum total of the technical and socioeconomic processes that occur in cities, resulting in growth, production of energy, and elimination of waste” (Kennedy et al. 2007). Therefore, assessing the urban metabolism is related to quantifying inputs, outputs and storage of energy, water, nutrients, materials and wastes (Kennedy et al. 2011). This concept could be easily

associated to the metabolism of organisms; hence, resources are consumed from the hinterland of a city and wastes are thrown out exactly like an organism works (Decker et al. 2003). Starting from the concept of urban metabolism many studies have been developed. Moreover, accounting for flows, materials and resources makes more understandable if the balance between a city and the outside is provided and how could be reached a sustainable city.

In this framework, the concept of planetary boundaries, introduced in 2009, represent a milestone to understand how human activities and actions have become the main driver of unsustainable environmental changes. According to Rockström et al. (2009) the planetary boundaries are defined as the “safe operating space for humanity with respect to the Earth system”. Steffen et al. (2011) identified nine areas that need to set planetary boundaries and they are: climate change; biodiversity loss; excess nitrogen and phosphorus production; stratospheric ozone depletion; ocean acidification; global consumption of freshwater; land use changes; air pollution; and chemical pollution.

The concept of planetary boundaries highlights how balance of cities and overexploitation of resources can influence the balance of our Planet. In fact, urban areas and, more generally, human activities, such as massive energy demand for traffics, infrastructures, buildings and industries, are recognized as one of the main causes of passing some of these boundaries (Chen et al. 2021).

Moreover, the concept of planetary boundaries is also related to the carrying capacity of ecosystems and, therefore, the sustainability of anthropic activities and human development. Goodland and Daly (1996) explained the notion of sustainable development “as development without increases in the through-put of materials and energy beyond the biosphere’s capacity for regeneration and waste assimilation”. Hence, urban sustainable development could be reached when materials, energy inflows and wastes disposal do not exceed the capacity of its hinterlands. Therefore, starting from this point it is also possible quantifying greenhouse gas emissions for cities. Another important issue to be considered when analyzing urban growth is the spatial dimension that urbanization phenomenon can assume. Spatial patterns of urban settlements are different and they might vary from region to region. It can assume a compact, dispersed, fragmented, or extensive pattern. However, when it corresponds to a scattered urban texture is defined as urban sprawl. Usually, this pattern is characterized by a low density population. As explained by the European Environment Agency (EEA) (2006) “development is patchy, scattered and strung out, with a tendency for discontinuity”. The causes of this phenomenon are various, but the most important is the unplanned development and uncontrolled growth of cities (Tian et al. 2017; Artmann et al. 2019).

Typically, this phenomenon characterizes US cities. Indeed, during the first decades of the 20th century the growth of private cars and single-family houses caused the rapid low-density outward expansion of cities (Brueckner et al. 2001). Wells in its book “Car Country: an Environmental History” (2013) explains how after the Second World War, in the USA different forces favored car-dependent suburban growth. These are identified in: i) transportation policies that promoted the convenience of cars over all other form of transportation; ii) government subsidization of low-density, car-oriented

development; iii) legal and institutional sanction of car-oriented development as the most acceptable form of development; iv) and government policies that made suburban construction profitable and largely risk-free.

More recently, also European cities, that in the past were developed around an historical core, show a similar phenomenon (EEA 2006). Manifest are the economic, social and ecological consequences of low-density cities, such as landscape fragmentation, loss of agricultural lands, reduction or loss of ES, increasing in air pollution due to longer commuting times, fuel and oil causing water pollution, and biodiversity loss (Pauleit et al. 2005; Tu et al. 2007; Inostroza et al. 2013; Wilson and Chakraborty 2013).

Many European countries are affected by urban sprawl. At country level, Netherlands, Belgium and Luxembourg presents the highest values, while very low values are shown in Iceland and Scandinavian countries (European Environment Agency 2016). In each country, the level of sprawl varies widely, for example, mountainous territories present more concentrate population compared with flat territory and industrial areas. A remarkable example is the Po Plain in Italy: sprawl is mainly located in the plain, while in the Alps is observed only on the valley. Moreover, it affected areas around city centers, along large transportation corridors and along many coastlines, such as the French one (Hennig et al. 2015).

1.2. The forgotten: soil and ecosystem services in urban development

Soil is a fundamental non-renewable resource for life on Earth and for the future of humankind on this planet (Amundson et al. 2015). It is considered as the “skin of earth”, through which many liquids and gases flows are exchanged. Soil filtered and stored water and it is a major carbon reservoir. Moreover, its nutrient cycle is significant for plant growth, it is also a habitat for organisms and a genetic pool (Jobbágy and Jackson 2000; Koch et al. 2013). Soil is considered as the ~1-m layer of the Earth’s surface, composed by mineral particles, organic matter, water, air and living organisms. It is completely distinguished from its geological sources, due to the numerous qualities acquired during its exposure to the atmosphere (Jenny 1941) and the complex pedogenetic processes in the interrelations among geological component, vegetation and climate.

At present, due to many pressure which are underpinning soils, FAO in 2015 listed 10 main risks which are compromising the health status of such resource (FAO 2015): soil erosion, soil organic carbon loss, nutrient imbalance, soil acidification, soil contamination, waterlogging, soil compaction, soil sealing, salinization and loss of soil biodiversity. Moreover, in urban ecosystems soils are usually altered by human activities by higher magnitude and extension: road network and transportation infrastructuring, new buildings and industrial areas, production and management of wastes, and unsustainable agricultural activities (Lovett et al. 2000; Louwagie et al. 2011).

However, among these phenomena soil sealing is considered one of the most relevant threat in urban contexts. In this massively anthropized ecosystem the construction of new infrastructures and

built-up areas, such as buildings, streets, and parking lots, are causing natural and semi-natural soil reduction. The process of soil coverage is defined as soil sealing and it corresponds to “the destruction or covering of soils by buildings, constructions and layers of completely or partly impermeable artificial material” (Prokop et al. 2011). In more details, when agricultural lands, forests or meadows are transformed in buildings or streets, a drastic change in land cover/land use is resulted; moreover, when natural and semi-natural soils are covered by artificial materials, such as asphalts and concrete, water infiltration processes are completely impeded. More broadly, Strollo et al. (2020) defined the phenomenon as the conversion “from a non-artificial land cover to an artificial land cover”.

It is worth noting that such phenomenon is considered an irreversible process as the biogeochemical processes able to regenerate the soil system requires long time-scales. Recent studies have shown that biophysical processes to restore an agricultural soil are re-activated in no less than 15 years (Tobias et al. 2018). Due its long time of restoration, it is considered a non-renewable natural resource (European Commission 2010). At present, soil restoration and regeneration are considered important achievements to be pursued in urban sustainable development.

Natural and semi-natural soils are fundamental not only for human wellbeing, but also for ecosystem balance of cities. A natural or semi-natural soil system provides multiple functions and services in urban areas as well. Indeed, if not completely sealed, urban soils still maintain the capacity to provide different ecological services. Effects of soil sealing cause drastic changes in hydrologic cycle and water balance. For instance, it dramatically alters urban runoff and infiltration processes, reduce the ability to store water and, consequently, the groundwater recharge. Moreover, hydrogeological risk and decrease of water quality might occur (Arnold and Gibbons 1996; Shuster et al. 2005; Pistocchi et al. 2015). Soil sealing also directly affects functions provided by vegetation systems hosted by natural soil, such as evapotranspiration, carbon sequestration, pollution mitigation and regulation of urban micro-climate (Scalenghe and Marsan 2009; Fini et al. 2017; dos Santos et al. 2017). More sealed surfaces also imply less urban green parks and open spaces which might guarantee human mental and physical well-being. In fact, parks, green spaces, street trees, urban forests, and community gardens might improve physical activities, facilitate social interactions, and reduce individual stress (Hartig et al. 2014; Artmann et al. 2019) creating healthy landscapes and landscapes of health (Nogué et al. 2008). On the other hand, food production and, therefore, food supply and food security are strongly related to availability of arable fertile lands. In different territorial contexts, expansion and sprawling of urban areas might directly affect agricultural and rural lands: in the so-called developed countries sealing of fertile soil is partly compensated by transferring food production abroad, increasing social and environmental implications and land pressure abroad; in developing countries it might directly compromise food security (European Commission 2012a; Gardi 2017; Aksoy et al. 2017).

Effects of soil sealing are exerted not only on surfaces converted into artificial areas, but also on neighboring unsealed areas. Indeed, it is also driver of landscape fragmentation and ecosystem degradation; for example, too small or isolated fragmented vegetation areas might not be able to warranty ecological processes for some species. For such reasons, the phenomenon is considered one of the main drivers of loss of worldwide biodiversity (Pauchard et al. 2006; Seto et al. 2012). Even if soil system embodies such important properties (ecological functions and services) its importance still remains concealed. In fact, the role of soil and its functions is not often taken into adequate account, especially in urban planning and in policy making (Artmann 2014). Usually, urban planners and architects consider soil solely as a platform to be built or as a waste to be relocated in other places. For this reason, the awareness of the importance and potential of this resource and its functions is almost completely missing (Blanchart et al. 2018; Teixeira da Silva et al. 2018). Only after 2009, scientific literature started exploring how soil and its ES might contribute to human well-being and how they could tackle some environmental issues (Bristow et al. 2010; Dominati et al. 2010; Robinson and Lebron 2010). While soil science community is investigating soil since decades, only in recent years defining, monitoring and mapping soil-related ES gains more attention (Adhikari and Hartemink 2016). In fact, up to 2009, explicit reference to soils are absent in the majority of ES frameworks (De Groot et al. 2002; Millennium Ecosystem Assessment 2005). Starting from this background, it could be easy to understand how city planners have not yet considered to include urban soil and its functions in planning processes. Hence, it is fundamental the role of scientific research in exploring how soil and ES can be counted and implemented in order to contribute to urban design.

However, some examples of direct references to soil ES as a core element of urban planning recently started to be mentioned. Teixeira da Silva et al. (2018) analyzed the urban plans of seven representative cities of all the continents, with the exception of Antarctica. Results show that, even if all the urban plans aims to urban sustainable development, most of them do not directly refer to soil as a critical natural resource itself, whereas many soil functions are identified as important. In more details, Boston is, among the seven cities analyzed, the only one showing clear referencing to soil-related functions and, along with the city of London, defines indicators to monitor the impact of the plan on urban soil. In the other plans, most of the references to soil are indirect, for example fixing goals to increase urban green areas and food production. Usually, the analyzed plans present a reference to ES to contrast climate change issues and others environmental impacts. In conclusion, the study highlights the lack of proposal and implementation of indicators to be integrated into monitoring and urban planning. Assessing soil-related functions need monitoring systems linked to indicators that define and quantify benefits of soil to sustainable urban development.

Lam et al. (2018) analyzed how ES are incorporated in each land use plan of ten municipalities in Ontario (Canada), nevertheless few references are found on soil. Another relevant example is reported by Blanchart et al. (2018) analyzing more than 100 French planning documents. The study

reveals that soil is a relatively infrequent issue in French urban plans, even if it is considered in relation to fertility of agricultural soils, or to potential contamination. The study confirms also that exists a manifold view about soils in urban plans: soil is usually considered as a surface especially in land use approaches, and it is also more recently considered as a resource in terms of “dynamic volume, as a potential source of pollution and as a support for food production”. An interesting example is provided by the Municipality of Berlin. The inner city is regulated by the “Berlin Landscape Programme”, which includes a regulation for new buildings, in order to guarantee an area left to green space (Senate Department for the Environment Mobility Consumer and Climate Protection 2021a). Computation of green areas for each urban parcel is provided by an ecological urban index called Biotope Area Factor (BAF).

The main objective of the Municipality is to guarantee some ES related to green spaces, such as improvement of the urban microclimate, urban cooling, sustainable drainage, improvement of natural habitats and enhancement of the quality of the residential environment. The objectives are achieved calculating for each urban plot the proportion that needs to be green and it “expresses the ratio of the ecologically effective surface area to the total land area” (Landschaft Planen & Bauen et al. 1990). It is calculated by the following formula:

$$\text{BAF} = \frac{\text{Ecologically-Effective Surface Areas}}{\text{total land area}}$$

The Ecologically-Effective Surface Areas is referred to different categories of green spaces that are weighted differently according to their “ecological value”, based on evapotranspiration capacity, permeability, possibility to store rainwater, relationship to soil functioning and provision of habitat for plants and animals. In this framework, sealed surfaces present a weighting factor of 0, while completely permeable surfaces present a weighting factor of 1 (Senate Department for the Environment Mobility Consumer and Climate Protection 2021b). It is important to highlight that BAF index considers also as green categories vertical greenery and roof greening. The index was introduced for the first time some years ago and it is mandatory for some district of the city, whereas in the others it could be an option of urban planners and designers.

It is worth noting that the index never refers to the term ES, but it is a clear example of how it could be possible to introduce in urban plans a regulation to incorporate soil ES and to contrast soil loss.

1.3. Defining soil sealing: disputed terms

At present, many keywords and definitions of soil sealing are adopted worldwide, not only in the scientific literature, but also in documentation for policy-making. In 2020, an important study, based on a focus group of experts, on a literature review and on policy-relevant documents, tried to categorize different definitions adopted for policy-making at EU level (Marquard et al. 2020). The

study highlights that in the EU land policy context, “soil sealing”, “land take”, “soil consumption”, and “land consumption” are the most adopted terms. Since 2002, the European Commission used the term “soil sealing” referring to the phenomenon of imperviousness of soil (Commission of the European Communities 2002). Finally, the article suggested to prioritize the term “land take”. On the other hand, at international level, the 2030 Agenda for Sustainable Development dedicated a specific SDG to cities and its development (SDG-11). In more detail, the SDG-indicator “Ratio of land consumption rate to population growth rate”, defined this land-surface impermeabilization phenomenon as “land consumption” (United Nations 2015).

Overall, the most used and common definitions are:

- i) soil sealing: “the destruction or covering of soils by buildings, constructions and layers of completely or partly impermeable artificial material (asphalt, concrete, etc.)” (Prokop et al. 2011);
- ii) land consumption: “the change from a non-artificial to an artificial land cover of the ground, with the distinction between permanent land consumption (due to permanent artificial cover) and non-permanent land consumption (due to a reversible artificial cover)” (Strollo et al. 2020);
- iii) soil consumption: it is used as a synonymous of “land consumption” and it describes the transition from natural to artificial land (Amato et al. 2017). It is scarcely used in the scientific literature, however Scalenghe and Marsan (2009), one of the most important articles that highlights the impact of soil sealing, adopts this term;
- iv) impervious surface: “can be generally defined as any material-of natural or anthropogenic source- that prevents the infiltration of water into soil and thereby changing the flow dynamics, sedimentation load and pollution profile of storm water runoff” (Slonecker et al. 2001); in addition “features that commonly account for 80% of impervious cover include buildings e.g., roofs, driveways, and patios, roads, and parking lots” (Theobald et al. 2009);
- v) land take: according to Prokop et al. (2011) the term refers to the rising of artificial areas over time. This practice is usually performed to the detriment of agricultural areas.

Among these definitions, “impervious surface” is the most used by far, especially in non EU countries, such as the USA and China. In scientific literature, the majority of articles mapping and evaluating the phenomenon refer to it as “impervious surfaces”; on the contrary, all five definitions are adopted equally in EU. However, as already explained by Marquard (2020), it is paramount and priority identifying a shared definition, not only in EU, but also at international level. The increasing numbers of population in urban areas and the expansion of cities need an accurate, tested, and shared monitoring system of soil sealing phenomenon in order to develop specific strategies and regulations that lead to the same direction. It is also very important to avoid contradictions and ambiguities, especially in binding regulations, due to their further application at regional and local level. Ambiguities can lead to an interpretation and application of the law that may be vague or unclear, resulting in fragmented and uneven regulation across areas. An emblematic case is reported by Pileri (2018) in his book: in Italy a regulation limiting soil sealing is absent, but some

regional administrations approved regional laws trying to address the phenomenon. However, every regulation presents a different definition of the phenomenon: in some case it is referred only to agricultural soil sealing avoiding others typologies of the phenomenon (Apulia Region), in another case the term is “artificialization”, that could consider a wide range of meanings (Autonomous Province of Trento), or, in Emilia Romagna Region, soil sealing is considered as what is outside of the urbanized boundaries.

Both standardized monitoring systems and strategies/policies harmonization between different countries and institutions are crucial in order to reduce and limit soil sealing and to straightaway contrast local effects of climate change (Aragón-Durand et al. 2014; Decoville and Schneider 2016). It is also important to identify a term that takes into account not only the physical phenomenon of non-infiltration of water into the ground, as evoked by the “impervious surface”, but it should evoke both the physical water process and ecosystem functions related to it. As already explained, ES provide by soil are several and for this reason it should be identify a definition that is able to embrace all these services.

1.4. Monitoring and measuring soil sealing in EU and in Italy

The Copernicus Programme was established in 2014 with the Regulation (EU) N° 377/2014 of the European Parliament and of the Council and it includes “a service component ensuring delivery of information in atmosphere monitoring, marine environment monitoring, land monitoring, climate change, emergency management and security” (European Union 2014). It is the replace of the Global Monitoring for Environment and Security (GMES). Also the Copernicus Programme, as well as the GMES, is based on a partnership between the EU, European Space Agency (ESA) and the Member States.

Copernicus is a complex set of systems collecting information from multiple sources, from satellites to ground, sea and airborne sensors. All these resources are integrated and processed, providing reliable and up-to-date information to policymakers, scientists, private companies, and citizens. What is worth noting is that Copernicus data and information “should be available freely and openly” in order to support the Digital Agenda for Europe, as referred in the Digital Agenda for Europe (European Parliament 2021).

The Copernicus Land Monitoring Service (CLMS) is part of the Copernicus Programme and it provides geographical information on land cover and land use mapping and other components of land, for example vegetation state and water cycle (Copernicus Europe’s eyes on Earth n.d.). Since 2012, CLMS is implemented by the EEA and the JRC. Land Cover and Land Use mapping is composed by three main layers (European Environment Agency and European Commission 2018):

1. Corine Land Cover (CLC) corresponding to LCLU status and change;
2. Corine Land Cover plus (CLC +) corresponding to CLC-backbone, CLC-core, CLC+ instance, CLC – legacy;
3. High Resolution Layers (HRL) corresponding to Imperviousness, Forest, Grassland, Wetness & Water Small Woody Features layers.

Moreover, in the category “Thematic Hotspot Mapping” the product “Urban Atlas”. The CLC is provided for 1990, 2000, 2006, 2012, and 2018. The dataset includes 44 land cover and land use classes. The time-series highlight changes in land cover and land-use during the years. The HRLs are raster-based datasets and the majority of them are available for 2006, 2009, 2012, 2015 and 2018.

Regarding soil sealing monitoring, the EEA provides the imperviousness HRL that shows the status of and change in soil sealing (measured as imperviousness) in Europe from 2006 to 2018 (every 3 years).

Soil sealing is categorized adopting a semi-automated classification, based on calibrated NDVI, by using satellite imagery from ESA’s Sentinel-2 with different spatial resolutions (10 m, 20 m and 100 m). The HRL Imperviousness shows impermeable soil as an index for the degree of imperviousness (0-100%).

2018 year presents an increased spatial resolution compared to time series 2006-2015: in this way also small features can be detected and the more accuracy leads to a more accurate classification of impermeable areas (HRL Imperviousness 2018 presents a spatial resolution of 10m x 10m). However, it is important to highlight that the increase of the spatial resolution of 2018 is not comparable with historical layers of 2015 and backwards. Comparability and analysis is only ensuring for the 20 m spatial resolution (European Environment Agency 2018). As a consequence, the most recent data on soil sealing at EU level are in 2018. Figure 1 shows the sealed surface in 2018 per each country in EEA38 + UK², while Table 1 shows the first 10 countries that mostly sealed in 2018 year. At the first rank is located Germany, with 18.5 km² of sealed surfaces, followed by France (15.88 km²) and Italy (10.52 km²). However, taking into account the total country area for each countries, Malta is the first country, showing 19.40% of completely sealed surfaces (Figure 2 and Table 2). At the second and third place are located Netherlands and Belgium (8.2%), followed by Luxemburg (5.4%). The three countries that in 2018 mostly sealed, now are at fifth (Germany - 5.11%), ninth place (Italy - 3.49%), and twelfth place (France - 2.88%).

It is important to highlight that “Imperviousness” layer of CMLS, especially with 2018 improvements, is a systematic approach for data collection which enables to compare between European countries. Moreover, it creates a harmonizing instrument of information and data.

² List of countries of EEA 38+UK: Albania, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Kosovo, Latvia, Liechtenstein, Lithuania, Luxemburg, Malta, Montenegro, Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom.

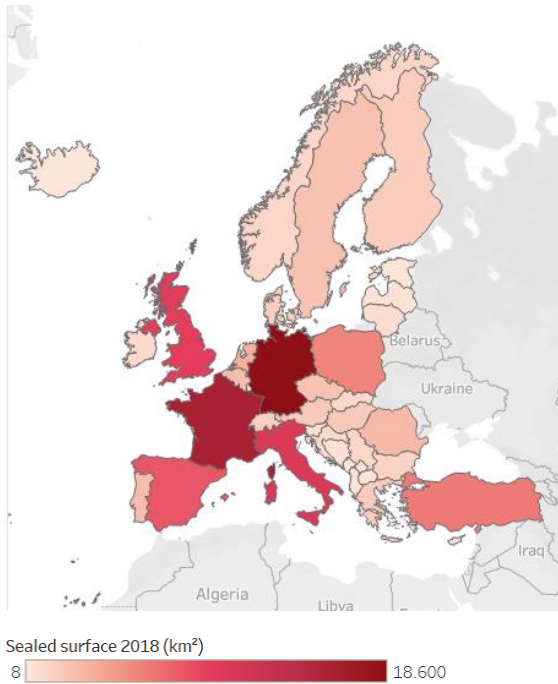


Figure 1 The map shows sealed surface in 2018 per each country in EEA38 + UK

(Source: Copernicus Land Monitoring Service)

Country	Sealed surface in 2018 (km ²)	Sealed surface 2018 %
Germany	18,509	5.11
France	15,884	2.88
Italy	10,528	3.49
United Kingdom	9,338	3.76
Spain	8,010	1.58
Turkey	6,229	0.80
Poland	5,704	1.82
Netherlands	3,285	8.23
Romania	2,743	1.15
Portugal	2,541	2.75

Table 1 The table shows the first 10 countries that mostly sealed in 2018 year

(Source: Copernicus Land Monitoring Service)

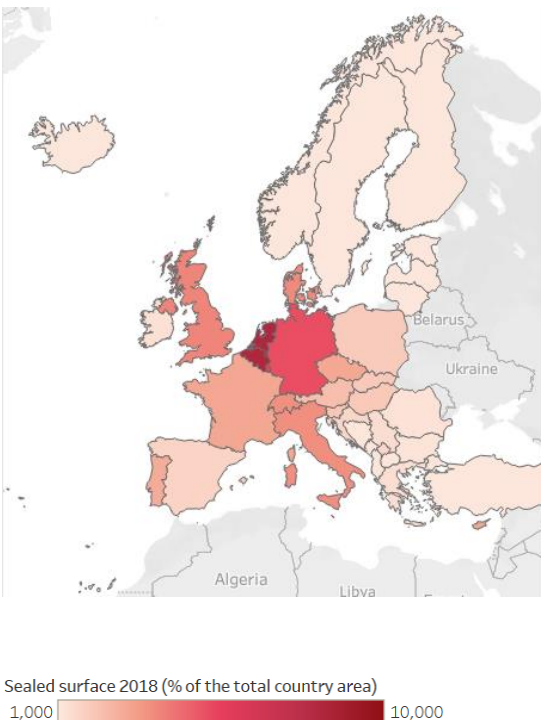


Figure 2 The map shows the percentage of sealed surface in 2018 of total country area in EEA38 + UK

(Source: Copernicus Land Monitoring Service)

Country	Sealed surface in 2018 (km ²)	Sealed surface 2018 %
Malta	61	19.40
Netherlands	3,285	8.23
Belgium	2,515	8.20
Luxembourg	140.06	5.40
Germany	18,509	5.11
Liechtenstein	8	5.10
United Kingdom	9,338	3.76
Denmark	1,596	3.61
Italy	10,528	3.49
Switzerland	1,432	3.47

Table 2 The table shows the percentage of sealed surface in 2018 of total country area in top 10 countries

(Source: Copernicus Land Monitoring Service)

In Italy, monitoring of soil sealing is assured by the National System for Environment Protection (Sistema Nazionale per la Protezione dell'Ambiente, SNPA) instituted by the Italian Law 132/2016 (Gazzetta Ufficiale 2016). The SNPA ensures monitoring activities related not only to soil sealing but also to other environmental issues and it is composed by the Italian Institute for Environmental Protection and Research (ISPRA), playing a coordinating role, and the Agencies for Environmental Protection of the Regions and Autonomous Provinces (ARPA-APPA).

Monitoring of soil sealing is performed every year for the entire Italian territory, by using satellite Sentinel-2 images at a spatial resolution of 10 m. A first step is to classify soil sealing by using a semi-automatic classification and, secondly, a visual analysis is provided at a more detailed scaled ($\geq 1:5,000$) to obtain a more detailed feature extraction. The last process is provided by experts of Agencies and ISPRA. Soil sealing classification system includes buildings, paved streets, railways, airports, harbors, other impermeable areas, such as parking lots, ground sports, and squares, permanent paved greenhouses, and dumps. It is important to highlight that artificial surfaces are detected if they cover more than 50% of the 10x10 m cell (ISPRA 2021).

Every year, the results of the monitoring are published in a public report, publicly available. The 2021 report, related to 2020, showed that new artificial areas covered 56.7 km², with an average of 15 ha per day. At country level, the total sealed surfaces are estimated in 21,400 km² (7.11%). Lombardy, Veneto, and Campania are the three Italian regions showing the higher level of soil sealing and they present, respectively, 12.08%, 11.87%, and 10.39% of impermeable surfaces (Figure 3). However, there are other five regions that show values of soil sealing higher than national average (Emilia Romagna, Apulia, Lazio, Friuli Venezia Giulia, and Liguria). In general, north Italy shows higher percentage value of soil sealing.

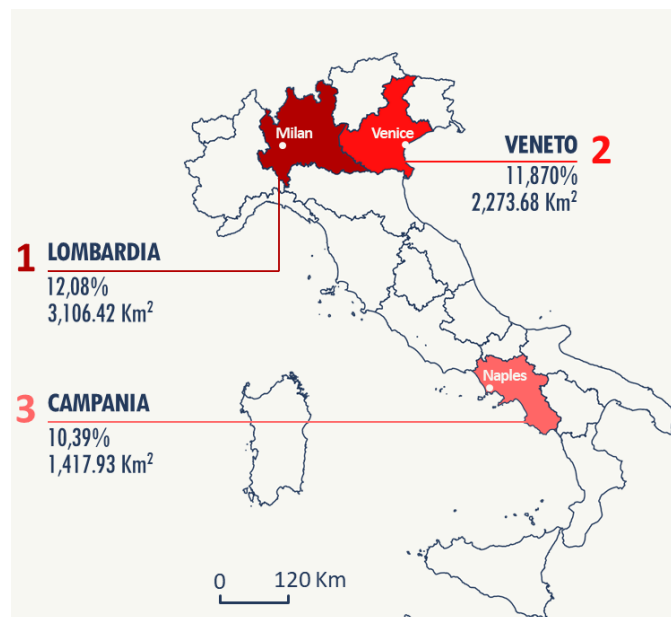


Figure 3 The three Italian regions showing the higher level of soil sealing

At province level, Monza and Brianza are the province with the highest percentage of soil sealing (about 41%) in relation to the provincial surface area. Above 20% are located the provinces of Naples (34%), Milan (32%), Trieste (21%) and Varese (21%) and, slightly below, Padua (19%) and Treviso (17%). 45 provinces are below the national average and eight of them are below 3%. The province of Rome growth the most between 2019 and 2020 (+271 ha), followed by the provinces of Brescia (+214 ha), Vicenza (+172 ha) and Verona (+166 ha).

In the province of Padua, soil sealing increased of 134 ha between 2019 and 2020 and similar values are presented by the provinces of Turin, Bari, Sassari, and Lecce.

At municipal level, Rome presents the largest net increase in soil sealing (123 ha) 2019 and 2020. Among cities with more than 100,000 inhabitants, there are also Ravenna, Vicenza, Catania, Foggia (+34 hectares) and the municipalities of Bari, Sassari and Novara (almost 20 ha). Some municipalities, such as Turin (65%), Naples (63%), and Milan (58%), present an urban fabric very compact and close to saturation, with values higher than 65% in terms of soil sealing in relation to the municipal surface area. Padua presents 49.6% of total soil sealing and it is the fifth among the municipalities with more than 100,000 inhabitants. Between 2019 and 2020 soil sealing in the city increase of 11,15 ha. Overall, the city of Padua shows 46,08 km² of soil sealing in 2020.

1.5. EU and Italy regulations on soil sealing

At international level, FAO is the United Nation's agency advocated to soils; indeed, natural and no-polluted soils are essential for food production and sovereignty. Starting from this background, FAO elaborates guidelines and manuals about all aspects of soils and it assists member countries in soil matters, directly in the field, with advices and project implementation (FAO 2021b). Moreover, FAO supports and fosters many studies and researches on soil-related issues. For example, during the Global Symposium on Soil Biodiversity of 2021, experts from different part of the world discussed the state of global soil biodiversity, trends and opportunities. Furthermore, in 2012, the Global Soil Partnership was established in order to develop a strong collaboration between all stakeholders, such as policymakers and land users, and to promote sustainable soil management (FAO 2012). In this direction, the Voluntary Guidelines for Sustainable Soil Management are an important tool providing technical and policy recommendations on soil management. Concerning soil sealing, recommendations are addressed to protect soils which contain significant ES, for instance high agricultural suitability, high soil carbon stocks and high biological diversity, and to encourage densification and re-use of existing urban or industrial areas such as abandoned areas and brownfields. In general, the guidelines highlights the necessity to review laws and land use planning in order to preserve agricultural soils (FAO 2017).

The guidelines published by FAO are not binding for member countries, but they aim to "contribute to addressing global challenges and meeting international commitments", such as the 2030 Agenda for Sustainable Development.

The 2030 Agenda - adopted in 2015 by all United Nations Member States - set a specific goal to “make cities and human settlements inclusive, safe, resilient, and sustainable” (United Nations 2015). SDG-11 is mainly focused on sustainable development of cities; however, other SDGs are related to soil protection and improvement. Before to list these SDGs, it is important to clarify how SDGs work. Indeed, to make goals more actionable and monitorable, each of them are specified by some targets and indicators represent the metrics by which targets could be achieved.

SDG 2 has a specific target (2.4) that seeks to ensure sustainable food production in order to maintain ecosystems and progressively improve land and soil quality (United Nations and Department of Economic and Social Affairs 2015a). Also target 3.9 aims to increase human health reducing not only water pollution and air pollution, but also by soil contaminants; while target 12.4 aims to achieve the environmentally sound management all wastes by reducing their release to air, water and soil in order to minimize their adverse impacts on human health and the environment (United Nations and Department of Economic and Social Affairs 2015b,2015c). Goal 15 is more related to environment and among its objectives halting and reversing land degradation are included. More specifically, indicator 15.3.1 defines how to monitor land degradation by “proportion of land that is degraded over total land area”(United Nations and Department of Economic and Social Affairs 2015d).

Back to SDG 11, it is composed by 10 targets and 15 indicators for SDG 11. . . Among the different targets of Goal 11, Target 11.3 refers to “inclusive and sustainable urbanization”, explained as “by 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries”. Overall, specific indicators for this target are two and indicator 11.3.1 monitors “Ratio of land consumption rate to population growth rate”. UN-Habitat, the specialized agency for sustainable urbanization in UN, defined the workflow that every country should follow to obtain this specific indicator, providing a complete guidance for data sources and collection method, computational methodology, period of analysis (5-year cycles) and a guidance for scaling up and aggregating data from city/urban level - data are collected at this scale - to national level (UN-Habitat 2021). More specifically, if the result value is <1 , land consumption increases slower than urban population and there is no waste of land; on the contrary, if the result value is >1 , land consumption grows disproportionately than urban dwellers. However, “while a value of <1 might be a good indicator of compactness, in some cases an analysis of the intra-urban situation might reveal high levels of congestion and poor quality of life. For this reason, UN-Habitat introduced a secondary indicator, the built-up index, that help explain the truth pattern of growth” (UN-Habitat 2020).

However, it is important to highlight what UN-Habitat defined as “land consumption”: it means “the uptake of land by urbanized land uses, which often involves conversion of land from non-urban to urban functions”. Hence, the definition refers in a more generic way to urban development (Marquard et al. 2020).

By signing the Agenda, all countries have agreed to participate in a monitoring process of SDGs objectives.

At European level, the phenomenon of soil sealing is always considered as part of strategies and policy related, more generally, to soil protection. As already explained in the previous section, soil sealing is classified as one of the 10 threats of soil (FAO 2015). However, in EU, a specific legislation to protect soil is not already promulgated. Indeed, policy priorities or parameters for soil protection are not governed by a binding overarching framework. Other EU laws refer to soil, such as Common Agriculture Policy (CAP), Environmental Impact Assessment Directive (85/337/EEC), or Land use, land use change and forestry Regulation (Regulation (EU) 2018/841), are not explicit focused on it. It means that soil protection derived as a consequence of delivering environmental objectives, such as reducing contamination, offsetting GHG emissions, and preventing other environmental threats, but there is no a targeted legislation for soil (European Commission 2021a).

In 2014, the Soil Framework Directive was withdrawn, due to the objections of some Member States (Germany, France, The Netherlands, the United Kingdom and Austria) that argued soil is a local issue, regulated by local authority (European Commission 2006; Stankovics et al. 2020). The Directive was an attempt promoted by the EU Commission to design a community framework for soil protection (Stankovics et al. 2018). The EU law was addressed to protect soil from all its threats, from soil erosion to salinization, from contamination to compaction, focusing also to reduce the negative effects of soil sealing (FAO 2015). The Soil Framework Directive was proposed in 2006 by the Thematic Strategy for Soil Protection where a common framework was set out for protecting soil across Europe (European Commission 2012b). Moreover, in 2012, a policy report was published by European Commission in order to implement the Strategy and current activities, improving the four pillars of the Strategy, namely awareness raising, research, integration, and legislation. Furthermore, it exhibited soil degradation trends in Europe and globally, as well as challenges to ensure protection (European Commission 2012c). In 2015, following the withdrawal of the Directive, the European Commission designated a pool of experts to investigate how policies and measures already existing are able protect soil not only at EU level, but also in national and regional context. The final report stressed how existing regulation instruments are still inadequate to protect Europe's soils sufficiently (Bowyer et al. 2016). Ronchi et al. (2019), analyzing the EU member states policies and measures for soil protection, detected three very notable issues: coordination, scarce regulations, monitoring system capacity.

About the first issue, coordination between soil protection national laws is not guaranteed; it means there are no specific and clear definitions for soil threats and not all countries defined the same phenomena as a threat. It is important to report that in the majority of cases; agricultural practices are often recognized as threat. This could also have a negative effect between possible coordination of countries to find the right policy for a specific threat;

Secondly, even if the threat of soil sealing is included in some national policies, few governments adopted specific regulations to contrast soil sealing; moreover, land use planning is usually regulated at local level, without following any specific soil-related EU regulations. Finally, very few countries adopted fiscal practices to limit new urban expansion;

Finally, soil sealing monitoring systems are provided not only by Copernicus Programme, but also many EU member states monitor land use changes and, more specifically, soil sealing changes at national and regional level. These data could be more detailed, such as data produced in Italy by the ISPRA, and they could also be used for more specific processes and policies.

As result, soil legislation is extremely fragmented across EU countries, governance levels, and policy domains (Paleari 2017).

1.6. After soil sealing, preventing land take: the new EU Soil Strategy for 2030

On 17th November 2021, the European Commission adopted the new EU Soil Strategy for 2030 (COM/2021/699 final and SWD/2021/323 final), that is an important deliverable of the European Green Deal and the EU Biodiversity Strategy for 2030, two measures that aim to tackle climate change and biodiversity loss (European Commission 2021b). The EU Soil Strategy aims to achieve by 2050: i) healthful and resilience of soil ecosystems in order to provide all ES; ii) zero net land take and reduction of soil pollution in order not to be detrimental to people and ecosystems; iii) protecting, restoring and managing sustainable all soils (European Commission 2021g). These objectives will be achieved with specific actions. The main action is the scheduling of a new Soil Health Law by 2030 that will enhance good soil health by 2050. By the approval of this “law”, also soil resource will obtain in EU the same level protection of water, marine environment, and air. Steps to achieve the legislation will not be easy and EU Commission already define a path that will engage stakeholders, Member States and an impact assessment. Finally, it is worth noting that the EU Soil Strategy for 2030 aims to achieve results defining two different steps: i) medium-term objectives by 2030, ii) long-term objectives by 2050.

However, in the Strategy, the objective of “no net land take by 2050” is directly derived from the Roadmap to a Resource Efficient Europe of 2011 (European Commission 2011) with the aim to compensate elsewhere the same amount of land when soil is sealed. This approach is not aiming to limit new buildings areas or infrastructures but it accounts the final balance of new soil sealing and soil unsealing that have to be zero. For example, unused or abandoned land could be renaturalised and they will be count as unsealed areas, while natural or semi-natural soil areas could be built (Science Communication Unit 2016). It also important to highlight that in this framework, the adopted term is “land take”. However, as already explained land take refers to increase of artificial surfaces, such as buildings, streets, parking but also urban green areas. Decoville and Schneider (2016) stressed how “speaking of the increase of artificial surfaces implies that the previous status of these surfaces was, by contrast, ‘natural’” but to identify if a land was before natural or not, it is a complex

issue. For example, an agricultural land or a commercial forest could not be considered “natural”, especially in terms of biodiversity. On the contrary, urban fabric not necessarily should be not natural, for instance an urban park could host many plants and animals compared with a crop or a commercial forest. According to Decoville and Schneider (2016), the definition of land take shows the risk and constrains of dichotomously classifying, by using natural and artificial, in particular if “no net land take” as to be quantify by each EU countries and by different administrations.

In Italy, there is no a specific legislation to contrast soil sealing. Many efforts were attempted to propose a law to limit soil sealing: firstly, in 2012 and, secondly, in 2016. The first law proposal focused on contrasting soil sealing in order to mainly protect agricultural areas, while the second proposal was directly focused on limiting soil sealing. However, the last proposal received many critics due to numerous waivers, a complex procedure for setting limits, and the lack of a reduction percentages to be achieved over the years up to 2050 (ISPRA 2018). However, both proposal laws were not approved due to an early end of the Legislatures, even if the second one was already passed in the Italian Chamber of Deputies. Finally, the application of the 2030 Agenda is covered by the National Strategy for Sustainable Development (SNSvS) of 2017 (Ministero della Transizione Ecologica 2017). The Strategy 2017-2030 is divided in five thematic areas and an objective of the “planet” area is to “Halt soil consumption and combat desertification” (Ministero dell’Ambiente 2017). More recently, the Italian National Recovery and Resilience plan (known as PNRR), the tool to contrast social and economic impacts caused by COVID-19, highlights as fundamental the adoption of a specific law to contrast soil sealing, by supporting urban renovation and limiting soil sealing to fostering future of building sector and enhancement of agricultural activities (Italia Domani 2021). Moreover, the “Mission 5” of the PNRR plan deals with soil sealing in the “urban regeneration and social housing” topic, by investing in urban renovation for municipalities with populations over 15,000 inhabitants. Moreover, it aims to enhance suburban areas of the Metropolitan Cities with the objective of transforming vulnerable territories into sustainable cities with reference to smart cities, by limiting soil sealing (Governo Italiano 2021). Finally, the Innovative Housing Quality Program stressed how renovation and increasing of social housing should be provide without new soil sealing (Italia Domani 2021).

1.7. Regional and local legislation: performing multiple meanings on soil sealing

At present in Italy, soil protection is not regulated by any national legislation. However, some regions approved their own legislations over the last few years. The lack of a national law able to provide clear and precise references and definition about soil sealing results into inconsistencies and substantial differences in territorial policies among regional regulations. For instance, in some cases soil sealing definitions are not consistent to EU description or waivers; exceptions are present in order to exclude some land use changes that should be considered as soil sealing, such as public works of over municipal relevance or implementation of existing urban plans (Pileri 2018). Moreover, it is important to highlight that many regions adopted specific regulations on soil sealing, while some others included or set targets on soil sealing in their spatial planning laws (ISPRA 2020).

In 2017, the Regional Council of Veneto published the regulation known as LR 14/2017 “Disposizioni per contenimento del consumo di suolo”. The main target of the Veneto Regional Law 14/2017 is to achieve ‘no net land take’ by 2050, in accordance with the EU zero net land take by 2050 (European Commission 2021g). Indeed, the law attempts to limit the construction of new buildings and infrastructures, defining a maximum net share of new sealed surfaces for each municipality in the region (Regione del Veneto 2017). However, the regional legislation in different cases allows some specific new constructions, such as public works (streets and highways), quarries, and all the projects planned and approved before 2017. Hence, according to Veneto Region, Padua Municipality has the possibility to build 262 ha up to 2050, excluding already mentioned waivers (Legambiente Padova 2019a). However, since the adoption of the “Piano di Assetto del Territorio” (PAT)³ the Padua Municipality plans other 200 ha that have already been urbanized or are affected by Urban Development Plans (Piani Urbanistici Attuativi - PUA) already agreed and/or approved (of which about half are not yet in execution).

In the end of 2021, Padua Municipality is supposed to approve the new PI which claims to eliminate between 300-350 ha planned by the PAT of 2014 (Comune di Padova 2021a). According to the proposal of the new PI of Padua, planned by the famous architect Stefano Boeri, other strategies related to limitation of soil sealing and, more generally, to urban sustainability will be promoted. For instance, the new PI plans a massive urban forestation, implementation of green and blue infrastructures, more awareness of land use, and urban regeneration (Boeri 2021). However, at present, only the main objectives were presented during some public meeting in December 2021 (one general meeting and six meeting in each urban neighbor units of the city of Padua) and a final project is not yet published.

³ The municipal urban planning is achieved through the City Plan, named in Italian as “Piano Regolatore Comunale” (PRG) that is divided into general measures, contained in the “Piano di Assetto del Territorio) (PAT) and in operational measures, contained in the “Piano degli Interventi” (PI) (Regione del Veneto 2004).

The word cloud shows the most used words in the document: the bigger they are in the image; the more times they are used in the document. All articles and conjunctions have been deleted. The document has a total number of x words, hence, the main words that appeared in the document are “Città” (city) with 283 entries, “Urban*” (urban) 224 results, “Sistem*” (system) 151 “Parco” (park) 128, “Piano” (plan) 112, “Padova” (Padua) 107, “Spazi” (spaces) 103, “Public*” (public) 101 “Territorio” (territory) 98, “Rete” (network) 83, and “Verd*” (green) with 80 outcomes. What is worth noting is that between the first 30 words most used in the document, only “regeneration” (49 outcomes) could be referred to soil sealing topic. The word “soil” presents 21 outcomes, “urban abandon” shows 17 outcomes, while “soil sealing” presents 23 outcomes. Moreover, the analysis shows that the document presents very few times words related to other important environmental issues, such as ES (1 outcome), climate change (5 outcomes), UHI (2 outcomes), green infrastructures (8 outcomes), organic agriculture (1 outcome), mitigation (3 outcomes), biodiversity (3 outcomes), water (10 outcomes), agriculture (8 outcomes). No outcomes are found for words as agroecology, ecological transition, resilience, adaptation, and about social dimension of sustainability in the framework of Agenda 2030, no word is resulted about social inclusion, integration, rights to home, and gender.

Other further steps are required before the final adoption of the plan; however, from this first analysis about keywords adopted in the Major’s Document it seems that some of the most environmental, social and territorial issues related to soil sealing, such as climate change impacts and ES are little considered or not included in the document.

1.8. EU 2012 -guidelines: actions to contrast soil sealing

In 2012, the EU Commission published the guidelines to contrast soil sealing, entitled “Guidelines on best practice to limit, mitigate or compensate soil sealing”. The Commission identified three complementary strategies, confirming the hierarchy of sustainable uses of resources (limitation, mitigation and compensation) to reduce the phenomenon and concretely reach the 2050 milestone (European Commission 2012a). These strategies are addressed not only to policymakers at national and local levels, but also to experts, urban planners and, more generally, stakeholders.

The primary action is identified to limit soil sealing. The main effort of each Member State is addressed to avoid conversion of natural and semi-natural soils, such as green or agricultural areas, in artificial surfaces. If new constructions are necessary, they should be concentrated in already urbanized areas, discouraging urban sprawl and preserving “best” soils, for example agricultural lands. On one hand, this strategy of urban densification has manifold benefits: it decreases commuting time and prevents habitat fragmentation; on the other hand, it could represent source of impacts. For instance, when infill development involves conversion of open areas in high density neighborhoods it could cause a decrease of green areas availability for citizens (Pristeri et al. 2021). For instance, in Oslo from 1999 to 2004 open access areas showed a reduction of 5% due to

densification policies. It means that, citizens had less opportunities to practice physical exercises and spent their leisure time in green spaces (Næss et al. 2019). Moreover, inner-city densification could increase dwellers exposed to air pollution and Urban Heat Island (UHI) phenomenon (Næss 2014; Li et al. 2020).

Infill development strategies means also reuse of abandoned or underused areas and buildings. The socio-economic dynamics of recent and past decades have produced in developed countries, a building heritage that is not always valued: military sites, brownfield, abandoned industrial areas and buildings, empty residential buildings and disused railway stations (Hayek et al. 2010). Nevertheless, there are considerable gaps in information on spatial distributions, sizes and types and there is not a complete mapping of abandoned heritage at EU level (Siebielec 2012). In this framework, an insufficient comprehension of brownfields makes it difficult for policymakers to plan policies and strategies supporting the reuse of these places and monitor progress against possible targets and objectives (Van Long et al. 2014). This strategy highlights the necessity of high investments to recycle unused sites, not only due to the price of lots, but also to potentially costs of remediation due to contamination of soil. Therefore, financial incentives for the development of brownfield sites play a key role. Another important measure could be to create incentives to rent unoccupied houses. It would relieve the pressure on areas of the European territory that could otherwise be subject to unnecessary and wasteful land take.

The second measure proposed by the EU Commission is defined mitigation of soil sealing. When new soil sealing is unavoidable or its effects are manifold, mitigation measures can reduce some of the negative impacts of the phenomenon and it can be paramount to restore some ecosystem functions "taken away" from the soil. In more details, innovative building materials and methodologies (i.e. permeable materials) can reduce the loss of some soil functions, such as increasing drainage of rainwater, reducing surface water run-off, reducing effect of UHI and more in general, keeping in balance hydrological cycle. Hence, substitution of traditional building materials, as for example asphalt, can deliver significant benefits besides supporting vehicles and pedestrians (Fini et al. 2017). For instance, permeable materials could be adopted in parking areas by using forced grass systems with gravel or grass grids (Prokop et al. 2011).

According to Rodríguez-Rojas et al. (2020) which analyzed for five years the behavior of three different permeable pavements covering an area of 813 m² of a parking lot in Granada, the capacity of these pavements for mitigating rain events is very high (i.e. infiltrating rain events, increasing drainage time, and decreasing peak flow). Hence, these data show how could be possible reduce impacts of soil sealing in cities. However, it is worth noting an important issue related to permeable materials, that is caused by clogging of pores after some years of laying. The effects caused by clogging is a reduction of infiltration rates caused by deposition of particles and stressed due to vehicle driving (Kumar et al. 2016; Brunetti et al. 2017).

Some urban design strategies and projects could help to mitigate soil sealing, in particular those replicate Green Infrastructures (GI) concept and Nature-based solutions (NBS). Green roofs and walls are two outstanding examples. These solutions have demonstrated not only an improvement in hydrological cycle and in stormwater management, but also a contribution to urban microclimate (i.e. reducing effects of UHI), as well as to foster human wellbeing by increasing green spaces (Czemiel Berndtsson 2010; Castleton et al. 2010). These strategies can also reduce air pollution and help loss of biodiversity in cities (Rowe 2011). Green roofs are also very useful to reduce energy consumption of buildings and, for this reason, the implementation of this technology started in the early 1960s in Germany in conjunction with energy crises. During these 50 years, innovation and application of this technology have continued and spread in Germany. In 2021, the German Association of Building Greening (Bundesverband GebäudeGrün e.V. - BuGG) published the first BuGG-Market Report on Building Greening 2020 giving a general overview on vegetated roofs, green facade and interior greening in Germany (BuGG 2021). The monitoring system adopted by BuGG combines aerial and satellite images to detect green areas, by adopting NDVI index, with high spatial resolution and building data, such as 3D city models and cadastral data. The combination of datasets allows an analysis of green roofs at a building scale (BuGG 2020). The results show that in 2019, 7.2 km² of green roof are added, grouped in 83.5% of extensive green roofs (*Federal Nature Conservation Act (Bundesnaturschutzgesetz, BNatSchG) 1998*) and 16.5% of intensive roofs. Overall, there are 120 km² of this urban design technique in Germany. Munich is the leader in the BuGG Green Roof National League with 3,1 km² of green roof areas, while, according to the green roof index of square meters per inhabitants, Stuttgart is the leader showing 4.1 m² of green roof per inhabitant. It is important to highlight that the average of green roof index in Germany is 1.2 m² per inhabitant (Mann et al. 2021). The report highlights also that 26% of cities with more than 50,000 inhabitants provide subsidies, coming from municipal funds or in combination with federal and state funds, for the construction of green roofs. Indeed, one of the main issue related to green roofs are initial high construction costs and high maintenance costs, hence investments of public administrations are fundamental to encourage the spread of this technique. Adoption of green roofs became an important strategy also in urban plans. Already in 2010, 34% of investigated cities and 32% had made respectively, green roofs and façade greening mandatory in development plans, that are binding urban land-use plan⁶. In 2019, these values growth up to, respectively, 67% and 45%. Another measure adopted by municipalities is the reduction for the split wastewater fee and, according to BuGG, percentage of cities with more than 50,000 inhabitants adopting this measure

⁶ The instrument adopted by BuGG to conduct these analyses are city surveys. BuGG 2019 continued the survey previously conducted by Fachvereinigung Bauwerksbegrünung e.V. (FBB now BuGG) and the Nature and Biodiversity Conservation Union Germany (Naturschutzbund Deutschland e.V. - NABU) on the promotion of building greening. Until 2016/2017, FBB and NABU included all German cities with more than 10,000 inhabitants, while BuGG limited the survey in 2019 to all cities with more than 20,000 inhabitants (Mann et al. 2021).

are at 72%. Finally, green roofs are also part of the Impact Compensation Regulation according to the Federal Natural Conservation Act, the German law to preserve and develop nature and landscape not only in rural areas, but also in cities. In more detail, when negative effects are provided on nature and landscape, the German law foresees clear measures of compensation, defined by value points or ecopoints and assigned to specific biotope types. In this framework, green roofs could be identified as ecopoints, being part of the eco-balance interventions. Hence, the report shows for 2019 that 24% of cities with more than 50,000 inhabitants awarded ecopoints for green roofs (Mann et al. 2021).

Worldwide, other cities outside Germany present high values of green roofs. For example, in North America the first city to introduce a law to require the construction of green roofs was Toronto (Canada). The law, introduced in 2009 and named the Green Roof Bylaw (Toronto Municipal Code Chapter 492) requires all new buildings or building addition with a gross floor area of $\geq 2000 \text{ m}^2$ to include a green roof on 20–60% of the roof area (City of Toronto 2017). At present, green roof in Toronto are more than 500 and a research conducted by Bass and Koukids (2012) showed that UHI phenomenon are reduced with vegetated roof increasing (Koblensky 2016). Other representative cities are Portland (Oregon), Tokyo (Japan), Linz (Austria), Basel (Switzerland), and Singapore (Carter and Fowler 2008; Köhler and Kaiser 2021).

In conclusion, both green roofs and permeable materials could represent two noteworthy technologies to revitalize part of cities ecologically oversimplified by soil sealing.

One of the last example adopted by Germany to foster implementation of green roofs are ecopoints. More in general, ecopoints are part of the measures presented by EU in 2012 to compensate soil sealing. Indeed, compensation, is the last strategy identified to reduce soil sealing and more specifically it is also considered the last attempt in case neither limitation nor mitigation of soil sealing can be achieved (European Commission 2012a). This strategy is proposed with great caution by the Commission, underlining its risks. Compensation measure means giving back, in case of unavoidable new constructions, ecosystem functions of land in a different area of a city. However, compensation measures should not be perceived as by doing “something else, somewhere else”, because soil functions nullified in a specific location could not be recovered anywhere else. For example, urbanization of agricultural land should be compensated by converting degraded agricultural lands to agricultural use; it means that compensation has to be equal and related to soil functions lost. Pileri (2007) suggested that when local transformations occur, compensation should be provided at local scale; on the other hand, when transformations involve a regional or national scale, compensation should be provide not only in local scale, but also in a s scale. EU Commission identified four different measures to compensate soil sealing:

- re-using topsoil;
- de-sealing (soil recovery);
- eco-accounts and trading development certificates;

- sealing fee.

The first strategy is referred to the reuse topsoil excavated to prepare the area for a new building in another place, in order to improve quality of soil. However, this action presents some critical elements, for example soil transport costs.

De-sealing and soil recovery is also part of compensation measures. When a soil is built, another soil is de-sealed and impermeable layers (i.e. asphalt or concrete) are demolished in order to connect again with the natural sub-soil. De-sealing is not a new topic, indeed it is strictly connected to the concept of urban regeneration, by eliminating abandoned brownfields and creating new green areas and restoring its ES. In many cases, unsealing soil means also de-contaminate and restore degraded sites, which often require important investments. Many European high population densities countries, such as Germany, the UK, Belgium, and the Netherlands, unsealed brownfields in order to increase greenfield (Oliver et al. 2005). The Chicago Millennium Park, the Emscher Landscape Park in the Ruhr region in Germany, or the Thames Barrier Park in London are some of the most famous examples of brownfield re-naturalisation (Villella et al. 2006; Texas A&M University and DePaul University 2011). When the practice of unsealing is realized, it is also very important to understand how a restored soil could return to deliver ES. The case studies analyzed by Tobias S. et al. (2018), showed that they have a potential to supply ES if they are restored, even if subsoil compaction could cause some problems, such as restriction of soil's water regulation services (i.e. water infiltration to groundwater aquifers). Usually, restoring an unsealed soil means using a backfill soil, for example fertile agriculture topsoil, for leveling and allowing a best plant rooting. However, Maienza A. et al. (2021) showed that quality and fertility of unsealed soils could be restored without carrying exogenous topsoil, by using ornamental shrubs to enrich the soil organic carbon. Their case studies were located in three different sites in Italy (Emilia Romagna Region) and they were de-sealed in 2017. However, while there are many studies on the effects of soil sealing, studies on soil unsealing are still scarce and their costs and benefits should be still investigated (Tobias et al. 2018). The third compensation measure presented by EU Commission are ecoaccounts. The objective of this measure is to identify the value of new sealed soil and its ecological costs. As previously explain, in Europe the first country to implement a similar measure was Germany in the early 2000s in the Federal Nature Conservation Act. Indeed, the requirement of the Act was addressed not only to soil but more generally to loss of biodiversity and species. In this framework, some Federal States introduced the Eco-Account System, such as Bavaria. Eco-accounts are a sort of "currency" and they have to be acquired by developers from officially authorized agencies, before to build in order to realize compensation measures. Hence these measure are achieved by authorized agencies (Pileri 2007; Prokop et al. 2011; Sponagel et al. 2021).

Finally, the last compensate measure proposed by EU Commission is the payment of a fee for new sealing of soil. This strategy could be interpreted as a limitation action, but at present fees are not very high and developers are not totally discouraged to build. Hence, money gained should be spend

for restoration projects. For example, in Czech Republic conversion of agricultural soils is paid with a tax in relation to the quality of soil (Prokop et al. 2011).

The three strategies proposed by the European Commission highlight how the phenomenon of soil sealing must be addressed according to different strategies and approaches to achieve a progressive reduction of the phenomenon. Causes, impacts, actors, different levels of governance and policies to be adopted make soil sealing quite complex to manage, not only at European level, but also at national and regional level. In fact, there is no single solution to tackle the phenomenon, but rather a comprehensive and shared strategy that is able to redirect processes of land transformation (Artmann 2014).

In conclusion, these guidelines are dated 2012 and almost 10 years are passed from its publishing. In the EU Soil Strategy for 2030, EU Commission delineated the necessity to publish guidance to policymakers and stakeholders on how to reduce soil sealing, reviewing and updating the EU Soil Sealing Guidelines (European Commission 2021g). Moreover, some of the example reported on the Guidelines of 2012 are weak due to a lack of analysis on benefits and risks of best practices and no indicators are set in order to monitor and evaluate objectives (Artmann 2014). Indeed, some Member State defined targets to reduce soil sealing, but results have been scarce. For instance, Germany set a target of 30 ha/per day in order to decrease soil sealing from 80 ha/day, however, this target was not achieved due to a lack of political commitments (Jörissen and Coenen 2004).

1.9. Resilience and adaptation of cities with Nature-Based Solutions to contrast climate change

Cities and urban areas are considered one of the most vulnerable context to climate change. According to the last report of IPCC (2021), there is a high confidence that global warming will impact cities and urban areas severely by more frequent occurrence of extreme climate events, such as heatwaves, with more hot days and warm nights as well as, heavy precipitation, flooding and drought.

Overall, urbanization has aggravated the effects of global warming by its contribution to the warming trend in and near urban settlements. Moreover, combining climate change projections and urban growth trends it is reported that urban expansion will amplify the increasing of the projected local air temperature. Focusing only on IPCC European projection, while northern countries will observe an increase in pluvial flooding, there is a high confidence that the projected southern countries summer temperature increase will be larger than in the global mean (IPCC 2021). In addition, southern European cities will be affected by increasing in the number of heatwave days (Guerreiro et al. 2018). It is reported that cities usually experienced higher air temperatures than rural areas due to UHI effects (World Meteorological Organization 2020). The causes of UHI are an increased anthropogenic heat sources and impermeable materials, such as concrete and asphalt, that reduce evaporative cooling (Fokaides et al. 2016). Soil sealing induces higher surfaces temperature, due to darker color of impermeable surfaces and low reflectivity to solar radiations (albedo). Indeed,

anthropic surfaces have a high capacity to absorb solar radiation and become very hot, raising the surrounding air temperatures (Kaloustian and Diab 2015).

Another consequence of climate change is the intensification of heavy precipitation events. According to Donat et al. (2013), even if precipitation extremes are spatially heterogeneous compared to variation in temperature, the results shows a majority of areas with a rise in extreme events, such as rainfall intensity and frequency than areas with decreasing trends. Moreover, the EEA highlights as in Europe these rising trends will occur over the majority of the continent, driving to the frequency increase of pluvial and fluvial flooding (European Environment Agency 2020). Also in this case cities and, more specifically, soil sealing negatively affects impacts of extreme weather events, by influencing the flood regulation capacity of urban soils and decreasing both infiltration and water holding capacity (Saco et al. 2021). Moreover, urbanized soils can increase surface runoff (Recanatesi et al. 2017). For example, Skougaard Kaspersen et al. (2015), by using Landsat satellite images from 1984 to 2004, examined susceptibility of the city of Odense (Denmark) to pluvial flooding related to urban land use changes. In the last 30 years, results showed that city's exposure to pluvial flooding increased by 6% for rainfall with 10-year payback time up to 26% for rainfall with 100-year payback time. Analyzing estimates for climate change scenarios from 2071 to 2100 showed an increasing, respectively, of 40 and 100%. These measures clearly indicate that urban expansion and land use changes can increase cities' exposure to flooding and, at the same time, for their adaptation to climate change.

In its EU Climate Adaptation Strategy, EU Commission recognized the urgency to build more resilient environment, to promote adaptation strategies and to reduce vulnerability (European Commission 2021c).

At present, some reports highlighted the necessity to significantly increase and accelerate knowledge and preparation in adaptation measures and actions (Global Center on Adaptation 2020; United Nations Environment Programme 2021). Indeed, climate change is recognized as a global phenomenon and its mitigation, by reducing greenhouse gas emissions, need global efforts, but efforts and actions at local context are fundamental considering also that impacts of climate change occur at a local scale. However, not always at local scale policymakers, urban planners and stakeholders internalize climate change issue, especially in local plan. Moreover, as declared in the Global Commission on Adaptation and World Resources Institute (2019) "there are knowledge gaps, short-term biases, fragmented responsibilities, poor institutional cooperation, and lack of resources". In this framework, NBS are recognized as one of the most effective adaptation solutions for climate change, also in urban ecosystems. The concept of NBS was developed during the UNFCCC negotiations in 2009 and it was later introduced in the 2013-2016 IUCN Global Programme (IUCN 2016). While IUCN definition of NBS is more generic, EU define NBS as "solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature

and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions” (European Commission 2021d). Hence, according to EU Commission, NBS have two main objectives: to foster biodiversity and to support the supply of a range of ES. It is also important to highlight that NBS are an evolution of terms used to express similar ideas, for instance urban forestry, green and blue infrastructure, or the delivery of ES (European Commission 2021e).

The EU Climate Adaptation Strategy stressed the promotion of NBS for adaptation in order to help build climate resilience, such as protecting and restoring wetlands, peatlands, coastal and marine ecosystems and promoting and sustainably managing forests and farmland. Among the listed strategies, some of them are addressed to urban ecosystems. For instance, the Strategy mentions the increasing of urban green spaces, such as creating new parks, urban forests or planting individual urban trees, improving urban water management and greening building, by installing green roofs and walls (European Commission 2021f; European Environment Agency 2021).

By increasing evapotranspiration and shading of vegetation, heat storage capacity of urban surfaces as well as air temperature are reduced. For instance, a case study in Porto showed that to reduce maximum temperature of built-up areas located near green areas of 1 °C during the day and of 0.3 - 0.5 °C during the night, green areas should be implemented from 5% to 10% in order to contrast a future heatwave event (Carvalho et al. 2017). Implement adaptation measures is also fundamental to reduce mortality from extreme temperatures. For example, in 2003 Paris registered a high number of dead due to a heavy heatwave. Since then, many action plans and measures have been implemented not only at national level, but also at local level. In 2020, 116 ha of green roofs and walls were implemented, 20,000 new trees were planted and nine “green streets” were created (European Environment Agency 2020).

Other studies investigated the powerful effect of NBS: a comparison of temperature of grass surfaces and concrete surface showed that, respectively, the first present 2-4 °C less than the second, while trees can reduce air temperature until 5-7 °C (Armson et al. 2012). Urban parks are very valuable not only because they present an average temperature lower than 0.94 °C compared with urban areas, that could increase according on the quantity of trees, but they are very helpful in the regulation of storm water and mitigation of flood hazard, by evapotranspiration, infiltration on the ground or delaying urban run-off (Bowler et al. 2010; Berland et al. 2017). In fact, according to Pataki et al. (2011) supposing similar precipitation events, urban areas can lose from 40% to 83% of rainfall to surface run-off, while forested landscape loses about 13% of rainfall to run-off following. Also individual trees and green streets are very important to reduce stormwater run-off. Berland et al. Hopton (2014) quantified that a wood plant can collect 6.7 m³ water per year, which can support to decrease the frequency and severity of combined sewage water overflow events.

In addition, water systems are recognized as NBS and they play an important role in urban areas in order to adopt adaptation measures to reduce effects of rainfall extreme events. Water NBS include

river restoration, bioswale⁷, retention and detention basins, constructed wetlands, rain gardens, permeable pavements, and riparian vegetation strips. Some of these approaches are advantageous in order to reduce the pressure on sewerage systems. For instance, a good strategy considers to combine sewerage infrastructure with water NBS, i.e. bioswales, street trees or rain gardens in order to rise evapotranspiration and infiltration before to reach sewerage systems (Wild et al. 2020). Moreover, to adopt some of these NBS measures could be possible remove excess asphalt and concrete, both in private and public spaces, that could control surface run-off volumes and timing in order to reduce the risk of flooding (Vojinovic 2020).

Both water and heat management could be controlled by adopting greening roofs. Concerning water management, retention of water and delay in water run-off is better in green roofs than in conventional roofs (Oberndorfer et al. 2007; Pataki et al. 2011). According to Ruangpan et al. (2020) a green roof can decrease run-off volume by up to 70% and peak flow volume by up to 96%. Furthermore, vegetated roofs and green facades can reduce UHI and air temperature, enhance indoor thermal comfort and reduce energy demand, such as air-conditioning use that can be decrease up to 40-60 % in a Mediterranean climate (Mazzali et al. 2012; Perini and Rosasco 2013; European Environment Agency 2020).

It is worth noting that NBS are also essential for other multiple benefits that are able to provide to humans, for example improvement of air quality with the reduction of air pollutants, carbon sequestration, production of local food, human wellbeing, and increasing biodiversity (European Environment Agency 2021).

As reported by Hartig et al. (2011) physical and mental wellbeing is positively affected by nature. Hence, in cities, urban parks and urban green spaces play an important role also for physical and mental health and socio-cultural benefits that they can provide to citizens. In the last two years, COVID-19 has stressed the urgent necessity of more vegetated areas and local parks across cities as an important element of quality life of people (Kleinschroth and Kowarik 2020). According to the online survey in six European countries of Ugolini et al. (2020), some behaviors and attitudes related to urban green spaces changed during social isolation of COVID-19. Indeed, the study highlighted as people had the necessity to stay on open air and it was willing to move for long distances across its own city just to access to an urban park. Hence, it showed that urban fabric is very often densely urbanized and sealed, leaving few spaces for vegetated areas.

Many researchers sustained that the pandemic underlined the importance of maintain and developing urban green spaces in the future (Honey-Rosés et al. 2020). The pandemic on one side and the climate crisis on the other side become two very important drivers for the reshaping our

⁷ Bioswales are vegetated open channels specifically designed to attenuate and treat stormwater runoff for a defined water volume. There are some design variations of the bioswale, including grassed channels, dry swales and wet swales [Source: <https://www.crd.bc.ca/education/stormwater-wastewater-septic/green-stormwater-infrastructure/bioswales>].

cities. Increasing the availability of greening and the distribution of it across urban areas has to be reflected in local and regional urban plans and strategies.

As already reported by the report of EEA named “Nature-based solutions in Europe” (2021) some farming systems adopt NBS and some of them are already spread in EU. These systems combine ecologically based diversification and increasing of production and, at the same time, they decrease vulnerability to hazards and extreme events. EEA listed some of them, for instance integrated crop-livestock systems, soil organic matter management, mixed cropping, crop rotations, biological control of pests, and agroforestry. It is worth noting that agroecology represents per se an NBS. In fact, agroecology aims to foster efficiency of biological processes and to enhance biological activities above and below the soil, not only in rural areas but also in the urban environment (Altieri and Nicholls 2019). In EU, the EU Biodiversity Strategy for 2030 aims to increase biodiversity on crops and agricultural areas, and agroecology is considered as a possible choice (European Commission 2020). While this agricultural approach is considered for suburban areas, in urban settlements there are very few examples of dissemination of agroecology. In fact, it usually requires more labor and practitioners news many experience before to obtain certain results.

Moreover, at present the attention on Urban Agriculture (UA) is increased by gaining space in urban plans of many European cities; however, scarce attention is dedicated on urban agroecology. UA aims to achieve food security, to enhance social cohesion, equity, and education (Veolia Institute 2019). In developed countries, the debate and the initiatives related to UA are particularly spread and they are recognized by institutions, policymakers, and citizens for several benefits and services provided (Artmann and Sartison 2018). The general role identified for UA is to create a more sustainable lifestyle and to create social ties within communities.

Hence, UA and, more specifically urban agroecology, could contribute to enhance urban environment, by implementing vegetative systems and urban parks in order to foster the potential of NBS in cities.

2. MY ROLE IN THE RESEARCH: Personal contribution in a collective research

The present geographic research on soil sealing takes roots into my advanced education in GIScience, by attending in 2016 the Professional Master in “GIScience and UAV for the integrated management of territory and natural resources” (University of Padua). In this “learning environment” I started my research path on soil sealing by developing a Master thesis named “Consumo di suolo a Padova e scenari verdi: il caso San Lazzaro” which focused on two main objectives: i) mapping soil sealing in a specific area of Padua (San Lazzaro); ii) developing alternative scenarios (green and grey scenario) for the study area.

I therefore get the opportunity to present and disseminate my first research findings at the first international conference organized by EURAC on “Smart and Sustainable Planning for Cities and Regions” (Bolzano, 2017) and at ASITA conference (Salerno, 2017). The research findings from the Master thesis were also presented for a wider public in a city events named “Quale Padova? Idee per la rinascita” (title of the speech “Consumo di suolo e partecipazione”) which gathered different stakeholders involved into the management of the soil sealing issue (organized by the GIShub Association on the 15th December 2017). From the very beginning of my research, it was fundamental the dissemination of the study not only to scientists but also to a general public in order to communicate soil sealing phenomenon directly to citizens and stakeholders. Starting from this phase of the research process, different formal and informal meetings were organized both with local organizations from civil society and policy-makers to stimulate dialogue between science and stakeholders. Since these first research experiences and outcomes, I was even more deeply involved in a such complex and interdisciplinary research which represent one of the main actual challenges for the urban territorial sustainability. In this context of interactions, I became part of the research group “Climate change, territories, diversity” of the ICEA Department (University of Padua). The research group, composed by different geographers, was carrying out interdisciplinary studies about sustainability pathways and energy transition scenarios in Amazon rainforest: from mapping socio-environmental impacts of fossil fuel production to drawing local development alternatives related to “unburnable carbon” areas, community-based ecotourism and agroecology. Such geographic researches are performed by completely adopting approaches from GIScience, such as remote sensing, spatial modelling, PPGIS and VGI methodologies.

These working environment gave me the possibility to pursued my research topic focusing on GIScience methodologies and by discussing approaches and techniques with experts in the field. In addition, the research group was not only a learning environment, but also a place of debate and proposals. Indeed, I had the possibility to coordinate, collaborate and participate to different research activities, workshops, lessons, and public events, in which the group participated (Veneto Night, Geo Night and GIS day). In this context I got the possibility to propose and to develop together with other colleagues the research line about urban sustainability: from mapping soil sealing to assessing urban ES, from VGI experiences to data geovisualization.

In 2017, within the framework of calls for Innovative Projects for students, selected and funded by the University of Padua, I promoted and supported the project “Il Valore del Suolo” developed in eight workshop for students and citizens. The main objective was to investigate soil sealing issue by adopting the GIScience approach. During the eight workshops, VGI and PGIS activities for all the participants were organized to analyze soil sealing in GIS environment. During the workshops I had the opportunity to teach to students how to approach to soil sealing, explaining GIS techniques and methodologies, supported by the professors of the research group. Outputs of this project became later part of the study included in Article I.

Through the PhD research program, I continued to deepen and develop the topic, by integrating the human geography approach with a focus on the urban territory of Padua. The PhD program represented also an opportunity to take directly part to other projects and initiatives focused on urban sustainable management and urban regeneration.

In 2018, I was responsible of the selected project “MUES. Mapping Urban Empty Spaces” (DAFNAE Department, University of Padua), pinpointing the issue of abandoned areas and brownfield in Padua. During this project, students took part to seminar and lessons in classroom as well as “urban workshops”. Urban workshops were fieldwork activities developed within the city of Padua, where students learned directly on the field how to collect spatial data by their mobile phones. Lessons and workshop were focused on GIS methods. Therefore, I had the possibility to explore how VGI approaches should be developed and implemented in research activities. Results and outputs of this project were also included in Article I.

In 2019, my proposal about urban ES and ecological networks was selected as innovative project “Walls and Rivers: servizi ecosistemici urbani e green infrastructures a Padova” (DAFNAE Department, University of Padua). This project investigated the role of urban ES and green infrastructures, focusing on the renaissance walls and the canals and rivers of the city. Research was conducted on the field, by participative “urban walking” with students to collect geographical data. In 2020, the project “MAPMi - Mappatura del Microclima Urbano e Aree Verdi” was selected by University of Padua as Innovative project. It aimed to study the UHI and the relationship between vegetative systems and soil sealing.

My path was also enriched by the experience of co-tutor of different bachelor thesis in Natural Sciences, Environmental Sciences, and professional master thesis (Master in GIScience and UAV) of the University of Padua. The thesis were related to soil sealing issue (Castaldo 2018; Crescini Di Montecchio Benedetti 2018), brownfield and abandoned areas and buildings (Zago 2018) and land use/land cover analyses, urban ES and NBS (Vezzelli 2019; De Simone 2020; Grezzani 2020; Buscemi 2021; Cibrario 2021; Facchinelli 2021).

I would also highlight that, before the spread COVID pandemic (March 2020), the research would have included two case studies, Padua and Columbia (South Carolina, USA). The objective was twofold: understanding how this issue is tackle in the USA and which are the adopted policies

compared to Europe framework. Due to the first pandemic outbreak world-wide, the research in the USA was interrupted after one month (March 2020); due to the limitations caused by the pandemic and the difficulty of proceeding with fieldwork in Columbia this case study was therefore not included in the thesis.

During the three years of PhD, I took part at different conferences as speaker at Italian as well as at international meetings (3rd International Conference on “Smart and Sustainable Planning for Cities and Regions - SSPCR 2019” and Annual International Conference Royal Geographical Society with IBG) presenting my research work. Moreover, I also participated at public conference as invited speaker and expert. Just to mention some of them: the conference “Consumo di Suolo in Italia e in Veneto” organized within the project “GIS and Science per l’ambiente, la società e il territorio” (University of Padua) in September 2019 with a speech named “BAF Index per il calcolo del consumo di suolo a Padova”; the seminar “Sostenibilità urbana: consumo di suolo e il valore delle aree verdi” organized by NGO Osteria Volante and the Municipality of Padua in September 2020; the conference “Verde urbano a Padova: “patrimonio ambientale” o suolo da consumare?” organized by the NGO FAI (Padua Delegation) in November 2021.

The research was also presented to students of the University of Padua during different lessons. In particular, from 2019, I was invited by professor Massimo De Marchi to conduce two lectures. The first lesson was developed in the course or “Environmental Impact Assessment” (Master Degree in Natural Science, at Biology Department) named “Urban Ecosystem Services: Evaluating the change in Padua”; the second lesson was developed in the course of “Ecologia e Politiche Ambientali” (Bachelor Degree, at Biology Department) named “Ecosistema urbano: il consumo di suolo a Padova”. In 2018 and 2019 I also took part to the course “Territoires, acteurs et enjeux du developpement” (Master Degree in Sustainable Territorial Development, DiSSGeA Department, University of Padua) of prof. Daria Quatrida with a seminar called “Soil sealing and urban sustainability: a geographical approach”.

In addition, the first map of soil sealing produced in this thesis was included in the annual report of ISPRA “Consumo di suolo, dinamiche territoriali e servizi ecosistemici”, in a brief article named “Mappatura del consumo di suolo a Padova mediante l’uso dell’Indice ecologico urbano Biotope Area Factor” (Peroni et al. 2019); in 2021 the Italian magazine “Madrugada” of the NGO “Macondo” published an article named “Proteggere il suolo. Consumo di suolo e tutela delle funzioni ecosistemiche” (Peroni 2021).

Finally, it is worth noting that a great effort of communication has been performed to reach a more general public, not only through public conferences, but also using other channels. Both Article III and Article IV have been published on local daily newspapers (paper and online) such as Il Mattino di Padova, Il Gazzettino, and PadovaOggi (2021) as well as the Padua’s University press (Il Bo Live (Università di Padova) 2021). In order to facilitate the understanding of the articles, press releases

in Italian were prepared and accessible on the website of the Master GIScience and UAV (University of Padua) (Master GIScience e SPR (Università di Padova) 2020,2021).

Moreover, since the article IV was published during the public and politic debate on the issues of urban sustainability and the adoption of new plan PI, scientific divulgation was maximized by email networking with all associations listed in the Municipal Register of Associations of the City of Padua (Comune di Padova 2021b). Also social media platforms have been used to share these studies, by spreading not only the open access articles, but also images, videos and Italian texts of more easy comprehension for citizens.

In conclusion, being part of this interdisciplinary research group gave me the possibility to be engaged in multiple dimensions and covering different inter-connected roles: from young researcher to project coordinator, from communication and networking to tutoring of bachelor and master theses.

3. PIXEL, PEOPLE AND POLICIES: APPROACHES AND PERSPECTIVES FROM GISCIENCE

The studies included in the present thesis are based on the adoption of Geographic Information Science (GIScience) approaches both in research design, development and territory analyses. According to Crews-Meyer (2002) GIScience refers to the integration of scientific theory and information systems, by the inclusion of the geographical dimension. More specifically, GIScience implies that any application should be simultaneously based on the scientific comprehension of the phenomenon as well as software and methodologies used to investigate it. Furthermore, GIScience enables to better understand interactions between people and places and how they are conditioned and they condition policies (Crews-Meyer 2002).

One of the most comprehensive definition of GIScience is reported by David Mark (2003), by using the University Consortium for Geographic Information Science quotation of 2002: GIScience is “the development and use of theories, methods, technology, and data for understanding geographic processes, relationships, and patterns.”

The main tool used in GIScience are Geographic Information Systems (GIS); such systems are able to manage geographic information by which spatially explicit data could be stored and retrieved into a spatial database (Tomlin 1990). GIS and geo-technologies give the possibility to integrate different components of a territorial system, able to manage both quantitative and qualitative information and, at the same time, to handle different scales of analysis: from local to global scale (Randy Gimblett 2002). Moreover, GIS enable to process geo-referenced data related to bio-physical, geographical, ecological, anthropic and socio-economic components and to elaborate geographical models able to interface environmental and social systems. In other words, GIS could manage processes that present a complex behavior and dynamics over time (Randy Gimblett 2002). Through the use of GIS, it is possible to integrate data into a Database Management System (DBMS), creating a data storage not only geographically and temporally referenced, but also thematically differentiated (Westervelt 2002).

GIScience, as science behind the system, allows a "top-down" analysis, using, for instance, satellite images, orthophotos and spatialized databases for territorial analysis, as well as “bottom-up” analysis, which includes the participation and involvement of citizens in the understanding the phenomenon and the validation of data by ground truth.

3.1. GIScience and its role to tackle wicked problems

In this framework, GIScience allows to articulate a systemic analysis of soil sealing and to integrate the complex dimensions of the phenomenon for understanding the geographic processes and interactions.

As above mentioned, soil sealing is a complex phenomenon due to the different driving forces and impacts as well as interactions between measures, strategies, actors and constraints involved in its management (Artmann 2013c). As reported by Artmann (2015), urban soil sealing management

could be defined as a “wicked problem”. The term was introduced in 1973 by Rittel and Weber on the “Dilemmas in a General Theory of Planning” where they gave a definition and highlighted the rules. The concept was born as a critique to the domain of top-down, expertise-based and ‘engineering’ approaches and solutions to complex social and urban dynamics (Head 2008). Wicked problems, such as forest and water management, ecosystem management, housing and transportation in urban areas, needs the combination of different perspectives, answers and a creative way to manage them (Chapin et al. 2008; Balducci 2012; Defries and Nagendra 2017; Markowska et al. 2020). It is important to highlight that wicked problems do not have a definitive formulation, clear definitions, open-ended, immediate or ultimate test of a solution, and defining solutions (Sousa-Poza 2013).

According to Gaston (2010), urban environmental management is considered as a wicked problem; in this framework, Artmann (2013c) stressed as soil sealing management could be a “wicked sub-problem”. Tackling soil sealing needs multiples approaches and information to have a better overview of the phenomenon, hence a holistic approach should be considered. According to this perspective, strategies should be addressed on management of soil sealing and urban areas as well as on urban green and agricultural areas as the flip side of the same coin (Artmann 2015). A holistic view of the phenomenon means also to analyze and investigate by combining a quantitative approach (limiting soil sealing and safeguarding vegetated areas) with a qualitative approach (surveys and questionnaire to understand the perception of people on the phenomenon) (Artmann 2013a).

Soil sealing could be defined a wicked problem also due to its different solutions according to each city. For example, in growing cities, urbanization surely will convert agricultural areas into urban lands and soil sealing will increase, while in shrinking cities new abandoned areas and brownfield will appear (Artmann 2013b). Consequently, the strategies for the two examples will be completely different and they will depend on the features of each urban area. Moreover, stakeholders and dwellers can play an important role in how to tackle the phenomenon, even if their perception and ideas could be completely opposite.

In conclusion, several elements and dynamics could play different but interactive roles in dealing with soil sealing such as the specific feature of each urban settlements, stakeholders and dwellers perceptions, political commitments, economic and social consequences and impacts.

In this framework, the present research articles use the GIScience approaches to tackle the wicked problem of soil sealing. In more detail, the articles adopt three of the main components of GIScience, in order to analyze, manage and geovisualize the complexity of the soil sealing phenomenon. According to Goodchild (1992) and the National Center for Geographic Information Analysis (NCGIA) (2007), there are many components of GIScience, from “data collection and measurement” to “spatial statistics”, from “analytical tools” to “institutional, managerial, and ethical issues”. Following the technology evolution, most of these components evolved, changed or were aggregated (Mark 2003). In 2010, Goodchild and leaders of NCGIA brought back up a conceptual framework for

GIScience, which make different topics to be investigated in a straightforward way. The conceptual framework is represented as a triangle, where at each vertex are located the three main domains of GIScience: computer, individual user, society. The others components of the field are distributed in the triangle, depending on its topic proximity to one of the three domains (Figure 4) (Goodchild 2010). Also the Varenius Project, a project from 1997 to 2000 funded by the US National Science Foundation to advance GIScience, adopted this tripartite division: the individual, the system and society. More specifically, the project gave the following definitions:

- the individual, as user of technology, observer of geographical phenomena, source of conceptualizations, and maker of decisions;
- the system, defined as the entire complex of digital geographic information technologies and its supporting hardware, software, and networking foundations;
- society, including its institutions, customs, communities, norms, and standards (Goodchild et al. 1999).

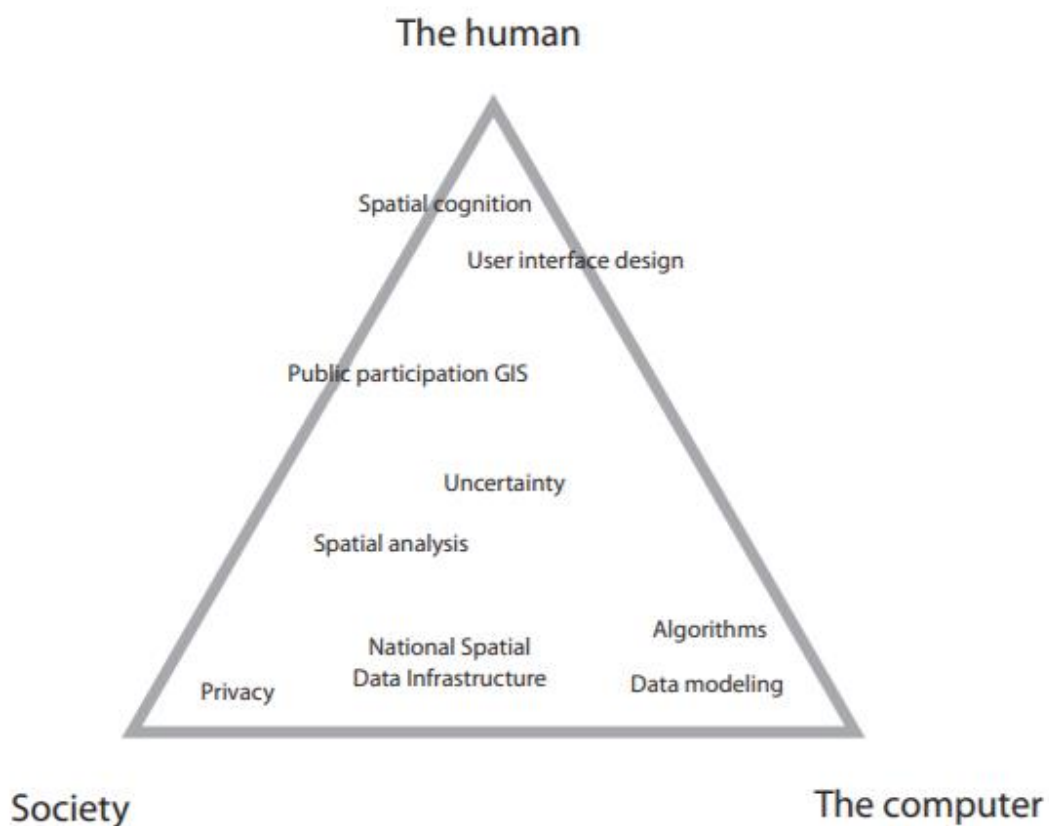


Figure 4 A conceptual framework for GIScience (Goodchild 2010)

Within such conceptual framework, the following research articles adopted the GIScience approaches and perspectives structured among three main elements: Pixel domain (the Computer), People domain (the Human) and Policies domain (Society).

3.2. Pixel

GIScience combines and integrates a variety of spatial digital technologies and analyses approaches by including GIS, remote sensing (the science of Earth observation), spatial analysis and statistics, spatial simulations and modelling, data visualization, and global positioning systems (Crews-Meyer 2002). These techniques could be related to quantitative methods (Fotheringham et al. 2000). Soil sealing is a phenomenon that has inherent spatial dimension, thus it can be easily represented by spatial data.

The combined use of GIS and remote sensing was predominantly adopted in the articles in order to provide spatial analysis of the articles objectives. Both Article III and IV integrated remoted sensed data in GIS, respectively to quantify soil sealing in Padua and to investigate urban green areas in the same city. In article III remote sensed data are areal images, while in article IV are both areal images and satellite images.

Concerning soil sealing spatial dimension, the increasing availability of data from aerial platforms made remote sensing together with GIS the most widely adopted technology to map and to assess the phenomenon, at different geographic scales and temporal resolutions of analysis. In recent past, more qualitative approaches were adopted to evaluate spatial dimension of soil sealing, such as field survey, census data or ground-based data collection, however they are costlier, time-consuming and less accurate (Weng 2012). LUCAS Program (Land Use/Land Cover Area Frame Survey) is one of the most famous example and it was managed by EU to measure land cover and its use (Ballin et al. 2018). Hence, remote sensing data and technologies, including also aerial images, are at present the most used tools to perform spatial analysis on soil sealing. Moreover, remote sensing technologies present several benefits, such as:

- allowing to perform spatial analysis on large areas (Weng 2020);
- providing open access big spatial data (i.e. NASA Landsat or Sentinel EU mission);
- high spatial resolutions;
- allowing high-frequency re-visit time over the same area, making feasible multitemporal analyses and monitoring soil sealing processes over years and decades.

Data collected by remote sensing devices and platforms requires additional processing before they can be used for spatial analysis.

Article III quantified soil sealing in Padua, by using 2015 multispectral aerial images (VIS and NIR) at very high resolution (0.2 m/pixel) of the Veneto Region. A first phase of photo-interpretation analysis in GIS environment was carried out in order to map and classify the land cover of Padua in four representative sample areas. The very high geometric resolution of the aerial images has allowed the extraction of features (geographical elements) at a variable scale between 1:2000 and 1:1000, up to a scale of 1:500. Later, the quantification of soil sealing was calculated through the application of the BAF index, attributing a ranking of soil sealing to the previously extracted areas.

A similar methodology is followed also in article IV in order to obtain a quantitative assessment of Urban Green Spaces (UGS). Firstly, a screening and detection of UGS, adopting the Normalised Difference Vegetation Index (NDVI) to perform a multispectral analysis on very high-resolution aerial images. NDVI analysis is performed on 2015 multiband orthophotos at very high spatial resolution (20 cm pixel⁻¹), provided by AGEA/Veneto Region. The NDVI-derived raster image is then vectorised into a shapefile. It is important to highlight that urban indexes may produce flaws consisting in the underrepresentation of ploughed or fallow land but also in the overrepresentation of tree canopies on streets or other artificial features. Thus, results are integrated with ancillary data from the topographic database of Padua Municipality. Later, a polygonal shapefile representing UGS is obtain.

Finally, UGS maps extracted by Article III are used as data validation, by using a spatial linear regression.

By using GIS it was feasible to manipulate a large amount spatial data in many ways and later it was also possible display the outcomes on maps.

3.3. People

Until recently, the only sources and producers of spatial data were governmental agencies, cartographic centers, and private companies: high fees and copyright restrictions were obstacles to more widespread access to geodata (Arsanjani et al. 2015). However, in last decades, development of digital technologies, such as mobile devices, Web 2.0, access to satellite images and online maps, completely changed spatial data collection and mapping moving from an entirely professional activity to participation of citizens and no-experts people (See et al. 2016). Contribution of citizens in collection of spatial data covers different topics and disciplines, for example, ecological studies, astronomy, zoology (Wiersma 2010; Raddick and Szalay 2010; Dickinson et al. 2010; Crooks et al. 2013). Moreover, the availability of high resolution images in Google Earth or other Digital Earth platforms with free satellite images allows land use/land cover mapping directly performed by volunteers. For instance, Geo-Wiki is a web-based geospatial application used open to everyone that allows to collect, visualize and validate global land cover data by using Google Earth images as base (Fritz et al. 2009).

Different terms refer to involvement of citizens in activities related to data collection and community involvement- i. e. citizen science, neogeography, crowdsourcing - and they are usually classified by active and passive contributions of citizens and type of collected data (not all data are spatial data) (See et al. 2016).

Indeed, Article I focuses on three projects developed in the framework of urban sustainable development (soil sealing, urban mobility, abandoned urban areas), that aims to collect specific geographical information and data by involving citizens and students. Moreover, these projects are developed within the general framework of citizen science, which refers to contribution of citizens in

scientific research activities. According to the Green Paper on Citizen Science for Europe, it could be defined as “the general public engagement in scientific research activities when citizens actively contribute to science either with their intellectual effort or surrounding knowledge or with their tools and resources. Participants provide experimental data and facilities for researchers, raise new questions and co-create a new scientific culture. While adding value, volunteers acquire new learning and skills, and deeper understanding of the scientific work in an appealing way” (SOCIENTIZE 2014). In addition, the projects explained in Article I are more specifically referred to the subcategory of Geographical Citizen Science. According to Haklay (2013), the term includes “projects where the collection of location information is an integral part of the activity”.

Hence, the main methodologies used are:

- PPGIS is defined as a “field within geographic information science that focuses on ways the public uses various forms of geospatial technologies to participate in public processes, such as mapping and decision making” (Tulloch 2014). While use of the term PPGIS originated during a workshop organized by the National Center for Geographic Information and Analysis (NCGIA) in 1996, the term PGIS came from participatory approaches in rural areas of developing countries (Brown and Kyttä 2014);
- VGI is a term coined by Goodchild in 2007 in order to describe “the harnessing of tools to create, assemble, and disseminate geographic data provided voluntarily by individuals” (Goodchild 2007). A well-know and famous example of VGI is OpenStreetMap, a project born in 2004 with the aim to create a free, editable map of the whole world (Mooney and Minghini 2017). According to Arsanjani et al. (2015), OSM revolutionized the collection of geodata: data are not collected or produced by only experts, but they are mapped directly from thousands of volunteers;
- Crowdsourcing is defined as “a type of participative online activity in which an individual, an institution, a non-profit organization, or company proposes to a group of individuals of varying knowledge, heterogeneity, and number, via a flexible open call, the voluntary undertaking of a task” (Estellés Arolas and González Ladrón-de-Guevara 2012).

The projects could be defined according to these definitions; however, it is important to highlight that these terms are not fixed, and usually the categorization could be flexible. “Il Valore del Suolo” is an example of Geographical Citizen Science but it could also be an example of Public Participation in Scientific Research (PPSR) due to its strict relation to scientific research analyses. “Piste RiCiclabili” is classified as VGI example, but at the same time it could be also a crowdsourcing project and also a project promoting public debate and supporting citizen organization fostering bike mobility in the city. Finally, “MUES” is classified as a VGI practice, but it involves also the term Collaborative Mapping and sharing citizen awareness on the opportunities of empty space and alternative city design.

All these projects were not part of formal participatory decision making process, but research supported citizen awareness, knowledge sharing, transformative learning.

Participants are known in “Il Valore del Suolo” and “MUES”, while in “Piste RiCiclabili” the majority of participants are anonymous. Indeed, no registration were required by using the geoODK collect. It is also important to mention that two out of three projects mainly involved students of the University of Padova, while “Piste RiCiclabili” were spread to all citizens of the city.

Collection of data are provided in three main methods: i) restrict group of works, such as workshop or urban walks (“Il Valore del Suolo” and “MUES”); ii) public events and meetings (“Piste RiCiclabili” and “MUES”); iii) online (“Piste RiCiclabili”). Overall, the three projects adopted similar mapping methodologies. Indeed, they mainly use digital tools and applications to perform data collection, mapping, analyses and processes, such as My Maps, ODK and Jotform, QGIS, and Lizmap. Only “Piste RiCiclabili” adopts also paper maps. In this framework, two out of three projects provide collection of geographical data by using mobile phone of volunteers, whereas one project creates spatial data directly on laptop (“Il Valore del Suolo”). Analyses of data are directly provided by citizens only in one case, while in the other two cases volunteers provided only the collection of data.

The experience required from participants varied widely across the three projects. “MUES” needs very little expertise: students and citizens manually report on an online map (My Maps of Google or GeoPaparazzi App) the location of the abandoned areas, the typology (building, brownfield, area, mixed) and finally upload a photo of the specific site. According to See et al. (2016), these activities need the most basic level of training. Also in “Piste RiCiclabili” project the collection of critical issues on bicycle paths is quite easy, but the difficulty was provided by the categorization of the different critical issues. Hence, online instructions and video are provided. “Valore del Suolo” is the project that needs the majority for experience: students were directly trained by researches in GIS environment due to the complexity of the topic and the visual analysis procedure to map soil sealing. Involvement of non-experts people needs also raise concerning on quality of data. Hence, validation of data was necessary especially in “Il Valore del Suolo” project. Firstly, during each workshop students could directly ask to researchers in case of doubts or problems and secondly, an accurate validation was provided at the end of student’s work (Crescini Di Montevicchio Benedetti 2018).

These participatory mapping methodologies developed in GIS environment engage students and citizens on research topics related to urban sustainable management, while they simultaneously produce spatial and geographic data useful for the research. Data provided in “Il Valore del Suolo” are part of Article II, while data provided by “Piste RiCiclabili” are part of Bicipolitana project of the Municipality of Padova, a net of bicycle paths that connects the city to suburban areas.

Participants had the possibility to investigate some specific topic of urban sustainability that, as for example of “Il Valore del Suolo”, could be difficult topic to understand. Moreover, in this particular case they gain the possibility to learn how to use a GIS tool. Furthermore, these activities show how geography is a discipline that can adopt and combine quantitative and qualitative methodologies for

the analysis of urban ecosystems and how geovisualization and visual thinking are powerful tools for place based awareness and imagine changes.

3.4. Policies

Policy domain in this thesis is based on two dimensions: i) investigating regulations and strategies developed international and country level, in order to have a general and complex overview on the issue; ii) providing methodological tools and recommendations to stakeholders and policymakers in order to tackle the phenomenon.

Firstly, a bibliographic survey is carried out at different levels of governance understanding which strategies have been developed or are on the roadmap to be applied. If on one hand legislation and regulations overview might be really wide, on the other hand, a scale approach is adopted, by analyzing international level, national level (Italy), regional level (Veneto) and municipal level (Padua). The research is carried out mainly by webs resources, since all the non-European (FAO, United Nations, COP, IPCC) and European (European Commission, European Environment Agency, Joint Research Centre) references are directly available online. Also for the Italian references, such as the ISPRA reports and local legislation is possible to acquire territorial data by an online search.

Secondly, scientific researchers and discoveries play a fundamental role in boosting environmental policies and strategies, as for example is demonstrated by the IPCC that provide relevant recommendations to policy making since the first report in 1990 (Richards 2019). Indeed, policymakers are influenced also by scientific information to support changes in legislation.

Against this backdrop, this thesis could have important implications for stakeholders and policymakers, by trying to give some contributions to the local public policy debate on soil sealing. In fact, Article III compares two alternative urban management scenarios, a roof-top green scenario and a grey scenario that plans the construction of the new hospital of the city. These two alternatives are a practical example of how Padua policy-makers could include into the development of that specific area of the city by using simulated scenarios.

In Article IV provides accurate data and thematic maps on distribution and property status of UGS as well as an assessment of related urban ES. These results could be baseline to help planners in designing site-specific, citizen-oriented urban Green Infrastructures. The focus on urban units of the Padua could help politicians to identify in which areas is more urgent to operate adopted more green and vegetated areas. In this framework, the article suggests some examples for four urban units, such as increasing accessibility to municipality UGS, or makes some specific public areas accessible to all citizens especially in that neighborhoods where there is a shortage of municipal UGS.

Finally, Article III and Article IV provides useful geospatial data and applicative tools for sustainable urban monitoring and management. Materials used for the analyses (aerial images and data), are

easily available to the Municipality as well as the methodologies adopted could be integrated by Municipalities' technicians in order to continue the monitoring during the next years.

Article II suggests as the majority of the studies are mainly focusing on quantities research, focusing on merely techniques testing and performances, on efficiency of feature extraction or on study cases comparison. Hence, they do not highlight recommendations some policy implications for sustainable territory management or spatial urban planning.

However, interface elements between science and policy should cooperate closely to understand specific needs, identifying policies and strategies to actively address the phenomenon.

3.5. Bibliographic survey

The initial phase of the research was addressed to perform a systematic bibliographic survey, analyzing both scientific and grey literature, such as indexed articles, books, PhD thesis, reports, conference proceedings, thematic blogs, and web pages. Bibliographic survey was performed on different topics, focused into the main research issue (soil sealing) as well as methodologies and current techniques.

3.5.1. Literature review (soil sealing and methodology)

Overall, scientific literature survey was performed by searching into the Springer Scopus database and Google Scholar. The search was performed by Italian internet providers. Firstly, a particular focus was dedicated to soil sealing processes, in order to understand how so far the phenomenon is studied and managed. A specific search on Scopus database was performed by searching articles within a time-frame from 2000 to 2020, in English language. Results show 1,277 peer-reviewed papers published in international scientific journals. The search includes soil sealing term and synonyms (impervious surface, land take, soil consumption, and land consumption) in title article and keywords. Moreover, a preliminary search shows that before 2000 articles related to soil sealing are limited, less than 2 or 3 per year.

It is worth noting that papers are mainly focused on mapping, analyzing and quantifying the phenomenon (quantitative research). In fact, 503 out of 1,277 articles investigate this specific area of the topic. These articles investigate and test materials and methods to quantify and geovisualize soil sealing in order to identify the best approach to detect the phenomenon. Satellite and aerial images, scale and location of analyses, AI algorithms and classification methodologies are tested and compared in most of articles. Usually these papers are mainly technical and quantitative articles. Secondly, less results are found on a more holistic view of the phenomenon, providing an overall framework of soil sealing, i.e. analyzing drivers, constrains, consequences as well as possible solutions and management scenarios.

Exploring drivers and causes of soil sealing means address a research related to urbanization processes, development of urban areas, urban population growth as well as territorial dynamics and

relationships among actors. Another relevant issue strictly related to soil sealing and its consequences are ES. Since the 1990s, and especially since the Millennium Ecosystem Assessment publication (2005), ES became a mainstream topic in scientific literature; however, only recently researches analyze ES in urban areas and cities. A deep analysis of urban ES is useful to understand how soil sealing severely affects benefits provided by natural and semi-natural areas. Hence, a comprehensive analysis should take into account which are these areas supplying urban ES (vegetated systems such as agricultural and equipped green areas), where are located and how it could be possible to safeguard them.

Dealing with these topics allows to investigate alternative strategies to tackle the phenomenon.

On the other hand, measures and policies facing the reduction and limitation of soil sealing are mainly developed by policy reports, or technical and administrative guidelines and less by scientific literature.

Overall, scientific literature used in the research is mainly focused on worldwide case studies and examples, from the USA to European countries, from China to African study cases. However, two important features to take into account during scientific search are i) scale of analysis; ii) location of the study cases. These two characteristics are fundamental in order to find relevant examples to compare to the study case of this thesis, Padua. Indeed, in this work the scale of analysis of Padua is considered as a large scale (according to geographical concept of scale); moreover, it is worth noting the physical dimension of the urban fabric according to the territorial context; i.e., the urban fabric might be completely different if we consider the urban context of cities in Europe, US or China. By following these two characteristics, the main relevant articles helpful for the present research are located in Europe by showing small-medium dimension of the city. The search related to these two features influence also materials and methods adopted to map and to quantify soil sealing in Padua. Finally, literature survey investigates GIScience approaches and GIS techniques that might be strengthen the comprehension of the phenomenon as well as to perform territorial analyses.

3.5.2. Technical reports for policy making

Soil sealing is a topic that is deeply reported in grey literature by aiming to reach a wider public such as local institutions and organizations from civil society. Grey literature is published by institutions and administrations as well as national and international NGOs and local associations, books, reports, thesis, articles proceedings, web pages and news are some of the formats that could be read and used by these stakeholders. Information, territorial data and spatial data from the grey literature is used in this thesis.

At international level, the role of institutions is paramount to investigate the phenomenon. FAO instituted in 2015 the International Year of Soil, stressing the importance of this non-renewable natural resource and the anthropic risk, such as soil sealing, related to it (FAO 2015,2017). Moreover, UN and more specifically UN-Habitat are the worldwide institutions that developed and spread some guidelines on urbanization and soil sealing. The most important “call to action” is represented by the SDG-11 which play a key role as an important source of information and a baseline for sustainable urban planning.

An important role is also covered by EU and by EU Commission; hence, for this research it is fundamental refers to reports, legislations and regulations published by this international institution. Moreover, technical reports and data from Copernicus Monitoring System and EEA are of great interest to enhance the knowledge on the extension of soil sealing in EU.

In Italy, at national level, ISPRA is the main institution that is responsible to assess and to map soil sealing, by publishing an annual report on the national, regional and local dimension of such phenomenon. Data and publications of ISPRA are the basis to have a general overview of the topic. Moreover, Legambiente NGO is one of the key organization which spread reports on soil sealing animating the public debate about such issue. The annual report on Urban Ecosystem provides a ranking of the environmental performance of 105 Italian provincial capital: among 18 parameters, an indicator is dedicated to soil sealing, while another indicator is addressed to public urban green areas. Overall, other institutions, NGOs and authors cover very widely the topic, such as Centro di Ricerca sui Consumi di Suolo (CRCS) (CRCS 2018) and studies written by Paolo Pileri (Pileri 2007,2018; Ronchi et al. 2013). Also some specific web sites, for example Edilportale, are an example of secondary literature useful to understand the issue and its implications in the public debate.

At local level, Legambiente Padova follows the issue of soil sealing at municipal level, by publishing web articles and news on the main relevant decisions and strategies (Sergio Lironi 2018; Legambiente Padova 2019b,2021). Finally, local newspapers are referred to collect the main news in Padua.

3.6. Aims of the thesis

The general objective of the thesis aims to investigate the complex phenomenon of soil sealing. As mentioned, soil sealing affects different aspects of the urban territory, compromising natural and semi-natural soils, such as green and agricultural areas, human and physical wellbeing of citizens, and others ES related to soil.

Hence, soil sealing is firstly analyzed for its geographical dimension, mapping the phenomenon or detecting temporal changes; secondly, the thesis investigates other dimensions of the phenomenon, such as ecological, economic and social dimensions in order to achieve a more sustainable and inclusive urban management.

The specific objectives are the followings:

- I. assessing and mapping soil sealing at different scales of analysis by identifying and analyzing the main sources, methodologies and techniques;
- II. mapping and classifying soil sealing in Padua by testing the Biotope Area Factor as urban ecological index;
- III. mapping and assessing UGS according to the property status in the city of Padua for sustainable spatial planning based on ES and NBS;
- IV. investigating the phenomenon of UA in modern cities, focusing on agroecology approach and which methodologies might be used in order to adopt this practice in urban areas;
- V. investigating participatory mapping methodologies in support of urban sustainability analysis.

The objectives are developed and addressed in the five articles included in this thesis.

3.7. Geographical framework: the city of Padua

Padua was selected as main case study for analyzing the complex phenomenon of soil sealing, indeed three out of five articles are focused territorial analyses on in this city. Due to the specific nature of the review, there are no case studies in Article II and also Article V.

Padua is a city located in the Veneto Region, in the North-East of Italy, 35 km west of Venice. The municipality area covers 93 km² and, in 2021, resident population accounts for 208,350 inhabitants (Comune di Padova 2021c) (Figure 5 and 6).

After the II World War, Padua experimented a rapid urban development: new medium-density residential districts were built around the downtown, while a new industrial area, named “Zona Industriale di Padova - ZIP” was located in the east sector of the city. The city of Padua is affected also by the phenomenon of urban sprawl and sparse new buildings or complexes spreading on the urban fringes (Marzari 2008).

Padua, is a city of great interested for this research due to its phenomenon of soil sealing. Indeed, as already explained, Padua is one of the most affected cities in Italy, ranked as fifth between cities of more than 100,000 inhabitants by ISPRA 2020 report (ISPRA 2021). It is worth noting that in this rank, it is preceded by three cities with a population of almost one million people or more, that are

Turin (886,837 inhabitants and 65% of soil sealing in 2020), Naples (3,085,000 inhabitants and 62,9% of soil sealing in 2020) and Milan (1,352,000 inhabitants and 58,2% of soil sealing in 2020). Later, Pescara, Padua and Monza present a similar percentage of soil sealing with almost 50% of impermeable surfaces. All of these city has a population have a much lower population than the top three cities, ranging from 200,000 to 100,000 inhabitants (Table 3).

Regarding administrative units, Padua is currently divided into 6 neighborhoods (quartieri) and 40 sub-neighborhood urban units (unità urbane) and 10 neighborhood consultation units (consulte di quartiere).

Finally, it is important to highlight that the choice of the city of Padua as the main study case is twofold: i) it is my home town; ii) it is a paradigmatic case in relation to the studied phenomenon.

Firstly, Padua is the city of my birth and the city where for most of my time I lived; hence, knowledge about territory, its dynamics and its changes during these years is consolidated. Hence, it was paramount for me understanding soil sealing and socio-environmental impacts on the urban territory, stakeholder dynamics, and possible solutions related to the phenomenon.

Secondly, Padua for its dimension, population and urban fabric is a model city in Europe. Indeed, as many other European cities it is a little-medium size city, developed around a river (Bacchiglione river), with a medieval city center and suburban areas mainly composed by agricultural areas. Moreover, is one five cities in Italy with the majority of sealed surfaces (about 50%). For this reason, it could be used as a paradigmatic study case to tackle soil sealing not only in Italy, but more generally in Europe.



Figure 5 Geographical framework: Veneto region in Europe (left image) and the Municipality of Padua in Veneto (right image)

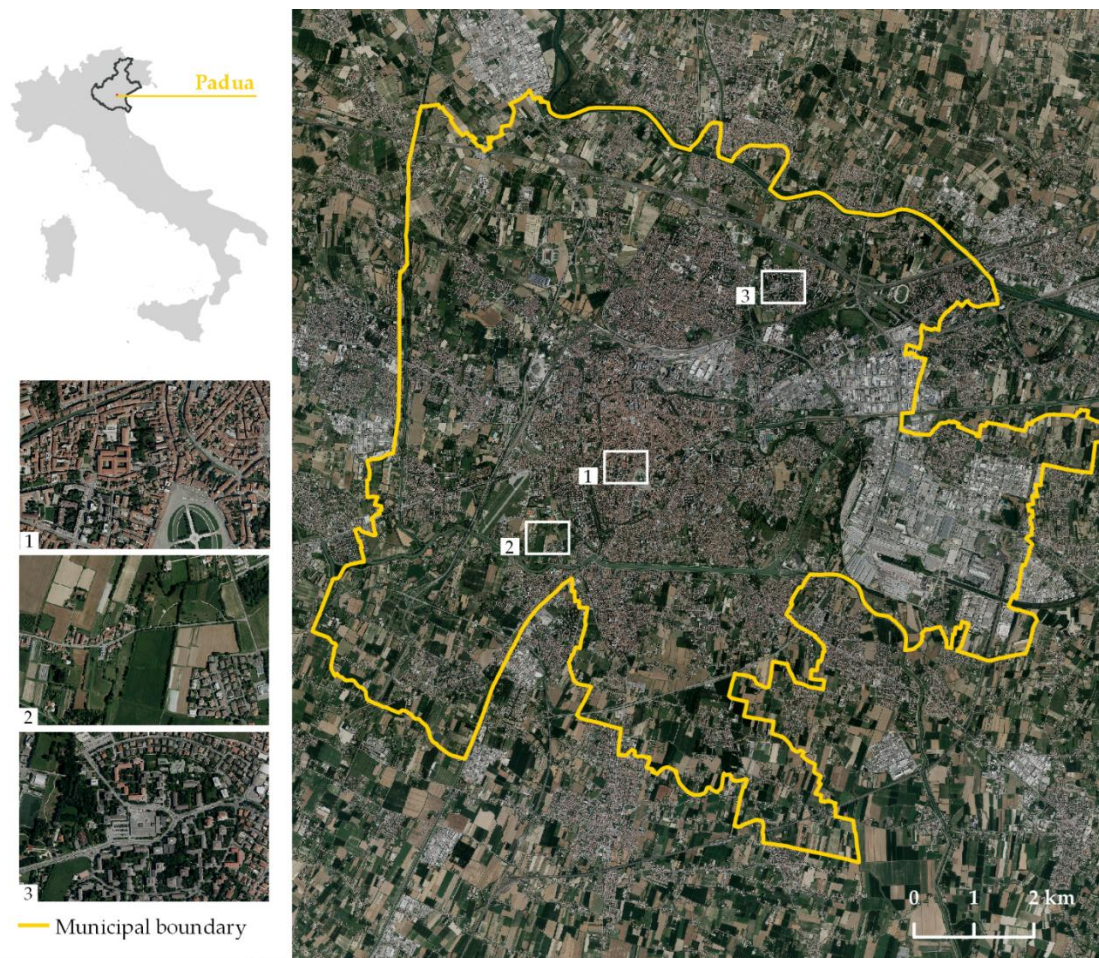


Figure 6 Geographical framework of Padua and a zoomed-in image on different types of urban fabric of the city

City	Inhabitants	Percentage of soil sealing in 2020
1 Turin (Piedmont)	886,837	65%
2 Naples (Campania)	3,085,000	62,9%
3 Milan (Lombardy)	1,352,000	58,2%
4 Pescara (Abruzzo)	120,420	51,3%
5 Padua (Veneto)	209,829	49,6%
6 Monza (Lombardy)	122,813	49,3%
7 Bergamo (Lombardy)	120,287	44,6%
8 Brescia (Lombardy)	196,670	44,1%

Table 3 Soil sealing in percentage (2020) at municipal level (first 8 municipalities with more than 100,000 inhabitants).

Source: ISPRA elaborations, 2021

3.8. Presentation of the articles

Article I is titled “Geografia urbana e partecipazione nell’era digitale: tre esperienze a Padova tra GIScience e VGI” (2019, Bollettino della Associazione Italiana di Cartografia).

The general objective of the paper aims to investigate how participatory mapping methodologies, such as VGI and PGIS, could involve cities in support urban sustainability analysis. Three case study cases are used and they focused on three different topics of urban sustainability: “Il Valore del Suolo”, to map soil sealing in a sample area in Padova; “Piste Riciclabili”, to detect critical issues cycle paths in Padova; “MUES – Mapping Urban Empty Spaces”, to map abandoned sites, such as buildings, brownfield and abandoned areas in Padua.

Methodologies used to develop these project are within the general frame of the citizen science approach which implies the enrollment of non-expert public in specific research activities. However, the methods are strictly related to geographical framework and spatial data.

The use of these methodologies show that: i) non-expert population could actively participate in scientific research, by the production of spatial data with GIS, webmap or geotool; ii) citizens could approach and learn complex research topics.

Citizens involved are able to produce maps and cartographic data that, after expert validation, are useful for scientific research. Hence, local experience of dwellers is fundamental to enrich specific research topics, thanks to the collection of geographical information that only those living the city are able to report. For example, results from the project “MUES: Mapping Urban Empty Spaces”, was made possible thanks to the contribution of citizens that know abandoned areas of the city.

In conclusion, these three examples show how the participation of citizens can both make a real contribution to scientific research and can increase the empowerment and awareness of citizens investigating socio-environmental issues.

Article II is titled “How to map soil sealing? A systematic review” (manuscript submitted to Environmental Research Letter in November 2021). The manuscript performed a systematic review on soil sealing mapping techniques. In the last two decades, only two recent review articles analyzed papers on the identification and mapping of soil sealing/impervious surfaces (Weng 2012; Wang and Li 2019) and a third older review published in 2001 examined the phenomenon (Slonecker et al. 2001). All these reviews focused only on keywords “impervious surface”, without including scientific articles which use other terminology in representing the phenomenon. In fact, such irreversible land use change phenomenon is still not uniquely defined in scientific literature. According to a recent study other terms are commonly adopted such as “soil sealing”, “land take”, “soil consumption”, and “land consumption” (Marquard et al. 2020).

Hence, a systematic Scopus search was conducted between the period 2000-2020, identifying 1,177 articles on the topic of soil sealing. Of these, 392 scientific articles focused on quantifying and mapping the phenomenon.

The main keywords were analyzed: "Impervious surfaces" is the most used definition (77%), followed by "soil sealing" (10%), "land consumption" (5%), "land take" (4%), and "soil consumption" (4%). Soil sealing is mainly studied by USA, China and Italy (418, 311 and 124 results). The results show that most of the studies focused on mapping soil sealing at urban scale (209 results). Landsat satellite platforms are the most adopted (392); Landsat 4-5 are the most used (162), followed by Landsat 7 (118), Landsat 8 (112). The results also show that multi-temporal analyses are frequent (48% of studies). 11 different methodologies were identified: automatic classifications are the most adopted (92.75%), with the pixel/sub-pixel approach dominating (SMA 26.35%; Decision/Regression Tree 23.22%); other methods include band ratio (14.5%), supervised (7.41%), OBIA (7.08%), ANN (5.44%). Because Landsat imagery is the most widely used, most mapping analyses (392) were performed on 30 m resolution imagery in study areas of 1,000-10,000 km², primarily adopting SMA (74) and Decision/Regression Tree (29) methodologies; Landsat imagery is less used for areas ≤ 100km² (30), modeled by SMA (14), unsupervised (9) and supervised (4) classification, and band ratio (3). Thus, the results provide an application framework for understanding the relationships among remote sensing platforms, spatial and temporal scales, study area size, and methodologies. Generally, as area size increases, there is a decrease in image resolution with the use of fully automated classification methodologies

Most studies have focused on testing and comparing classification techniques, highlighting the need to direct research in support of soil protection policies and sustainable urban planning. Hence, we encourage to fill the gap by developing approaches that applicable to international policies.

Article III is titled "Biotope Area Factor: An Ecological Urban Index to Geovisualize Soil Sealing in Padua, Italy" (Sustainability 2020). The general aim is to estimate and geovisualize soil sealing at urban scale in Padua. The specific aims are (i) quantifying the amount of soil sealing at a very detailed scale; (ii) testing the use of the BAF index; and (iii) simulating an alternative mitigated scenario by using the BAF index in a specific study area of the city. Spatial analyses are performed in GIS environment and using aerial ortho-photos at very high resolution. The study is focused on four representative macro-areas in the city of Padua, that present an average area of 290 ha. These areas are two residential neighborhoods located near the center, an agricultural-dominant neighborhood located in the western sector and part of the industrial area of the city located in the east sector.

The results show different values of the BAF index for all four neighborhoods from 0.35 to 0.69 (the index present a range of value from 0, completely impermeable surfaces, to 1, completely permeable surfaces).

To perform a simulated mitigation scenario, the article followed a strategy proposed by the EU guidelines (2012a) to tackle the phenomenon. The area identified to test this mitigation scenario is the industrial neighborhood, that presents the lowest value of BAF index. The strategy proposes the

installation of green roofs; hence this scenario is modeled using the BAF index, assigned 0.7 value to plan roof of industrial buildings (according to BAF index, 0.7 value expresses the rooftop surface permeability). The result shows a BAF index that increases from 0.35 to 0.59.

In conclusion, the paper provides an insightful case study for enriching the debate about soil sealing and it shows how BAF index is a successful tool to calculate soil sealing at urban scale, to geovisualize the degree of soil permeability and to modeling future scenario that aims to achieve a more sustainable urban planning.

Article IV is titled “Whose Urban Green? Mapping and Classifying Public and Private Green Spaces in Padua for Spatial Planning Policies” (Journal of Geo-Information 2021). The general aim of this article is mapping and classifying urban green spaces in Padua by integrating NDVI-based analyses. Specific aims are (i) testing an NDVI extraction from very high-resolution aerial images; (ii) classifying property status and land use of UGS; (iii) highlighting multilevel relationships and possible strategies for urban green spaces implementation and management; (iv) assess the distribution and the amount of UGS in relation to per capita population, an indicator to assess environmental quality and availability of vegetated areas by dwellers.

UGS are obtained combining remote sensing and GIS analysis. Afterward, UGS data are classified in three binary categories:

1. Rural–non-rural: UGS are divided in vegetated areas and agricultural areas;
2. Public–private: UGS are divided according to their property status, thus it is possible to identify public and private UGS.
3. Municipal–non-municipal: public UGS are divided into UGS owned by Padua Municipality and UGS owned by others public administrations, such as university UGS, Province of Padua UGS, Veneto Region UGS, and Italian Ministry of Defence UGS.

To obtain the second and third classification, an overlay between cadastral maps of land parcels owned by public institutions in Padua and UGS is performed. This task was possible thanks to Padua Municipality, which provided a table of Italian public institutions that were filtered to select public administrations and institutions owning land plots in Padua.

Results show that, among total green spaces (52.23 km²), more than half are rural 28.8 km² (55%), while vegetated areas are 23.4 km². Moreover, private green spaces represent 41.9 km² (80%), while within public areas (20%) less than 10% are municipal (5 km²). We therefore highlight scenarios for planning policies in Padua by providing tools to policymakers for an integrated management of green spaces, where private greenery might also contribute to ecosystem services implementation for common urban well-being. Results of per capita indicator show that there are 247.35 m² of per capita UGS, whereas public UGS amount to 48.54 m² per capita, and municipal UGS areas are 23.77 m² per capita.

Overall, these results are quite remarkable, but it is important to highlight that they are calculated considering both vegetated and agricultural areas, while EU data reported this value only in relation to public green areas. Considering 42 urban units of Padua, these results completely change. Urban unit located in the city center or in the densely populated northern district show the lowest rates of total, public and municipal UGS, while the highest rates are shown in scarcely populated, mostly agricultural peripheral urban units. Finally, the article highlights scenarios for planning policies in Padua by providing tools to policymakers for an integrated management of green spaces and to develop site-specific strategies to enhance environmental and social benefits provided by vegetated and permeable areas to citizens. For instance, some strategies could be a major balance in green space distribution, increasing municipal UGS especially in more densely urban areas or considering that private green areas might contribute to ES implementation for common urban well-being.

Article V is entitled “Smart Cities and Agroecology: Urban Agriculture, Proximity Food and Urban Ecosystem Services” (in press, chapter of the book “Drones and Geographical Information Technologies in Agroecology and Organic Farming: Contributions to Technological Sovereignty”, CRC Press).

Firstly, the chapter provides a critical perspective on one of the most promising models of the city of the future (smart cities) and it highlights how the issue of “urban food” is not covered in smart city debate; secondly it stresses how academic research as well as the social demands on UA are constantly growing, in order to understand how to feed a growing population and to achieve a more sustainable agricultural production. Hence, the chapter investigates if and how the diffusion of the agroecological approach in UA could be feasible and how it could foster human wellbeing in cities. Finally, the research shows that, due to the high skills required by citizens and farmers, the spread of these agricultural approach could be difficult, even if the use of Information Communication System (ICT), common tools of smart cities, could involve innovative devices and resources to support the diffusion and knowledge of this practice in urban environments.

Indeed, according to some innovative examples, ICT could help every phase of the agroecological system, from the design of the agroecosystem to the maintenance of the unit, and they could be a great support to experts, new practitioners and citizens (Norton et al. 2019). The introduction of ICT in agroecosystems could be applied through two different methods:

1. models to disseminate practices and to connect experts and citizens;
2. introduction and application of open source IoT technologies.

At present, these two methods are an emerging field in the urban agroecology discourse and only in recent years, researchers and agroecologists have joined forces to develop these technologies for serving citizens. Hence, the chapter analyses two of these models, focusing on smartphone app farmbetter.

Smartphone app farmbetter is mainly addresses for rural communities in developing countries and it is developed for measuring and improving resilience of farmers in face of climate change, for example providing them with right strategies to adapt and to contrast extreme events or specific shocks, as floods and drought.

These examples illustrate how ICT are important tools in the development of cities of the future and, at the same time, how new technologies and data could be applied also to develop sustainable UA, with the introduction of an agroecological approach.

4. RESEARCH PERSPECTIVES

The present applied research has responded to a first need of increasing geographical knowledge about soil sealing and it has been continuously fed by the scientific and public debate on limiting the phenomenon and adopting possible solutions to increase urban sustainability. As shown by recent EU data, soil sealing is still not under control, even if the new EU Soil Strategy for 2030 sets new ambitious goals. Further applied researches both for monitoring soil sealing by using open geospatial data and technologies and to perform ES-based mitigation scenarios might be useful for a more sustainable urban management and development.

This research on soil sealing is a long lasting research inside the research group “Climate change, territories, diversity” of the ICEA Department (University of Padua). Since before my PhD, I had the possibility to take and to develop my specific topics in the group; hence, the issue of soil sealing and more generally of urban sustainability became one of the three lines of research of group: unburnable carbon and energy transition scenarios in Amazon rainforest; urban sustainability and inclusive cities; agroecology and agricultural sustainability.

From this perspective, I have planned to continue the research developing different issues. Hence, three main research pathways linked to the present thesis are under development: i) integrated analysis of UES along green and blue infrastructures within the urban territory of Padua; ii) how citizens perceive and value urban green areas during the time of COVID pandemic iii) how policy maker are facing the challenge of urban sustainability.

The first research pathway was designed and ongoing. More specifically, it aims to map and to assess UES along the system of ancient walls, canals and rivers of the city of Padua. By the coordination and the support of research activities, developed in the framework of the bachelor degree in Natural Science (Department of Biology, University of Padua) and the professional Master in GIScience and UAV (University of Padua) different studies investigated specific areas of the city, focusing on the estimation of carbon storage and sequestration ES, in a time-frame from 1955 to 2018. Materials used to provide this analysis are aerial images (1955, 1981, and 2018) that were analyzed in GIS environment to detect land use/land cover changes. The second step was to estimate carbon storage and sequestration by using the suite model InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs), used to map and value ES (Natural Capital Project 2021).

The second research pathway aims to assess the perceptions and values of urban green areas by performing a qualitative survey through an online form. A questionnaire has already been designed and spread in Padua citizenship starting from June 2021. Questions addressed by the survey are almost 30 and they are focused on:

- general overview about the neighborhoods in which the person lives, focusing on environmental and social issues;
- behaviors and habits in green areas, which areas are mainly visited;

- pandemic and green areas: how are changing behaviors during COVID 19 and how is changing perception of these areas;
- soil sealing, value of natural and built areas and measures to contrast the phenomenon;
- personal data.

The questionnaire is provided online and, at present, more than 600 forms were collected. The research plan provides for a time of survey until March 2022.

According to some researches (Kothencz et al. 2017; Ugolini et al. 2020), perception of green areas changed during these years of pandemic; hence it is interesting to investigate if citizens have a stronger awareness of these areas.

Finally, of great interest for research is also the way policymakers are acting to face the challenge of urban sustainability in the context of climate adaptation. This path follows a parallel approach from one side by interviewing policymakers and from the other side the participant observation of the planning process to prepare the new Padua PI. As mentioned, the implementation of the new PI is underway and it is currently at the center of the public debate about the future urban development of the city. In Autumn 2021, I took part into different meeting with Padua policymakers to discuss about the new PI. In particular, I had the possibility to share my research and to discuss with the “Council Member of Environment, Green areas, Parks and Agriculture” (deleghe: politiche del lavoro e dell'occupazione, ambiente, verde, parchi e agricoltura, Agenda 21) Chiara Gallani and with Ciro Degli Innocenti, main responsible of the “Green, Parks and Urban Agriculture Sector”. In the same period, I had also the opportunity to meet the “Council Member of Territorial policies, sustainable urban management, and mobility” Andrea Ragona (deleghe: politiche del territorio e sviluppo urbano sostenibile, mobilità e viabilità.) and to Danilo Guarti, manager of “Urban Planning and Cadastral Srvices Sector”. Also this meeting was useful to analyze future scenario for the city according to the new PI.

During the meetings policymakers had the possibility to directly know and to interact with the present research as well as to discuss about future strategies for the city to mitigate the effects of soil sealing. In addition, I participated at the public meetings of presentation of the new PI. During these meetings, I saved the videos in order to review it during the next phases of the research and better understand the further steps and the roadmap of the Municipality. Moreover, it gives me the possibility to assess the involvement of stakeholders of the city for a more inclusive urban development.

REFERENCES

- Adhikari, K. and A. E. Hartemink. 2016. Linking soils to ecosystem services — A global review. *Geoderma*. 262:101–111.
- Aksoy, E. M. Gregor C. Schröder M. Löhnertz and G. Louwagie. 2017. Assessing and analysing the impact of land take pressures on arable land. *Solid Earth*. 8:683–695.
- Alamanos, A. S. Sfyris C. Fafoutis and N. Mylopoulos. 2020. Urban water demand assessment for sustainable water resources management, under climate change and socioeconomic changes. *Water Supply*. 20:679–687.
- Alberti, V. M. Alonso Raposo C. Attardo D. Auteri R. Barranco F. Batista e Silva P. Benczur P. Bertoldi F. Bono I. Bussolari S. Caldeira J. Carlsson P. Christidis A. Christodoul B. Ciuffo S. Corrado C. Fioretti M. C. Galassi L. Galbusera B. Gawlik F. Giusti J. Gomez M. Grosso Â. Guimarães Pereira C. Jacobs-Crisioni B. Kavalov M. Kompil A. Kucas A. Kona C. Lavallo A. Leip L. Lyons A. R. Manca M. Melchiorri F. Monforti-Ferrario V. Montalto B. Mortara F. Natale F. Panella G. Pasi C. Perpiña M. Pertoldi E. Pisoni A. Polvora A. Rainoldi D. Rembges G. Rissola S. Sala S. Schade N. Serra L. Spirito A. Tsakalidis M. Schiavina G. Tintori L. Vaccari T. Vandyck D. Vanham S. Van Heerden C. Van Noordt M. Vespe N. Vetter N. Vilahur Chiaraviglio P. Vizcaino U. Von Estorff and G. Zulian. 2019. The future of cities : opportunities, challenges and the way forward. Publications Office, Luxembourg. Retrieved from https://op.europa.eu/publication/manifestation_identifier/PUB_KJNA29752ENC. Accessed September 2021.
- Altieri, M. A. and C. I. Nicholls. 2019. Urban agroecology. *AgroSur*. 46:46–60.
- Amato, F. F. Martellozzo G. Nolè and B. Murgante. 2017. Preserving cultural heritage by supporting landscape planning with quantitative predictions of soil consumption. *Journal of Cultural Heritage*. 23:44–54.
- Amundson, R. A. A. Berhe J. W. Hopmans C. Olson A. E. Sztein and D. L. Sparks. 2015. Soil and human security in the 21st century. *Science*. 348.
- Aragón-Durand, F. J. Corfee-Morlot R. B. R. Kiunsi M. Pelling D. C. Roberts and W. Solecki. 2014. Urban Areas. 535–612 *In* V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. . Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, N. Levy, S. MacCracken, P. R. Mastrandrea, and L. L. White, editors. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Armson, D. P. Stringer and A. R. Ennos. 2012. The effect of tree shade and grass on surface and globe temperatures in an urban area. *Urban Forestry & Urban Greening*. 11:245–255.
- Arnold, C. L. and C. J. Gibbons. 1996. Impervious Surface Coverage: The Emergence of a Key Environmental Indicator. *Journal of the American Planning Association*. 62:243–258.
- Arsanjani, J. J. A. Zipf P. Mooney and M. Helbich. 2015. An Introduction to OpenStreetMap in Geographic Information Science: Experiences, Research, and Applications. 1–15 *In* J. J. Arsanjani, A. Zipf, P. Mooney, and M. Helbich, editors. *OpenStreetMap in GIScience. Experiences, Research, and Applications*. Springer.
- Artmann, M. 2013a. Spatial dimensions of soil sealing management in growing and shrinking cities - A systemic multi-scale analysis in Germany. *Erdkunde*. 67:249–264.

- Artmann, M. 2013b. Driving Forces of Urban Soil Sealing and Constraints of Its Management - the Cases of Leipzig and Munich (Germany). *Journal of Settlements and Spatial Planning*. 4:143–152.
- Artmann, M. 2013c. Response-efficiency-assessment: A conceptual framework for rating policy's efficiency to meet sustainable development on the example of soil sealing management. *Journal of Environmental Assessment Policy and Management*. 15.
- Artmann, M. 2014. Institutional efficiency of urban soil sealing management - From raising awareness to better implementation of sustainable development in Germany. *Landscape and Urban Planning*. 131:83–95.
- Artmann, M. 2015. Managing urban soil sealing in Munich and Leipzig (Germany)-From a wicked problem to clumsy solutions. *Land Use Policy*. 46:21–37.
- Artmann, M. L. Inostroza and P. Fan. 2019. Urban sprawl, compact urban development and green cities. How much do we know, how much do we agree? *Ecological Indicators*. 96:3–9.
- Artmann, M. and K. Sartison. 2018. The Role of Urban Agriculture as a Nature-Based Solution: A Review for Developing a Systemic Assessment Framework. *Sustainability*. 10:1937.
- Balducci, A. 2012. Creative Governance in Dynamic City Regions. <https://doi.org/10.1080/02513625.2004.10556889>. 40:21–26.
- Ballin, M. G. Barcaroli M. Masselli and M. Scarnó. 2018. Redesign sample for Land Use/Cover Area frame Survey (LUCAS) 2018. Luxembourg. Retrieved from <https://ec.europa.eu/eurostat/documents/3888793/9347564/KS-TC-18-006-EN-N.pdf/26cbdb1a-c418-4dfa-bc24-a27d1bc5599c?t=1540804305000>. Accessed July 2021.
- Bass, B. and E. Koukidis. 2012. Reducing urban heat islands: simulating aggregate green roof performance. *CitiesAlive! 10th Annual Green Roof & Wall Conference*.
- Berland, A. and M. E. Hopton. 2014. Comparing street tree assemblages and associated stormwater benefits among communities in metropolitan Cincinnati, Ohio, USA. *Urban Forestry & Urban Greening*. 13:734–741.
- Berland, A. S. A. Shiflett W. D. Shuster A. S. Garmestani H. C. Goddard D. L. Herrmann and M. E. Hopton. 2017. The role of trees in urban stormwater management. *Landscape and Urban Planning*. 162:167–177.
- Bhatta, B. 2010. Causes and Consequences of Urban Growth and Sprawl. 17–36 *Analysis of Urban Growth and Sprawl from Remote Sensing Data*. Advances in Geographic Information Science. Springer, Berlin, Heidelberg.
- Blanchart, A. J. N. Consalès G. Séré and C. Schwartz. 2018. Consideration of soil in urban planning documents—a French case study. *Journal of Soils and Sediments* 2018 19:8. 19:3235–3244.
- Il Bo Live (Università di Padova). 2021. Quanto sono verdi le nostre città? . Retrieved from <https://ilbolive.unipd.it/it/news/quanto-sono-verdi-nostre-citta>. Accessed January 2022.
- Boeri, S. 2021. Padova Città dei Rioni. Verso il Piano degli Interventi . Retrieved from <https://www.padovanet.it/sites/default/files/attachment/Padova 2030 - Verso il Piano degli interventi.pdf>. Accessed December 2021.
- Bowler, D. E. L. M. Buyung-Ali T. M. Knight and A. S. Pullin. 2010. A systematic review of evidence for the added benefits to health of exposure to natural environments. *BMC Public Health*. 10:1–10.
- Bowyer, C. S. Albrecht C. Keenleyside M. Kemper S. Nanni S. Naumann D. Mottershead R. Landgrebe E. Andersen P. Banfi S. Bell I. Brémere J. Cools S. Herbert A. Iles E. Kampa M. Kettunen Z. Lukacova G.

- Moreira Z. Kiresiewa J. Rouillard J. Okx M. Pantzar K. Paquel R. Pederson A. Peepson F. Pelsy D. Petrovic E. Psaila B. Šarapatka J. Sobocka A.-C. Stan J. Tarpey and R. Vidaurre. 2016. Updated Inventory and Assessment of Soil Protection Policy Instruments in EU Member States. Final Report to DG Environment. Berlin.
- Bristow, K. L. S. M. Marchant M. Deurer and B. E. Clothier. 2010. Enhancing the ecological infrastructure of soils.
- Brown, G. and M. Kytä. 2014. Key issues and research priorities for public participation GIS (PPGIS): A synthesis based on empirical research. *Applied Geography*. 46:122–136.
- Brown, L. R. 2001. *Eco-economy: building an economy for the earth*. Earthscan.
- Brueckner, J. K. E. Mills and M. Kremer. 2001. *Urban Sprawl: Lessons from Urban Economics*. Brookings-Wharton Papers on Urban Affairs.:65–97.
- Brunetti, G. J. Šimůnek M. Turco and P. Piro. 2017. On the use of surrogate-based modeling for the numerical analysis of Low Impact Development techniques. *Journal of Hydrology*. 548:263–277.
- BuGG. 2020. *Inventory and Potential Analysis of Green Roofs*. Retrieved from https://www.gebaeudegruen.info/fileadmin/website/Englisch/Inventory_Pot/Inventory_and_potential_analysis.pdf. Accessed December 2021.
- BuGG. 2021. *BuGG Market Report Building greening 2020*. Retrieved from <https://www.gebaeudegruen.info/aktuelles/pressemitteilungen/details/bugg-market-report-building-green-2020-published>. Accessed December 2021.
- Buscemi, L. 2021. *Analisi dei cambiamenti di uso del suolo e dei servizi ecosistemici lungo i Canali e le Mura di Padova*. Università degli Studi di Padova.
- Carter, T. and L. Fowler. 2008. Establishing green roof infrastructure through environmental policy instruments. *Environmental Management*. 42:151–164.
- Carvalho, D. H. Martins M. Marta-Almeida A. Rocha and C. Borrego. 2017. Urban resilience to future urban heat waves under a climate change scenario: A case study for Porto urban area (Portugal). *Urban Climate*. 19:1–27.
- Castaldo, A. G. 2018. *Dai quartieri alla scala urbana: modellizzazione e scale-up della mappatura del consumo di suolo a Padova mediante l'uso dell'indice Biotope Area Factor*. Università degli Studi di Padova.
- Castleton, H. F. V. Stovin S. B. M. Beck and J. B. Davison. 2010. Green roofs; building energy savings and the potential for retrofit. *Energy and Buildings*. 42:1582–1591.
- Chapin, F. S. S. F. Trainor O. Huntington A. L. Lovcraft E. Zavaleta D. C. Natcher A. D. McGuire J. L. Nelson L. Ray M. Calef N. Fresco H. Huntington T. S. Rupp L. DeWilde and R. L. Naylor. 2008. Increasing Wildfire in Alaska's Boreal Forest: Pathways to Potential Solutions of a Wicked Problem. *BioScience*. 58:531–540.
- Chen, X. C. Li M. Li and K. Fang. 2021. Revisiting the application and methodological extensions of the planetary boundaries for sustainability assessment. *Science of The Total Environment*. 788:147886.
- Cibrario, M. 2021. *Analisi diacronica dei corridoi ecologici della città di Padova utilizzando indici di ecologica del paesaggio tramite FRAGSTATS*. Università degli Studi di Padova.
- City of Toronto. 2017. *Toronto Municipal Code*. Chapter 492, Green roofs.
- Collins, J. P. A. Kinzig N. B. Grimm W. F. Fagan D. Hope J. Wu and E. Borer. 2000. A New Urban Ecology. *American Scientist*. 88:416–425.

- Commission of the European Communities. 2002. Towards a Thematic Strategy for Soil Protection. CEC, Brussels, Belgium.
- Comune di Padova. 2021a. Il nuovo Piano degli Interventi - Iter e Interlocutori.
- Comune di Padova. 2021b. Registro comunale delle associazioni . Retrieved from <https://www.padovanet.it/informazione/registro-comunale-delle-associazioni-0>. Accessed January 2022.
- Comune di Padova. 2021c. La statistica per la città. Demografia del mese: ottobre 2021. Retrieved from <https://www.padovanet.it/sites/default/files/attachment/Demo202110.pdf>. Accessed December 2021.
- Copernicus Europe's eyes on Earth. (n.d.). Land | Copernicus. Retrieved from <https://www.copernicus.eu/en/copernicus-services/land>. Accessed November 2021.
- CRCS. 2018. CRCS 2018: consumo di suolo, servizi ecosistemici e green infrastructures. (A. Arcidiacono, D. Di Simine, S. Ronchi, and S. Salata, Eds.). INU Edizioni, Roma, Italia.
- Crescini Di Montevecchio Benedetti, E. 2018. Consumo di suolo a Padova: analisi GIS del quartiere Forcellini (PD) e calcolo dell'indice Biotope Area Factor. Università degli Studi di Padova.
- Crews-Meyer, K. A. 2002. Challenges for GIScience: assessment of policy relevant human-environment interaction. *In* S. J. Walsh and K. A. Crews-Meyer, editors. Linking people, place, and policy. A GIScience Approach. Springer Science+Business Media, New York.
- Crooks, A. A. Croitoru A. Stefanidis and J. Radzikowski. 2013. #Earthquake: Twitter as a Distributed Sensor System. *Transactions in GIS*. 17:124–147.
- Czemiel Berndtsson, J. 2010, April. Green roof performance towards management of runoff water quantity and quality: A review.
- Dasmann, R. F. 2002. *Called by the Wild*. University of California Press, Berkeley and Los Angeles, California.
- Decker, E. H. S. Elliott F. A. Smith D. R. Blake and F. Sherwood, Rowland. 2003. Energy and material flow through the urban ecosystem. <http://dx.doi.org/10.1146/annurev.energy.25.1.685>. 25:685–740.
- Decoville, A. and M. Schneider. 2016. Can the 2050 zero land take objective of the EU be reliably monitored? A comparative study. *Journal of Land Use Science*. 11:331–349.
- Defries, R. and H. Nagendra. 2017. Ecosystem management as a wicked problem. *Science*. 356:265–270.
- Dickinson, J. L. B. Zuckerberg and D. N. Bonter. 2010. Citizen Science as an Ecological Research Tool: Challenges and Benefits. <http://dx.doi.org/10.1146/annurev-ecolsys-102209-144636>. 41:149–172.
- Dominati, E. M. Patterson and A. Mackay. 2010. A framework for classifying and quantifying the natural capital and ecosystem services of soils. *Ecological Economics*. 69:1858–1868.
- Donat, M. G. L. V. Alexander H. Yang I. Durre R. Vose R. J. H. Dunn K. M. Willett E. Aguilar M. Brunet J. Caesar B. Hewitson C. Jack A. M. G. Klein Tank A. C. Kruger J. Marengo T. C. Peterson M. Renom C. Oria Rojas M. Rusticucci J. Salinger A. S. Elrayah S. S. Sekele A. K. Srivastava B. Trewin C. Villarroel L. A. Vincent P. Zhai X. Zhang and S. Kitching. 2013. Updated analyses of temperature and precipitation extreme indices since the beginning of the twentieth century: The HadEX2 dataset. *Journal of Geophysical Research: Atmospheres*. 118:2098–2118.
- EEA. 2006. *Urban Sprawl in Europe: The ignored challenge*. Urban Sprawl in Europe: Landscapes, Land-Use Change & Policy. Luxemburg.
- Estellés Arolas, E. and F. González Ladrón-de-Guevara. 2012. Towards an integrating crowdsourcing definition. *Journal of Information Science* . 32:189–200.
- European Commission. 2006. Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE

COUNCIL Establishing a Framework for the Protection of Soil and Amending Directive 2004/ 35/EC, Brussels, 22.9.2006 COM(2006) 232 Final 2006/0086 (COD). Retrieved from <https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2006:0232:FIN:EN:PDF>. Accessed November 2021.

European Commission. 2010. Soil. A key resource for the EU:4.

European Commission. 2011. Roadmap to a Resource Efficient Europe. Communication from the Commission to the European Parliament, the Council, the European economic and social committee and the committee of the regions. Brussels. Retrieved from <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0571&from=EN>. Accessed April 2019.

European Commission. 2012a. Guidelines on best practice to limit, soil sealing mitigate or compensate. EC, Belgium.

European Commission. 2012b. Thematic Strategy and ongoing activities. Retrieved from https://ec.europa.eu/environment/soil/three_en.htm. Accessed November 2021.

European Commission. 2012c. Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. The implementation of the Soil Thematic Strategy and ongoing activities, COM(2012) 46 final.

European Commission. 2013. Green Infrastructure (GI) — Enhancing Europe’s Natural Capital. COM(2013) 249 final . Brussels. Retrieved from https://eur-lex.europa.eu/resource.html?uri=cellar:d41348f2-01d5-4abe-b817-4c73e6f1b2df.0014.03/DOC_1&format=PDF. Accessed December 2021.

European Commission. 2020. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions “EU Biodiversity Strategy for 2030 - Bringing nature back into our lives.” Retrieved from <https://ec.europa.eu/research/environment/index.cfm?pg=nbs>. Accessed December 2021.

European Commission. 2021a. EU Soil policy. Retrieved from https://ec.europa.eu/environment/soil/soil_policy_en.htm. Accessed November 2021.

European Commission. 2021b. European Green Deal: Commission adopts new proposals to stop deforestation, innovate sustainable waste management and make soils healthy for people, nature and climate. Retrieved from https://ec.europa.eu/commission/presscorner/detail/en/ip_21_5916. Accessed November 2021.

European Commission. 2021c. Forging a climate-resilient Europe - the new EU Strategy on Adaptation to Climate Change. Brussels. Retrieved from <https://ec.europa.eu/jrc/en/peseta-iv/economic-impacts>. Accessed December 2021.

European Commission. 2021d. The EU and nature-based solutions. Retrieved from https://ec.europa.eu/info/research-and-innovation/research-area/environment/nature-based-solutions_en. Accessed December 2021.

European Commission. 2021e. Evaluating the impact of nature-based solutions: A Summary for Policy Makers. Brussels. Retrieved from <https://op.europa.eu/en/web/eu-law-and-publications/publication-detail/-/publication/aeb73167-0acc-11ec-adb1-01aa75ed71a1>. Accessed December 2021.

European Commission. 2021f. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Forging a climate-resilient Europe - the new EU Strategy on Adaptation to Climate Change. Brussels. Retrieved from <https://ec.europa.eu/jrc/en/peseta-iv/economic-impacts>. Accessed September 2021.

- European Commission. 2021g. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. EU Soil Strategy for 2030 Reaping the benefits of healthy soils for people, food, nature and climate. COM(2021) 699 final. European Commission, Brussels.
- European Environment Agency. 2016. Urban sprawl in Europe. Copenhagen. Retrieved from <https://www.eea.europa.eu/publications/urban-sprawl-in-europe>. Accessed March 2020.
- European Environment Agency. 2018. Copernicus Land Monitoring Service. User Manual. Retrieved from <https://land.copernicus.eu/user-corner/technical-library/imperviousness-2018-user-manual.pdf>. Accessed November 2021.
- European Environment Agency. 2020. Urban adaptation in Europe : how cities and towns respond to climate change. Luxembourg.
- European Environment Agency. 2021. Nature-based solutions in Europe policy, knowledge and practice for climate change adaptation and disaster risk reduction. Luxembourg. Retrieved from <https://op.europa.eu/en/publication-detail/-/publication/da65d478-a24d-11eb-b85c-01aa75ed71a1/language-en/format-PDF/source-210308869>. Accessed December 2021.
- European Environment Agency and European Commission. 2018. Copernicus Land Monitoring Service. Europe's eyes on the terrestrial environment Space. Retrieved from <https://land.copernicus.eu/global/>. Accessed November 2021.
- European Parliament. 2021. Digital Agenda for Europe . Retrieved from <https://www.europarl.europa.eu/factsheets/en/sheet/64/digital-agenda-for-europe>. Accessed November 2021.
- European Union. 2014. Regulation (EU) No 377/2014 of the European Parliament and of the Council of 3 April 2014 establishing the Copernicus Programme and repealing Regulation (EU) No 911/2010. Retrieved from <https://www.eumonitor.eu/9353000/1/j9vvik7m1c3gyxp/vjjc00ibmhx5>. Accessed November 2021.
- Facchinelli, S. 2021. Uso del suolo, stoccaggio e sequestro del carbonio: analisi spaziale multitemporale su un'area circostante il fiume Bacchiglione a Padova. Università degli Studi di Padova.
- FAO. 2012. Why the partnership? | Global Soil Partnership | Food and Agriculture Organization of the United Nations. Retrieved from <https://www.fao.org/global-soil-partnership/about/why-the-partnership/en/>. Accessed November 2021.
- FAO. 2015. Status of the World's Soil Resources: Main Report. Retrieved from <http://www.fao.org/documents/card/en/c/c6814873-efc3-41db-b7d3-2081a10ede50/>. Accessed February 2020.
- FAO. 2017. Voluntary Guidelines for Sustainable Soil Management. Rome.
- FAO. 2021a. Agroecology Knowledge Hub . Retrieved from <https://www.fao.org/agroecology/overview/en/>. Accessed December 2021.
- FAO. 2021b. FAO SOILS PORTAL | Food and Agriculture Organization of the United Nations. Retrieved from <https://www.fao.org/soils-portal/en/>. Accessed November 2021.
- Federal Nature Conservation Act (Bundesnaturschutzgesetz, BNatSchG) . 1998. .
- Fini, A. P. Frangi J. Mori D. Donzelli and F. Ferrini. 2017. Nature based solutions to mitigate soil sealing in urban areas: Results from a 4-year study comparing permeable, porous, and impermeable pavements. Environmental Research. 156:443–454.

- Fokaides, P. A. A. Kyllili L. Nicolaou and B. Ioannou. 2016. The effect of soil sealing on the urban heat island phenomenon. *Indoor and Built Environment*. 25:1136–1147.
- Folke, C. A. Jansson J. Larsson and R. Costanza. 1997. Ecosystem Appropriation by Cities. *Ambio*. 26.
- Fotheringham, A. S. C. Brunsdon and M. Charlton. 2000. *Quantitative Geography: Perspectives on Spatial Data Analysis*. SAGE Publications Inc.
- Fritz, S. I. McCallum C. Schill C. Perger R. Grillmayer F. Achard F. Kraxner and M. Obersteiner. 2009. Geo-Wiki.Org: The Use of Crowdsourcing to Improve Global Land Cover. *Remote Sensing 2009*, Vol. 1, Pages 345-354. 1:345–354.
- Gardi, C. 2017. Impact of land take on global food security. 146–156 *In* C. Gardi, editor. *Urban Expansion, Land Cover and Soil Ecosystem Services*. Routledge.
- Gaston, K. J. 2010. Urban ecology. 1–9 *In* K. J. Gaston, editor. *Urban Ecology*. Cambridge University Press, Cambridge.
- Gazzetta Ufficiale. 2016. Legge 28 giugno 2016, n. 132. Retrieved from <https://www.gazzettaufficiale.it/eli/id/2016/07/18/16G00144/sg>. Accessed November 2021.
- Global Center on Adaptation. 2020. *State and Trends in Adaptation. Report 2020*. Rotterdam.
- Global Commission on Adaptation and World Resources Institute. 2019. *Adapt NOW: A Global Call for Leadership on Climate Resilience*.
- Goodchild, M. F. 1992. Geographical information science. *International Journal of Geographical Information Systems*. 6:31–45.
- Goodchild, M. F. 2007. Citizens as sensors: the world of volunteered geography. *GeoJournal*. 69:211–221.
- Goodchild, M. F. 2010. Twenty years of progress: GIScience in 2010. *Journal of Spatial Information Science*. 1:3–20.
- Goodchild, M. F. M. J. Egenhofer K. K. Kemp D. M. Mark and E. Sheppard. 1999. Introduction to the Varenus project. <http://dx.doi.org/10.1080/136588199240996>. 13:731–745.
- Goodland, R. and H. Daly. 1996. Environmental Sustainability: Universal and Non-Negotiable. *Ecological Applications*. 6:1002–1017.
- Governo Italiano. 2021. DL 6 novembre 2021, n. 152. Disposizioni urgenti per l'attuazione del Piano nazionale di ripresa e resilienza (PNRR) e per la prevenzione delle infiltrazioni mafiose.
- Grezzani, M. 2020. *Assessing urban ecosystem services along the San Gregorio canal: from carbon sequestration to community garden (Padua)*. Università degli Studi di Padova.
- Grimm, N. B. S. H. Faeth N. E. Golubiewski C. L. Redman J. Wu X. Bai and J. M. Briggs. 2008. Global change and the ecology of cities. *Science (New York, N.Y.)*. 319:756–60.
- Grimm, N. S. Pickett and C. Redman. 2000. *Integrated Approaches to Long-Term Studies of Urban Ecological Systems*. *BioScience*. 50:571–584.
- De Groot, R. S. M. A. Wilson and R. M. J. Boumans. 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics*. 41:393–408.
- Guerreiro, S. B. R. J. Dawson C. Kilsby E. Lewis and A. Ford. 2018. Future heat-waves, droughts and floods in 571 European cities. *Environmental Research Letters*. 13:034009.
- Haklay, M. 2013. *Citizen Science and Volunteered Geographic Information: Overview and Typology of Participation*. 105–122 *Crowdsourcing Geographic Knowledge*. Springer Netherlands, Dordrecht.
- Hartig, T. A. E. Van Den Berg C. M. Hagerhall M. Tomalak N. Bauer R. Hansmann A. Ojala E. Syngollitou G.

- Carrus A. Van Herzele S. Bell M. T. C. Podesta and G. Waaseth. 2011. Health Benefits of Nature Experience: Psychological, Social and Cultural Processes. 127–168 *In* K. Nilsson, M. Sangster, C. Gallis, T. Hartig, S. de Vries, K. Seeland, and J. Schipperijn, editors. *Forests, Trees and Human Health*. Springer, Dordrecht.
- Hartig, T. R. Mitchell S. de Vries and H. Frumkin. 2014. *Nature and Health*. <https://doi.org/10.1146/annurev-publhealth-032013-182443>. 35:207–228.
- Hayek, M. M. Novak G. Arku and J. Gilliland. 2010. Mapping Industrial Legacies: Building a Comprehensive Brownfield Database in Geographic Information Systems. *Planning Practice & Research*. 25:461–475.
- Head, B. W. 2008. Wicked Problems in Public Policy. *Public Policy*.:101–118.
- Hennig, E. I. C. Schwick T. Soukup E. Orlitová F. Kienast and J. A. G. Jaeger. 2015. Multi-scale analysis of urban sprawl in Europe: Towards a European de-sprawling strategy. *Land Use Policy*. 49:483–498.
- Honey-Rosés, J. I. Anguelovski V. K. Chireh C. Daher C. K. van den Bosch J. S. Litt V. Mawani M. K. McCall A. Orellana E. Oscilowicz U. Sánchez M. Senbel X. Tan E. Villagomez O. Zapata and M. J. Nieuwenhuijsen. 2020. The impact of COVID-19 on public space: an early review of the emerging questions – design, perceptions and inequities. <https://doi.org/10.1080/23748834.2020.1780074>.:1–17.
- Huneus, N. H. Denier van der Gon P. Castesana C. Menares C. Granier L. Granier M. Alonso M. de Fatima Andrade L. Dawidowski L. Gallardo D. Gomez Z. Klimont G. Janssens-Maenhout M. Osses S. E. Puliafito N. Rojas O. S. Ccoyllo S. Tolvett and R. Y. Ynoue. 2020. Evaluation of anthropogenic air pollutant emission inventories for South America at national and city scale. *Atmospheric Environment*. 235:117606.
- Inostroza, L. R. Baur and E. Csaplovics. 2013. Urban sprawl and fragmentation in Latin America: A dynamic quantification and characterization of spatial patterns. *Journal of Environmental Management*. 115:87–97.
- IPCC. 2021. *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Retrieved from https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf. Accessed October 2021.
- ISPRA. 2018. *Consumo di suolo, dinamiche territoriali e servizi ecosistemici*. Edizione 2018. (M. Munafò, Ed.). 1st ed. ISPRA, Roma, Italia.
- ISPRA. 2020. *Consumo di suolo, dinamiche territoriali e servizi ecosistemici*. Edizione 2020. (M. Munafó, Ed.). Roma.
- ISPRA. 2021. *Consumo di suolo, dinamiche territoriali e servizi ecosistemici Edizione 2021 Rapporto ISPRA SNPA*. Roma.
- Italia Domani. 2021. *Piano Nazionale di Ripresa e Resilienza*.
- IUCN. 2016. *Defining Nature-based Solutions*. Retrieved from https://portals.iucn.org/library/sites/library/files/resrecfiles/WCC_2016_RES_069_EN.pdf. Accessed December 2021.
- Jenny, H. 1941. *Factors of soil formation. A system of quantitative pedology*. McGraw-Hill, New York.
- Jobbágy, E. G. and R. B. Jackson. 2000. The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological Applications*. 10:423–436.
- Jörissen, J. and R. Coenen. 2004. *Instrumente zur Steuerung der Flächennutzung. Auswertung einer*

- Befragung der interessierten und betroffenen Akteure [Instruments for controlling land use. Evaluation of a survey of interested and affected actors (Hintergrundpapier Nr. 10)]. Berlin. Retrieved from <https://www.itas.kit.edu/pub/v/2004/joco04a.pdf>. Accessed December 2021.
- Kaloustian, N. and Y. Diab. 2015. Effects of urbanization on the urban heat island in Beirut. *Urban Climate*. 14:154–165.
- Kennard, N. J. and R. H. Bamford. 2020. Urban Agriculture: Opportunities and Challenges for Sustainable Development. 1–14 In W. Leal Filho, A. Azul, L. Brandli, P. Özuyar, and T. Wall, editors. *Zero Hunger. Encyclopedia of the UN Sustainable Development Goals*. Springer, Cham, Switzerland.
- Kennedy, C. J. Cuddihy and J. Engel-Yan. 2007. The changing metabolism of cities. *Journal of Industrial Ecology*. 11:43–59.
- Kennedy, C. S. Pincetl and P. Bunje. 2011. The study of urban metabolism and its applications to urban planning and design. *Environmental Pollution*. 159:1965–1973.
- Kleinschroth, F. and I. Kowarik. 2020. COVID-19 crisis demonstrates the urgent need for urban greenspaces. *Frontiers in ecology and the environment*. 18:318–319.
- Koblensky, W. 2016. How Toronto Became a Hub for Green Roofs. Retrieved from <https://torontoist.com/2016/09/how-toronto-became-a-hub-for-green-roofs/>. Accessed December 2021.
- Koch, A. A. McBratney M. Adams D. Field R. Hill J. Crawford B. Minasny R. Lal L. Abbott A. O'Donnell D. Angers J. Baldock E. Barbier D. Binkley W. Parton D. H. Wall M. Bird J. Bouma C. Chenu C. B. Flora K. Goulding S. Grunwald J. Hempel J. Jastrow J. Lehmann K. Lorenz C. L. Morgan C. W. Rice D. Whitehead I. Young and M. Zimmermann. 2013. *Soil Security: Solving the Global Soil Crisis*. *Global Policy*. 4:434–441.
- Köhler, M. and D. Kaiser. 2021. Green Roof Enhancement on Buildings of the University of Applied Sciences in Neubrandenburg (Germany) in Times of Climate Change. *Atmosphere* 2021, Vol. 12, Page 382. 12:382.
- Kothencz, G. R. Kolcsár P. Cabrera-Barona and P. Szilassi. 2017. Urban Green Space Perception and Its Contribution to Well-Being. *International Journal of Environmental Research and Public Health*. 14:766.
- Kumar, K. J. Kozak L. Hundal A. Cox H. Zhang and T. Granato. 2016. In-situ infiltration performance of different permeable pavements in a employee used parking lot – A four-year study. *Journal of Environmental Management*. 167:8–14.
- Lam, S. T. and T. M. Conway. 2018. Ecosystem services in urban land use planning policies: A case study of Ontario municipalities. *Land Use Policy*. 77:641–651.
- Landschaft Planen & Bauen C. W. Becker U. Giseke B. Mohren and W. Richard. 1990. *The Biotope Area Factor as an Ecological Parameter - Principles for its Determination and Identification of the Target*. Berlin, Germany. Retrieved from http://www.stadtentwicklung.berlin.de/umwelt/landschaftsplanung/bff/download/Auszug_BFF_Gutachten_1990_eng.pdf. Accessed.
- Legambiente Padova. 2019a. Elevati i limiti del consumo di suolo: un provvedimento da respingere! Retrieved from <https://ecopolis.legambientepadova.it/elevati-i-limiti-del-consumo-di-suolo-un-provvedimento-da-respingere/>. Accessed December 2021.
- Legambiente Padova. 2019b. Stop al consumo di suolo, gli agricoltori padovani chiedono di invertire la rotta. Retrieved from <http://ecopolis.legambientepadova.it/?p=24601>. Accessed November 2019.

- Legambiente Padova. 2021. Per la salvaguardia degli spazi verdi del tessuto urbano consolidato - Ecopolis NewsLetter. Retrieved from <https://ecopolis.legambientepadova.it/per-la-salvaguardia-degli-spazi-verdi-del-tessuto-urbano-consolidato/>. Accessed April 2021.
- Li, Y. S. Schubert J. P. Kropp and D. Rybski. 2020. On the influence of density and morphology on the Urban Heat Island intensity. *Nature Communications* 2020 11:1. 11:1–9.
- Van Long, L. A. Tan S. Lockwood M. Sarteel S. Mudgal N. Zglobisz B. Grebot N. Schulp P. Verburg M. Bruckner L. de Schutter and S. Giljum. 2014. Study supporting potential land targets under the 2014 land communication . Luxembourg. Retrieved from <https://op.europa.eu/en/publication-detail/-/publication/fdbdf00a-87ac-4c85-8eab-ef60118963c5/language-en>. Accessed November 2021.
- Louwagie, G. S. H. Gay F. Sammeth and T. Ratering. 2011. The potential of European Union policies to address soil degradation in agriculture. *Land Degradation & Development*. 22:5–17.
- Lovett, G. M. M. M. Traynor R. V. Pouyat M. M. Carreiro W. Zhu and J. Baxter. 2000. Nitrogen de- position along an urban-rural gradient in the New York City metropolitan area. *Environ. Sci. Technol.* 34:4294–300.
- Maienza, A. F. Ungaro S. Baronti I. Colzi L. Giagnoni C. Gonnelli G. Renella F. Ugolini and C. Calzolari. 2021. Biological Restoration of Urban Soils after De-Sealing Interventions. *Agriculture* 2021, Vol. 11, Page 190. 11:190.
- Mann, G. R. Gohlke and F. Wolff. 2021. BuGG-Market Report on Building Greening 2020. Green Roofs, Green Facades and Interior Greening. Berlin. Retrieved from www.gebaeudegruen.info. Accessed December 2021.
- Mark, D. M. 2003. Geographic Information Science: Defining the Field. 1–18 *In* M. Duckham, M. F. Goodchild, and M. F. Worboys, editors. *n Foundations of Geographic Information Science*. Taylor and Francis, New York.
- Markowska, J. W. Szalińska J. Dąbrowska and M. Brząkała. 2020. The concept of a participatory approach to water management on a reservoir in response to wicked problems. *Journal of Environmental Management*. 259:109626.
- Marquard, E. S. Bartke J. Gifreu i Font A. Humer A. Jonkman E. Jürgenson N. Marot L. Poelmans B. Repe R. Rybski C. Schröter-Schlaack J. Sobocká M. Tophøj Sørensen E. Vejchodská A. Yiannakou and J. Bovet. 2020. Land Consumption and Land Take: Enhancing Conceptual Clarity for Evaluating Spatial Governance in the EU Context. *Sustainability*. 12:8269.
- Marsal-Llacuna, M. L. J. Colomer-Llinàs and J. Meléndez-Frigola. 2015. Lessons in urban monitoring taken from sustainable and livable cities to better address the Smart Cities initiative. *Technological Forecasting and Social Change*. 90:611–622.
- Marzari, S. 2008. Padova e la città metropolitana. 1807-2007 la metamorfosi del paesaggio urbano. (S. Marzari, Ed.). I Antichi Editori, Venezia, Italia.
- Master GIScience e SPR (Università di Padova). 2020. Pubblicato articolo su SUSTAINABILITY sulla geovisualizzazione del consumo di suolo della città di Padova . Retrieved from <https://www.mastergisscience.it/2020/02/04/pubblicato-articolo-su-sustainability-sulla-geovisualizzazione-del-consumo-di-suolo-della-citta-di-padova/>. Accessed January 2022.
- Master GIScience e SPR (Università di Padova). 2021. Quant'è e di chi è il verde urbano a Padova? Retrieved from <https://www.mastergisscience.it/2021/09/14/verde-urbano-a-padova/>. Accessed January 2022.

- Mazzali, U. F. Peron and M. Scarpa. 2012. Thermo-physical Performances Of Living Walls Via Field Measurements And Numerical Analysis. *WIT Transactions on Ecology and the Environment*. 165:251–259.
- McDonald, R. I. P. Kareiva and R. T. T. Forman. 2008. The implications of current and future urbanization for global protected areas and biodiversity conservation. *Biological Conservation*. 141:1695–1703.
- Melchiorri, M. A. J. Florczyk S. Freire M. Schiavina M. Pesaresi and T. Kemper. 2018. Unveiling 25 Years of Planetary Urbanization with Remote Sensing: Perspectives from the Global Human Settlement Layer. *Remote Sensing 2018*, Vol. 10, Page 768. 10:768.
- Millennium Ecosystem Assessment. 2005. *Ecosystems and Human Well-being*. Island Press.
- Ministero dell'Ambiente. 2017. *Strategia Nazionale di Sviluppo Sostenibile*. Retrieved from www.minambiente.it. Accessed.
- Ministero della Transizione Ecologica. 2017. *La Strategia Nazionale per lo Sviluppo Sostenibile*. Retrieved from <https://www.mite.gov.it/pagina/la-strategia-nazionale-lo-sviluppo-sostenibile>. Accessed November 2021.
- Mooney, P. and M. Minghini. 2017. A Review of OpenStreetMap Data. 37–59 *In* G. Foody, L. See, S. Fritz, P. Mooney, A.-M. Olteanu-Raimond, C. Costa Fonte, and V. Antoniou, editors. *Mapping and the Citizen Sensor*. Ubiquity Press Ltd., London, UK.
- Næss, P. 2014. *Urban Form, Sustainability and Health: The Case of Greater Oslo*. Routledge.
- Næss, P. I. L. Saglie and T. Richardson. 2019. Urban sustainability: is densification sufficient? *European Planning Studies*. 28:146–165.
- National Center for Geographic Information. 2007. The research plan of the National Center for Geographic Information and Analysis. <https://doi.org/10.1080/02693798908941502>. 3:117–136.
- Natural Capital Project. 2021. *INVEST*. Retrieved from <https://naturalcapitalproject.stanford.edu/software/invest>. Accessed December 2021.
- Nogué, J. L. Puigbert and G. Bretcha. 2008. Paisatge i benestar individual i social. (J. Nogué, L. Puigbert, and G. Bretcha, Eds.) *Paisatge i salut*. Landscape Observatory of Catalonia, Barcelona.
- Norton, J. B. Tomlinson B. Penzenstadler S. McDonald E. Kang N. Koirala R. Konishi G. P. Carmona J. Shah and S. Troncoso. 2019. The SAGE Community Coordinator: A Demonstration. 1–10 *In* S. Easterbrook, editor. *Proceedings of the Fifth Workshop on Computing within Limits*. Association for Computing Machinery, Lappeenranta, Finland.
- Oberndorfer, E. J. Lundholm B. Bass R. R. Coffman H. Doshi N. Dunnett S. Gaffin M. Köhler K. K. Y. Liu and B. Rowe. 2007. Green Roofs as Urban Ecosystems: Ecological Structures, Functions, and Services. *BioScience*. 57:823–833.
- Oliver, L. U. Ferber D. Grimski K. Millar and P. Nathanail. 2005. The Scale and Nature of European Brownfield. Retrieved from https://www.researchgate.net/publication/228789048_The_Scale_and_Nature_of_European_Brownfield. Accessed December 2021.
- PadovaOggi. 2021. Di chi è il verde urbano? Uno studio dell'Università mappa il verde di Padova. Retrieved from <https://www.padovaoggi.it/attualita/verde-urbano-studio-universita-mappa-verde-padova-19-settembre-2021.html>. Accessed January 2022.
- Paleari, S. 2017. Is the European Union protecting soil? A critical analysis of Community environmental policy

and law. *Land Use Policy*. 64:163–173.

- Pataki, D. E. M. M. Carreiro J. Cherrier N. E. Grulke V. Jennings S. Pincetl R. V. Pouyat T. H. Whitlow and W. C. Zipperer. 2011. Coupling biogeochemical cycles in urban environments: ecosystem services, green solutions, and misconceptions. *Frontiers in Ecology and the Environment*. 9:27–36.
- Pauchard, A. M. Aguayo E. Peña and R. Urrutia. 2006. Multiple effects of urbanization on the biodiversity of developing countries: The case of a fast-growing metropolitan area (Concepción, Chile). *Biological Conservation*. 127:272–281.
- Pauleit, S. R. Ennos and Y. Golding. 2005. Modeling the environmental impacts of urban land use and land cover change—a study in Merseyside, UK. *Landscape and Urban Planning*. 71:295–310.
- Perini, K. and P. Rosasco. 2013. Cost–benefit analysis for green façades and living wall systems. *Building and Environment*. 70:110–121.
- Peroni, F. 2021. Proteggere il suolo. Consumo di suolo e tutela delle funzioni ecosistemiche. *Madrugada. Trimestrale di incontri e di racconti*.:9–11.
- Peroni, F. G. Pristeri S. E. Pappalardo D. Codato and M. De Marchi. 2019. Mappatura del consumo di suolo a Padova mediante l'uso dell'Indice ecologico urbano Biotope Area Factor. *In* M. Munafò, editor. Consumo di suolo, dinamiche territoriali e servizi ecosistemici. Edizione 2019. Report SNPA 08/19, Rome.
- Pesaresi, M. D. Ehrlich T. Kemper A. Siragusa A. J. Florczyk S. Freire and C. Corbane. 2017. Atlas of the human planet 2017 : Global exposure to natural hazards. Luxembourg.
- Pileri, P. 2007. *Compensazione ecologica preventiva. Principi, strumenti e casi.* (C. Editore, Ed.). Università. Roma.
- Pileri, P. 2018. *100 parole per salvare il suolo.* Altraeconomia Edizioni, Milan, Italy.
- Pistocchi, A. C. Calzolari F. Malucelli and F. Ungaro. 2015. Soil sealing and flood risks in the plains of Emilia-Romagna, Italy. *Journal of Hydrology: Regional Studies*. 4:398–409.
- Press, C. U. 2021. Wordle | Definition.
- Pristeri, G. F. Peroni S. E. Pappalardo D. Codato A. Masi and M. De Marchi. 2021. Whose Urban Green? Mapping and Classifying Public and Private Green Spaces in Padua for Spatial Planning Policies. *ISPRS International Journal of Geo-Information* 2021, Vol. 10, Page 538. 10:538.
- Prokop, G. H. Jobstmann and A. Schönbauer. 2011. Report on best practices for limiting soil sealing and mitigating its effects. European Commission.
- Raddick, M. J. and A. S. Szalay. 2010. The universe online. *Science*. 329:1028–1029.
- Randy Gimblett, H. 2002. Integrating Geographic Information Systems and Agent-Based Technologies for Modeling and Simulating Social and Ecological Phenomena. *In* H. R. Gimblett, editor. Integrating Geographic Information Systems and Agent-Based Modeling Techniques for Simulating Social and Ecological Processes. Oxford University Press, New York.
- Recanatesi, F. A. Petroselli M. N. Ripa and A. Leone. 2017. Assessment of stormwater runoff management practices and BMPs under soil sealing: A study case in a peri-urban watershed of the metropolitan area of Rome (Italy). *Journal of Environmental Management*. 201:6–18.
- Regione del Veneto. 2004. Legge regionale 23 aprile 2004, n. 11 (BUR n. 45/2004) - Norme per il Governo del Territorio e in materia di Paesaggio.
- Regione del Veneto. 2017. Disposizioni per il contenimento del consumo di suolo e modifiche della legge regionale 23 aprile 2004, n. 11 “Norme per il governo del territorio e in materia di paesaggio.” 1–22. Italy.

- Richards, G. W. 2019. The Science–Policy Relationship Hierarchy (SPRHi) model of co-production: how climate science organizations have influenced the policy process in Canadian case studies. *Policy Sciences*. 52:67–95.
- Robinson, D. A. and I. Lebron. 2010. On the natural capital and ecosystem services of soils. *Ecological Economics*. 70:137–138.
- Rockström, J. W. Steffen K. Noone Å. Persson F. S. Chapin E. F. Lambin T. M. Lenton M. Scheffer C. Folke H. Joachim Schnellhuber B. Nykvist C. A. de Wit T. Hughes S. van der Leeuw H. Rodhe S. Sörlin P. K. Snyder R. Costanza U. Svedin M. Falkenmark L. Karlberg R. W. Corell V. J. Fabry J. Hansen B. Walker D. Liverman K. Richardson P. Crutzen and J. K. Foley. 2009. A safe operating space for humanity. 491–501 *The Future of Nature: Documents of Global Change*. Yale University Press.
- Rodríguez-Rojas, M. I. F. Huertas-Fernández B. Moreno and G. Martínez. 2020. Middle-Term Evolution of Efficiency in Permeable Pavements: A Real Case Study in a Mediterranean climate. *International Journal of Environmental Research and Public Health*. 17:7774.
- Ronchi, S. S. Salata A. Arcidiacono E. Piroli and L. Montanarella. 2019. Policy instruments for soil protection among the EU member states: A comparative analysis. *Land Use Policy*. 82:763–780.
- Ronchi, S. D. Di Simine and P. Pileri. 2013. Consumo di suolo e questioni ambientali. *Focus*.
- Rowe, D. B. 2011. Green roofs as a means of pollution abatement. *Environmental Pollution*. 159:2100–2110.
- Ruangpan, L. Z. Vojinovic S. Di Sabatino L. S. Leo V. Capobianco A. M. P. Oen M. E. McClain and E. Lopez-Gunn. 2020. Nature-based solutions for hydro-meteorological risk reduction: a state-of-the-art review of the research area. *Natural Hazards and Earth System Sciences*. 20:243–270.
- Saco, P. M. K. R. McDonough J. F. Rodriguez J. Rivera-Zayas and S. G. Sandi. 2021. The role of soils in the regulation of hazards and extreme events. *Philosophical Transactions of the Royal Society B*. 376:2021.
- dos Santos, A. R. F. S. de Oliveira A. G. da Silva J. M. Gleriani W. Gonçalves G. L. Moreira F. G. Silva E. R. F. Branco M. M. Moura R. G. da Silva R. S. Juvanhol K. B. de Souza C. A. A. S. Ribeiro V. T. de Queiroz A. V. Costa A. S. Lorenzon G. F. Domingues G. E. Marcatti N. L. M. de Castro R. T. Resende D. E. Gonzales L. A. de Almeida Telles T. R. Teixeira G. M. A. D. A. dos Santos and P. H. S. Mota. 2017. Spatial and temporal distribution of urban heat islands. *Science of the Total Environment*. 605–606:946–956.
- Scalenghe, R. and F. A. Marsan. 2009. The anthropogenic sealing of soils in urban areas. *Landscape and Urban Planning*. 90:1–10.
- Science Communication Unit. 2016. No net land take by 2050? Bristol. Retrieved from <https://www.eea.europa.eu/data-and-maps/indicators/land-recycling-and-densification/no-net-land-take-by>. Accessed October 2019.
- See, L. P. Mooney G. Foody L. Bastin A. Comber J. Estima S. Fritz N. Kerle B. Jiang M. Laakso H.-Y. Liu G. Milčinski M. Nikšič M. Painho A. Pődör A.-M. Olteanu-Raimond M. Rutzinger L. See P. Mooney G. Foody L. Bastin A. Comber J. Estima S. Fritz N. Kerle B. Jiang M. Laakso H.-Y. Liu G. Milčinski M. Nikšič M. Painho A. Pődör A.-M. Olteanu-Raimond and M. Rutzinger. 2016. Crowdsourcing, Citizen Science or Volunteered Geographic Information? The Current State of Crowdsourced Geographic Information. *ISPRS International Journal of Geo-Information*. 5:55.
- Senate Department for the Environment Mobility Consumer and Climate Protection. 2021a. BAF – Biotope area factor . Retrieved from <https://www.berlin.de/sen/uvk/en/nature-and-green/landscape-planning/baf->

- biotope-area-factor/. Accessed December 2021.
- Senate Department for the Environment Mobility Consumer and Climate Protection. 2021b. Calculating the BAF. Retrieved from <https://www.berlin.de/sen/uvk/en/nature-and-green/landscape-planning/baf-biotope-area-factor/calculating-the-baf/>. Accessed January 2022.
- Sergio Lironi. 2018. Un nuovo Piano Regolatore per una nuova idea di città. Retrieved from <http://ecopolis.legambientepadova.it/?p=>. Accessed November 2018.
- Seto, K. C. S. Dhakal A. Bigio H. Blanco G. C. Delgado D. Dewar L. Huang A. Inaba A. Kansal S. Lwasa J. E. McMahon D. B. Müller J. Murakami H. Nagendra and A. Ramaswami. 2014. Human Settlements, Infrastructure and Spatial Planning. *In* O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel, and J. C. Minx, editors. *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Seto, K. C. B. Güneralp and L. R. Hutyrá. 2012. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences of the United States of America*. 109:16083–16088.
- Shuster, W. D. J. Bonta H. Thurston E. Warnemuende and D. R. Smith. 2005. Impacts of impervious surface on watershed hydrology: A review. *Urban Water Journal*. 2:263–275.
- Siebielec, G. 2012. Brownfield redevelopment as an alternative to greenfield consumption in urban development in Central Europe. Pulawy.
- De Simone, M. 2020. Studio di una rete ecologica urbana: analisi multitemporale dei servizi ecosistemici lungo il canale Piovego (Padova). Università degli Studi di Padova.
- Skougaard Kaspersen, P. N. Høegh Ravn K. Arnbjerg-Nielsen H. Madsen and M. Drews. 2015. Influence of urban land cover changes and climate change for the exposure of European cities to flooding during high-intensity precipitation. 21–27 IAHS-AISH Proceedings and Reports. Copernicus GmbH.
- Slonecker, E. T. D. B. Jennings and D. Garofalo. 2001. Remote sensing of impervious surfaces: A review. *Remote Sensing Reviews*. 20:227–255.
- SOCIENTIZE. 2014. White Paper on Citizen Science in Europe. Zaragoza, Spain. Retrieved from <https://eu-citizen.science/resource/8>. Accessed December 2021.
- Sousa-Poza, A. 2013. Introduction and Overview. 1–9 *In* S. F. Kovacic and A. Sousa-Poza, editors. *Managing and Engineering in Complex Situations*. Springer, Dordrecht.
- Sponagel, C. E. Angenendt H. P. Piepho and E. Bahrs. 2021. Farmers' preferences for nature conservation compensation measures with a focus on eco-accounts according to the German Nature Conservation Act. *Land Use Policy*. 104:105378.
- Stankovics, P. L. Montanarella P. Kassai G. Tóth and Z. Tóth. 2020. The interrelations of land ownership, soil protection and privileges of capital in the aspect of land take. *Land Use Policy*. 99:105071.
- Stankovics, P. G. Tóth and Z. Tóth. 2018. Identifying Gaps between the Legislative Tools of Soil Protection in the EU Member States for a Common European Soil Protection Legislation. *Sustainability*. 10:2886.
- Steffen, W. W. Rockström and J. Costanza. 2011. How Defining Planetary Boundaries Can Transform Our Approach to Growth Recommended Citation. Retrieved from http://pdxscholar.library.pdx.edu/iss_pub.

Accessed November 2019.

- Strollo, A. D. Smiraglia R. Bruno F. Assennato L. Congedo P. De Fioravante C. Giuliani I. Marinosci N. Riitano and M. Munafò. 2020. Land consumption in Italy. *Journal of Maps*. 16:113–123.
- Teixeira da Silva, R. L. Fleskens H. van Delden and M. van der Ploeg. 2018. Incorporating soil ecosystem services into urban planning: status, challenges and opportunities. *Landscape Ecology* 2018 33:7. 33:1087–1102.
- Texas A&M University and DePaul University. 2011. Millennium Park Quadruple Net Value Report. Retrieved from <https://studylib.net/doc/8081025/millennium-park-quadruple-net-value-report>. Accessed December 2021.
- Theobald, D. M. S. J. Goetz J. B. Norman and P. Jantz. 2009. Watersheds at Risk to Increased Impervious Surface Cover in the Conterminous United States. *Journal of Hydrologic Engineering*. 14:362–368.
- Tian, L. Y. Li Y. Yan and B. Wang. 2017. Measuring urban sprawl and exploring the role planning plays: A shanghai case study. *Land Use Policy*. 67:426–435.
- Tobias, S. F. Conen A. Duss L. M. Wenzel C. Buser and C. Alewell. 2018. Soil sealing and unsealing: State of the art and examples. *Land Degradation & Development*. 29:2015–2024.
- Tomlin, C. D. 1990. *Geographic information systems and cartographic modeling*. Prentice Hall.
- Tu, J. K. Clarke and A. Frei. 2007. Impact of Urban Sprawl on Water Quality in Eastern Massachusetts, USA Calibrating SLEUTH using a Genetic Algorithm View project Birth Outcome in Georgia View project.
- Tulloch, D. 2014. Public Participation GIS (PPGIS). 352–355 *In* K. K. Kemp, editor. *Encyclopedia of Geographic Information Science*. SAGE Publications, Inc., Thousand Oaks, CA.
- UCLG Congress and World Summit of Local and Regional Leaders. 2019. *Inclusive and Accessible Cities*. Durban, Sudafrica.
- Ugolini, F. L. Massetti P. Calaza-Martínez P. Cariñanos C. Dobbs S. K. Ostoic A. M. Marin D. Pearlmutter H. Saaroni I. Šaulienė M. Simoneti A. Verlič D. Vuletić and G. Sanesi. 2020. Effects of the COVID-19 pandemic on the use and perceptions of urban green space: An international exploratory study. *Urban Forestry and Urban Greening*. 56:126888.
- UN-Habitat. 2016. *The fundamentals of urbanitazion: Evidence base for Policy Making*. Nairobi, Kenya.
- UN-Habitat. 2020. *Utilisation efficace des terres*. Nairobi, Kenya.
- UN-Habitat. 2021. UN Habitat Metadata sheet on SDG indicator 11.3.1. Retrieved from <https://unstats.un.org/sdgs/metadata/files/Metadata-11-03-01.pdf>. Accessed April 2021.
- United Nations. 2015. Goal 11: Make cities inclusive, safe, resilient and sustainable. Retrieved from <https://www.un.org/sustainabledevelopment/cities/>. Accessed August 2021.
- United Nations. 2019, September 18. Cities: a “cause of and solution to” climate change . Retrieved from <https://news.un.org/en/story/2019/09/1046662>. Accessed September 2021.
- United Nations and Department of Economic and Social Affairs. 2015a. Target 2.4 (Goal 2). Retrieved from <https://sdgs.un.org/goals/goal2>. Accessed January 2022.
- United Nations and Department of Economic and Social Affairs. 2015b. Target 3.9 (Goal 3). Retrieved from <https://sdgs.un.org/goals/goal3>. Accessed January 2022.
- United Nations and Department of Economic and Social Affairs. 2015c. Target 12.4 (Goal 12). Retrieved from <https://sdgs.un.org/goals/goal12>. Accessed January 2022.
- United Nations and Department of Economic and Social Affairs. 2015d. Goal 15 . Retrieved from

- <https://sdgs.un.org/goals/goal15>. Accessed January 2022.
- United Nations Department of Economic and Social Affairs and Population Division. 2019a. World Urbanization Prospects 2018: Highlights (ST/ESA/SER.A/421).
- United Nations Department of Economic and Social Affairs and Population Division. 2019b. World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420). New York.
- United Nations Environment Programme. 2021. Adaptation Gap Report 2020 . Nairobi. Retrieved from <https://www.unep.org/resources/adaptation-gap-report-2020>. Accessed December 2021.
- Veolia Institute. 2019. Urban Agriculture: another way to feed cities. Retrieved from www.institut.veolia.org. Accessed.
- Vezzelli, D. 2019. Carbon storage and sequestration along the Piovego canal in Padova: multitemporal spatial analysis and future scenarios of renaturalization. Università degli Studi di Padova.
- Villella, J. G. Sellers A. J. Moffat and T. R. Hutchings. 2006. From contaminated site to premier urban greenspace: investigating the success of Thames Barrier Park, London. *WIT Transactions on Ecology and the Environment*. 94:153.
- Vojinovic, Z. 2020. Nature-based solutions for flood mitigation and coastal resilience. Luxembourg. Retrieved from <https://op.europa.eu/en/publication-detail/-/publication/d6e80dca-d530-11ea-adf7-01aa75ed71a1/language-en>. Accessed December 2021.
- Wang, Y. and M. Li. 2019. Urban Impervious Surface Detection From Remote Sensing Images: A review of the methods and challenges. *IEEE Geoscience and Remote Sensing Magazine*. 7:64–93.
- Wells, C. W. 2013. *Car Country: An Environmental History*. University of Washington Press, Seattle.
- Weng, Q. 2012. Remote sensing of impervious surfaces in the urban areas: Requirements, methods, and trends. *Remote Sensing of Environment*. 117:34–49.
- Weng, Q. 2020. *Techniques and Methods in Urban Remote Sensing*. IEEE Press.
- Westervelt, J. D. 2002. Geographic Information Systems and Agent-Based Modeling. 83–103 *In* H. R. Gimblett, editor. *Integrating Geographic Information Systems and Agent-Based Modeling Techniques for Simulating Social and Ecological Processes*. Oxford University Press, New York, USA.
- Wezel, A. S. Bellon T. Doré C. Francis D. Vallod and C. David. 2009. Agroecology as a science, a movement and a practice. A review. *Agronomy for Sustainable Development* 2009 29:4. 29:503–515.
- Wiersma, Y. F. 2010. Birding 2.0: Citizen Science and Effective Monitoring in the Web 2.0 World. *Avian Conservation and Ecology*. 5.
- Wild, T. H. Bulkeley C. Calfapietra and K. Whiteoak. 2020. Nature-based solutions. State of the art in EU-funded projects. Brussels. Retrieved from <https://op.europa.eu/en/publication-detail/-/publication/8bb07125-4518-11eb-b59f-01aa75ed71a1>. Accessed December 2021.
- Wilson, B. and A. Chakraborty. 2013. The Environmental Impacts of Sprawl: Emergent Themes from the Past Decade of Planning Research. *Sustainability* 2013, Vol. 5, Pages 3302-3327. 5:3302–3327.
- World Bank. 2021. Inclusive Cities: Development news, research, data . Retrieved from <https://www.worldbank.org/en/topic/inclusive-cities#1>. Accessed January 2022.
- World Meteorological Organization. 2020. Urban heat island . Retrieved from <https://community.wmo.int/activity-areas/urban/urban-heat-island>. Accessed December 2021.
- Zago, D. 2018. Mappatura aree abbandonate all'interno del comune di Padova nell'ambito del progetto MUES. Università degli Studi di Padova.

ARTICLES I-V

GEOGRAFIA URBANA E PARTECIPAZIONE NELL'ERA DIGITALE: TRE ESPERIENZE A PADOVA TRA GISCIENCE E VGI

Urban geography and participation in the digital era: three studies in Padova between GIScience and VGI

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Parole chiave: Sostenibilità urbana, Partecipazione, Tecnologie dell'Informazione Geografica, GIS

Riassunto

Con il rapido sviluppo delle tecnologie digitali per la raccolta, gestione e diffusione di dati spaziali, la ricerca geografica ha beneficiato in anni recenti di numerosi contributi basati sulla partecipazione o collaborazione di cittadini, singolarmente o in gruppo, facilitata da tecnologie dell'informazione geografica, *geotool*, *geoapp*. Processi di questo genere possono essere catalogati sotto diverse terminologie: Citizen Science, *Volunteered Geographic Information* (VGI), *Participatory Mapping*, *Public Participation Geographic Information Systems* (PPGIS) e altre ancora. Uno dei campi di applicazione più diffusi delle ricerche basate sull'interazione tra ricercatori e cittadini è la realtà urbana, in special modo le azioni di mappatura di tematismi rilevanti dal punto di vista sociale o ambientale.

Nel Laboratorio *GIScience e Drones for Good* attivo presso il Dipartimento di Ingegneria Civile Edile e Ambientale dell'Università di Padova, e con la collaborazione di altri dipartimenti, il gruppo di ricerca collegato al Master di II livello in GIScience e Sistemi a Pilotaggio Remoto per la gestione integrata del territorio e delle risorse naturali sviluppa da alcuni anni una linea di ricerca fondata su metodologie di mappatura partecipata a supporto di analisi sulla sostenibilità urbana. In questo contributo vengono illustrati tre dei progetti afferenti a tale linea di ricerca: "Il Valore del Suolo", per mappare la permeabilità delle superfici in un quartiere campione di Padova; "Piste riCiclabili", per individuare le criticità dei percorsi ciclabili padovani; "MUES – Mapping Urban Empty Spaces", per la mappatura di spazi abbandonati nel comune di Padova. Per ogni progetto si descrivono obiettivi, metodologie, tecnologie dell'informazione geografica utilizzate, attori coinvolti e risultati ottenuti, allo scopo di trovare connessioni tra questi elementi e ragionare su pregi e limiti di tali operazioni.

Abstract

The rapid development of digital technologies to collect, manage and spread spatial data has led the geospatial research field to be involved in a great number of projects based on participation by citizens, both individually and in groups, facilitated by geographic information technologies, geotools, geoapps. Such processes may be classified under different terms and definitions: Citizen Science, Volunteered Geographic Information (VGI), Participatory Mapping, Public Participation Geographic Information Systems (PPGIS) and more. One of the most common fields of application for interaction-based geographical researches is the urban context, especially mapping features and themes which are relevant from a social or environmental point of view.

Within the GIScience e Drones for Good Lab, part of the Department of Civil, Environmental and Architectural Engineering of University of Padova, and with the collaboration of other departments, the group linked to the post-graduate Master in GIScience and UAV has been leading for several years a line of research based on participatory mapping methodologies in support of urban sustainability analysis. Here, three of the performed projects are presented: “Il Valore del Suolo”, to map perviousness of surfaces in a sample neighbourhood in Padova; “Piste Riciclabili”, to detect critical issues in Padova cycle paths; “MUES – Mapping Urban Empty Spaces”, to map abandoned sites in Padova.

For each of these projects, objectives, methodologies, involved geographic information technologies and actors, results are described, with the aim to find connections between such elements and think about pros and cons of these kinds of processes.

1. Introduzione

Nel campo della geografia, in particolare dagli anni 1980, le attività di raccolta dati, mappatura e analisi spaziale si sono arricchite di esperienze e ricerche accomunate dal contributo a vari livelli di singoli cittadini o gruppi in una o più fasi del processo. A partire dallo scorso decennio, poi, una serie di circostanze concomitanti – disponibilità di dati spaziali open e gratuiti anche a seguito della direttiva comunitaria Inspire (Commissione Europea 2007), diffusione di massa di *device* quali smartphone e tablet con opzioni di geolocalizzazione e connessi in rete, sviluppo di siti e applicazioni di web mapping – ha prodotto il proliferare di tali azioni in ambiti molto diversi. Il paradigma in cui ricadono questi tipi di attività si può far coincidere con il concetto di *Citizen Science*, termine-ombrello di grande diffusione che accorpa una serie di attività variamente articolate, in cui è rilevante un qualche tipo di coinvolgimento da parte di pubblico non esperto, cittadini o comunque figure non identificabili con scienziati o ricercatori responsabili dei progetti.

Per orientarsi nel variegato panorama della *Citizen Science* nella sua accezione geografica, diversi studiosi hanno prodotto contributi volti a classificare le pratiche a essa afferenti, chiarendo i significati

dei termini usati e definendo ambiti di applicazione e tipo di coinvolgimento pubblico. Una rassegna molto puntuale ed efficace (See et al. 2016), che qui si prende come riferimento, nel suo titolo raccoglie le esperienze in esame sotto la definizione di *Crowdsourced Geographic Information*. Di seguito si ricorrerà dunque a lessico e categorie dell'articolo citato per inquadrare i progetti trattati. Tra i termini definiti nel testo in questione, ne riprendiamo alcuni di particolare interesse per i nostri scopi.

- La *Citizen Science*, secondo il *White Paper on Citizen Science for Europe* (Socientize 2014), è "il coinvolgimento dei cittadini in attività di ricerca scientifica a cui essi contribuiscono attivamente con il loro impegno intellettuale, attraverso la conoscenza diffusa o con i propri strumenti e risorse" (Socientize, cit., p. 8).
- *Collaborative Mapping* indica "la creazione collettiva di mappe online che possono essere oggetto di consultazione, modifiche e annotazioni da parte di molteplici contributori" (See et al., cit., p. 4).
- La *Contributed Geographic Information* è definita in opposizione alla VGI come "informazione geografica raccolta senza la consapevolezza e l'esplicito consenso di un utente di dispositivi mobili che registrano la posizione" (See et al., cit., p. 5).
- Il *Crowdsourcing* è "un tipo di attività partecipativa online in cui un individuo, un'istituzione, un ente non profit, una società propongono a un gruppo di individui [...] lo svolgimento volontario di un compito [che] implica un mutuo beneficio" (Estellés Arolas and González Ladrón-de-Guevara 2012 p. 197).
- Per *Geocollaboration* si intende la "collaborazione su interfaccia visiva con informazioni geospaziali attraverso tecnologie geospaziali" (See et al., cit., p. 6).
- Il *GeoWeb* è "la fusione di informazioni spaziali con attributi non spaziali sul web, che permette ricerche spazializzate su internet" (See et al., cit., p. 6).
- La *Involuntary Geographic Information* (iVGI) fa uso di "dati georeferenziati non forniti volontariamente dagli individui, che possono essere usati per molti scopi inclusi quelli di mappatura, ma anche per applicazioni commerciali come il profiling geodemografico" (See et al., cit., p. 6).
- Il *Participatory Sensing* è "l'impiego di dispositivi mobili in una rete di sensori interattivi da utilizzare per raccogliere dati e condividere conoscenza" (See et al., cit., p. 7).
- I *Public Participation Geographic Information Systems* (PPGIS) sono "un insieme di applicazioni GIS per facilitare un più ampio coinvolgimento pubblico nei processi di pianificazione e decisione" mentre la *Public Participation in Scientific Research* (PPSR) rappresenta "il coinvolgimento pubblico nella scienza, tra cui: scegliere e definire ambiti di studio; reperire informazioni e risorse; sviluppare ipotesi; pianificare metodologie;

- raccogliere, analizzare, interpretare dati e trarre conclusioni; diffondere e discutere risultati ponendo nuove questioni” (See et al., cit., p. 7).
- Lo User-Generated Content “consiste di utenti che pubblicano i propri contenuti in forma digitale (ad esempio dati, video, blog, messaggi su forum, immagini, mappe, file audio, arte pubblica ecc)” (See et al., cit., p. 8).
 - La *Volunteered Geographic Information* (VGI) è “l’utilizzo di strumenti per creare, assemblare e disseminare dati geografici forniti volontariamente da individui” (See et al., cit., p. 8).
 - Infine, il termine Web Mapping indica “lo studio delle rappresentazioni cartografiche che usano il web come medium, con enfasi sulla progettazione centrata sull’utente [...] sui contenuti generati dagli utenti e sull’accesso universale” (See et al., cit., p. 8).

Alla luce delle definizioni riportate verranno illustrate tre esperienze nate come Progetti Innovativi degli Studenti dell’Università di Padova, basate su metodologie di mappatura partecipata in ambiente GIS e volte a produrre mappe di tematismi urbani rilevanti dal punto di vista sociale o ambientale. La città è infatti uno dei campi di applicazione più diffusi delle ricerche basate sull’interazione tra ricercatori e cittadini, e processi collaborativi come quelli messi in atto possono servire a sensibilizzare la collettività sui temi della sostenibilità urbana.

I progetti presi in esame sono: “Il Valore del Suolo” coordinato dal Dipartimento di Scienze Economiche e Aziendali “Marco Fanno”, che attraverso la partecipazione e il lavoro di un gruppo di studenti ha prodotto una mappatura di dettaglio della permeabilità di un quartiere campione a Padova; “Piste riCiclabili”, del Dipartimento di Ingegneria Civile Edile e Ambientale, che attraverso un sistema di segnalazioni e raccolta dati sia su supporto cartaceo che in digitale ha individuato, classificato e rappresentato su un webGIS le criticità dei percorsi ciclabili padovani; “MUES – Mapping Urban Empty Spaces”, del Dipartimento di Agronomia Animali Alimenti Risorse Naturali e Ambiente, che ha integrato diverse fonti e metodologie per una mappatura GIS e webGIS di edifici, aree e complessi abbandonati o sottoutilizzati in un’area campione di Padova.

Nelle sezioni seguenti, ognuno di questi progetti sarà letto in rapporto alla terminologia di cui sopra e analizzato secondo parametri quali obiettivi, metodologie, tecnologie impiegate, attori coinvolti, controllo del dato e risultati ottenuti.

I tre progetti verranno poi confrontati tra loro per trovare possibili connessioni tra metodologie applicate, numero dei cittadini coinvolti e loro livello di partecipazione, tipologia dei dati raccolti ed esiti finali. Va ricordato come questo tipo di progetti partano dalla necessità di sviluppare forme di didattica innovativa e trovino nella sperimentazione di metodologie collaborative di

ricerca insieme a studenti e cittadini un valore aggiunto tanto sul versante didattico quanto per i risultati scientifici raggiunti⁸.

2. Analisi dei progetti

2.1. Il Valore del Suolo

Il progetto “Il Valore del Suolo” ha l’obiettivo generale di attivare gli studenti sul tema della sostenibilità urbana all’interno del loro territorio, indagando il fenomeno del consumo di suolo e fornendo gli strumenti concettuali e tecnologici per analizzare la problematica. Nello specifico il progetto si è prefisso di far adottare agli studenti gli strumenti propri della GIScience e trasmettere il potenziale della mappatura partecipata come strumento per affrontare tematiche complesse e specialistiche come quella del consumo di suolo.

Si sottolinea che tale progetto rientra in una linea di ricerca più ampia, volta all’analisi della sostenibilità urbana a Padova, che si pone come obiettivo futuro quello di mappare, a scala di dettaglio, la permeabilità del suolo dell’intero territorio comunale.

Il progetto si è svolto mediante una serie di laboratori didattici rivolti agli studenti universitari. I workshop, 8 in totale, hanno visto la partecipazione volontaria e continuativa di 26 studenti provenienti da ambiti disciplinari differenti (Fig. 1). L’analisi è stata svolta in ambiente GIS mediante l’applicazione di un indice ecologico urbano, denominato *Biotopo Area Factor* (BAF) (Becker and Mohren 1990), che restituisce, in output cartografici a grande scala, il grado di impermeabilizzazione delle aree in esame. Per ottenere un’analisi di dettaglio, sono state utilizzate ortofoto del 2015 della Regione del Veneto (volo REVEN 2015) ad altissima risoluzione geometrica (0.2 m/pixel).

Il fenomeno del consumo di suolo è un tema di notevole interesse a livello sia nazionale che europeo (ISPRA 2017). L’ISPRA, da alcuni anni, monitora il fenomeno su scala nazionale attraverso le tecnologie del *remote sensing*, che consentono, con procedure di classificazione semi-automatica, di dare uno sguardo complessivo alla problematica. Dai dati dei rapporti annuali dell’ISPRA sul consumo di suolo emerge come il Comune di Padova sia uno dei comuni con il più alto tasso di suolo impermeabilizzato: 49,4%(ISPRA 2018).

Si è scelto quindi di effettuare l’analisi del consumo di suolo in un quartiere rappresentativo di Padova, Forcellini, di circa 300 ha, situato ad est del centro storico (Fig. 2). Il quartiere presenta una struttura urbana eterogenea, a carattere prevalentemente residenziale con presenza di aree agricole e di alcune aree industriali.

⁸ Gli autori ringraziano chiunque abbia contribuito alla riuscita dei progetti, e in particolare: per Il valore del Suolo Edoardo Crescini e Stefano Brugnaro; per Piste riCiclabili Elena Ghezzi e Diego Malacarne; per MUES Daniele Zago, Francesco Facchinelli e Giuseppe Della Fera.



Figura 1 Attività partecipate di “Il Valore del Suolo”

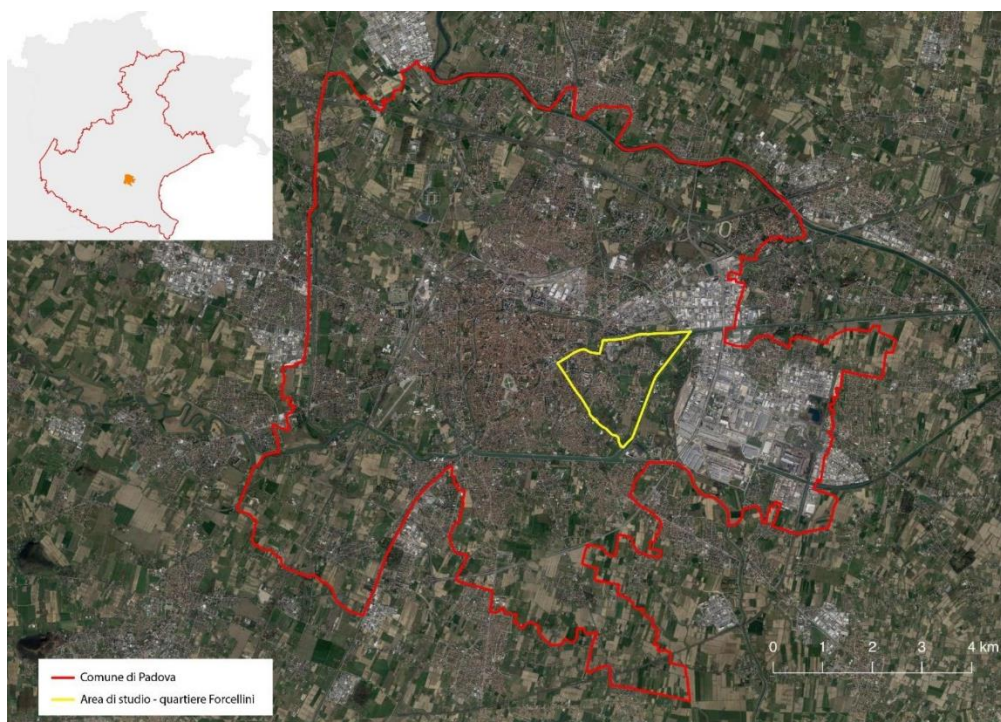


Figura 2 Inquadramento territoriale del quartiere Forcellini nel Comune di Padova

Durante i primi workshop sono state fornite agli studenti le basi del software *open source* QGIS, nonché gli strumenti conoscitivi per svolgere le elaborazioni vettoriali utili ai fini dell'analisi. L'area di studio è stata poi suddivisa in 26 settori affinché ciascun studente potesse concentrarsi sull'analisi BAF di una porzione del quartiere. Ogni studente ha quindi operato svolgendo, mediante fotointerpretazione, una prima classificazione al fine di mappare gli usi del suolo al 2015 (Fig. 3). Alle *features* estratte durante la prima classificazione sono stati in seguito assegnati i valori di BAF (compresi in una scala di valori da 0 a 1, dove 0 indica i suoli impermeabili e 1 i suoli permeabili). Infine ogni studente ha calcolato il BAF medio all'interno della propria area, anche attraverso la produzione di cartografie di sintesi come l'*hexagon tessellation* (Fig. 4).

Nelle fasi di mappatura di uso del suolo e classificazione BAF gli studenti sono stati accompagnati e supervisionati da ricercatori del Master in GIScience e del Laboratorio GIScience e Drones for Good dell'Università di Padova (Fig. 1). I workshop iniziali e l'affiancamento di ricercatori esperti hanno prodotto una qualità del dato elevata. Si è reso tuttavia necessario un lavoro di omogeneizzazione e pulizia dei dataset per unire tutti i settori ed ottenere il quadro complessivo della permeabilità del quartiere Forcellini. L'accuratezza della mappatura è stata verificata attraverso un confronto con mappe satellitari. L'esito finale ha consentito il calcolo del valore medio di BAF, ovvero 0,56. Il risultato ha mostrato come circa metà della superficie del quartiere sia totalmente sigillata.

Il coinvolgimento degli studenti ha permesso di mappare, ad altissima risoluzione e in maniera speditiva, un'area vasta come il quartiere Forcellini, poiché la fotointerpretazione è avvenuta a scale

comprese tra 1:500 e 1:1000. Si può affermare che, se da un lato gli studenti sono stati spinti dal desiderio di apprendere le basi della GIScience e dei software GIS, dall'altro hanno aumentato la loro consapevolezza sulle tematiche del consumo di suolo e dello sviluppo sostenibile delle città.



Figura 3 Mappatura partecipata: i 26 settori mappati dagli studenti
Fonte: tesi triennale Edoardo Crescini (Crescini Di Montevecchio Benedetti 2018)

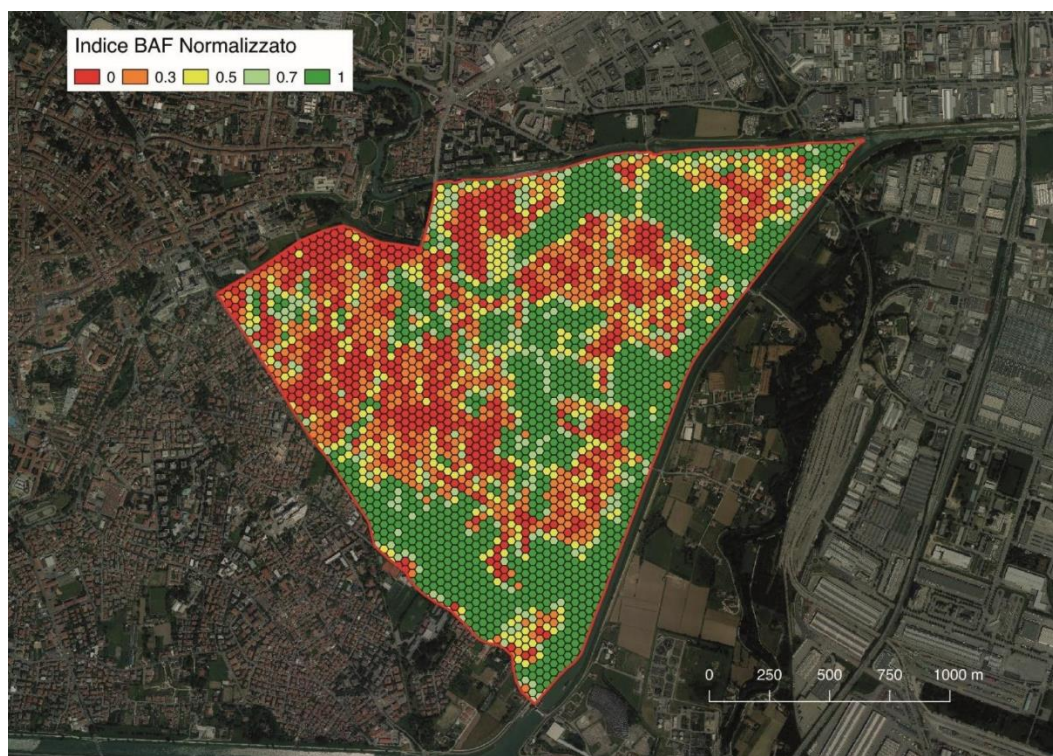


Figura 4 Hexagon tessellation della mappatura BAF. In verde le superfici permeabili (valore BAF =1), in rosso le superfici impermeabili (valore BAF =0), in colori intermedi le superfici con valori compresi tra 0 e 1.

Fonte: tesi triennale Edoardo Crescini (Crescini Di Montevecchio Benedetti 2018)

2.2. Piste riCiclabili

Il progetto denominato “Piste riCiclabili” ha avuto sviluppo tra settembre 2016 e ottobre 2017, inizialmente come laboratorio didattico in seno a un corso di *Volunteered Geographic Information* (VGI) del Master in GIScience e Sistemi a Pilotaggio Remoto per la gestione del territorio e delle risorse naturali e poi come progetto innovativo degli studenti finanziato dall’Università di Padova. Gli obiettivi erano il coinvolgimento della cittadinanza padovana e degli studenti universitari, tra i principali fruitori della bicicletta, nella mappatura e raccolta di informazioni partecipata di 11 tipologie di criticità delle piste ciclabili di Padova (pista interrotta, incrocio pericoloso, pista dissestata, ecc.) e l’elaborazione e restituzione dei dati raccolti attraverso un geoportale liberamente consultabile. Il fine ultimo era costruire un sistema aperto di informazioni utili a promuovere il dialogo sul tema tra i cittadini e tra questi e l’amministrazione pubblica, avviando un processo che potesse portare infine a un miglioramento della ciclabilità padovana.

Per poter raggiungere il maggior numero di potenziali utilizzatori delle piste ciclabili senza distinzioni di categoria, il progetto fin dalle sue fasi iniziali ha fatto grande uso di interazioni dirette con le associazioni, attraverso social network, sito internet e altri canali. Collo di bottiglia di molte attività di questo tipo è proprio la bassa partecipazione o la sovrappartecipazione di certe categorie di attori o singoli mappatori rispetto ad altre, per differenti cause (poca dimestichezza con le tecnologie usate,

bassa motivazione a partecipare, ecc.) che portano a risultati parziali, viziati o non credibili e quindi inutilizzabili (Brown 2004; Haklay 2016). L'utilizzo di queste piattaforme di comunicazione è stato gestito anche nell'ottica educativa di diffondere informazioni di interesse su buone pratiche e progetti di sostenibilità ciclabile. Inoltre una sezione apposita del sito è stata strutturata per aiutare il cartografo volontario nell'utilizzo degli strumenti di mappatura e di consultazione dei dati, attraverso video tutorial e istruzioni dettagliate. A questo scopo anche il processo di mappatura è avvenuto in più modalità (Fig. 5): da un lato attraverso l'uso di cartografia in formato cartaceo della città di Padova durante eventi e manifestazioni pubbliche o in zone di affluenza studentesca come le mense universitarie, dove dei facilitatori aiutavano i presenti a rappresentare con pin colorati le differenti criticità e a segnalare altre informazioni di interesse; dall'altro attraverso tecnologie digitali, utilizzando la suite Open Data Kit (ODK, opendatakit.org). ODK mette a disposizione una serie di strumenti *open source* per costruire formulari di raccolta dati georeferenziati ad hoc, scaricare e compilare via smartphone o tablet Android questi formulari grazie all'app geoODK collect (anche offline) e infine inviare le segnalazioni raccolte a un server appositamente strutturato.

Dato che ODK funziona solo su dispositivi Android, per gli utenti con altri sistemi operativi era stato predisposto un formulario simile da compilare via web. La struttura del formulario e le tipologie di criticità da raccogliere sono state frutto di un processo di dialogo e test con alcune associazioni della società civile padovana che si occupano di tematiche ambientali e di sostenibilità, nell'ottica di validare socialmente il lavoro e raccogliere dati di effettivo interesse. Tutte le informazioni raccolte sono state in seguito aggregate in un progetto GIS utilizzando il software QGIS, sottoposte ad analisi geografiche e statistiche (come la creazione di mappe di densità di punti per evidenziare le zone a maggior concentrazione di un certo tipo di criticità) e pubblicate sul web attraverso un webGIS costruito tramite l'applicativo Lizmap, un plugin di QGIS (Fig. 6). Il webGIS è consultabile alla pagina pistericiclabilipd.wordpress.com.

Al 31 ottobre 2017, data di chiusura del progetto, si contavano 379 followers su Facebook e oltre 5.000 visualizzazioni del sito Wordpress.



Figura 5 Dall'alto in senso orario: pagina Facebook del progetto, due screenshot dell'app geoODK collect, un momento della mappatura cartacea. Fonte: elaborazione degli autori

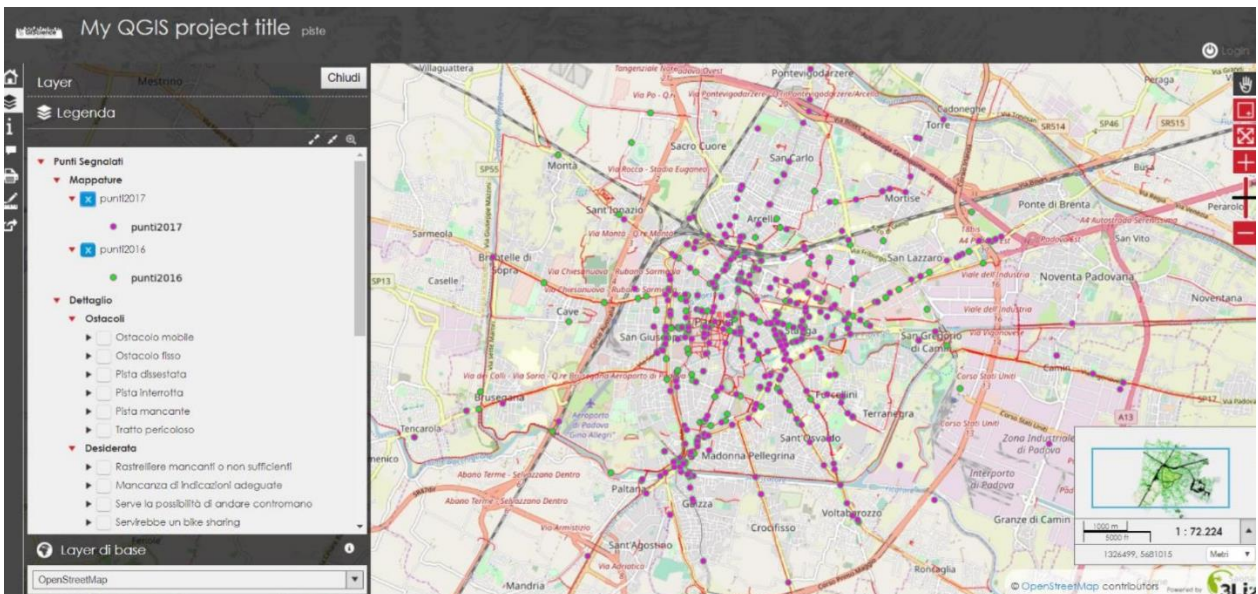


Figura 6 Screenshot del webGIS del progetto Piste riCiclabili

Per quanto riguarda il coinvolgimento della cittadinanza e i punti raccolti, sono stati inclusi nell'analisi e nel webGIS oltre 798 punti relativi a differenti tipi di criticità, di cui 116 raccolti con la mappatura cartacea e i restanti 682 via digitale. I cittadini che hanno segnalato almeno un punto critico via digitale sono stati 152, mentre 278 sono stati quelli che hanno segnalato il loro interesse ad essere informati del progetto e delle sue novità via mailing list. I dati raccolti dal progetto sono stati inoltre utilizzati dall'amministrazione comunale per il piano di Bicipolitana di Padova, relativo alla creazione di un sistema integrato di percorsi ciclabili rapidi e sicuri.

Date le caratteristiche qui esposte, in particolare l'ideazione e primo sviluppo da parte di un ente di ricerca poi evoluto nel coinvolgimento di cittadini, studenti e l'amministrazione pubblica e l'approccio multimodale di raccolta dati, il progetto può essere inserito nelle definizioni di PGIS/PPGIS, VGI in un'ottica di crowdsourcing.

2.3. MUES – Mapping Urban Empty Spaces

Il progetto "MUES – Mapping Urban Empty Spaces" si è svolto da aprile a settembre 2018. Il suo obiettivo era di avviare la costruzione di un Atlante dell'abbandono del comune di Padova, sulla scia di quanto fatto in altre città italiane (Casti 2014), per individuare spazi disponibili a nuove funzioni urbane e limitare così il consumo di suolo attraverso il riuso. L'area di studio principale sono stati i quartieri cittadini Portello e Stanga, dove sono presenti numerosi spazi abbandonati, ma nel corso della mappatura sono stati aggiunti anche elementi esterni a queste zone. Il progetto si è articolato in due fasi: 1) seminari e raccolta dati, 2) costruzione e diffusione banca dati.

La prima fase ha compreso 7 seminari sull'uso dei GIS in ambito urbano e le procedure di raccolta dati. Quest'ultima si è basata su fonti eterogenee, tra cui: esame di articoli di giornale, siti web, gallerie fotografiche dedicate al tema e alla cronaca dell'abbandono; ricognizione di cartografie e banche dati digitali messe a disposizione dalle amministrazioni locali; sperimentazione di un rilievo termografico invernale con APR per cercare di individuare strutture non utilizzate usando come indizio le coperture non riscaldate; uscite sul campo (*urban walk*) con gli studenti per la mappatura diretta dei luoghi anche tramite l'uso dell'app GeoPaparazzi; azioni di mappatura partecipativa collegate ad eventi pubblici, in cui i cittadini hanno potuto segnalare siti di loro conoscenza su mappe cartacee oppure tramite tablet aperti sull'applicazione My Maps di Google Maps, usata per la sua semplicità come supporto digitale per la localizzazione degli elementi da mappare.

Tra le fonti della mappatura, dunque, una (le *urban walk*) ha visto la collaborazione degli studenti coinvolti nel progetto, un'altra (gli eventi pubblici) si è aperta alle segnalazioni da parte di tutti i cittadini (Fig. 7).

La seconda fase del progetto è consistita nell'importazione in ambiente desktop GIS (QGIS), tramite il formato di scambio KML/KMZ, dei siti mappati in My Maps e nella creazione di una tabella informativa per ogni elemento mappato, con attributi quali: indirizzo; superficie; tipologia; epoca di costruzione; tipo di abbandono; livello di abbandono; destinazione d'uso prevista. La banca dati risultante è stata infine trasposta in un webGIS sulla piattaforma *open source* Lizmap. La seconda e ultima fase del lavoro, ovvero l'elaborazione dei dati raccolti e la produzione dell'output finale, è stata dunque svolta quasi esclusivamente in studio e non si è basata su metodologie collaborative. Il progetto ha curato attentamente le comunicazioni sui social media con corsisti e persone interessate al tema, attraverso un canale Facebook e uno Instagram dedicati.

Dal lato dei contenuti l'output principale è il webGIS con i siti mappati, disponibile online a questo indirizzo:

<http://62.77.153.17/mastergis/lizmap/www/index.php/view/map/?repository=230918&project=mues2309>. Qui è possibile visualizzare, sullo sfondo di una basemap di Padova, i luoghi oggetto di indagine, suddivisi nelle tre categorie di edifici, aree e complessi abbandonati o sottoutilizzati. Interrogando uno di essi si apre un popup con la tabella attributi, contenente tutte le informazioni raccolte, e per i luoghi più noti e rilevanti il link a un'immagine fotografica (Fig. 8).

In totale sono stati catalogati 79 elementi, in gran parte concentrati nell'area di studio descritta in precedenza, per un'estensione totale di circa 865.000 m². Naturalmente questa cifra rappresenta solo una porzione del totale delle superfici abbandonate a Padova. Sui dati raccolti sono poi state prodotte suddivisioni percentuali, da cui risulta ad esempio che la tipologia di siti più estesa è quella delle aree permeabili incolte o inutilizzate (28%), seguita dagli edifici o complessi commerciali, da quelli militari e da quelli industriali.

Dal punto di vista della partecipazione pubblica, come detto essa si è concentrata nella prima fase del progetto, secondo pratiche di VGI (Goodchild 2007). I seminari – tenuti a frequenza settimanale tra aprile e maggio 2018 e riservati agli studenti dell'Università di Padova – hanno visto il coinvolgimento di 12-15 partecipanti per volta.



Figura 7 Seminari, uscite sul campo e mappatura partecipativa nell'ambito del progetto MUES Fonte: elaborazione degli autori

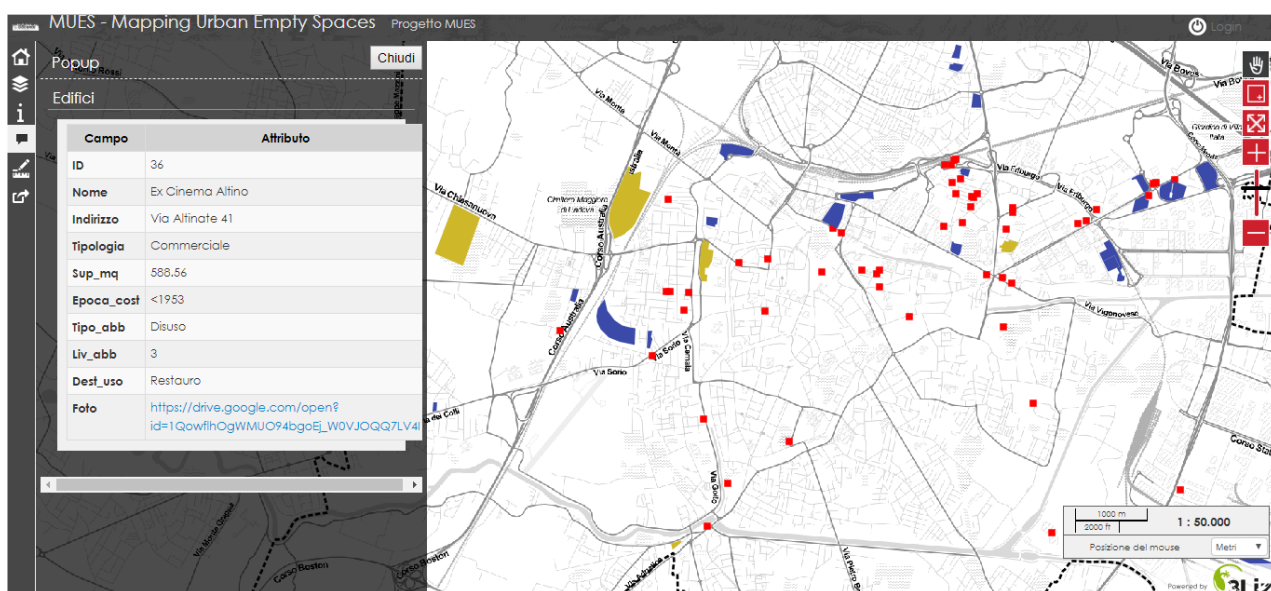


Figura 8 Il webGIS del progetto MUES. In rosso gli edifici, in blu le aree, in giallo i complessi

Nello stesso periodo studenti e collaboratori del progetto hanno svolto passeggiate urbane all'interno dell'area di studio per mappare, fotografare e raccogliere informazioni. Gli eventi di mappatura

partecipata tenuti tra maggio e luglio hanno ampliato la platea degli attori coinvolti permettendo a cittadini informati, spesso membri di associazioni attive sul territorio, di segnalare luoghi in abbandono di propria conoscenza. Inoltre questi sono stati momenti di diffusione al pubblico dei contenuti di sostenibilità urbana del progetto, in cui si è spiegato come il riuso degli spazi liberi possa servire a limitare il consumo di suolo. Sul versante degli strumenti e delle tecnologie impiegate, così come in Piste riCiclabili si sono integrate, durante gli eventi aperti alla cittadinanza, interfacce digitali e analogiche (le mappe cartacee), per favorire l'interazione anche con chi è meno abituato all'uso di nuove tecnologie e *device*. A livello di controllo del dato, infine, la condizione di abbandono o sottoutilizzo dei siti mappati attraverso segnalazioni è stata verificata dai coordinatori del progetto in fase di costruzione della banca dati.

3. Discussione e conclusioni

Si propone ora una tabella (Tabella 1) che riassume le caratteristiche dei tre progetti descritti secondo i parametri di riferimento elencati nel primo capitolo: tipologia o tipologie prevalenti di appartenenza, in rapporto alle definizioni iniziali; obiettivi; metodologie e procedure; tecnologie impiegate; attori coinvolti nelle diverse fasi; risultati raggiunti dal punto di vista dei contenuti. Sono diversi i possibili temi di confronto e discussione fra i progetti presentati. Per semplicità possiamo individuare quattro assi: 1) metodologie di partecipazione e tecnologie dell'informazione geografica; 2) formazione, opportunità di apprendimenti e coscientizzazione dei partecipanti; 3) complessità del quadro conoscitivo da costruire in forma collaborativa; 4) credibilità/affidabilità del dato.

Riguardo il primo punto, si può notare come "Il Valore del Suolo" si sia basato essenzialmente sulla metodologia del lavoro in aula per le operazioni di mappatura, e come di conseguenza l'unico strumento di gestione dati spaziali impiegato sia stato QGIS. Gli altri due progetti avevano bisogno, per i loro scopi, di procedure di raccolta dati più vicine al *crowdsourcing* o di esplorazioni conoscitive sul campo. Le tecnologie dell'informazione geografica usate hanno quindi coperto le fasi di raccolta e aggregazione dati e di trasmissione di informazioni georiferite. Il punto d'incontro dei diversi processi e strumenti descritti è stato il software *open source* QGIS con i suoi plugin.

Le operazioni svolte nei tre casi affrontati hanno richiesto differenti livelli di formazione. Per "Il Valore del Suolo", data la complessità tecnica e interpretativa della procedura di produzione del dato, i partecipanti hanno seguito durante i seminari un corso tematico di formazione GIS; sono stati inoltre affiancati da persone esperte nella fase dell'*hexagon tessellation*. Per Piste riCiclabili sono stati prodotti e diffusi online tutorial per compilare i moduli di segnalazione su ODK. In MUES, i laboratori in aula hanno incluso lezioni sull'uso di applicazioni di *web mapping* e *geotool*, tra cui l'app GeoPaparazzi che è stata utilizzata nella mappatura sul campo. Tutti i progetti hanno poi accresciuto la consapevolezza degli attori coinvolti circa le dinamiche urbane e ambientali.

Al tema della formazione si collega quello della complessità nella raccolta o produzione del dato. In questo senso, “Il Valore del Suolo” ha scelto la via della *geocollaboration* lungo tutta la filiera dalla fotointerpretazione al calcolo del BAF sulle aree di lavoro in cui era stato suddiviso il quartiere Forcellini. Piste riCiclabili ha richiesto un impegno medio ai suoi partecipanti, soprattutto quelli coinvolti nella raccolta dati per via digitale: essi hanno di fatto prodotto i contenuti informativi sui singoli punti mappati, che dopo un processo di aggregazione e conversione sono confluiti nel webGIS disponibile online. Il progetto MUES ha optato per una fase di raccolta dati partecipata “ibrida”, dove cioè è stato possibile sia limitarsi alla segnalazione di un sito abbandonato che aggiungere informazioni su di esso, in particolare attraverso la *geoapp* usata. Il lavoro di costruzione delle schede informative associate è stato svolto a schermo in seguito, poiché voci come quelle su superficie o destinazione d’uso prevista necessitavano di un supplemento di indagine.

Progetto	Il Valore del Suolo	Piste riCiclabili	MUES
Tipologia/e	Geographic Citizen Science, Public Participation in Scientific Research, Geocollaboration	PPGIS, VGI, Crowdsourcing	VGI, Collaborative mapping, GeoWeb
Obiettivi	Mappatura della permeabilità secondo l'indice BAF in un quartiere campione a Padova	Mappatura delle criticità dei percorsi ciclabili nel Comune di Padova	Mappatura degli spazi abbandonati in un'area campione di Padova
Metodologie	Fotointerpretazione, ridisegno in GIS e classificazione per livello di permeabilità su ortofoto RGB ad alta risoluzione	Raccolta dati geolocalizzati attraverso form online o pin su mappe cartacee	Raccolta dati da fonti pregresse, urbanwalk e segnalazioni, creazione banca dati per ogni sito
Tecnologie di informazione geografica impiegate	QGIS	ODK, Jotform (raccolta dati), QGIS (elaborazioni), Lizmap (webGIS)	GeoPaparazzi, My Maps (raccolta dati), QGIS (elaborazioni), Lizmap (webGIS)
Attori coinvolti	Studenti (seminari e lavoro in aula)	Studenti e cittadini (raccolta segnalazioni)	Studenti (seminari e urbanwalk), cittadini (raccolta segnalazioni)
Controllo del dato	Controllo in aula e revisione in fase di aggregazione dati	Visita di alcune zone per verificare presenza criticità segnalate	Verifica segnalazioni da parte dei realizzatori del webGIS
Risultato	Mappatura GIS normalizzata della permeabilità nel quartiere Forcellini di Padova	WebGIS dei punti critici della rete ciclabile del Comune di Padova	WebGIS con localizzazione e schede informative di edifici, aree e complessi mappati

Tabella 1 I tre progetti a confronto

Per ciò che concerne la credibilità o affidabilità dei dati prodotti, emerge come un progetto quale Il valore del suolo, basato sulle attività in presenza dedicate allo svolgimento di un preciso compito, abbia il vantaggio di un controllo in tempo reale sulla creazione del dato, nonché del supporto tecnico e conoscitivo da parte di figure esperte. Gli altri due progetti hanno condotto verifiche a valle delle segnalazioni: in Piste riCiclabili sono stati controllati alcuni punti campione distribuiti sul territorio mappato, riscontrando una buona corrispondenza con lo stato di fatto; in MUES tutti gli elementi segnalati sono stati verificati in fase di realizzazione della banca dati. Una questione ulteriore è la possibile incompletezza o non piena rappresentatività del dato finale in relazione agli obiettivi: nel caso de Il valore del suolo lo scopo ben definito e la circoscrizione dell'area di intervento hanno permesso il raggiungimento di un risultato compiuto. In Piste riCiclabili la concentrazione di

partecipanti tra giovani e studenti può avere condizionato gli esiti finali, nonostante la predisposizione di un doppio canale di mappatura cartacea e digitale. In MUES, infine, sono state accettate segnalazioni esterne ai quartieri campione scelti in partenza, in previsione di un successivo ampliamento dell'Atlante dell'abbandono; ciò ha condotto a un risultato che, rispetto all'intera superficie comunale, risulta incompleto e aperto a integrazioni future.

In conclusione, si può dire che progetti di questo tipo testimoniano la vitalità della *Geographic Citizen Science* come strumento per mettere a sistema conoscenze diffuse tra la popolazione nonché per diffondere consapevolezza e competenze scientifiche su temi di forte presa sociale come la mobilità e l'uso sostenibile degli spazi urbani. In questo contesto le geotecnologie e l'interoperabilità nello scambio dati tra app per *device* mobili e software desktop GIS rappresentano un supporto tecnico di grande utilità in processi di mappatura collaborativa.

Per ovviare agli inconvenienti discussi riguardo squilibri nella partecipazione, incompletezze o difetti di validazione dei dati, è opportuno bilanciare l'ambizione degli obiettivi prefissati con la prudenza nella stima dei partecipanti attesi e delle effettive possibilità di controllo dei risultati.

BIBLIOGRAFIA

- Becker C., Giseke U., Mohren B., Richard W., *Landschaft planen und bauen* (1990), *The Biotope Area Factor as an Ecological Parameter: Principles for Its Determination and Identification of the Target*, Berlin Senate Department for Urban Development and the Environment, Berlin
- Bonney R., Ballard H., Jordan R., McCallie E., Phillips T., Shirk J., Wilderman C.C. (2009), *Public Participation in Scientific Research: Defining the Field and Assessing Its Potential for Informal Science Education*, Center for Advancement of Informal Science Education (CAISE), Washington, DC.
- Brown G. (2004), "Mapping Spatial Attributes in Survey Research for Natural Resource Management: Methods and Applications", *Society and Natural Resources*, 18, pp. 17-39.
- Brown G., Kyttä M. (2014), "Key issues and research priorities for public participation GIS (PPGIS): A synthesis based on empirical research", *Applied Geography*, 46, pp. 122-136.
- Capineri C., Haklay M., Huang H., Antoniou V., Kettunen J., Ostermann F., Purves R. (2016), "Introduction", in Capineri C., Haklay M., Huang H., Antoniou V., Kettunen J., Ostermann F., Purves R. (a cura di), *European Handbook of Crowdsourced Geographic Information*, Ubiquity Press, Londra, pp. 1 -11.
- Casti E. (2014, a cura di), *Aree dismesse e obsolete in Lombardia, Rapporto I fase di ricerca del progetto Rifo/It*, DiathesisLab, Bergamo.
- Codato D., Malacarne D., Ghezzeo E., Pappalardo S., Diantini A., Artico C., Gianoli F., De Marchi M. (2017), "Mapping from below: mappatura partecipata della rete ciclabile e delle sue criticità nella città di Padova", in: *Atti della XXI Conferenza Nazionale ASITA, Salerno 21-23 novembre 2017*, pp. 263-270.
- Commissione Europea, "Direttiva 2007/2/CE del Parlamento europeo e del Consiglio, del 14 marzo 2007, che istituisce un'Infrastruttura per l'informazione territoriale nella Comunità europea (Inspire)", *Gazzetta ufficiale dell'Unione Europea*, 25 aprile 2007.
- Crescini Di Montevecchio Benedetti E. (2018), *Consumo di suolo a Padova: analisi GIS del quartiere Forcellini (PD) e calcolo dell'indice Biotope Area Factor*, tesi di laurea triennale, corso di laurea in Scienze Naturali, Dipartimento di Biologia, Università degli Studi di Padova.
- Elwood S., Goodchild, M.F., Sui, D.Z. (2012), "Researching volunteered geographic information: Spatial data, geographic research, and new social practice", *Annals of the Association of American Geographers*, 102, pp. 571 -590.
- Estellés-Arolas E., González-Ladrónde-Guevara F. (2012), "Towards an integrated crowdsourcing definition", *Journal of Information Science*, 38, pp. 189–200.
- Goodchild M.F. (2007), "Citizens as sensors: The world of volunteered geography", *GeoJournal*, 69, pp. 211 - 221.
- Haklay M. (2016), "Why is participation inequality important?", in: Capineri C., Haklay M., Huang H., Antoniou V., Kettunen J., Ostermann F., Purves R. (eds.), *European Handbook of Crowdsourced Geographic Information*, Ubiquity Press, Londra, pp. 35 -44.
- Harvey F. (2013), "To volunteer or to contribute locational information? Towards truth in labeling for crowdsourced geographic information", in Sui, D., Elwood, S., Goodchild, M. (a cura di), *Crowdsourcing Geographic Knowledge*, Springer Netherlands, Dordrecht, pp. 31 -42.
- Howe J. (2006), "The rise of crowdsourcing", *Wired Magazine*, 14, pp. 1–4.

- ISPRA (2018), "Consumo di suolo, dinamiche territoriali e servizi ecosistemici", in: Munafò M. (a cura di), *Rapporti 288/2018*, Roma.
- Jiang B., Thill J.-C. (2015), "Volunteered Geographic Information: Towards the establishment of a new paradigm", *Computers, Environment and Urban Systems*, 53, pp. 1-3.
- La Varra G. (2016, a cura di), *Architettura della rigenerazione urbana*, Forum Editrice, Udine.
- Leggieri E., Loret E. (2014), "Telerilevamento e GIS per la riqualificazione degli insediamenti industriali dismessi", in: *Atti della XVIII Conferenza Nazionale ASITA, Firenze 14-16 ottobre 2014*, pp. 727-734.
- MacGillivray, E. (2003), *Collaborative Mapping, Webmapper*, Utrecht.
- Peroni F., Brugnaro S., Sozzi M., Crescini E., Pappalardo S., Codato D., Gianoli F., Lanzavecchia A., De Marchi M. (2017), "BAF Index e mappatura del consumo di suolo a Padova: quantificazione e simulazione di scenari alternativi", in: *Atti della XXI Conferenza Nazionale ASITA, Salerno 21-23 novembre 2017*, pp. 853-860.
- Pristeri G., Peroni F., Brugnaro S., Pappalardo S., De Marchi M. (2018), "Mappatura GIS degli spazi urbani abbandonati: un caso studio a Padova", in: *Atti della XXII Conferenza Nazionale ASITA, Bolzano 27-29 novembre 2018*, pp. 803-810
- See L., Mooney P., Foody G., Bastin L., Comber A., Estima J., Fritz S., Kerle N., Jiang B., Laakso M., Liu H-Y., Milcinski G., Nikšić M., Painho M., Podör A., Olteanu-Raimond A-M., Rutzinger M. (2016), "Crowdsourcing, Citizen Science or Volunteered Geographic Information? The Current State of Crowdsourced Geographic Information", *ISPRS International Journal of Geo-Information*, 5, 5, pp. 55-77.
- Sieber R. (2006), "Public participation geographic information systems: A literature review and framework", *Annals of the American Association of Geography*, 96, 3, pp. 491-507.
- Socientize (2014), *White Paper on Citizen Science for Europe*, Socientize Consortium, Zaragoza
- Steiniger S., De La Fuente H., Fuentes C., Barton J., Muñoz J-C. (2017), "Building a geographic data repository for urban research with free software – learning from Observatorio.CEDEUS. cl", *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume XLII-4/W2, pp. 147-153.

HOW TO MAP SOIL SEALING? A SYSTEMATIC REVIEW

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Keywords: soil sealing, soil, impervious surface, land consumption, soil consumption, land take, sustainable urban planning

Abstract

Soil degradation is one of the main environmental issues debated in the international agendas on sustainability and climate adaptation. Among degradation processes, soil sealing represents the major threat for soils, as ecosystem services dramatically decrease or are even nullified. The increasing use of big open data from remote sensing satellites combined with AI algorithms are making geodata mining and mapping techniques essential to quantify soil sealing. Different keywords are adopted to define the phenomenon; we analyzed: i) impervious surface, ii) soil sealing, iii) land take, iv) soil consumption, v) land consumption. The present work provides a systematic review of remote sensing platforms and methodologies to map and to classify soil sealing, by highlighting: i) keywords definitions; ii) relationships among study area, scales, platforms, resolutions, and classification methodologies; iii) emerging trends and policy implications. We performed a systematic search using Scopus within 2000-2020 time-frame, identifying 1,277 papers; 392 focused on mapping soil sealing. "Impervious surface" was the dominant definition. The phenomenon was more studied by the USA, China and Italy and, "soil sealing" is recently more adopted in EU, due to policies to address soil protection. Most studies focused on mapping soil sealing at urban scale. We found Landsat satellites are the most adopted platforms; they are frequently used for multi-temporal analyses. 11 different methodologies were identified: automatic classifications were the most adopted, dominated by pixel/sub-pixel-based approaches; other methods include band ratios, supervised, OBIA, ANN. The majority of mapping analyses were performed on 30 m spatial resolution in study areas of 1,000-10,000 km². Landsat images were less used for smaller areas. In conclusion, as study area size increases, a decrease in image resolution

with the use of more completely automatic classification methodologies were recorded. However, most studies focused on testing and comparing classification techniques rather than specifically supporting policy making for sustainable urban planning. Thus, we encourage to fill the gap by developing approaches that applicable to international policies.

1. Introduction

1.1. Soil sealing: defining the phenomenon

Soil degradation is recognized as one of the main environmental issues debated in the international and national agendas on sustainability and climate adaptation (Montgomery 2012; Koch et al. 2013; FAO 2015; European Environment Agency 2016). Among degradation processes, land-surface impermeabilization represents the major threat for soils, as ecosystem functions and services drastically decrease or are even nullified (Scalenghe and Marsan 2009). In fact, despite different definitions reported in the scientific literature, such irreversible human-driven land-use dynamics are related to the covering of natural and semi-natural soil with impermeable surfaces such as concrete, asphalt and other impervious materials (Prokop et al. 2011).

Recently, due to international strategies and policies adopted for increasing sustainability and resilience of urban ecosystems such as “Zero Land Take 2050” (European Commission 2011; Prokop et al. 2011; Decoville and Schneider 2016), the global attention on “soil sealing” notably increased, by involving both scientists and stakeholders from different disciplines and institutions: civil and environmental engineers, urban planners, ecologists, geographers, geologists, economists on one hand; policy makers from different level of institutions and governance on the other one. Such increasing attention is related to the multiple and multiscale effects of land cover/land use changes of soil sealing which affects forests, grasslands, agricultural lands, and bare soils (Burghardt 2006; Murata and Kawai 2018). Moreover, as reported in the latest AR6 IPCC Report on Climate Change, the frequency increase of extreme meteorological events such as heat waves, extreme rainfall, and floods will exacerbate impacts of soil sealing in urban ecosystems (2021).

Direct impacts of soil sealing are strictly related to drastic changes in hydrologic cycle such as alteration of urban runoff and infiltration processes, reduction of groundwater recharge, which might increase the hydrogeological risk and decrease of water quality (Arnold and Gibbons 1996; Shuster et al. 2005; Pistocchi et al. 2015). Important impacts of soil sealing also directly affects ecosystems and, therefore, goods and services they provide: landscape fragmentation and ecosystem degradation, changes in thermoregulation, carbon sequestration and pollution mitigation as services and functions provided from vegetation systems (Scalenghe and Marsan 2009; Fini et al. 2017; dos Santos et al. 2017). Moreover, soil sealing is recognized as one of the first causes of biodiversity loss worldwide (Seto et al. 2012). In urban context it affects human well-being and health by reducing green and open spaces (Artmann et al. 2019). Finally, by the expansion and sprawling of urban areas, it affects agricultural and semi-natural lands which are covered by new buildings and

terrestrial infrastructures, reducing the availability of food and jeopardizing food security, especially in developing countries (Gardi 2017a).

Due to its inherent geographic dimension, studies about soil sealing are often spatially-explicit and quantitative, generally oriented to map the phenomenon or to detect temporal changes. Hence, a common requirement is to quantify, to map and to geovisualize the amount of sealed surfaces. In addition, many scientists investigate the spatial evolution of soil sealing over the years, by performing multitemporal analyses to identify land cover changes related to the urban expansion. Finally, an important task is to annually monitor the phenomenon and to verify the effectiveness of new laws and regulations promulgated to limit soil sealing (Langella et al. 2020).

Despite in the last 20 years, scientific literature includes a significant number of research articles which deal with this issue, only three review articles focused on methodologies to map the phenomenon (Slonecker et al. 2001; Weng 2012; Wang and Li 2019). However, such review articles only include “impervious surface” as a search keyword, excluding other common terms and definitions of the same phenomenon. By considering the growing need to respond both at Sustainable UN Development Goals as well as international, national and regional policies for limiting such phenomenon, we firstly perform a comprehensive screening of definitions and terms commonly adopted in scientific literature:

i) soil sealing: “the destruction or covering of soils by buildings, constructions and layers of completely or partly impermeable artificial material (asphalt, concrete, etc.)” (Prokop et al. 2011);

ii) land consumption: “the change from a non-artificial to an artificial land cover of the ground, with the distinction between permanent land consumption (due to permanent artificial cover) and non-permanent land consumption (due to a reversible artificial cover)” (Strollo et al. 2020);

iii) soil consumption: it is used as a synonymous of “land consumption” and it describes the transition from natural to artificial land (Amato et al. 2017). It is scarcely used in the scientific literature, however Scalenghe and Marsan (2009), one of the most important articles that highlights the impact of soil sealing, adopts this term;

iv) impervious surface: “can be generally defined as any material-of natural or anthropogenic source- that prevents the infiltration of water into soil and thereby changing the flow dynamics, sedimentation load and pollution profile of storm water runoff” (Slonecker et al. 2001); in addition “features that commonly account for 80% of impervious cover include buildings e.g., roofs, driveways, and patios, roads, and parking lots” (Theobald et al. 2009);

v) land take: according to Prokop et al. (2011) the term refers to the rising of artificial areas over time. This practice is usually performed to the detriment of agricultural areas.

According to a recent study on “Standard and Strategies for the reduction of land consumption” (2020), which investigated definitions within scientific literature and EU land policy context, “soil sealing”, “land take”, “soil consumption”, and “land consumption” are, at present, the most adopted terms. The authors suggested to prioritize the term land take (Marquard et al. 2020). It is worth noting

that, since 2002, the European Commission used the term “soil sealing” referring to the phenomenon of imperviousness of soil (Commission of the European Communities 2002). Since then, “soil sealing” as keyword started to be used by other European national institutions and in the scientific literature. Furthermore, in the UN Sustainable Goal (SDG-11), the SDG-indicator “Ratio of land consumption rate to population growth rate”, defined this land-surface impermeabilization phenomenon as “land consumption”.

In this perspective, review articles presenting the state-of-the-art on mapping soil sealing and analyzing the most common definitions are currently not available. Hence, this study attempts to fill the gap by including in the systematic review five keywords: i) impervious surface, ii) soil sealing, iii), land take, iv) soil consumption, v) land consumption. In the present study, authors adopt the term “soil sealing” to define such phenomenon.

1.2. Remote sensing technologies to map soil sealing

In last decades, the increasing availability of data from aerial platforms made remote sensing together with Geographic Information Systems (GIS) the most widely adopted technology to map and to assess soil sealing, at different geographic scales of analysis. In fact, satellites, airplanes, and fixed-wing UAV platforms, equipped with a wide range of sensors, can provide an ever more increasing spatial, temporal and radiometric resolution. At present, the spread of big open data from satellites combined with the development of AI algorithms are making geodata mining and mapping techniques essential to quantify soil sealing at different spatial and temporal resolutions. In fact, the use of GIS and geodata allows to analyze and to model spatial data at different scale, from small portion of land surface, up to the national or global scale (Slonecker et al. 2001; Zhang et al. 2019). Other technologies such as field survey, census data or ground-based data collection are generally costly and time-consuming. However, they were frequently used in recent past years for monitoring soil sealing (Lu and Weng 2006). An important example is represented by LUCAS Program (Land Use/Land Cover Area Frame Survey) which was managed by EU Member States to measure the nature of land cover and its use (Ballin et al. 2018).

Overall, remote sensing technologies present many advantages: i) they enable to perform spatial analysis on large areas (Weng 2020); ii) they can provide open access big spatial data (i.e. NASA Landsat or EU Copernicus satellite missions; iii) they can allow high-frequency re-visit time over the same area, making feasible multitemporal analyses and monitoring soil sealing processes over years and decades. Indeed, two important studies which express the strength of combining open satellite data with GIS modelling are represented by the use of imageries from the Landsat satellites constellations and the Sentinel missions; the former adopted Landsat image series to map the urban expansion in 50 global cities (Bagan and Yamagata 2014); the latter provided the “Urban Atlas” from the EU monitoring service which used Copernicus Sentinel Satellite to map soil sealing in EU27 plus European 11 countries (European Commission 2020). In fact, through the launch of Sentinel

missions in 2015 different satellites are recently available by providing open spatial data to monitor worldwide land use/land cover changes and to detect new urbanization. It is noteworthy the case of the Italian National Institute for Environmental Protection and Research (ISPRA) that since 2015 adopted Sentinel satellite open data from Copernicus Program to monitor soil sealing for the whole Italian country, annually (2021).

1.3. Mapping soil sealing: an issue of scale and resolution

Undoubtedly, relationship between the nominal spatial resolution of remotely sensed images and the scale of analysis is a crucial point that must be considered in land cover mapping, feature extraction and spatial analyses. The higher the spatial resolution of the image, the more detail can be detected from the analyzed surface.

In contrast to forests or agricultural landscapes which generally presents more uniform spatial patterns, most of city surfaces are heterogeneous as a result of a mash-up different geographic features which typically compose an urban fabrique. Sealed urban surfaces are generally represented by areal (buildings and parking lots) and linear (roads and streets) features. Geometric and spectral characteristics as well as features size of urban surface features vary a lot, making relationships between scales and resolution crucial for mapping soil sealing by remotely sensed data modelling (Weng 2014). In this paper we adopt a geographical approach to scale and resolution to better clarify such relationships. Firstly, the geographic scale (or observational scale) refers to the size or the spatial extent of the study on which analyses are performed (Quattrocchi and Goodchild 1997); it usually corresponds to the declared study area. Secondly, as quantitative analyses are often pursued, the measurement scale should be strongly investigated, as it represents the nominal resolution – namely spatial resolution - of the remotely sensed images (Quattrocchi and Goodchild 1997). Typically, it is related to smallest picture element which represent its spatial footprint on the ground and, therefore, the size of the smallest detectable feature. Theoretically, only features larger than one pixel can be detectable. Indeed, by considering both geographic scale and image resolution, a minimum mapping unit (MMU) - defined as “the smallest size areal entity to be mapped as a discrete entity” - for feature to be detected should be analyzed and identified (Lillesand and Kiefer 1994). However, it is generally agreed that the smallest feature that can reliably be mapped would need to fall at least 2x2 or 3x3 contiguous pixels in size, by defining a suitable MMU (Saura 2010; Álvarez 2017). The adoption of a certain MMU that is appropriate for a specific land use extraction and classification is therefore paramount as an earth surface phenomenon detectable on one given geographical scale may not exist in another one, due to the effect of spatial resolution. Mapping and classification accuracy of urban surfaces is therefore dependent on the MMU capable to detect different sizes and geometries of land cover. Hence, to accurately detect and to discriminate sealed urban surfaces such as buildings, parking lots, pavements and roads width, a spatial

resolution ranging from 0.25 to 1 m pixel size is strongly recommended (Jensen and Cowen 1999; Franklin et al. 2003; Rogan and Chen 2004).

In general, remote sensing sensors equipped on aerial platforms (satellites, airplanes and drones) acquire images in a wide range of spatial resolution. Even if classification of spatial resolution is changing over time due to the advances in sensor technology and computing capacity, it can be currently categorized in four main classes: coarse (> 1,000 m), medium (100-1,000 m), high (5-100 m), very high (<5 m) (Liang and Wang 2019). Coarse spatial resolution images are scarcely suitable for mapping soil sealing, with the exception of mapping at global scale; medium resolution images such as MODIS (250-1,000 m) and NOAA-VIIRS (750 m) dataset are usually adopted for mapping at small scale (national, macro-regional, continental regions, world-scale); fine resolution such as Landsat 8 (30 m) and Sentinel 2A/B (10 m) is commonly used for mapping at regional and local scale; very high spatial resolution such as images from Pléiades Neo airbus from the Space Agency of France (0.3 m), from commercial satellites from WorldView (0.3 m), and orthophotos generated from airborne optical sensors are used for mapping at large and very large scale (urban, sub-urban, neighbourhood scale) (Weng 2012; Asad et al. 2017; Wang and Li 2019; Radočaj et al. 2020). A complete overview of main satellite platforms, including spatial and spectral resolution, is presented by Sam and Agilandeewan (2020).

1.4. Methodologies and approaches to mapping soil sealing

A variety of classification methodologies and approaches have been used to map soil sealing - from the long-stand photo-interpretation of ortho-photos to advanced subpixel-based modelling and extraction from satellite imagery. Based on our analysis of previous research, a general workflow was utilized: i) to identify suitable remotely sensed imagery according to the study area size and spatial resolution requirements; ii) dataset preparation and preprocessing (image calibration, atmospheric correction, samples testing); iii) ancillary data preparation (for some articles); iv) feature classification; v) output and thematic map production.

In the scientific literature, a wide range of classification methodologies are used, generally grouped in: Spectral Mixing Analysis (SMA), Linear SMA (LSMA), vegetation indexes analyses (NDVI, NDBI, IBI), Image Classification (sub-pixel, pixel based, object based, machine learning and deep learning based). A complete overview of such classification methodologies is described by Wang and Li (2019) and not presented here.

For the purpose of the present work such classification methodologies were aggregated in macro-categories to better summarize the differences and approaches for mapping soil sealing. SMA includes standard SMA models and modified methods that helps to identify single and multiple endmembers (i.e. LSMA, MESMA, NSMA, and PNMESMA) (Phinn et al. 2002; Weng and Lu 2008; Franke et al. 2009; Li and Wu 2015; Chen and Yu 2016). The Decision/Regression tree category includes Regression trees and Decision Tree methods, but also Random Forest, multiple regression

tree, and Support Vector Machine (SVM) (Feng et al. 2016; Cao et al. 2018; Fu et al. 2019). Hereafter, we refer to vegetation indexes as Band ratio class, by including NDVI, NDBI, MNDISI, SAVI, and others indexes (García and Pérez 2016; Sun et al. 2017; Gong et al. 2019; Zhong et al. 2019). The reclassification process is referred to papers that used ancillary data, for example Land Cover data, to derive soil sealing coverage (Jennings et al. 2004; Pristeri et al. 2020). The image interpretation category includes scientific articles that adopted human visual analysis to identify and to map impervious areas (Hartcher and Chowdhury 2017; Lozano et al. 2019). In some cases human image interpretation might be used in combination with other methodologies (Xiao et al. 2020). The linear regression category represented the articles that adopted a deterministic equation to estimate soil sealing (Elvidge et al. 2007). In the majority of articles using linear regression, this methodology works in combination with other techniques (Ma et al. 2016). Finally, temporal filtering class was always associated with other methods and was usually employed in multitemporal analyses (Zhang and Weng 2016).

1.5. Aims of the research

Firstly, this review article provides a general overview about soil sealing in the period 2000-2020, by analyzing the five main terms adopted in the scientific literature to define the phenomenon. Based on these keywords outcomes, the present works aims to provide a systematic review of remote sensing technologies and methodologies adopted to map and to classify soil sealing, by focusing on the relationships between geographic scales, spatial resolution and classification techniques. Specific aims are to investigate the topic of soil sealing highlighting: i) the use of the main keywords during 20 years in different countries; ii) the geographic distribution of researches and study cases; iii) the main platforms, methodologies and techniques adopted; iii) relationships among study area size, scales, platforms, resolutions, and classification methodologies; iv) emerging trends and policy implications.

2. Approaches and methodologies for bibliometric analysis

2.1. Review approach

The analyzed papers were selected in the Scopus database within a time-frame of 20 years (last update: December 31, 2020). Search was performed from the Italian territory. The search resulted in 1,277 peer-reviewed papers published in international scientific journals. Gray literature was not included in the review, as well as books, proceedings and PhD Thesis, in order to analyze articles with secured high quality standards. The search in Scopus was provided using all the five keywords. Queries were performed in the "Article Title" and "Keywords" fields for the Scopus database; only papers in English from 2000 were selected. Indeed, a preliminary analysis showed that before 2000 articles related to soil sealing were limited, less than 2 or 3 per year. Moreover, as reported by Weng

(2012), in the 1990s papers on soil sealing defined as impervious surfaces were limited; only in the following years the topic gained interest in scientific community.

All articles were analyzed to include only papers which i) focused on the phenomenon of soil sealing and ii) performed mapping and spatial quantification analyses. 503 papers resulted in the selection process and they were then included in the review for detailed analyses. Then, papers were re-analyzed in order to exclude studies not directly related to the topic.

Finally, articles based only on predictive models without any aim of mapping as well as those which used secondary acquired data from other studies were excluded. Therefore, 392 papers are used for the review analysis.

2.2. Preliminary analysis

Firstly, preliminary analyses were conducted including all the 1,277 papers. We therefore performed: i) frequency and temporal analysis of the five keywords analyzed from 2000 to 2020, ii) country-based geographic distribution analysis at global level of articles which performed soil sealing mapping, and iii) country-based frequency analysis on adopted keywords.

For each article a single keyword was selected and extracted from the “article title”, the “authors keywords”, or the “indexed keywords” provided by Scopus. The “indexed keywords” are additional keywords adopted by Scopus to take into account synonyms, various spellings, and plurals of the “authors keywords” (Scopus 2021).

Identification of countries which more frequently investigated soil sealing is provided by identifying the affiliation of the first author of each article. Subsequently, the ten most frequent countries are selected to identify the frequency of each keyword. Analyses were performed by using Microsoft Excel[®] and R Studio software.

2.3. Bibliometric analysis and database construction

Bibliometric analysis was performed on a database by designing a standardized data extraction sheet. Articles were analyzed by single authors; subsequently, they were individually cross-checked by the other authors of this study to verify data and extraction. Database was structured into eight main categories: i) bibliographic references (paper title, author(s), year, issue/volume, journal); ii) goal of the study; iii) location and information on the case(s) study, such as the scope and the size of the case(s) studies; iv) duration analysis of the study (sampling frequencies of temporal images); v) input data and remote sensors platforms (main input, numbers of sensors of remote sensing platforms, specific category of remote sensing platform, resolution of the input data, and MMU); vi) classification methodologies; vii) output layers; viii) open data and open source software. All selected criteria are summarized and described in Table 1. Finally, results were analyzed by using R Studio, Microsoft[®] Excel and the open-source GIS software QGIS (version 3.16).

Table 1 Database construction: selected criteria, classification and observations.

	Database	Description	Observations
i)	Bibliographic references	Paper title, author(s), year of publication, journal, volume, issue, abstract, keywords, document type (article or review), objective(s) of the study.	
ii)	Goal of the study	Aim of the article, for example if the analysis is providing to assess climate change, water management or urban heat island. We identify 13 categories.	
iii)	Multiple location	Analysis of multiple locations.	
iv)	Dimension of the study area (s)	Eight main categories to classify the size of study areas were aggregated: <50 km ² , 50-100 km ² , 100-500 km ² , 500-1,000 km ² , 1,000-5,000 km ² , 5,000-10,000 km ² , 10,000-50,000 km ² , >50,000 km ² .	
v)	Scope of the study	According to the context, the territorial scale of analysis of the study was identified. Six categories were therefore aggregated: country, regional, watershed, urban, sub-urban (neighbourhood), and land parcel scale.	Urban scale identifies both a single municipality (i.e. the city of Beijing), but also a county in the USA. This class includes a single municipality and its surrounding urban territory.
vi)	Multi-temporal analysis	Multitemporal analysis or a yearly-based analysis.	Temporal scale
vii)	Duration analysis	Duration of the analysis in year.	Temporal scale
viii)	Sampling frequencies	Numbers of scenes used in the articles.	
ix)	Input data	14 categories were defined: orthophotos, optical imagery, near-infrared, SWIR, MID-infrared, PAN, VIIRS (Suomi), thermal, Hyperspectral, radar, LiDAR, Night time imagery.	Non remotely sensed data (e.g.: statistical data/field data/census data) were included. Input data category is adopted mainly as control reference.
x)	Numbers of sensors	1, 2, 3 or more than 3 sensors were categorized.	
xi)	Remote sensing platform	Which satellite(s) is/are employed for the study. In case of orthophotos we used the category "airborne sensor".	In case the article does not employ remote sensing platform we mark the category "ancillary data" in input data.
xii)	Multiple resolution	Studies based on different images at multiple resolutions.	
xiii)	Resolution of remote platform	Maximum and the minimum resolutions were reported in case of multiple resolution images. The aggregated categories are 12: sub-m (< 1 m), m (from 1 m up to 9.9 m), 10 m, 10-30 m (from 11 m up to 29.9 m), 30 m, 30-100 m (from 31 m up to 99.9 m), 100 m, 100-250 m (from 101 m up to 249.9 m), 250 m, 500 m, 750 m, 1,000 m.	Main sources used for the analysis were considered, excluding images for the data validation or for scaling-up analyses. DMSP/OLS images were considered at 500 m resolution.
xiv)	Comparative methodologies	We report if the study uses comparative approaches, providing a comparison between different methodologies, or if the study uses single methods.	
xv)	Classification methodologies	16 categories were identified and aggregated: Image Interpretation, Image Interpretation and Automated Processing, Band Ratios (e.g. NDVI, Spectral-angle mapper, SAVI, etc.), Supervised, Unsupervised, Object-oriented	Regarding both Band Ratio class and SMA category, we reported the specific methods adopted, for example SAVI, NDBI or NSMA, etc., but in

		methods (OBIA), ANN methods, Regression trees, Decision trees, Cubist, CART, Random Forest, SVM, SMA, Not Applicable (N.A.). These 16 categories were summarized in 11 classes: Regression/Decision trees include (Regression trees, Decision trees, Cubist, CART, Random Forest, SVM), while Image Interpretation and Automated Processing is included in Image Interpretation category.	the analyses we simplified in the main categories (see the annex to check the detailed classes). Main and secondary methodology(ies) were identified, but we included in the analysis only the main one (See the annex for secondary methods).
xvi)	Multiple methodologies	More than one main methods results were included	
xvii)	MMU	Declared Minimum Mapping Unit (MMU).	Supporting Material for further details.
xviii)	Output layer	Three categories were selected to identify the different output layers: binary (impervious/not-impervious), ordinal scale of imperviousness (e.g. low, medium, high impervious), percent impervious (0%, 10%, 30%, ~100%).	Supporting Material for further details.
xix)	Open data	Three categories were identified: open data, no open data, mixed, Not Declared (N.D.).	It is referred to the main data used for the analyses, not validation data.
xx)	Open source software	Three categories were identified: open source, no open source, mixed, Not Declared (N.D.).	See the annex for the details.

3. Results and discussion

3.1. Temporal and country-based frequency analyses

On the whole, “impervious surface” is the dominant keyword, with 983 papers adopting this term (76.98%). Other keywords present lower occurrences: “soil sealing” presents 127 occurrences (9.95%), whereas “land consumption”, “land take”, and “soil consumption” present 65 (5.09%), 53 (4.15%), and 33 (2.58%) occurrences, respectively. “Mixed” keywords include 16 occurrences (1.25%). See Figure 1.

In general, from 2008 soil sealing becomes a growing research topic from an average of 10-20 papers per year to more than 50 articles in 2008 (Figure 2). Later, the number of published papers steadily growth, to almost 100 papers in 2015. In the last five years, scientific articles on soil sealing almost doubled, from 100 in 2015 to almost 200 in 2020.

Temporal analysis on keyword show that the dominant keyword is “impervious surface” all over the time. Since 2000, it is the first keyword to appear together with “soil sealing” and it continued to be present until 2020. The growth of this keyword follows the general growth of the topic. Indeed, from 2008 to 2015 it maintains an occurrence between 50 and 60 articles per year, while from 2016 it presents a steady growth. However, in 2020 it shows a remarkable growth with 131 occurrences. The other four keywords show less outcomes. Since only 2013 a greater variability of adopted keywords is highlighted. In more detail, from 2013 to 2020, “soil sealing” ranges from 13 to 17 results per year, while “soil consumption”, “land consumption”, and “land take” show even lower results. Temporal analysis to investigate the occurrences of the five keywords from 2000 to 2020 is shown in Figure 2.

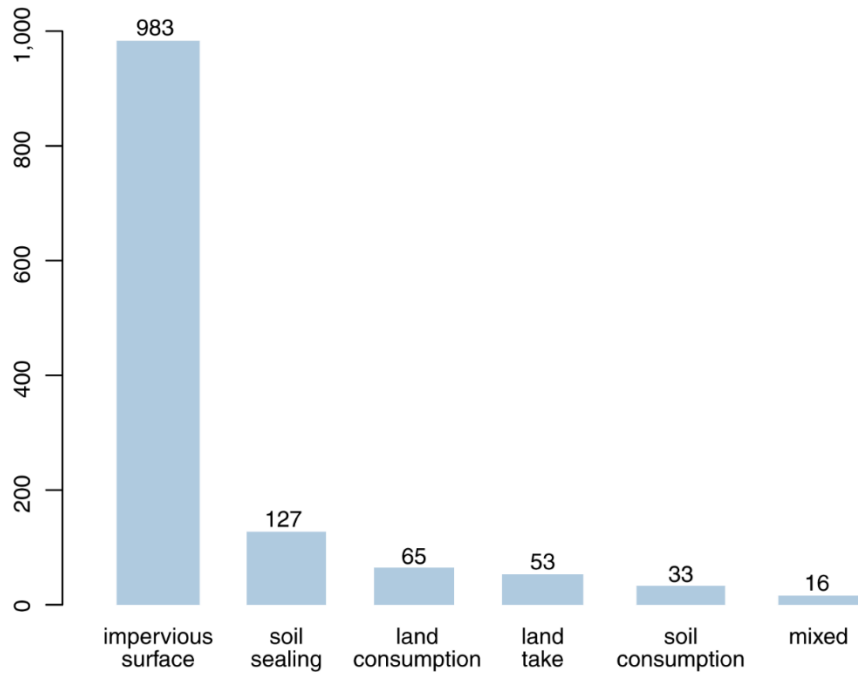


Figure 1 Relative frequency analysis for each of five keywords for all the 1,277 articles

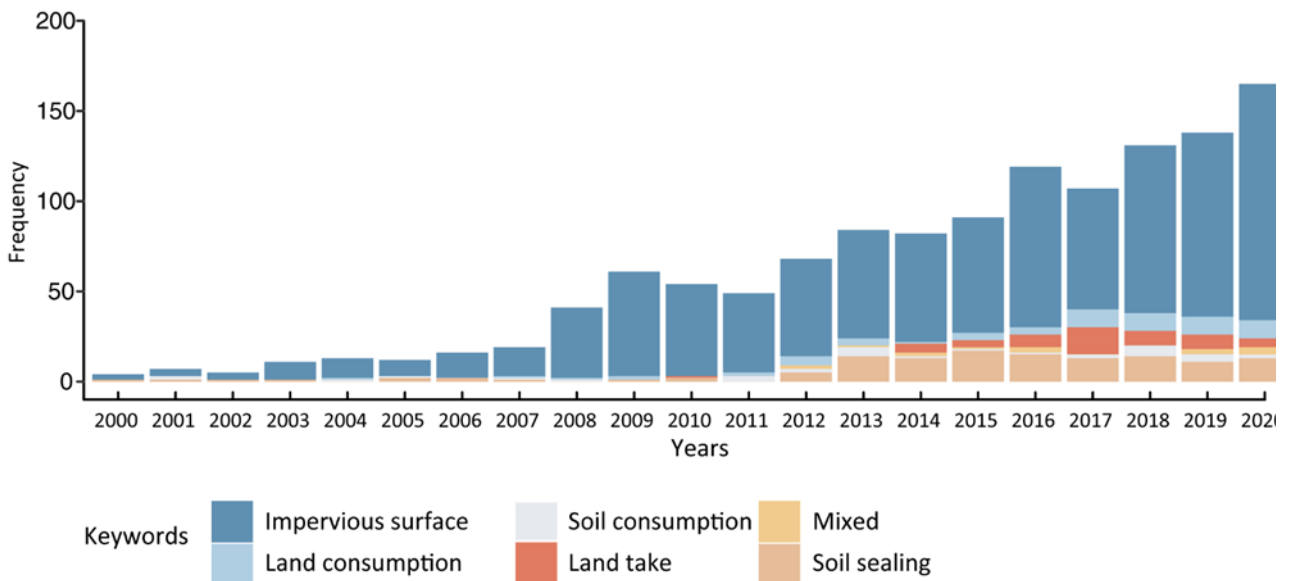


Figure 2 Temporal frequency analysis of the five keywords from 2000 to 2020

Furthermore, we analyzed which country more frequently investigated soil sealing (Figure 3). Analysis is performed by identifying the affiliation of the first author of each article. The choice to study only the first authors is due to the fact that 77,5% of the articles presented a single country of affiliation for all authors, while 18% of the articles presented two different countries of affiliation. Results show that the two countries most involved in this topic are the USA and China, with, respectively, 418 (32.73%) and 311 (24.35%) occurrences. Italy is the third country by showing 124 outcomes (9.71%). The other countries represented in the graphs show a drop in the results:

Germany, Spain, India, and Canada range between 30 and 45 outcomes; on the other hand, Brazil, Canada and Austria present less than 30 results. It is important to highlight that the 1,277 articles a total of 64 countries are covered; however most of countries present three outcomes on average. Finally, keyword analysis on the first ten countries which are studying soil sealing are grouped in continental regions (Figure 4). Results show that North America present 430 articles using “impervious surface” definition, avoiding other common keywords. Similarly, Asia adopted this keyword, by total result of 325 occurrences.

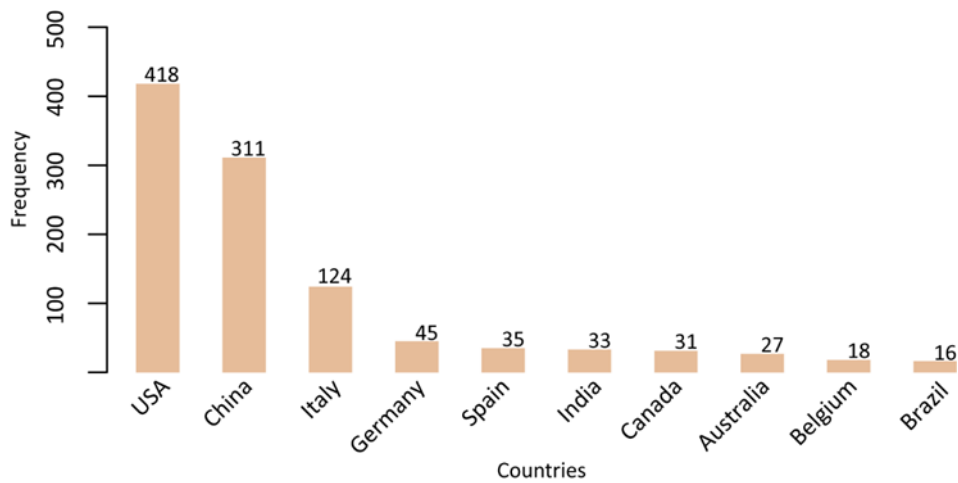


Figure 3 Top ten countries which more frequently investigated soil sealing

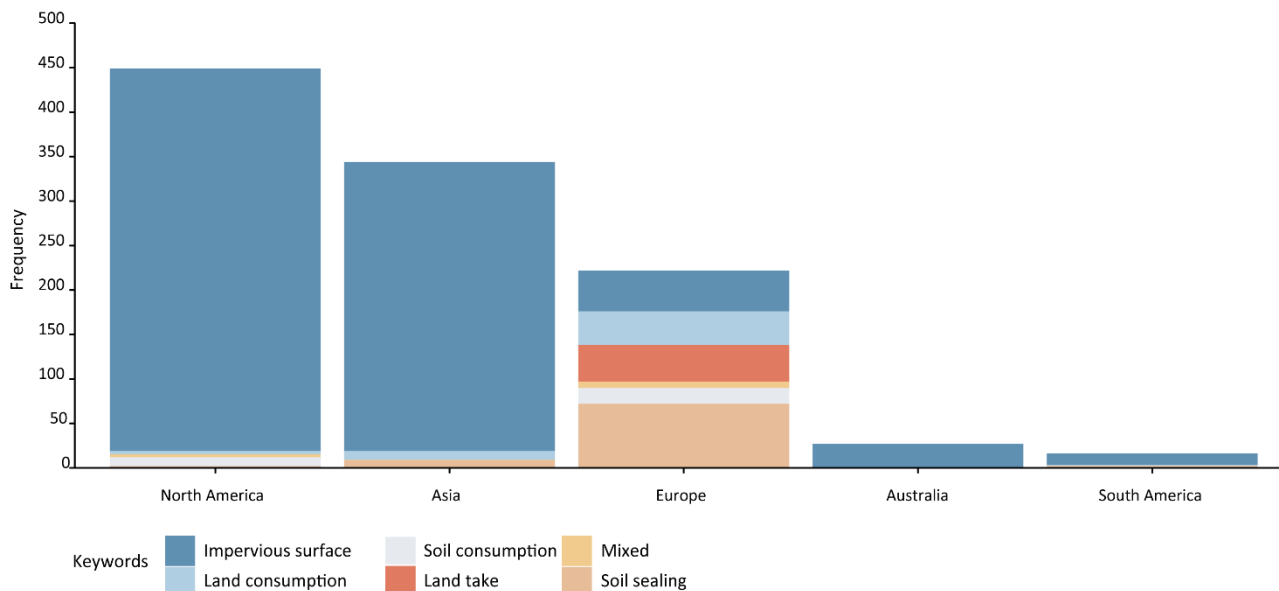


Figure 4 Distribution of keywords for each continental region aggregating the results of the top ten countries which more frequently investigated soil sealing

In European countries keyword definition for such earth-surface phenomenon is completely different. “Soil sealing” is the most frequently keyword adopted, presenting 72 outcomes; however, it is not completely dominant as “land take”, “land consumption”, and “impervious surface” are also adopted,

with approximately 40 outcomes respectively. “Soil consumption” is the less adopted keyword with only 18 outcomes. Finally, Australia and South America show again a preference in the use of “impervious surface” keyword. Results from analyzing 1,277 scientific papers suggests that soil sealing is an increasing topic of interest, mainly driven by North America, Asia and Europe. According to the last decade trend of publications, studies and researches on soil sealing are expected to notably increase in the next years. Moreover, it appears clear a distinction between the definitions adopted in Europe (“soil sealing”, “land take”, “soil consumption”, and “land consumption”) and those adopted in other continents (mainly “impervious surface”). This is probably due to the fact that EU made an effort to identify a “policy and research definition” that involved not only the physical phenomenon of non-infiltration of water into the ground, as evoked by the impervious surface term, but to find a definition which include both the physical process and implication caused by the phenomenon on ecosystems. Thus, since 2002 soil sealing definition is started to be adopted in EU; however, other terms appeared during the years and, still at present, different terms to be employed in academy, in the institutions and among policymakers are making soil sealing definition unclear. In 2020, an important study based on a focus group of experts, on a literature review and on policy-relevant documents, tried to categorize the different definitions adopted for policy-making at EU level (Marquard et al. 2020).

We therefore suggest that at international level, a unique definition should be adopted in order to avoid contradictions and ambiguities at institutional and policy levels, especially considering strategies and policies to be adopted both to mitigate and compensate soil sealing as well as reducing its impacts on urban ecosystems. In fact, the SDG-indicator “Ratio of land consumption rate to population growth rate”, defined the phenomenon as “land consumption” and not as “impervious surface” (UN-Habitat 2021). Moreover, in the framework of urban ecological transition and climate-resilient cities a wider definition of such phenomenon including ecosystem services is encouraged in order to make evaluable also functions and services provide by soil systems in urban context.

3.2. Geographical distribution of study cases per country

Hereafter, analyses were performed on the 392 papers which performed soil sealing mapping and classification. The ‘country’ labeled for each article was based on the study cases and not the affiliation of the authors. It is important to highlight that in this map we considered only defined locations, while global and bioregion case studies were excluded. The two countries showing the majority of the studies are China and the USA (Figure 5). China was the country with the most study cases, with a total of 226 different articles in cities such as Beijing, Guangzhou, and Shanghai, (Figure 5). The USA was the second most frequently studied country, by showing 138 different study cases. Subsequently other countries present considerably fewer case studies. Indeed, countries

such as India and Italy showed only 24 and 23 case studies, respectively. Other notable countries with an average of 10 case studies are the following: Germany, Spain, Brazil, and Canada.

It is worth noting that in big cities in continents such as South America or Africa soil sealing is much less studied probably due to the scarce attention in terms of environmental policies related to urban expansion.

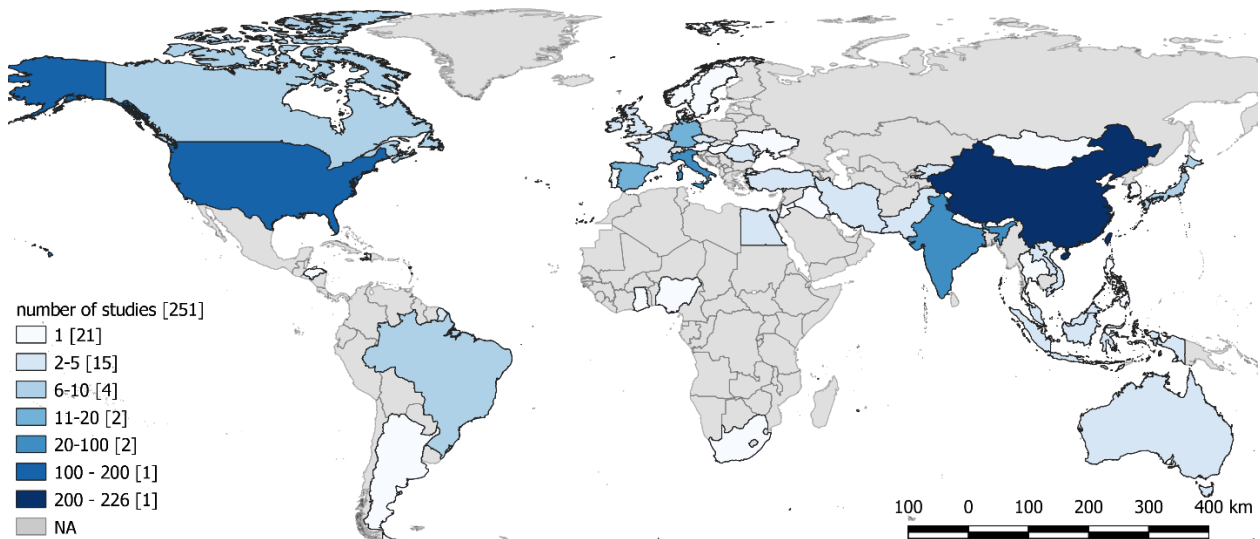


Figure 5 The locations of sites where soil sealing has been studied

3.3. Scope of the studies

Mapping soil sealing was most often performed at the urban scale, presenting 209 outcomes. This scale identifies both a single municipality (i.e. the whole city of Beijing) as well as spatial analyses performed at county-levels (e.g. in the USA). Moreover, this class include also those case studies constituted by a single municipality and its surrounding urban territory. The category sub-urban scale presented 67 study sites (16.84%), while regional, country, and watershed classes present similar frequencies, with about 35 findings (9.44%, 8.42%, 8.16% respectively). Finally, a few (9) studies of mapping soil sealing were performed at the land parcel scale. Only five articles were focused on global scales (Sutton et al. 2009; Schneider et al. 2010; Kuang 2019; Bian et al. 2019; Nowak and Greenfield 2020).

These results indicate that soil sealing is a phenomenon largely related to the expansion of cities and urban areas (Güneralp et al. 2020) which represent 52.32% of all analyzed papers (Figure 6). Moreover, it is worth noting that the phenomenon was investigated also at sub-urban scales, indicating that small sectors of cities or specific neighborhoods were also studied (Shahtahmassebi et al. 2016). On the contrary, studies at smaller scales (watershed, regional, and country scale) were less investigated as results highlights a total of only 26% of such studies. Studies at a very large scales (land parcel) were only 2.3%, mainly oriented to test specific methodologies or remote

sensing data (Im et al. 2012; Lin et al. 2019). Analyses on categorization of territorial scales are represented in Figure 6.

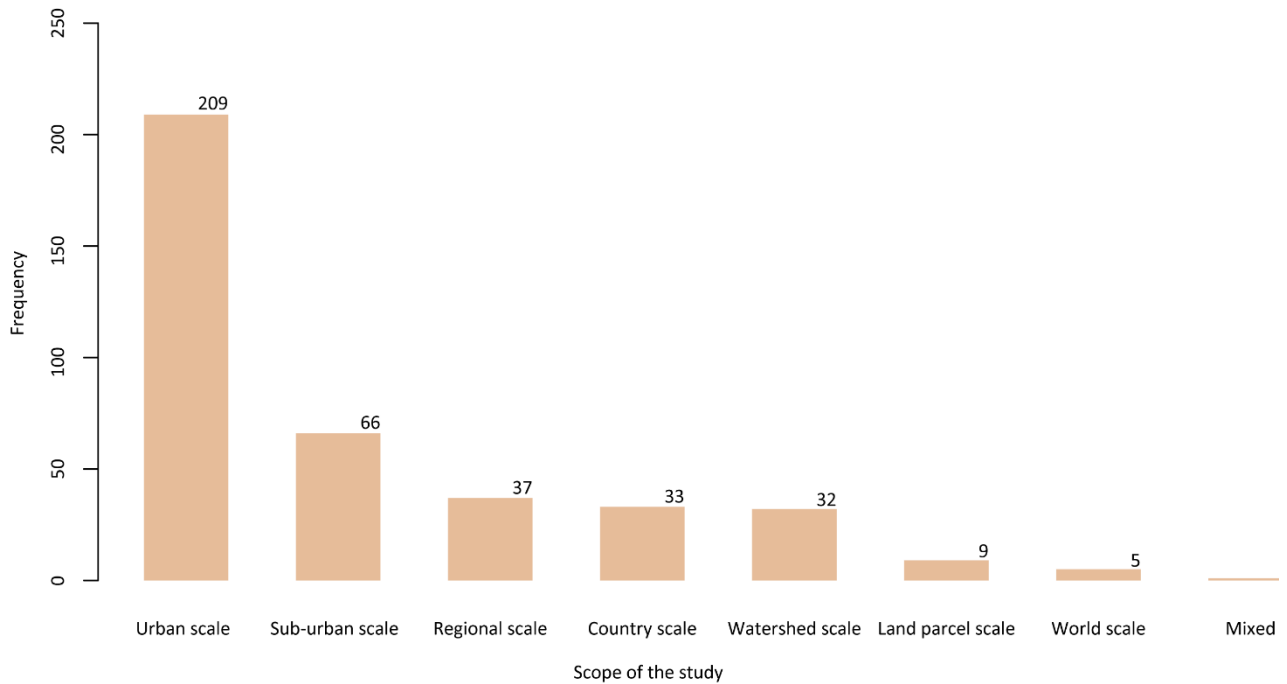


Figure 6 Scope of the study: mapping soil sealing and territorial scales of analysis

Table 2 The eight urban areas most often studied

Beijing (China)	Guangzhou (China)	Shanghai (China)	Indianapolis (USA)	Nanjing (China)	Wuhan (China)	Hong Kong (China)	Fuzhou (China)
27	21	13	9	8	8	7	6

Further analysis identified the most studied urban areas (Table). Seven out of eight are Chinese cities, whereas only one is from the USA. Beijing is the most studied city, followed by Guangzhou and Shanghai. In the USA, Indianapolis is the most investigated city (9), while the second most often studied city is New York (5 occurrences). It is worth noting that seven out of eight most studied cities are located in China, a country where the development and expansion of urban areas was very rapid in the last 20-30 years, following the increase together with economic and urban population growth (Zhao et al. 2015). Findings in Figure 5 and Table 2 shows the necessity by Chinese researches for more in-depth urban analyses in order to understand the features, processes, spatial patterns and future development of urbanization (Gu et al. 2012; Wu et al. 2014). Such urban studies are often compared to other cities in different countries (Wenhui et al. 2014). It is also important to highlight that the high number of cities for these two countries are associated with comparative analyses between multiple locations (Figure 5).

Explanations for the obvious concentration of study site locations (e.g. by country or city) and scale of analysis are multiple. If the research was funded (or otherwise motivated) by an institution/agency

managing the study site, then the explanation was being obvious. In other words, the management need (e.g. to meet a regulatory or policy requirement) for mapping soil sealing promulgated the research study. This explanation could be verified by acknowledgements in the article for the funding or participating entities. The targeted focus of studies on a unique city, such as Indianapolis, may also be attributed to the author's affinity for the city.

Another explanation for the large number of studies focused on cities in China is the availability of research funds from each country. Research funds from the Chinese Academy of Sciences has increased dramatically along with the large increase in the number of remote sensing researchers. This trend of research funds and the number of researchers also occurred in the United States in the 1990s through 2000s. It would be difficult to untangle what the dominant factor (i.e. funding or researcher) is in this relationship but we note this issue is an important explanatory factor in understanding the geographic distribution of study areas.

As the urban scale includes cities of different sizes (i.e. from 100 to 15,000 km²), highlighting substantial differences in urban territorial scale among different countries, we also analyzed relationships with study area size. Table 3 shows the percentage of study area size in urban scale category. It is worth noting that the total in Table 3 (664) does not correspond to urban scale category (209) due to the multiple locations that some studies provide. Moreover, it also highlights that urban scale analyses on areas of 1,000-5,000 km² are the most performed (30.07%).

Table 3 Percentage of urban scale dimension

Urban scale dimension	Total	Percentage
<50 km ²	96	14.46%
50 - 100 km ²	46	6.93%
100 - 500 km ²	96	14.46%
500 - 1,000 km ²	65	9.79%
1,000 - 5,000 km ²	147	22.14%
5,000 - 10,000 km ²	76	11.45%
10,000 - 50,000 km ²	66	9.94%
> 50,000 km ²	72	10.84%
	664	100%

3.4. Relationship between dimension of the study areas and spatial resolution

Firstly, we found that the highest value represented by areas with a dimension ranging from 1,000 to 5,000 km² (147 occurrences), which is mainly referred as mapping at territorial urban scale. The second study areas size are presented by two categories, 100-500 km² and <50 km²: they both present 96 outcomes. Case studies with 500-1,000 km², 5,000-10,000 km², 10,000-50,000 km² and >50,000 km² present similar outcomes, with about 60-70 results.

Figure 7 shows also the relationship between the study area size and the spatial resolution of the remote sensing platforms. Undoubtedly, 30 m category is the most adopted resolution and it corresponds to Landsat satellites (Figure 8). In each study area size category, such satellite platforms are the most employed, with the exception for areas $< 50 \text{ km}^2$. In some categories of study area size, other resolutions are slightly used; for instance, at $1,000\text{-}5,000 \text{ km}^2$, 30 m spatial resolution is overall the 66.67%, while m (1-10) and 10-30 m resolution are respectively at is 12.93% and 9.52%. Also at $100\text{-}500 \text{ km}^2$, 30 m resolution displays a marked prevalence (50%), whereas m resolution is 21.88% and 10-30 m resolution is 12.50%.

Study areas size $< 50 \text{ km}^2$, the m resolution is the highest occurrence (37); while 30 m resolution and sub-m class present respectively 27 and 17 occurrences. Even if, $50\text{-}100 \text{ km}^2$ category is usually analyzed at 30 m resolution (17), it is also studied at m resolution (15 results). In fact, the two classes present similar results. Finally, $> 50,000 \text{ km}^2$ shows a comparable result: 30 m class is the most adopted, however 1,000 m and 250 m classes display less but similar outcomes.

In the Figure 7 all the study area size classes are reported; it is important to note that 20% of articles analyzes multiple locations, methodology testing or comparative analyses.

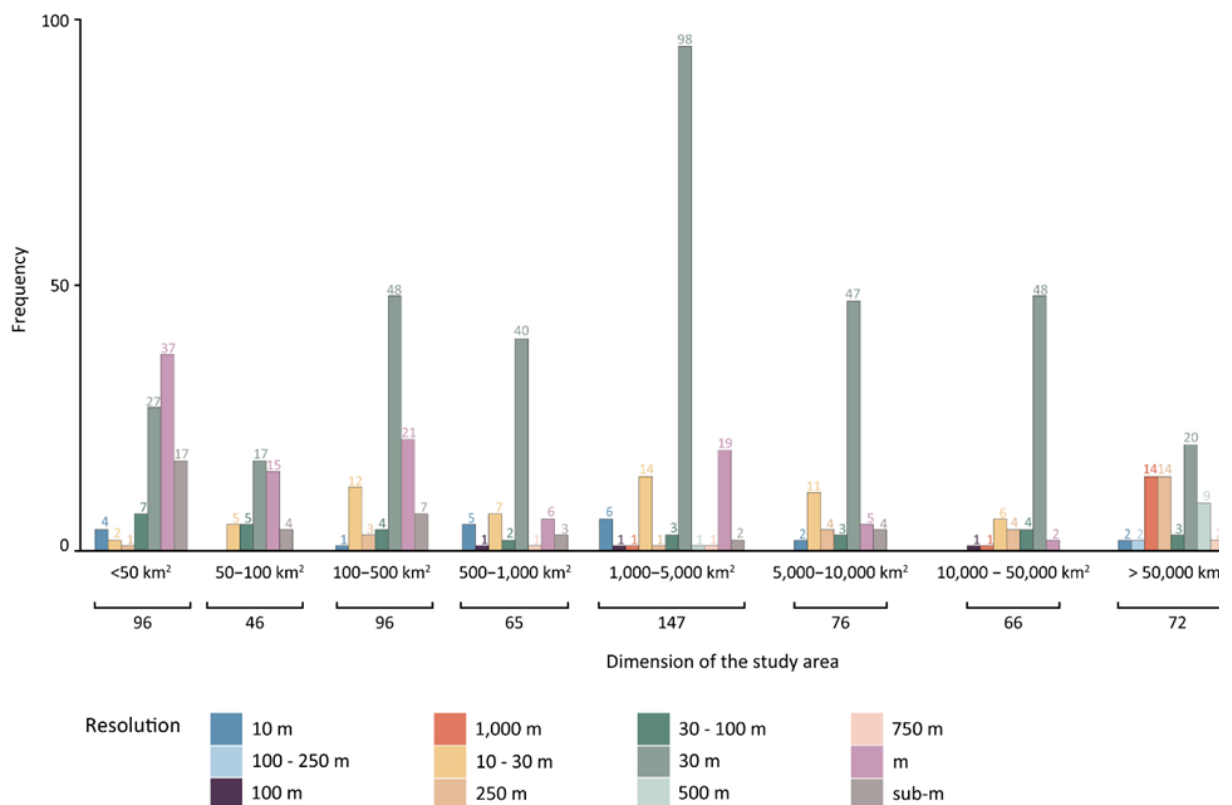


Figure 7 Relation between dimension of the study areas (x axis) and resolution (legend). Y axis shows the frequency of dimension of the study areas.

The relationship between study area size and spatial resolution is essential to investigate and to accurately map soil sealing. While for large study areas (i.e. $1,000\text{-}5,000 \text{ km}^2$) a medium resolution (30 m) was often adopted, for small areas ($< 50\text{-}100 \text{ km}^2$) high or very-high spatial resolution (sub-

m, m or 10 m) images were used. In fact, especially in urban context, geographic features which results in geometry and texture of the urban fabrique may vary a lot in size and shape: buildings, roads and parking lots of big cities (>1,000 km²) are generally larger than the same features in medium-small cities (<500 km²). Hence, in such cases high and very high spatial resolution images are required to detect and extract urban surfaces, minimizing the mixed-pixel effect due to different elements of land cover. On the contrary, for very-large areas (regional, national and continental scales, with areas > 50,000 km²) coarse spatial resolution images are recommended. Finally, a previous analysis between the image resolution, the study area and the resulting MMU is required to avoid under or super-estimation in mapping soil sealing.

3.5. Remote sensing platform and resolutions

The majority of remote sensing platforms are provided by Landsat missions (Landsat 4-5, 7, 8), with 392 outcomes (57.48%) (Figure 8). Results show that dataset from Landsat 4-5 are the most adopted (162 results, (23.75%)), whereas Landsat 7 and Landsat 8 present similar outputs, respectively 118 and 112. Other platforms show considerably lower results, with less than 40 occurrences. The class “airborne” is ranked immediately after Landsat platforms (39 results) highlighting that high resolution images such as orthophotos are still adopted. Other platform classes such as the MODIS series, SPOT 5 and OLS show approximately 15 results. However, a total of 50 remote sensing platforms were identified in all the analyzed articles, but the majority of them present only one or two occurrences. In Figure 8 we represent only platforms with more than 10 occurrences.

Analysis on the accessibility of adopted spatial dataset show that 65.56% were open data as they are publicly available and free under open license, while 17.09% were proprietary data and 15.31% adopted mixed open/non-open dataset. Proprietary data implies a license by a legal agreement or, more commonly, with cost. In general, studies strongly prefer the use of open data, consisting primarily of images from Landsat platforms. It is worth noting that the adoption of very high resolution images from optical airborne is relevant, probably due to the fact that ortho-photos, often provided by Institutions, are generally free access. In general, analyzed papers strongly prefer the use of open public data, consisting primarily of Landsat images as they are also frequently adopted for multi-temporal analyses (48% of studies) (Figure 8,9).

Although since the 2000s the spread of commercial satellite platforms made very high resolution images available and some public agencies such as NASA/USGS and ESA incorporated them into public programs for land-surface monitoring (Birk et al. 2003), soil sealing is still mainly investigated by using open and free data. In many cases, small sample areas from commercial satellites are adopted for validation or accuracy. Moreover, when available, in terms of high spatial resolution and temporal match, Google Earth imageries are used (Lu et al. 2011; Zhong et al. 2019). However, their use is still quite limited, probably due to the costs for performing soil sealing mapping in wide areas.

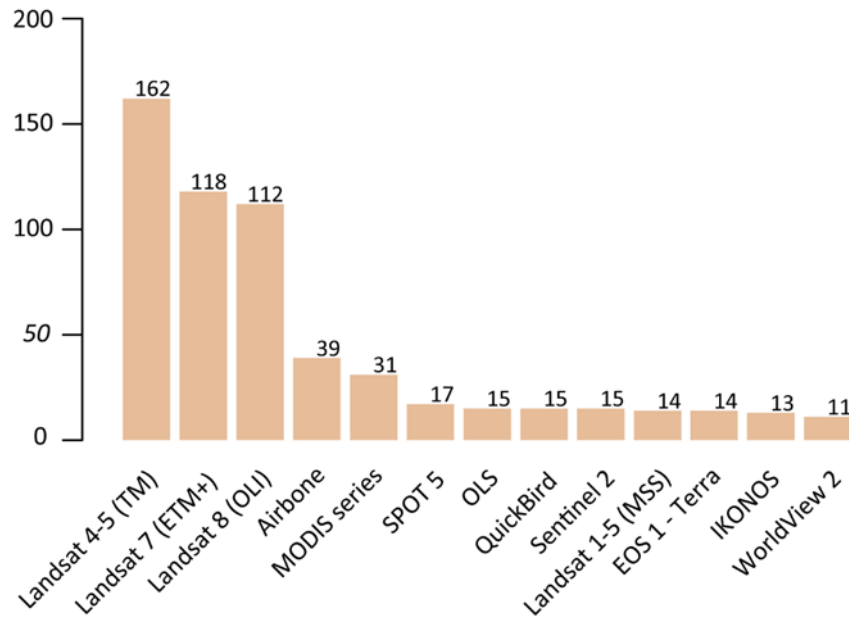


Figure 8 Frequency (y axis) of the main remote sensing platforms (x axis) adopted in scientific papers. The graph shows remote sensing platforms with more than 10 occurrences.

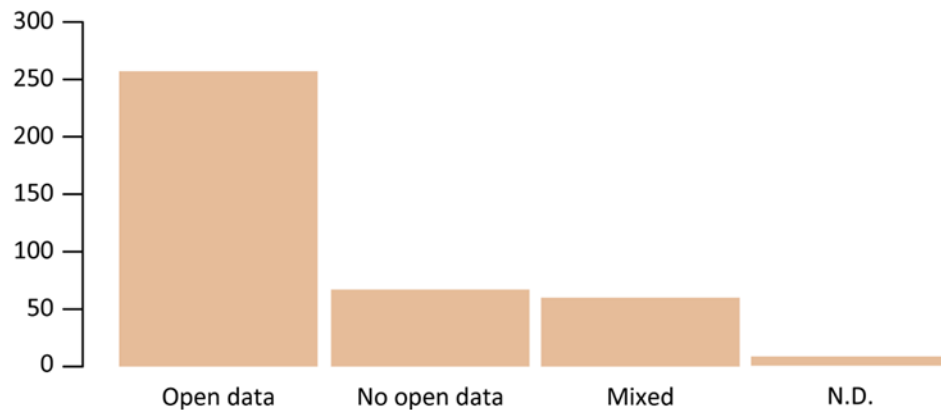


Figure 9 Frequency (y axis) of the use of open data in the scientific papers.

3.6. Multi-temporal analyses

Results on duration of the analyses show that 48.33% of scientific papers performs soil mapping to detect changes over the time, by multi-temporal analyses. Yearly-based analyses are more than 51.67% (201 occurrences), while multi-temporal analyses were divided in seven different categories: 41.33% of studies analyzed spatial evolution of soil sealing between 2-10 years, 11-20 years, and 21-30 years, respectively. Within such time-frame categories, 11-20 years of analysis shows the majority of the results by the 16.71% (65 occurrences), followed by 2-10 years category (12.34%, 48 occurrences) and 21-30 years category (12%, 47 occurrences). Such as time frame analyses are feasible as Landsat satellite have a long term frequency in revisiting time.

Long period analyses are scarcely presented. Only 4.11% performed an analysis between 31-40 years, while 1.8% between 41-50 years. Finally, articles analyzing very long time period (> 50 years) are very few (1.28%). The sources adopted in such studies generally do not integrated spacecraft remote sensing technologies but they are based on land cover maps, aerial photographs, and historical maps. For instance, multi-temporal analyses of Rome from 1949 to 2006 were performed by using aerial images and land cover maps (Munafò et al. 2010); on the other hand, Cortijo investigated the urbanization in Madrid over the last 150 years, by analyzing the historical cartographic sources from topographical maps (2017).

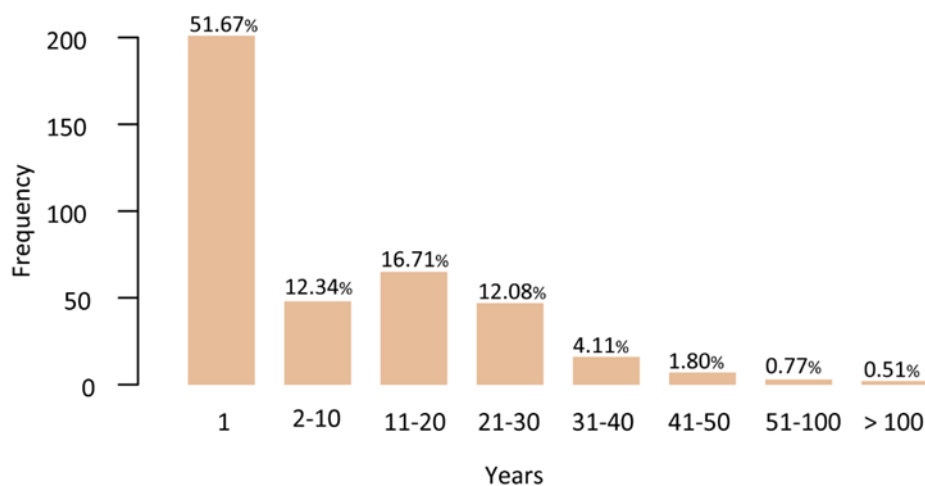


Figure 10 Duration of analyses: multi-temporal analyses and yearly-based analyses.

3.7. Main methods to assess soil sealing

In general, the most adopted methodology falls in the SMA category (26.36%; 160 results), following by decision/regression tree class by 23.23%; with almost 141 results (Table). Band ratio approach is the third one adopted, by the 14.50 (88 occurrences); subsequently, supervised and OBIA classification methodologies presents similar outcomes (45 and 43), while ANN presents 33 results. Image interpretation, Unsupervised classification and Linear Regression show similar outcomes, respectively 26, 22 and 21; Reclassification (18) and Temporal filtering (10) are less adopted to map soil sealing (Table 4). Globally, 11 different methodologies to assess soil sealing in the reviewed papers were identified (Table 4Table). The analysis includes all the main methods used in the articles and it includes both articles adopting single methodologies and articles adopting comparative methodologies or multiple methodologies. On the whole, single methodologies are employed by 293 scientific papers (75.76%), while comparative approaches are adopted by 99 papers (24.23%). Finally, multiple methodologies are adopted by 62 articles, of which most are single methodologies (72.60%) and the rest are comparative methodologies (27.40%).

Table 4 Main methodologies to assess soil sealing. The studies analysis includes both

Methodology	Frequency	%
SMA	160	26.36
Decision/Regression tree	141	23.23
Band ratio	88	14.50
Supervised	45	7.41
OBIA	43	7.08
ANN	33	5.44
Human Image interpretation	26	4.28
Unsupervised	22	3.62
Linear regression	21	3.46
Reclassification	18	2.97
Temporal filtering	10	1.65
	607	100

To investigate the temporal trend of different methodologies we analyzed the relationship between main methodologies (excluding comparative methods and multiple methods) and year of publication of the article.

Since the beginning of soil sealing analysis, SMA methods and Decision/Regression Tree methods are the most employed (Figure 11). SMA was adopted from 2000 and still remains a preferred methodology to map soil sealing when using Landsat-derived dataset, highlighting the need of optimizing the use of 30 m spatial resolution images by spectral mixture and sub-pixel analyses.

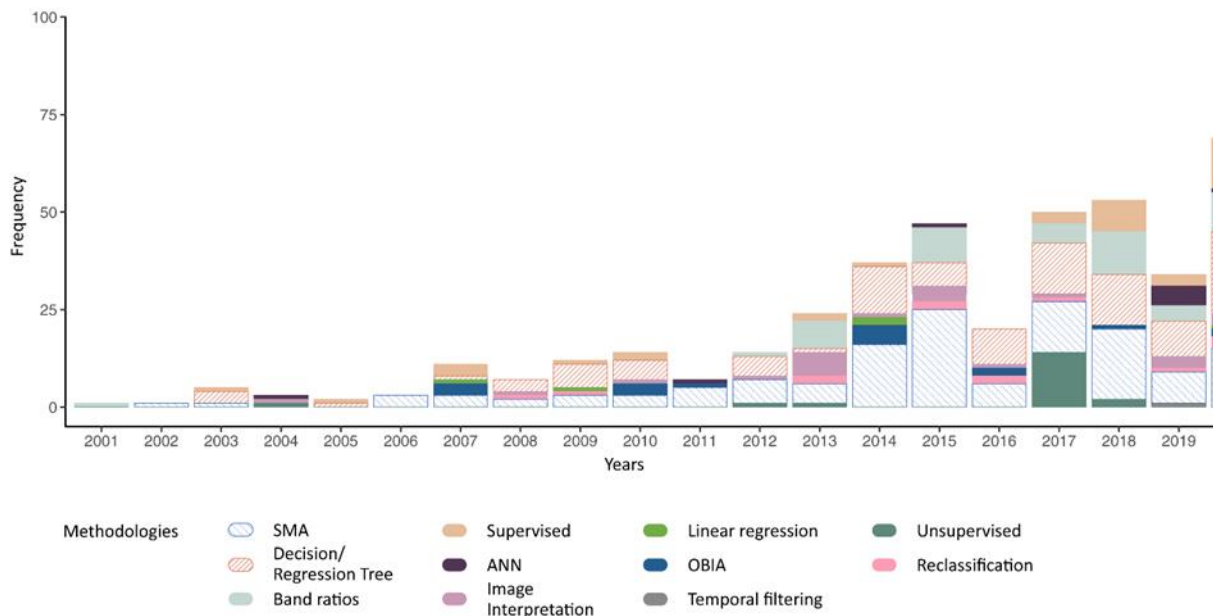


Figure 11 Relationship between main methodologies and year of publication of the articles. In the graph comparative methods and multiple methods are excluded.

From 2017, other methodologies start to be predominant, presenting more than five occurrences per year, and they continue to be present until now. They are Band Ratio and Supervised methods. In 2017 it is important to notice an increase in adopting unsupervised classification methodologies,

showing almost 15 results. Figure 12 shows the distribution of the methodologies in relation to the resolution of the remotely sensed images, adopted in each study. The resolution of the studies has been classified taking into account the minimum and maximum resolution used into the analyses. When processing images at high and very high spatial resolution, Image Interpretation, OBIA, Decision/Regression Tree, and Supervised are the preferred approaches; SMA classification is not adopted when using sub-m resolution images. Band ratio classification methodologies start to be used from 10 m image resolution, while it plays a relevant role at 30 m pixel size, together with Supervised, Decision/Regression Tree, and SMA techniques. The latter two approaches are the most adopted at 30 m resolution, by the 13.53% and 25.08% respectively (41 and 76 outcomes). Finally, a comprehensive overview is given by analyzing the relationships between methodologies, image resolutions, and study area size. This output proposes a relational framework to link the main geographic components to remote sensing models and methodologies for mapping soil sealing. Relationships among the three categorical variables are shown in the graphical summary (Figure 13). The majority of the results are located in the range of 30 m resolution and 1,000-5,000 km² by adopting three different approaches: SMA (47 outcomes), Decision/Regression Tree (21 outcomes), and Band Ratio (8 outcomes). At 30 m resolution, also the category 5,000-10,000 km² is well represented by SMA (27 outcomes) and Decision/Regression tree (8 outcomes). For mid and small size study areas (from <50 km² to 50-100 km²) images at 1 m spatial resolution are used, following by 10-30 m pixel size, mainly used by Image Interpretation and Decision/Regression Tree. Image spatial resolution of 30 m and 30-100 m are used to perform Unsupervised and Band Ratio land cover classification. On the contrary, for very large study areas (10,000 - 50,000 km² and > 50,000 km²) the preferred resolution is 30 m and the methodologies mostly adopted are Band Ratio, Decision/Regression Tree, and SMA. Finally, coarse image resolution is scarcely adopted for mapping soil sealing and they are acquired only for very large dimension of study areas. In these cases, at 1,000 m image resolution, SMA methods are used, while at 250 m it can be identified also Band ratio and Decision/Regression tree. Generally, they are adopted all for large-scale study areas, at continental and global scale.

Results with less than two outcomes are not represented in Figure 13; moreover, we included both single and comparative methodologies, but we exclude articles with multiple methodologies.

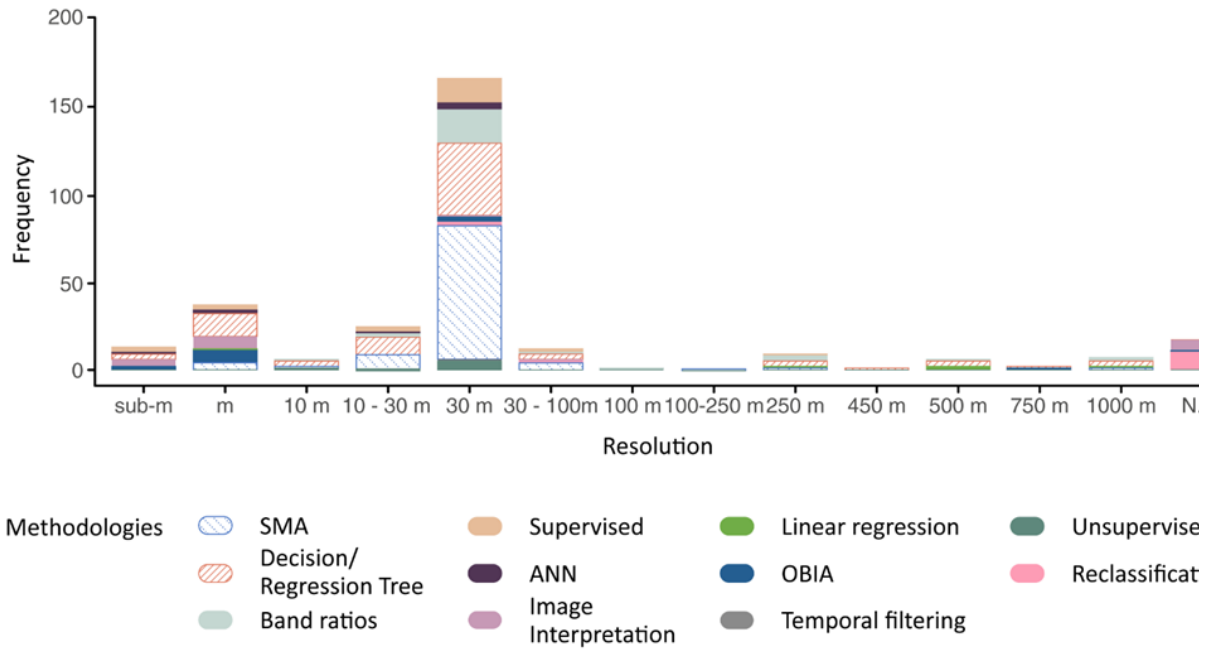


Figure 12 Distribution of methodologies (legend) in relation to the spatial resolution (x axis) of remotely sensed images. In y axis is reported the frequency of the resolutions.

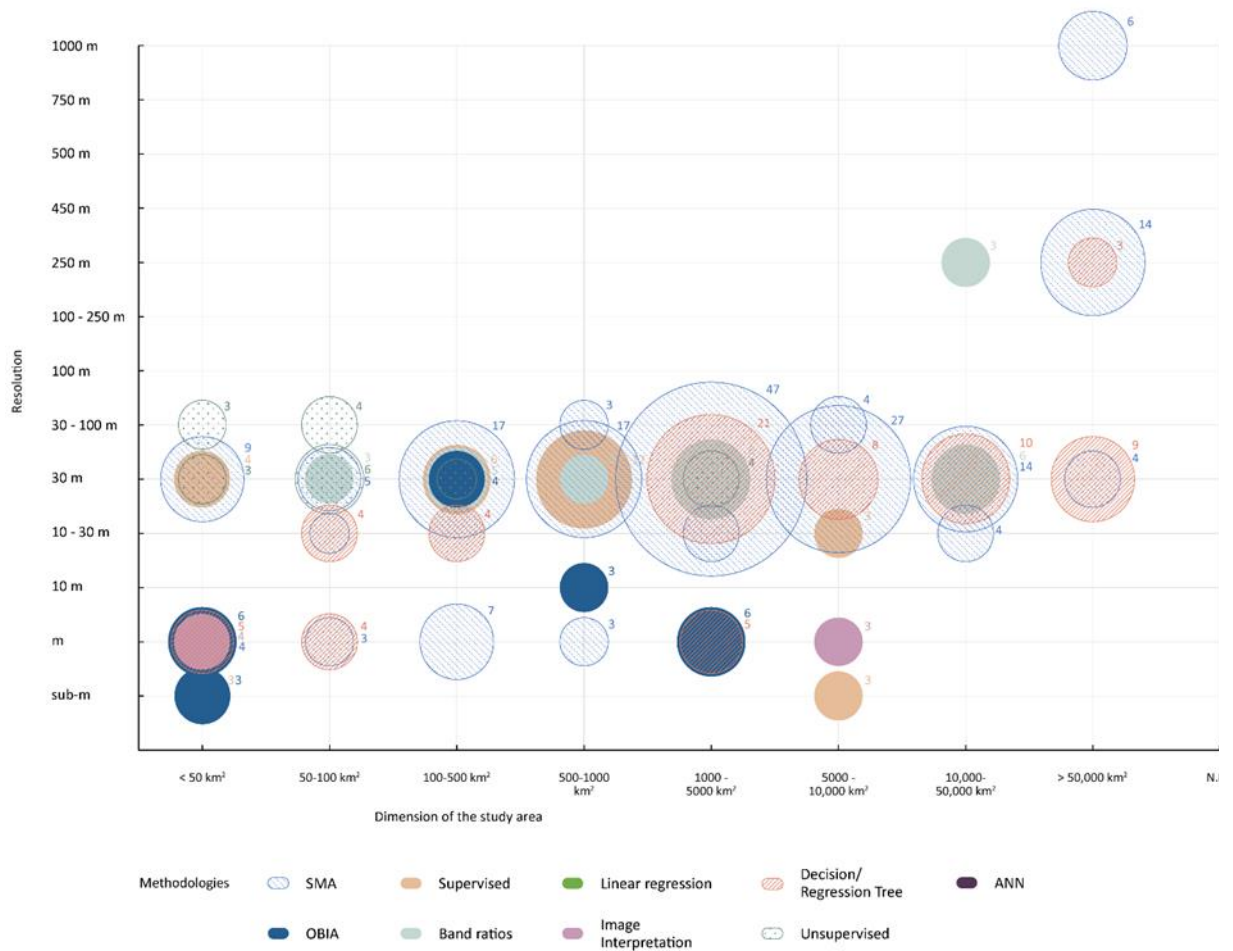


Figure 13 Relation between methodologies (legend), resolutions (y axis), and dimension of the study areas (x axis). The diameter of the bubbles indicates the frequency of the methodology used.

3.8. Goals and policy implications of the studies

An objective of the present work is also to investigate which studies were performed as applied research for mapping soil sealing or to highlight some policy implications for sustainable territory management or spatial urban planning. Results show that almost 90% of the analyzed studies focused on merely techniques testing and performances, on efficiency of feature extraction or on study cases comparison. Moreover, different articles were more oriented to more specific purposes, for example identification of urban heat islands or assessment of hydraulic drainage, by performing soil sealing mapping as preliminary analysis (Xu 2010; Coseo and Larsen 2019; Siddiqui et al. 2021). In general, the majority of the studies do not present direct or indirect links to urban policies and strategies. Only almost 10% of the articles resulted in outcomes as scientific support to policymakers and stakeholders to pursuit sustainable urban development. In such articles, an important section is dedicated to quantify soil sealing with the purpose of supporting territory planning.

In our opinion, scientific studies on soil sealing should have a strongest applied dimension and should better respond to the international calls from UN SDGs as well from “Zero net land take 2050” Strategy of European Commission to improve sustainability of management and development of urban ecosystems, as they are estimated to increase well beyond than 50% of global population in 2050 (European Commission 2011; Department of Economic and Social Affairs of United Nations 2015).

Moreover, due to this gap, methodologies and techniques for soil sealing mapping are missing from urban plans and strategies making monitoring soil-related ecosystem services still unexplored (Teixeira da Silva et al. 2018; Lam and Conway 2018; Calzolari et al. 2020). Even if some urban plans are framed on this concept, indicators and actions to monitor soil sealing and soil-related ecosystem services are almost absent, highlighting how city planners and designers are still far from a concept of soil as a natural resource to preserve and maintain. For this reason, the role of scientific community of producing applied research on soil sealing more connected to international and national policies is be fundamental to fill the gap.

4. Conclusions

Soil sealing is one of the main environmental issues of our decade. This topic is of great interest not only from a scientific perspective but also for policymaking for soil protection and sustainable development at local, regional, national, and international level. Our systematic review focused on studies approaching the phenomenon by using quantitative methodologies, analyzing the extension and the amount of soil sealing and investigating the spatial evolution of the phenomenon over years. Our first finding indicates that it is still unclear the definition of soil sealing in scientific literature and five are the main terms commonly adopted. Among these definitions, “impervious surface” is the most used by far, especially in non EU countries; on the contrary, all five definitions are adopted equally in EU. As already anticipated by Marquard (2020), it is fundamental, at present time, to

identify a unique and shared definition, not only in European context, but also at international levels. In fact, over 50% of the world population lives in urban areas today and, by 2045, the world's urban population will increase by 1.5 times to 6 billion (World Bank 2020). In this perspective, in cities and urban areas is essential to monitor soil sealing and identifying concrete pathways to protect soil functions and services. Hence, urban policies need to support and provide the ecosystem services required to human well-being and health, ensuring, within cities, adequate permeable areas, such as green areas and agricultural lands (Maes et al. 2019). Both standardized monitoring systems and strategies/policies harmonization between different countries are crucial in order to reduce and limit soil sealing and to straightaway contrast local effects of climate change (Aragón-Durand et al. 2014; Decoville and Schneider 2016). The effort provided in this review by analyzing five definitions is to go beyond a national perspective and strengthening a more global view, seeking to tackle this complex phenomenon with exchanging knowledge and experiences and fostering the communication on this topic.

As confirmed by our outcomes, soil sealing is a phenomenon mainly investigate at urban or sub-urban scale, while it is less studied at regional, national or global scale. The geographical scale of urban areas varies, from cities less than 100 km² to cities larger than 5,000 km². Surely, almost the 50% of the researches show the necessity to investigate the urban development of cities during a period of time that could vary from some years to some decades.

Landsat satellites are the most adopted satellite platforms, with 392 outcomes; Landsat 4 and 5 are the most used (162), followed by Landsat 7 (118), and Landsat 8 (112). Other satellite platforms are less adopted for mapping soil sealing, with less than 40 results.

The new imageries available in 2022 from Landsat 9 mission (launched in September 2021), by maintaining the same spatial resolution of its spectral bands, will allow the comparison between different years, confirming that NASA/USGS constellation is the “longest, running, continuously operating Earth observation satellite program” (Masek et al. 2020). Moreover, Landsat satellite missions provide open data to their users, unlike other satellites that are mostly commercial satellites. In the next future, also Copernicus Sentinel-2, which is based on a constellation of two satellites, launched in 2015 and 2017 respectively, will be an important silos of spatial data for monitoring urban environment, not only for its high temporal frequency (revisit time of 10 days), but also for its spatial resolution (10 m), and for its open source dataset (Misra et al. 2020). Our results show only that only 15 studies adopted Sentinel-2 imageries, indicating it is still not widely adopted for mapping soil sealing. However, it is worth noting that European Union is adopting these platforms since 2015 to monitor the trend of the phenomenon in all European countries (European Environment Agency 2018).

In perspective, the development of platforms for Big Earth Data management and analysis, i.e. Google Earth Engine and Sentinel Hub, could provide important advancements in soil sealing

mapping and analyses. In fact, these platforms might represent an important support to researchers to store, process, disseminate and analyze big geospatial data (Gomes et al. 2020).

REFERENCES

- Adams, D. and M. Hardman. 2014. Observing Guerrillas in the Wild: Reinterpreting Practices of Urban Guerrilla Gardening. *Urban Studies*. 51:1103–1119.
- Ahern, J. 2007. Green infrastructure for cities: the spatial dimension. 267–283 *In* V. Novotny and P. Brown, editors. *Cities of the Future: Towards Integrated Sustainable Water and Landscape Management*. IWA Publishing, London, UK.
- Aksoy, E. M. Gregor C. Schröder M. Löhnertz and G. Louwagie. 2017. Assessing and analysing the impact of land take pressures on arable land. *Solid Earth*. 8:683–695.
- Al-Kodmany, K. 2018. The Vertical Farm: A Review of Developments and Implications for the Vertical City. *Buildings*. 8:24.
- Albino, V. U. Berardi and R. M. Dangelico. 2015. Smart Cities: Definitions, Dimensions, Performance, and Initiatives. *Journal of Urban Technology*. 22:3–21.
- Alexandri, E. and P. Jones. 2008. Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates. *Building and Environment*. 43:480–493.
- Allwinkle, S. and P. Cruickshank. 2011. Creating smart-er cities: An overview. *Journal of Urban Technology*. 18:1–16.
- Altieri, M. A. 1995. *Agroecology. The science of sustainable agriculture*. CRC Press, Boca Raton, USA.
- Altieri, M. A. and F. R. F. Funes-Monzote. 2012. The Paradox of Cuban Agriculture. *Monthly Review*. Retrieved from <https://monthlyreview.org/2012/01/01/the-paradox-of-cuban-agriculture/>. Accessed February 2020.
- Altieri, M. A. and C. I. Nicholls. 2019. Urban agroecology. *AgroSur*. 46:46–60.
- Álvarez, D. G. 2017. Cartographic scale and minimum mapping unit influence on LULC modelling. 327–334 *In* L. Ragia, J. G. Rocha, and R. Laurini, editors. *Proceedings of the 3rd International Conference on Geographical Information Systems Theory, Applications and Management - GAMOLCS*. SciTePress, Porto.
- Amato, F. F. Martellozzo G. Nolè and B. Murgante. 2017. Preserving cultural heritage by supporting landscape planning with quantitative predictions of soil consumption. *Journal of Cultural Heritage*. 23:44–54.
- de Amorim, W. S. A. Borchardt Deggau G. do Livramento Gonçalves S. da Silva Neiva A. R. Prasath and J. B. Salgueirinho Osório de Andrade Guerra. 2019. Urban challenges and opportunities to promote sustainable food security through smart cities and the 4th industrial revolution. *Land Use Policy*. 87:104065.
- Andersson-Sköld, Y. J. Klingberg B. Gunnarsson K. Cullinane I. Gustafsson M. Hedblom I. Knez F. Lindberg Å. Ode Sang H. Pleijel P. Thorsson and S. Thorsson. 2018. A framework for assessing urban greenery's effects and valuing its ecosystem services. *Journal of Environmental Management*. 205:274–285.
- Angelidou, M. 2015. Smart cities: A conjuncture of four forces. *Cities*. 47:95–106.
- Aragón-Durand, F. J. Corfee-Morlot R. B. R. Kiunsi M. Pelling D. C. Roberts and W. Solecki. 2014. Urban Areas. 535–612 *In* V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. . Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, N. Levy, S. MacCracken, P. R. Mastrandrea, and L. L. White, editors. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

- Arcidiacono, A. S. Ronchi and S. Salata. 2016. Managing Multiple Ecosystem Services for Landscape Conservation: A Green Infrastructure in Lombardy Region. *Procedia Engineering*. 161:2297–2303.
- Arnold, C. L. and C. J. Gibbons. 1996. Impervious Surface Coverage: The Emergence of a Key Environmental Indicator. *Journal of the American Planning Association*. 62:243–258.
- Artmann, M. 2015. Managing urban soil sealing in Munich and Leipzig (Germany)-From a wicked problem to clumsy solutions. *Land Use Policy*. 46:21–37.
- Artmann, M. 2016. Urban gray vs. urban green vs. soil protection — Development of a systemic solution to soil sealing management on the example of Germany. *Environmental Impact Assessment Review*. 59:27–42.
- Artmann, M. and J. Breuste. 2015. Cities Built for and by Residents: Soil Sealing Management in the Eyes of Urban Dwellers in Germany. *Journal of Urban Planning and Development*. 141:1–13.
- Artmann, M. L. Inostroza and P. Fan. 2019. Urban sprawl, compact urban development and green cities. How much do we know, how much do we agree? *Ecological Indicators*. 96:3–9.
- Artmann, M. and K. Sartison. 2018. The Role of Urban Agriculture as a Nature-Based Solution: A Review for Developing a Systemic Assessment Framework. *Sustainability*. 10:1937.
- Arun, M. and M. Teng Yap. 2000. Singapore : The Development of an Intelligent Island and Social Dividends of Information Technology. *Urban Studies*. 37:1749–1756.
- Asad, M. S. Rashid Ahmad F. Ali R. Mehmoo M. A. Butt and S. Rathore. 2017. Use Of Remote Sensing For Urban Impervious Surfaces: A Case Study Of Lahore . *International Journal of Engineering and Applied Sciences*. 4.
- Atasoy, M. 2018. Monitoring the urban green spaces and landscape fragmentation using remote sensing: a case study in Osmaniye, Turkey. *Environmental Monitoring and Assessment*. 190:1–8.
- Babí Almenar, J. T. Elliot B. Rugani B. Philippe T. Navarrete Gutierrez G. Sonnemann and D. Geneletti. 2021. Nexus between nature-based solutions, ecosystem services and urban challenges. *Land Use Policy*. 100:104898.
- Badiu, D. L. C. I. Iojă M. PĂtroescu J. Breuste M. Artmann M. R. NițĂ S. R. GrĂdinaru C. A. Hossu and D. A. Onose. 2016. Is urban green space per capita a valuable target to achieve cities' sustainability goals? Romania as a case study. *Ecological Indicators*. 70:53–66.
- Bagan, H. and Y. Yamagata. 2014. Land-cover change analysis in 50 global cities by using a combination of Landsat data and analysis of grid cells. *Environmental Research Letters*. 9.
- Ballin, M. G. Barcaroli M. Masselli and M. Scarnó. 2018. Redesign sample for Land Use/Cover Area frame Survey (LUCAS) 2018. Luxembourg. Retrieved from <https://ec.europa.eu/eurostat/documents/3888793/9347564/KS-TC-18-006-EN-N.pdf/26cbdb1a-c418-4dfa-bc24-a27d1bc5599c?t=1540804305000>. Accessed July 2021.
- Baltimore Sun. 2018. Urban Farm Coming to Former Sparrows Point Steel Mill Site in Baltimore County. Retrieved from <http://www.baltimoresun.com/business/bs-md-sparrows-point-farm-20180508-story.html>. Accessed March 2020.
- Bates, J. 2012. “This is what modern deregulation looks like” : co-optation and contestation in the shaping of the UK's Open Government Data Initiative . Retrieved from <http://www.ci-journal.net/index.php/ciej/article/view/845/916>. Accessed March 2020.
- Becker, G. and R. Mohren. 1990. The Biotope Area Factor as an Ecological Parameter. *Landschaft: Planen &*

Bauen, Berlin, Germany.

- Beddington, J. M. Asaduzzaman A. Fernandez M. Clark M. Guillou L. Jahn M. van Erda T. Mamo N. Van Bo C. A. Nobre R. Scholes R. Sharma and J. Wakhungu. 2011. Achieving food security in the face of climate change. Copenhagen. Retrieved from www.ccafs.cgiar.org/commission. Accessed February 2020.
- Behnisch, M. H. Poglitsch and T. Krüger. 2016. Soil sealing and the complex bundle of influential factors: Germany as a case study. *ISPRS International Journal of Geo-Information*. 5:1–23.
- Bian Li Zuo Lei Zhang and Nan. 2019. Estimating 2009–2017 Impervious Surface Change in Gwadar, Pakistan Using the HJ-1A/B Constellation, GF-1/2 Data, and the Random Forest Algorithm. *ISPRS International Journal of Geo-Information*. 8:443.
- Birch, C. P. D. S. P. Oom and J. A. Beecham. 2007. Rectangular and hexagonal grids used for observation, experiment and simulation in ecology. *Ecological Modelling*. 206:347–359.
- Birk, R. J. T. Stanley G. I. Snyder T. A. Hennig M. M. Fladeland and F. Policelli. 2003. Government programs for research and operational uses of commercial remote sensing data. *Remote Sensing of Environment*. 88:3–16.
- Boschetto, P. and A. Schiavon. 2011. The Image of Metropolitan Territory. The Metropolitan City of Padua (in Italian: L'immagine del Territorio Metropolitano. La Città Metropolitana di Padova. (P. Boschetto and A. Schiavon, Eds.). Cleup, Padova, Italy.
- Brown, G. 2004. Mapping Spatial Attributes in Survey Research for Natural Resource Management: Methods and Applications. <http://dx.doi.org/10.1080/08941920590881853>. 18:17–39.
- Brown, K. H. M. Bailkey A. Meares-Choen J. Nasr J. Smit T. Buchanan and Mann Peter. 2003. Urban Agriculture and Community Food Security in the United States: Farming from the City Center to Urban Fring. Retrieved from <https://community-wealth.org/content/urban-agriculture-and-community-food-security-united-states-farming-city-center-urban-fringe>. Accessed February 2020.
- Buccola, N. and G. Spolek. 2011. A Pilot-Scale Evaluation of Greenroof Runoff Retention, Detention, and Quality. *Water, Air, & Soil Pollution*. 216:83–92.
- Burghardt, W. 2006. Soil sealing and soil properties related to sealing. Geological Society, London, Special Publications. 266:117–124.
- Bush, J. and A. Doyon. 2019. Building urban resilience with nature-based solutions: How can urban planning contribute? *Cities*. 95:102483.
- Calzolari, C. P. Tarocco N. Lombardo N. Marchi and F. Ungaro. 2020. Assessing soil ecosystem services in urban and peri-urban areas: From urban soils survey to providing support tool for urban planning. *Land Use Policy*. 99:105037.
- Cameron, R. W. F. T. Blanuša J. E. Taylor A. Salisbury A. J. Halstead B. Henricot and K. Thompson. 2012. The domestic garden – Its contribution to urban green infrastructure. *Urban Forestry & Urban Greening*. 11:129–137.
- Cao, S. D. Hu Z. Hu W. Zhao S. Chen and C. Yu. 2018. Comparison of spatial structures of urban agglomerations between the Beijing-Tianjin-Hebei and Boswash based on the subpixel-level impervious surface coverage product. *Journal of Geographical Sciences* 2018 28:3. 28:306–322.
- Caputo, P. F. Zagarella M. A. Cusenza M. Mistretta and M. Cellura. 2020. Energy-environmental assessment of the UIA-OpenAgri case study as urban regeneration project through agriculture. *Science of The Total Environment*. 729:138819.

- Cardullo, P. and R. Kitchin. 2019. Being a 'citizen' in the smart city: up and down the scaffold of smart citizen participation in Dublin, Ireland. *GeoJournal*. 84:1–13.
- Carr, D. B. A. R. Olsen and D. White. 1992. Hexagon Mosaic Maps for Display of Univariate and Bivariate Geographical Data. *Cartography and Geographic Information Systems*. 19:228–236.
- Carvalho, L. 2015. Smart cities from scratch? A socio-technical perspective. *Cambridge Journal of Regions, Economy and Society*. 8:43–60.
- Casella, V. M. Franzini and R. De Lotto. 2016. Geomatics for smart cities: obtaining the urban planning baf index from existing digital maps. 689–694 *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. Prague, Czech Republic.
- Casti, E. 2014. Aree dismesse e obsolete in Lombardia, Rapporto I fase di ricerca del progetto Rifo/It. Bergamo. Retrieved from www.unibg.it/diathesis. Accessed January 2022.
- Ceccarelli, T. S. Bajocco L. Salvati and L. Perini. 2014. Investigating syndromes of agricultural land degradation through past trajectories and future scenarios. *Soil Science and Plant Nutrition*. 60:60–70.
- Cervinka, R. M. Schwab R. Schönbauer I. Hämmerle L. Pirgie and J. Sudkamp. 2016. My garden – my mate? Perceived restorativeness of private gardens and its predictors. *Urban Forestry & Urban Greening*. 16:182–187.
- Chen, Y. and S. Yu. 2016. Assessment of urban growth in Guangzhou using multi-temporal, multi-sensor Landsat data to quantify and map impervious surfaces. *International Journal of Remote Sensing*. 37:5936–5952.
- Choptiany, J. M. B. E. Graeub S. Hatik D. Conversa and S. T. Ledermann. 2019. Participatory Assessment and Adaptation for Resilience to Climate Change. *Consilience*. 21:17–31.
- Clark, C. C. Ordóñez and S. J. Livesley. 2020. Private tree removal, public loss: Valuing and enforcing existing tree protection mechanisms is the key to retaining urban trees on private land. *Landscape and Urban Planning*. 203:103899.
- Climate ADAPT. 2016. Berlin Biotope Area Factor - Implementation of guidelines helping to control temperature and runoff - Climate ADAPT. Retrieved from https://climate-adapt.eea.europa.eu/metadata/case-studies/berlin-biotope-area-factor-2013-implementation-of-guidelines-helping-to-control-temperature-and-runoff/#challenges_anchor. Accessed November 2019.
- Colding, J. 2011. The Role of Ecosystem Services in Contemporary Urban Planning. 228–237 *In* J. Niemelä, J. H. Breuste, T. Elmqvist, G. Guntenspergen, P. James, and N. E. McIntyre, editors. *Urban Ecology: patterns, processes and applications*. Oxford University Press, Oxford, UK.
- Commission, E. 2019. Soil - Soil Sealing. Retrieved from https://ec.europa.eu/environment/soil/sealing_guidelines.htm. Accessed November 2019.
- Commission of the European Communities. 2002. Towards a Thematic Strategy for Soil Protection. CEC, Brussels, Belgium.
- Commission of the European Communities (CEC). 2002. Communication “Towards a Thematic Strategy for Soil Protection” COM(2002) 179 final. Brussels. Retrieved from <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52002DC0179&from=EN>. Accessed January 2019.
- Commissione Europea. 2007. Direttiva 2007/2/CE del Parlamento europeo e del Consiglio, del 14 marzo 2007, che istituisce un'Infrastruttura per l'informazione territoriale nella Comunità europea (Inspire). *Gazzetta ufficiale dell'Unione Europea*.

- Comune di Padova. 2004. Padova, città d'acque. Un modo diverso per conoscere la città. Ufficio Turismo Settore Comunicazioni ai Cittadini, Padova, Italia.
- Comune di Padova. 2014. Territorial Management Plan. Technical Implementation Standards (in Italian: Piano di Assetto del Territorio. Norme Tecniche di Attuazione. Padova, Italy.
- Comune di Padova. 2018. Plan of Interventions. Technical Implementation Standards (in Italian: Piano Degli Interventi. Norme Tecniche di Attuazione. Padova, Italy.
- Comune di Padova. 2019. Padua Bici Masterplan 2018-2022. Relation (in Italian: Bici Masterplan di Padova 2018–2022. Relazione). Padova, Italy.
- Comune di Padova. 2020. 2019 Statistical Yearbook (in Italian: Annuario Statistico 2019). Padova, Italy.
- Congedo, L. L. Sallustio M. Munafò M. Ottaviano D. Tonti and M. Marchetti. 2016. Copernicus high-resolution layers for land cover classification in Italy. *Journal of Maps*. 12:1195–1205.
- Contesse, M. B. J. M. van Vliet and J. Lenhart. 2018. Is urban agriculture urban green space? A comparison of policy arrangements for urban green space and urban agriculture in Santiago de Chile. *Land Use Policy*. 71:566–577.
- Cortijo, A. A. and M. E. P. González. 2017. Soil sealing in Madrid (Spain), study case of Colmenar Viejo. *Earth Sciences Research Journal*. 21:111–116.
- Cortinovis, C. and D. Geneletti. 2019. A framework to explore the effects of urban planning decisions on regulating ecosystem services in cities. *Ecosystem Services*. 38:100946.
- Coseo, P. and L. Larsen. 2019. Accurate Characterization of Land Cover in Urban Environments: Determining the Importance of Including Obscured Impervious Surfaces in Urban Heat Island Models. *Atmosphere* 2019, Vol. 10, Page 347. 10:347.
- CRCS. 2018. CRCS 2018: consumo di suolo, servizi ecosistemici e green infrastructures. (A. Arcidiacono, D. Di Simine, S. Ronchi, and S. Salata, Eds.). INU Edizioni, Roma, Italia.
- Crescini Di Montevecchio Benedetti, E. 2018. Consumo di suolo a Padova: analisi GIS del quartiere Forcellini (PD) e calcolo dell'indice Biotope Area Factor. Università degli Studi di Padova.
- Czemieli Berndtsson, J. 2010, April. Green roof performance towards management of runoff water quantity and quality: A review.
- Davies, C. and R. Laforteza. 2019. Transitional path to the adoption of nature-based solutions. *Land Use Policy*. 80:406–409.
- Decoville, A. and M. Schneider. 2016. Can the 2050 zero land take objective of the EU be reliably monitored? A comparative study. *Journal of Land Use Science*. 11:331–349.
- Department of Economic and Social Affairs of United Nations. 2015. Goal 11 . Retrieved from <https://sdgs.un.org/goals/goal11>. Accessed October 2021.
- Despommier, D. and E. Ellingsen. 2008. The Vertical Farm: The sky-scraper as vehicle for a sustainable urban agriculture. *In* A. Wood, editor. CTBUH 8th World Congress 2008. Dubai, United Arab Emirates.
- Dewaelheyns, V. E. Rogge and H. Gulinck. 2014. Putting domestic gardens on the agenda using empirical spatial data: The case of Flanders. *Applied Geography*. 50:132–143.
- Dobermann, A. B. S. Backmore S. E. Cook and V. Adamchuk. 2004. Precision farming: Challenges and future directions. *In* T. Fischer, N. Turner, J. Angus, L. McIntyre, M. Robertson, A. Borrell, and D. Lloyd, editors. Proceedings of the 4th International Crop Science Congress. Brisbane, Australia.
- Duru, M. O. Therond and M. Fares. 2015. Designing agroecological transitions; A review. *Agronomy for*

Sustainable Development. 35:1237–1257.

- Eigenbrod, F. V. A. Bell H. N. Davies A. Heinemeyer P. R. Armsworth and K. J. Gaston. 2011. The impact of projected increases in urbanization on ecosystem services. 3201–3208 *In* M. P. Hassell, S. H. Alonzo, G. R. Carvalho, I. C. Cuthill, H. A. P. Heesterbee, and M. T. Siva-Jothy, editors. Proc. R. Soc. B. London, UK.
- Elvidge, C. D. B. T. Tuttle P. S. Sutton K. E. Baugh A. T. Howard C. Milesi B. L. Bhaduri and R. Nemani. 2007. Global Distribution and Density of Constructed Impervious Surfaces. *Sensors* (Basel, Switzerland). 7:1962.
- Estellés Arolas, E. and F. González Ladrón-de-Guevara. 2012. Towards an integrating crowdsourcing definition. *Journal of Information Science* . 32:189–200.
- EU Commission. 2016. Mapping and Assessment of Ecosystems and their Services Urban ecosystems 4th Report Final. Retrieved from <http://ec.europa.eu>. Accessed November 2019.
- EU Parliament and EU Council. 2013. General Union Environment Action Programme to 2020 ‘Living well, within the limits of our planet.’ 171–200.
- European Commission. 2011. Roadmap to a Resource Efficient Europe. Communication from the Commission to the European Parliament, the Council, the European economic and social committee and the committee of the regions. Brussels. Retrieved from <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0571&from=EN>. Accessed April 2019.
- European Commission. 2012a. Soil Sealing. *Science for Environment Policy*.:1–41.
- European Commission. 2012b. Guidelines on best practice to limit, soil sealing mitigate or compensate. EC, Belgium.
- European Commission. 2020. Mapping Guide v6.2 for a European Urban Atlas Regional Policy. Retrieved from http://www.stadtentwicklung.berlin.de/umwelt/umweltatlas/ed610_03.htm. Accessed October 2021.
- European Environment Agency. 2016. The direct and indirect impacts of EU policies on land. Luxembourg. Retrieved from <https://www.eea.europa.eu/publications/impacts-of-eu-policies-on-land>. Accessed October 2021.
- European Environment Agency. 2018. Copernicus Land Monitoring Service – High Resolution Layer Imperviousness. Copernicus team at EEA. Retrieved from <https://land.copernicus.eu/user-corner/technical-library/hrl-imperviousness-technical-document-prod-2015>. Accessed January 2019.
- European Parliament. 2014. Precision agriculture: an opportunity for EU farmers - potential support with the CAP 2014-2020. Retrieved from https://www.europarl.europa.eu/thinktank/it/document.html?reference=IPOL-AGRI_NT%282014%29529049. Accessed February 2020.
- Fadini, U. 2013. Walls of Padua. A guide to the Renaissance Fortification System (in Italian: Mura di Padova. Guida al Sistema Bastionato Rinascimentale. (U. Fadini, Ed.). Edibus, Vicenza, Italy.
- Faivre, N. M. Fritz T. Freitas B. de Boissezon and S. Vandewoestijne. 2017. Nature-Based Solutions in the EU: Innovating with nature to address social, economic and environmental challenges. *Environmental Research*. 159:509–518.
- FAO. 2015. Status of the World’s Soil Resources: Main Report. Retrieved from <http://www.fao.org/documents/card/en/c/c6814873-efc3-41db-b7d3-2081a10ede50/>. Accessed February 2020.

- FAO Food and Agriculture Organization of the United Nations. 2010. Fighting Poverty and Hunger. What Role for Urban Agriculture? Retrieved from www.fao.org/fcit. Accessed March 2021.
- FAO Food and Agriculture Organization of the United Nations. 2018a. RIMA | Resilience Index Measurement and Analysis (RIMA). Retrieved from <http://www.fao.org/resilience/background/tools/rima/en/>. Accessed March 2020.
- FAO Food and Agriculture Organization of the United Nations. 2018b. Self-evaluation and Holistic Assessment of climate Resilience of farmers and Pastoralists (SHARP) | Food and Agriculture Organization of the United Nations.
- Feltynowski, M. and J. Kronenberg. 2020. Urban Green Spaces—An Underestimated Resource in Third-Tier Towns in Poland. *Land* 2020, Vol. 9, Page 453. 9:453.
- Feng, D. Y. Zhao L. Yu C. Li J. Wang N. Clinton Y. Bai A. Belward Z. Zhu and P. Gong. 2016. Circa 2014 African land-cover maps compatible with FROM-GLC and GLC2000 classification schemes based on multi-seasonal Landsat data. <http://dx.doi.org/10.1080/01431161.2016.1218090>. 37:4648–4664.
- Fernandez, M. 2017. Urban Agriculture in Cuba: 30 years of policy and practice. *Urban Agroecology*. Retrieved from <https://ruaf.org/document/urban-agriculture-magazine-no-33-urban-agroecology/>. Accessed.
- Fini, A. P. Frangi J. Mori D. Donzelli and F. Ferrini. 2017. Nature based solutions to mitigate soil sealing in urban areas: Results from a 4-year study comparing permeable, porous, and impermeable pavements. *Environmental Research*. 156:443–454.
- Food Tank. 2016. Twelve Organizations Promoting Urban Agriculture around the World. Retrieved from <http://www.fao.org/family-farming/detail/en/c/461898/>. Accessed February 2020.
- Fouilleux, E. N. Bricas and A. Alpha. 2017. 'Feeding 9 billion people': global food security debates and the productionist trap. *Journal of European Public Policy*. 24:1658–1677.
- Franke, J. D. A. Roberts K. Halligan and G. Menz. 2009. Hierarchical Multiple Endmember Spectral Mixture Analysis (MESMA) of hyperspectral imagery for urban environments. *Remote Sensing of Environment*. 113:1712–1723.
- Franklin, J. J. Rogan S. R. Phinn and C. E. Woodcock. 2003. Rationale and Conceptual Framework for Classification Approaches to Assess Forest Resources and Properties. 279–300 *In* M. A. Wulder and S. E. Franklin, editors. *Remote Sensing of Forest Environments*. Springer, Boston.
- Frew, T. D. Baker and P. Donehue. 2016. Performance based planning in Queensland: A case of unintended plan-making outcomes. *Land Use Policy*. 50:239–251.
- Frew, T. G. 2011. The implementation of performance based planning in Queensland under the integrated planning act 1997: an evaluation of perceptions and planning schemes. Queensland University of Technology.
- Fu, Y. J. Li Q. Weng Q. Zheng L. Li S. Dai and B. Guo. 2019. Characterizing the spatial pattern of annual urban growth by using time series Landsat imagery. *Science of The Total Environment*. 666:274–284.
- Gabrys, J. 2014. Programming environments: environmentality and citizen sensing in the smart city. *Environment and Planning D: Society and Space*. 32:30–48.
- Gao, Y. D. Wang A. Schmidt and Y. Tang. 2018. Exploring the Response of Combined Urban Sewer System to the Implementation of Green Roof. 1–7 4th International Conference on Environmental Systems Research. IOP Publishing Ltd.
- García, P. and E. Pérez. 2016. Mapping of soil sealing by vegetation indexes and built-up index: A case study

- in Madrid (Spain). *Geoderma*. 268:100–107.
- Gardi, C. 2017a. Impact of land take on global food security. 146–156 *In* C. Gardi, editor. *Urban Expansion, Land Cover and Soil Ecosystem Services*. Routledge.
- Gardi, C. 2017b. *Urban Expansion, Land Cover and Soil Ecosystem Services*. (C. Gardi, Ed.) Urban Expansion, Land Cover and Soil Ecosystem Services. 1st ed. Routledge, New York, USA.
- Gebbers, R. and V. I. Adamchuk. 2010. Precision agriculture and food security. *Science*. 327:828–831.
- Giachino, C. G. Pattanaro B. Bertoldi L. Bollani and A. Bonadonna. 2021. Nature-based solutions and their potential to attract the young generations. *Land Use Policy*. 101:105176.
- Glavan, M. U. Schmutz S. Williams S. Corsi F. Monaco M. Kneafsey P. A. Guzman Rodriguez M. Čenič-Istenič and M. Pintar. 2018. The economic performance of urban gardening in three European cities – examples from Ljubljana, Milan and London. *Urban Forestry & Urban Greening*. 36:100–122.
- Gliessman, S. R. 2015. *Agroecology: The Ecology of Sustainable Food Systems*. CRC Press, Boca Raton, USA.
- Goldblatt, R. M. F. Stuhlmacher B. Tellman N. Clinton G. Hanson M. Georgescu C. Wang F. Serrano-Candela A. K. Khandelwal W. H. Cheng and R. C. Balling Jr. 2018. Using Landsat and nighttime lights for supervised pixel-based image classification of urban land cover. *Remote Sensing of Environment*. 205:253–275.
- Gomes, V. C. F. G. R. Queiroz and K. R. Ferreira. 2020. An Overview of Platforms for Big Earth Observation Data Management and Analysis. *Remote Sensing 2020*, Vol. 12, Page 1253. 12:1253.
- Gómez-Baggethun, E. and D. N. Barton. 2013. Classifying and valuing ecosystem services for urban planning. *Ecological Economics*. 86:235–245.
- Gong, P. X. Li and W. Zhang. 2019. 40-Year (1978–2017) human settlement changes in China reflected by impervious surfaces from satellite remote sensing. *Science Bulletin*. 64:756–763.
- Goodchild, M. F. 2007. Citizens as sensors: the world of volunteered geography. *GeoJournal*. 69:211–221.
- Goucher, L. R. Bruce D. D. Cameron S. C. Lenny Koh and P. Horton. 2017. The environmental impact of fertilizer embodied in a wheat-to-bread supply chain. *Nature Plants*. 3:1–5.
- Grewal, S. S. and P. S. Grewal. 2012. Can cities become self-reliant in food? *Cities*. 29:1–11.
- Griffin, T. W. and J. Lowenberg-Deboer. 2005. Worldwide adoption and profitability of precision agriculture Implications for Brazil. Retrieved from <http://www.ers.usda.gov/Briefing/ARMS/>. Accessed February 2020.
- Gu, C. L. Wu and I. Cook. 2012. Progress in research on Chinese urbanization. *Frontiers of Architectural Research*. 1:101–149.
- Gullino, G. 2009. *Storia di Padova. Dall'antichità all'età contemporanea*. (G. Gullino, Ed.). Cierre Edizioni, Verona.
- Güneralp, B. M. Reba B. U. Hales E. A. Wentz and K. C. Seto. 2020. Trends in urban land expansion, density, and land transitions from 1970 to 2010: A global synthesis. *Environmental Research Letters*. 15:044015.
- Guthman, J. 2004. *Agrarian Dreams: The Paradox of Organic Farming in California*. Geographical Review of Japan, Series A. University of California Press, Oakland, USA.
- Haines-Young, R. and M. Potschin. 2013. *Common International Classification of Ecosystem Services (CICES): Consultation on Version 4, August-December 2012*. Copenhagen, Denmark. Retrieved from https://cices.eu/content/uploads/sites/8/2012/07/CICES-V43_Revised-Final_Report_29012013.pdf.

Accessed January 2022.

- Haklay, M. 2016. Why is participation inequality important? . 35–44 *In* C. Capineri, M. Haklay, H. Huang, V. Antoniou, J. . Kettunen, F. . Ostermann, and R. Purves, editors. *European Handbook of Crowdsourced Geographic Information*. Ubiquity Press, Londra.
- Hartcher, M. G. and R. K. Chowdhury. 2017. An alternative method for estimating total impervious area in catchments using high-resolution colour aerial photography. *Water Practice and Technology*. 12:478–486.
- Hatan, S. A. Fleischer and A. Tchetchik. 2021. Economic valuation of cultural ecosystem services: The case of landscape aesthetics in the agritourism market. *Ecological Economics*. 184:107005.
- Heitlinger, S. N. Bryan-Kinns and R. Comber. 2019. The right to the sustainable smart city. 1–13 *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. Glasgow, UK.
- Hendrickson, M. K. and M. Porth. 2012. *Urban Agriculture-Best Practices and Possibilities*. Retrieved from <http://extension.missouri.edu/foodsystems/urbanagriculture.aspx>,. Accessed March 2021.
- Hill, D. 2013. On the smart city. Or, a 'manifesto' for smart citizens instead. Retrieved from <https://medium.com/butwhatwasthequestion/on-the-smart-city-or-a-manifesto-for-smart-citizens-instead-7e0c6425f909>. Accessed March 2020.
- Hollands, R. G. 2008. Will the real smart city please stand up? *City*. 12:303–320.
- Holt-Giménez, E. and M. A. Altieri. 2013. Agroecology, food sovereignty, and the new green revolution. *Agroecology and Sustainable Food Systems*. 37:90–102.
- Horton, P. 2017. We need radical change in how we produce and consume food. *Food Security*. 9:1323–1327.
- Huete, A. R. 1988. A soil-adjusted vegetation index (SAVI). *Remote Sensing of Environment*. 25:295–309.
- Hung, C.-L. J. L. A. James and M. E. Hodgson. 2018. An automated algorithm for mapping building impervious areas from airborne LiDAR point-cloud data for flood hydrology. *GIScience & Remote Sensing*. 55:793–816.
- Im, J. Z. Lu J. Rhee and L. J. Quackenbush. 2012. Impervious surface quantification using a synthesis of artificial immune networks and decision/regression trees from multi-sensor data. *Remote Sensing of Environment*. 117:102–113.
- Ingegnoli, V. 2015. *Landscape Bionomics Biological-Integrated Landscape Ecology*. Springer, Milan, Italy.
- IPCC. 2021. *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Retrieved from https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf. Accessed October 2021.
- ISPRA. 2017. *Consumo di suolo, dinamiche territoriali e servizi ecosistemici - Edizione 2016*. Roma.
- ISPRA. 2018. *Consumo di suolo, dinamiche territoriali e servizi ecosistemici*. Edizione 2018. (M. Munafò, Ed.). 1st ed. ISPRA, Roma, Italia.
- ISPRA. 2019. *Consumo di suolo. Dinamiche territoriali e servizi ecosistemici*. Edizione 2019. (M. Michele, Ed.). 1st ed. ISPRA, Roma, Italia.
- ISPRA. 2020. *Consumo di suolo, dinamiche territoriali e servizi ecosistemici*. Edizione 2020. (M. Munafó, Ed.). Roma.
- ISPRA. 2021. *Consumo di suolo, dinamiche territoriali e servizi ecosistemici Edizione 2021 Rapporto ISPRA SNPA*. Roma.

- ISTAT. 2019. ASC - Atlante Statistico dei Comuni. Retrieved from http://asc.istat.it/asc_BL/. Accessed November 2019.
- Jennings, D. B. S. T. Jarnagin and D. W. Ebert. 2004. A modeling approach for estimating watershed impervious surface area from national land cover data 92. *Photogrammetric Engineering & Remote Sensing*. 70:1295–1307.
- Jensen, J. R. and D. C. Cowen. 1999. Remote Sensing of Urban/Suburban Infrastructure and Socio-Economic Attributes*. *Photogrammetric Engineering & Remote Sensing*. 65:611–622.
- Kabisch, N. M. Strohbach D. Haase and J. Kronenberg. 2016. Urban green space availability in European cities. *Ecological Indicators*. 70:586–596.
- Kago, J. S. Loose and R. Sietchiping. 2019. Implementing the New Urban Agenda: Urban and Territorial Integration Approaches in Support of Urban Food Systems. 27–293 *In* H. Ginzky, E. Dooley, I. L. Heuser, E. Kasimbazi, T. Markus, and T. Qin, editors. *International Yearbook of Soil Law and Policy 2018*. Springer, Cham, Switzerland.
- Karimi, A. H. Yazdandad and N. Fagerholm. 2020. Evaluating social perceptions of ecosystem services, biodiversity, and land management: Trade-offs, synergies and implications for landscape planning and management. *Ecosystem Services*. 45:101188.
- Keeley, M. 2011. The Green Area Ratio: an urban site sustainability metric. *Journal of Environmental Planning and Management*. 54:937–958.
- Kendig, L. 1980. *Performance zoning*. Planners Press American Planning Association, Washington D.C.
- Kennard, N. J. and R. H. Bamford. 2020. Urban Agriculture: Opportunities and Challenges for Sustainable Development. 1–14 *In* W. Leal Filho, A. Azul, L. Brandli, P. Özuyar, and T. Wall, editors. *Zero Hunger. Encyclopedia of the UN Sustainable Development Goals*. Springer, Cham, Switzerland.
- Koch, A. A. McBratney M. Adams D. Field R. Hill J. Crawford B. Minasny R. Lal L. Abbott A. O'Donnell D. Angers J. Baldock E. Barbier D. Binkley W. Parton D. H. Wall M. Bird J. Bouma C. Chenu C. B. Flora K. Goulding S. Grunwald J. Hempel J. Jastrow J. Lehmann K. Lorenz C. L. Morgan C. W. Rice D. Whitehead I. Young and M. Zimmermann. 2013. *Soil Security: Solving the Global Soil Crisis*. *Global Policy*. 4:434–441.
- Köhler, M. M. Schmidt F. W. Grimme M. Laar and F. Gusmão. 2001. Urban water retention by greened roofs in temperate and tropical climate. 151–162 38th IFLA World Congress (International Federation of Landscape Architects). Singapore.
- Kuang, W. 2019. Mapping global impervious surface area and green space within urban environments. *Science China Earth Sciences* 2019 62:10. 62:1591–1606.
- Lakes, T. and H. O. Kim. 2012. The urban environmental indicator “biotope Area Ratio” - An enhanced approach to assess and manage the urban ecosystem services using high resolution remote-sensing. *Ecological Indicators*. 13:93–103.
- Lam, S. T. and T. M. Conway. 2018. Ecosystem services in urban land use planning policies: A case study of Ontario municipalities. *Land Use Policy*. 77:641–651.
- Langella, G. A. Basile S. Giannecchini F. D. Moccia F. A. Mileti M. Munafó F. Pinto and F. Terribile. 2020. Soil Monitor: an internet platform to challenge soil sealing in Italy. *Land Degradation & Development*. 31:2883–2900.
- Li, J. Y. Wang Z. Ni S. Chen and B. Xia. 2020. An integrated strategy to improve the microclimate regulation

- of green-blue-grey infrastructures in specific urban forms. *Journal of Cleaner Production*. 271:122555.
- Li, W. and C. Wu. 2015. A geostatistical temporal mixture analysis approach to address endmember variability for estimating regional impervious surface distributions. *GIScience & Remote Sensing*. 53:102–121.
- Liang, S. and J. Wang. 2019. *Advanced remote sensing: terrestrial information extraction and applications*. (S. Liang and J. Wang, Eds.).
- Lillesand, T. M. and R. W. Kiefer. 1994. *Remote sensing and image interpretation*. 3rd Edition. Wiley & Sons.
- Lin, Y. H. Zhang G. Li T. Wang L. Wan and H. Lin. 2019. Improving Impervious Surface Extraction with Shadow-Based Sparse Representation from Optical, SAR, and LiDAR Data. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*. 12:2417–2428.
- Liu, O. Y. and A. Russo. 2021. Assessing the contribution of urban green spaces in green infrastructure strategy planning for urban ecosystem conditions and services. *Sustainable Cities and Society*. 68:102772.
- Lotter, D. W. 2003. Organic agriculture. *J. Sustain. Agric.* 21:59–128.
- De Lotto; E. M. Venco. 2013. Efficacia e attuabilità di indici ecologico ambientali nella pratica urbanistica. *In* F. Sbetti, F. Rossi, M. Talia, and C. Trillo, editors. *XXVIII Congresso dell'INU: Il governo della città nella contemporaneità. La città come motore di sviluppo*. INU Edizioni, Salerno, Italia.
- De Lotto, R. V. Casella M. Franzini V. Gazzola C. Morelli di Popolo S. Sturla and E. M. Venco. 2015. Estimating the Biotope Area Factor (BAF) by Means of Existing Digital Maps and GIS Technology. 617–632 *In* O. Gervasi, B. Murgante, S. Misra, M. L. Gavriloca, A. M. Alves Coutinho Rocha, C. Torre, D. Taniar, and B. O. Apduhan, editors. *Computational Science and Its Applications – ICCSA 2015*. Springer International Publishing AG Switzerland, Basel, Switzerland.
- Lozano, A. V. C. A. Vidal and J. S. Díaz. 2019. Urban growth (1956-2012) and soil sealing in the metropolitan area of Valencia (Eastern Spain). *Spanish Journal of Soil Science*. 9:88–104.
- Lu, D. E. Moran and S. Hetrick. 2011. Detection of impervious surface change with multitemporal Landsat images in an urban–rural frontier. *ISPRS Journal of Photogrammetry and Remote Sensing*. 66:298–306.
- Lu, D. and Q. Weng. 2006. Use of impervious surface in urban land-use classification. *Remote Sensing of Environment*. 102:146–160.
- Ma, Q. C. He and J. Wu. 2016. Behind the rapid expansion of urban impervious surfaces in China: Major influencing factors revealed by a hierarchical multiscale analysis. *Land Use Policy*. 59:434–445.
- MADRE. 2018. *Urban and Peri-Urban Agriculture. Best practice catalogue*. Retrieved from https://anima.coop/sites/default/files/madre_catalogue_web_light.pdf. Accessed.
- Maes, J. G. Zulian S. Guenther M. Thijssen and J. Raynal. 2019. *Enhancing Resilience Of Urban Ecosystems through Green Infrastructure (EnRoute)*. Luxembourg. Retrieved from <https://publications.jrc.ec.europa.eu/repository/handle/JRC115375>. Accessed.
- Marquard, E. S. Bartke J. Gifreu i Font A. Humer A. Jonkman E. Jürgenson N. Marot L. Poelmans B. Repe R. Rybski C. Schröter-Schlaack J. Sobocká M. Tophøj Sørensen E. Vejchodská A. Yiannakou and J. Bovet. 2020. Land Consumption and Land Take: Enhancing Conceptual Clarity for Evaluating Spatial Governance in the EU Context. *Sustainability*. 12:8269.
- Martellozzo, F. J. S. Landry D. Plouffe V. Seufert P. Rowhani and N. Ramankutty. 2014. Urban agriculture: A global analysis of the space constraint to meet urban vegetable demand. *Environmental Research Letters*. 9:064025 (8pp).

- Marzari, S. 2008a. Padova e la città metropolitana. 1807-2007 la metamorfosi del paesaggio urbano. (S. Marzari, Ed.). I Antichi Editori, Venezia, Italia.
- Marzari, S. 2008b. Padua and Metropolitan City. 1807-2007 Metamorphosis of the Urban Landscape (in Italian: Padova e la Città Metropolitana. 1807–2007 la Metamorfosi del Paesaggio Urbano. (S. Marzari, Ed.). I Antichi Editori Venezia, Venezia, Italy.
- Masek, J. G. M. A. Wulder B. Markham J. McCorkel C. J. Crawford J. Storey and D. T. Jenstrom. 2020. Landsat 9: Empowering open science and applications through continuity. *Remote Sensing of Environment*. 248:111968.
- Maxwell, D. C. Levin and J. Csete. 1998. Does urban agriculture help prevent malnutrition? Evidence from Kampala. *Food Policy*. 23:411–424.
- Maye, D. 2019. 'Smart food city': Conceptual relations between smart city planning, urban food systems and innovation theory. *City, Culture and Society*. 16:18–24.
- Milan Urban Food Policy Pact. 2015. Milan Urban Food Policy Pact. Retrieved from <https://www.milanurbanfoodpolicypact.org/the-milan-pact/>. Accessed March 2020.
- Mimet, A. C. Kerbirou L. Simon J. F. Julien and R. Raymond. 2020. Contribution of private gardens to habitat availability, connectivity and conservation of the common pipistrelle in Paris. *Landscape and Urban Planning*. 193:103671.
- Misra, M. D. Kumar and S. Shekhar. 2020. Assessing Machine Learning Based Supervised Classifiers For Built-Up Impervious Surface Area Extraction From Sentinel-2 Images. *Urban Forestry & Urban Greening*. 53:126714.
- Mok, H. F. V. G. Williamson J. R. Grove K. Burry S. F. Barker and A. J. Hamilton. 2014. Strawberry fields forever? Urban agriculture in developed countries: A review. *Agronomy for Sustainable Development*. 34:21–43.
- Montgomery, D. R. 2012. *Dirt: the erosion of civilizations*. University of California Press.
- Moreno, A. A. Bhattacharyya L. Jansen Y. Arkeman R. Hartanto and M. Kleinke. 2019. Environmental engineering and sustainability for smart agriculture: The application of UAV-based remote sensing to detect biodiversity in oil palm plantations. 012008 *In* A. G. Niam, I. Yusliana, and H. Imantho, editors. International Conference on Digital Agriculture from Land to Consumers. Bogor, Indonesia.
- Mougeot, L. J. A. 2000. Urban Agriculture: Definition, Presence, Potentials and Risks, and Policy Challenges Cities Feeding People Series. Retrieved from <http://www.idrc.ca/cfp>. Accessed February 2020.
- Moustier, P. and G. Danso. 2006. Local Economic Development and Marketing of Urban Produced Food. 174–195 *In* R. van Veenhuizen, editor. *Cities Farming for the Future: Urban Agriculture for Green and Productive Cities*. RUAF Foundation, IDRC and IIRR, Philippines.
- Mullins, P. D. 2017. The ubiquitous-eco-city of Songdo: An urban systems perspective on South Korea's Green city approach. *Urban Planning*. 2:4–12.
- Munafò, M. C. Norero A. Sabbi and L. Salvati. 2010. Soil sealing in the growing city: A survey in Rome, Italy. *Scottish Geographical Journal*. 126:153–161.
- Murata, T. and N. Kawai. 2018. Degradation of the urban ecosystem function due to soil sealing: involvement in the heat island phenomenon and hydrologic cycle in the Tokyo metropolitan area. <https://doi.org/10.1080/00380768.2018.1439342>. 64:145–155.
- Naumann, S. A. Frelih-Larsen G. Prokop S. Ittner M. Reed J. Mills F. Morari S. Verzandvoort, Simone Albrecht

- A. Bjuréus G. Siebielec and T. Miturski. 2019. Land Take and Soil Sealing—Drivers, Trends and Policy (Legal) Instruments: Insights from European Cities. 84–112 *International Yearbook of Soil Law and Policy* 2018.
- Nin, M. A. Soutullo L. Rodríguez-Gallego and E. Di Minin. 2016. Ecosystem services-based land planning for environmental impact avoidance. *Ecosystem Services*. 17:172–184.
- Norton, G. W. and S. M. Swinton. 2000. Precision Agriculture: Global Prospects and Environmental Implications. *Proceedings of the 24th International Conference of Agricultural Economists*:269–286.
- Norton, J. 2019. Information Systems for Grassroots Sustainable Agriculture. PhD Thesis. University of California, Irvine, USA.
- Norton, J. B. J. Pan S. Nayebaziz B. Tomlinson and S. Burke. 2014. Plant guild composer: An interactive online system to support back yard food production. 523–526 *Conference on Human Factors in Computing Systems - Proceedings*. Association for Computing Machinery, New York, USA.
- Norton, J. B. Tomlinson B. Penzenstadler S. McDonald E. Kang N. Koirala R. Konishi G. P. Carmona J. Shah and S. Troncoso. 2019. The SAGE Community Coordinator: A Demonstration. 1–10 *In* S. Easterbrook, editor. *Proceedings of the Fifth Workshop on Computing within Limits*. Association for Computing Machinery, Lappeenranta, Finland.
- Nowak, D. J. and E. J. Greenfield. 2020. The increase of impervious cover and decrease of tree cover within urban areas globally (2012–2017). *Urban Forestry and Urban Greening*. 49:126638.
- Oberndorfer, E. J. Lundholm B. Bass R. R. Coffman H. Doshi N. Dunnett S. Gaffin M. Köhler K. K. Y. Liu and B. Rowe. 2007. Green Roofs as Urban Ecosystems: Ecological Structures, Functions, and Services. *BioScience*. 57:823–833.
- Van Oijstaeijen, W. S. Van Passel and J. Cools. 2020. Urban green infrastructure: A review on valuation toolkits from an urban planning perspective. *Journal of Environmental Management*. 267:110603.
- Opolot, E. Y. Y. Yu and P. A. Finke. 2015. Modeling soil genesis at pedon and landscape scales: Achievements and problems. *Quaternary International*. 376:34–46.
- Orsini, F. R. Kahane R. Nono-Womdim and G. Gianquinto. 2013. Urban agriculture in the developing world: A review. *Agronomy for Sustainable Development*. 33:695–720.
- Pafi, M. A. Siragusa S. Ferri and S. Halkia. 2016. Measuring the Accessibility of Urban Green Areas : A comparison of the Green ESM with other datasets in four European cities. Luxembourg (Luxembourg). Retrieved from <http://publications.jrc.ec.europa.eu/repository/handle/JRC102525>. Accessed January 2022.
- Paleari, S. 2017. Is the European Union protecting soil? A critical analysis of Community environmental policy and law. *Land Use Policy*. 64:163–173.
- Paskaleva, K. A. 2011. The smart city: A nexus for open innovation? *Intelligent Buildings International*. 3:153–171.
- Pearsall, H. and J. K. Eller. 2020. Locating the green space paradox: A study of gentrification and public green space accessibility in Philadelphia, Pennsylvania. *Landscape and Urban Planning*. 195:103708.
- Pearson, L. J. L. Pearson and C. J. Pearson. 2010. Sustainable urban agriculture: Stocktake and opportunities. *International Journal of Agricultural Sustainability*. 8:7–19.
- Peroni, F. G. Pristeri D. Codato S. E. Pappalardo and M. De Marchi. 2019. Biotope Area Factor: An Ecological Urban Index to Geovisualize Soil Sealing in Padua, Italy. *Sustainability* 2020, Vol. 12, Page 150. 12:150.

- Phinn, S. M. Stanford P. Scarth A. T. Murray and P. T. Shyy. 2002. Monitoring the composition of urban environments based on the vegetation-impervious surface-soil (VIS) model by subpixel analysis techniques. *International Journal of Remote Sensing*. 23:4131–4153.
- Pistocchi, A. C. Calzolari F. Malucelli and F. Ungaro. 2015. Soil sealing and flood risks in the plains of Emilia-Romagna, Italy. *Journal of Hydrology: Regional Studies*. 4:398–409.
- Poulsen, M. N. 2017. Cultivating citizenship, equity, and social inclusion? Putting civic agriculture into practice through urban farming. *Agriculture and Human Values*. 34:135–148.
- Pretty, J. N. A. D. Noble D. Bossio J. Dixon R. E. Hine F. W. T. P. De Vries and J. I. L. Morison. 2006. Resource-conserving agriculture increases yields in developing countries. *Environmental Science and Technology*. 40:1114–1119.
- Pristeri, G. F. Peroni S. E. Pappalardo D. Codato A. G. Castaldo A. Masi and M. De Marchi. 2020. Mapping and Assessing Soil Sealing in Padua Municipality through Biotope Area Factor Index. *Sustainability* 2020, Vol. 12, Page 5167. 12:5167.
- Prokop, G. H. Jobstmann and A. Schönbauer. 2011. Report on best practices for limiting soil sealing and mitigating its effects. European Commission.
- Quattrocchi, D. A. and M. F. Goodchild. 1997. *Scale in Remote Sensing and GIS*. (D. A. Quattrocchi and M. F. Goodchild, Eds.). CRC Press.
- Radočaj, D. J. Obhodaš M. Jurišić and M. Gašparović. 2020. Global Open Data Remote Sensing Satellite Missions for Land Monitoring and Conservation: A Review. *Land* 2020, Vol. 9, Page 402. 9:402.
- Raghavan, B. B. Nardi S. T. Lovell J. Norton B. Tomlinson and D. J. Patterson. 2016. Computational Agroecology. 423–435 *In* J. Kaye and A. Druin, editors. *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. ACM Press, San Jose, USA.
- Regione del Veneto. 2004. Legge regionale 23 aprile 2004, n. 11 (BUR n. 45/2004) - Norme per il Governo del Territorio e in materia di Paesaggio.
- Regione del Veneto. 2017. Disposizioni per il contenimento del consumo di suolo e modifiche della legge regionale 23 aprile 2004, n. 11 “Norme per il governo del territorio e in materia di paesaggio.” 1–22. Italy.
- Regione del Veneto. 2019a. Legge Regionale n. 14 del 04 aprile 2019. Veneto 2050: politiche per la riqualificazione urbana e la rinaturalizzazione del territorio e modifiche alla legge regionale 23 aprile 2004, n. 11 “Norme per il governo del territorio e in materia di paesaggio”. Venezia, Italy.
- Regione del Veneto. 2019b. Deliberazione della Giunta Regionale n. 64 del 29 gennaio 2019. Venezia, Italy.
- Repubblica Italiana. 1968. Repubblica Italiana. Interministerial Decree, April 2, 1968, n. 1444 (in Italian: Decreto Interministeriale 2 Aprile 1968, n. 1444). Roma, Italy.
- RNDT. 2020. Metadata for Topographic DataBase of Padua Municipality. Retrieved from <https://geodati.gov.it/geoportale/>. Accessed January 2022.
- Rodríguez-Rojas, M. I. F. Huertas-Fernández B. Moreno G. Martínez and A. L. Grindlay. 2018. A study of the application of permeable pavements as a sustainable technique for the mitigation of soil sealing in cities: A case study in the south of Spain. *Journal of environmental management*. 205:151–162.
- Rogan, J. and D. M. Chen. 2004. Remote sensing technology for mapping and monitoring land-cover and land-use change. *Progress in Planning*. 61:301–325.
- Ronchi, S. A. Arcidiacono and L. Pogliani. 2020. Integrating green infrastructure into spatial planning regulations to improve the performance of urban ecosystems. Insights from an Italian case study.

Sustainable Cities and Society. 53:101907.

- Ronchi, S. S. Salata A. Arcidiacono E. Piroli and L. Montanarella. 2019. Policy instruments for soil protection among the EU member states: A comparative analysis. *Land Use Policy*. 82:763–780.
- Rondeaux, G. M. Steven and F. Baret. 1996. Optimization of soil-adjusted vegetation indices. *Remote Sensing of Environment*. 55:95–107.
- Rosset, P. M. and M. A. Altieri. 1997. Agroecology versus input substitution: A fundamental contradiction of sustainable agriculture. *Society and Natural Resources*. 10:283–295.
- Rowe, D. B. and K. L. Getter. 2006. The role of extensive green roofs in sustainable development. *HortScience*. 41:1276–1285.
- Russo, A. and G. T. Cirella. 2018. Modern Compact Cities: How Much Greenery Do We Need? *International Journal of Environmental Research and Public Health* 2018, Vol. 15, Page 2180. 15:2180.
- Sam Navin, M. and L. Agilandeewari. 2020. Comprehensive review on land use/land cover change classification in remote sensing. *J. Spectral Imaging*. 9:8.
- Sánchez-Bayo, F. and K. A. G. Wyckhuys. 2019. Worldwide decline of the entomofauna: A review of its drivers. *Biological Conservation*. 232:8–27.
- dos Santos, A. R. F. S. de Oliveira A. G. da Silva J. M. Gleriani W. Gonçalves G. L. Moreira F. G. Silva E. R. F. Branco M. M. Moura R. G. da Silva R. S. Juvanhol K. B. de Souza C. A. A. S. Ribeiro V. T. de Queiroz A. V. Costa A. S. Lorenzon G. F. Domingues G. E. Marcatti N. L. M. de Castro R. T. Resende D. E. Gonzales L. A. de Almeida Telles T. R. Teixeira G. M. A. D. A. dos Santos and P. H. S. Mota. 2017. Spatial and temporal distribution of urban heat islands. *Science of the Total Environment*. 605–606:946–956.
- Saura, S. 2010. Effects of minimum mapping unit on land cover data spatial configuration and composition. <https://doi.org/10.1080/01431160110114493>. 23:4853–4880.
- Scalenghe, R. and F. A. Marsan. 2009. The anthropogenic sealing of soils in urban areas. *Landscape and Urban Planning*. 90:1–10.
- Scheuer, C. E. Boot N. Carse A. Clardy J. Gallagher S. Heck S. Marron L. Martinez-Alvarez D. Masarykova P. Mcmillan F. Murphy E. Steel H. Van Ekdom and H. Vecchione. 2015. Integration of ecosystem services into decision-making. *Physical Education and Sport for Children and Youth with Special Needs Researches – Best Practices – Situation.*:73–80.
- Schmutz, U. 2017. Urban Agriculture or Urban Agroecology? RUAf. Retrieved from <https://ruaf.org/document/urban-agriculture-magazine-no-33-urban-agroecology/>. Accessed March 2021.
- Schneider, A. M. A. Friedl and D. Potere. 2010. Mapping global urban areas using MODIS 500-m data: New methods and datasets based on ‘urban ecoregions.’ *Remote Sensing of Environment*. 114:1733–1746.
- Scopus. 2021. How do Author / Indexed keywords work? - Scopus: Access and use Support Center. Retrieved from https://service.elsevier.com/app/answers/detail/a_id/21730/supporthub/scopus/. Accessed April 2021.
- See, L. P. Mooney G. Foody L. Bastin A. Comber J. Estima S. Fritz N. Kerle B. Jiang M. Laakso H.-Y. Liu G. Milčinski M. Nikšič M. Painho A. Pödör A.-M. Olteanu-Raimond M. Rutzinger L. See P. Mooney G. Foody L. Bastin A. Comber J. Estima S. Fritz N. Kerle B. Jiang M. Laakso H.-Y. Liu G. Milčinski M. Nikšič M. Painho A. Pödör A.-M. Olteanu-Raimond and M. Rutzinger. 2016. Crowdsourcing, Citizen Science or

- Volunteered Geographic Information? The Current State of Crowdsourced Geographic Information. *ISPRS International Journal of Geo-Information*. 5:55.
- Seiwert, A. and S. Rößler. 2020. Understanding the term green infrastructure: origins, rationales, semantic content and purposes as well as its relevance for application in spatial planning. *Land Use Policy*. 97:104785.
- Serbulova, N. S. Kanurny A. Gorodnyanskaya and A. Persiyanova. 2019. Sustainable food systems and agriculture: the role of information and communication technologies. 12127 *In* M. Pasetti and V. Murgul, editors. IOP Conf. Ser.: Earth Environ. Sci. Rostov-on-Don, Russia.
- Seto, K. C. M. Fragkias B. Güneralp and M. K. Reilly. 2011. A Meta-Analysis of Global Urban Land Expansion. *PLoS ONE*. 6:1–9.
- Seto, K. C. B. Güneralp and L. R. Hutya. 2012. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences of the United States of America*. 109:16083–16088.
- Shahtahmassebi, A. R. J. Song Q. Zheng G. A. Blackburn K. Wang L. Y. Huang Y. Pan N. Moore G. Shahtahmassebi R. Sadrabadi Haghghi J. S. Deng A. R. Shahtahmassebi J. Song Q. Zheng G. A. Blackburn K. Wang L. Y. Huang Y. Pan N. Moore G. Shahtahmassebi R. Sadrabadi Haghghi and J. S. Deng. 2016. Remote sensing of impervious surface growth: A framework for quantifying urban expansion and re-densification mechanisms. *IJAEO*. 46:94–112.
- Shi, L. Ü. Halik A. Abliz Z. Mamat and M. Welp. 2020. Urban Green Space Accessibility and Distribution Equity in an Arid Oasis City: Urumqi, China. *Forests* 2020, Vol. 11, Page 690. 11:690.
- Shuster, W. D. J. Bonta H. Thurston E. Warnemuende and D. R. Smith. 2005. Impacts of impervious surface on watershed hydrology: A review. *Urban Water Journal*. 2:263–275.
- Siddiqui, A. G. Kushwaha A. Raoof P. A. Verma and Y. Kant. 2021. Bangalore: Urban heating or urban cooling? *The Egyptian Journal of Remote Sensing and Space Science*. 24:265–272.
- Siebielec, G. S. Lazar C. Kaufmann and S. Jaensch. 2010. Handbook for measures enhancing soil function performance and compensating soil loss during urbanization process. Urban SMS-Soil Management Strategy project. Urban SMS project, Stuttgart, Germany.
- Siegner, A. J. Sowerwine and C. Acey. 2018. Does Urban Agriculture Improve Food Security? Examining the Nexus of Food Access and Distribution of Urban Produced Foods in the United States: A Systematic Review. *Sustainability*. 10:2988.
- Sinha, P. N. K. Verma and E. Ayele. 2016. Urban Built-up Area Extraction and Change Detection of Adama Municipal Area using Time-Series Landsat Images. *International Journal of Advanced Remote Sensing and GIS*. 5:1886–1895.
- Slonecker, E. T. D. B. Jennings and D. Garofalo. 2001. Remote sensing of impervious surfaces: A review. *Remote Sensing Reviews*. 20:227–255.
- Socientize. 2014. White Paper on Citizen Science for Europe. Zaragoza, Spain.
- Söderström, O. T. Paasche and F. Klauser. 2014. Smart cities as corporate storytelling. *City*. 18:307–320.
- Sonnino, R. 2009. Feeding the city: Towards a new research and planning agenda. *International Planning Studies*. 14:425–435.
- Spadoni, G. L. A. Cavalli L. Congedo and M. Munafò. 2020. Analysis of Normalized Difference Vegetation Index (NDVI) multi-temporal series for the production of forest cartography. *Remote Sensing*

Applications: Society and Environment. 20:100419.

- Specht, K. R. Siebert I. Hartmann U. B. Freisinger M. Sawicka A. Werner S. Thomaier D. Henckel H. Walk and A. Dierich. 2014. Urban agriculture of the future: An overview of sustainability aspects of food production in and on buildings. *Agriculture and Human Values*. 31:33–51.
- Stankovics, P. G. Tóth Z. Tóth P. Stankovics G. Tóth and Z. Tóth. 2018. Identifying Gaps between the Legislative Tools of Soil Protection in the EU Member States for a Common European Soil Protection Legislation. *Sustainability*. 10:1–17.
- Strollo, A. D. Smiraglia R. Bruno F. Assennato L. Congedo P. De Fioravante C. Giuliani I. Marinosci N. Riitano and M. Munafò. 2020. Land consumption in Italy. *Journal of Maps*. 16:113–123.
- Sun, Z. C. Wang H. Guo and R. Shang. 2017. A modified normalized difference impervious surface index (MNDISI) for automatic urban mapping from landsat imagery. *Remote Sensing*. 9:1–18.
- Sutton, P. C. S. J. Anderson C. D. Elvidge B. T. Tuttle and T. Ghosh. 2009. Paving the planet: impervious surface as proxy measure of the human ecological footprint. *Progress in Physical Geography*. 33:510–527.
- Swyngedouw, E. 2016. The mirage of the sustainable ‘smart city’: planetary urbanization and the spectre of combined and uneven apocalypse. 134–143 *In* O. Nel-lo and R. Mele, editors. *Cities in the 21st Century*. Routledge, New York, USA.
- Tahvonen, O. and M. Airaksinen. 2018. Low-density housing in sustainable urban planning – Scaling down to private gardens by using the green infrastructure concept. *Land Use Policy*. 75:478–485.
- Taylor, J. R. and S. T. Lovell. 2012. Mapping public and private spaces of urban agriculture in Chicago through the analysis of high-resolution aerial images in Google Earth. *Landscape and Urban Planning*. 108:57–70.
- Teixeira da Silva, R. L. Fleskens H. van Delden and M. van der Ploeg. 2018. Incorporating soil ecosystem services into urban planning: status, challenges and opportunities. *Landscape Ecology* 2018 33:7. 33:1087–1102.
- Theobald, D. M. S. J. Goetz J. B. Norman and P. Jantz. 2009. Watersheds at Risk to Increased Impervious Surface Cover in the Conterminous United States. *Journal of Hydrologic Engineering*. 14:362–368.
- Tobias, S. F. Conen A. Duss L. M. Wenzel C. Buser and C. Alewell. 2018. Soil sealing and unsealing: State of the art and examples. *Land Degradation & Development*. 29:2015–2024.
- Torres, A. V. C. Tiwari and S. F. Atkinson. 2021. Progress in ecosystem services research: A guide for scholars and practitioners. *Ecosystem Services*. 49:101267.
- Townsend, A. 2014. *Smart Cities-Big Data, Civic hackers and the question for a new utopia*. (W. W. Norton & Company, Ed.). New York, USA.
- UN-Habitat. 2021. UN Habitat Metadata sheet on SDG indicator 11.3.1. Retrieved from <https://unstats.un.org/sdgs/metadata/files/Metadata-11-03-01.pdf>. Accessed April 2021.
- UN Department of Economic and Social Affairs. 2019. *World Population Prospects 2019 Highlights*. Retrieved from www.population.un.org. Accessed February 2020.
- UNDP United Nations Development Programme. 2018. *Community-Based Resilience Analysis (CoBRA) Conceptual Framework and Methodology*. Retrieved from www.undp.org. Accessed March 2020.
- UNFPA United Nations Population Found. 2007. *State of world population 2007: unleashing the potential of urban growth*. New York. Retrieved from www.unfpa.org. Accessed February 2020.

- United States Department of Agriculture. 2016. Urban Agriculture Toolkit. Retrieved from <https://www.usda.gov/sites/default/files/documents/urban-agriculture-toolkit.pdf>. Accessed.
- University of Southampton. 2021. WorldPop. Retrieved from <https://www.worldpop.org/about>. Accessed January 2022.
- Vanolo, A. 2014. Smartmentality: The Smart City as Disciplinary Strategy. *Urban Studies*. 51:883–898.
- Vanolo, A. 2016. Is there anybody out there? The place and role of citizens in tomorrow's smart cities. *Futures*. 82:26–36.
- Vázquez Moreno, L. L. and F. Funes Aguilar. 2016. Avances de la agroecología en Cuba Avances de la agroecología en Cuba. Editora Estación Experimental de Pastos y Forrajes Indio Hatuey, La Habana, Cuba.
- Veolia Institute. 2019. Urban Agriculture: another way to feed cities. Retrieved from www.institut.veolia.org. Accessed.
- Vermeulen, S. J. B. M. Campbell and J. S. I. Ingram. 2012. Climate Change and Food Systems. *Annual Review of Environment and Resources*. 37:195–222.
- Walter, A. R. Finger R. Huber and N. Buchmann. 2017. Smart farming is key to developing sustainable agriculture. *Proceedings of the National Academy of Sciences of the United States of America*. 114:6148–6150.
- Wang, Y. and M. Li. 2019. Urban Impervious Surface Detection From Remote Sensing Images: A review of the methods and challenges. *IEEE Geoscience and Remote Sensing Magazine*. 7:64–93.
- Weng, Q. 2012. Remote sensing of impervious surfaces in the urban areas: Requirements, methods, and trends. *Remote Sensing of Environment*. 117:34–49.
- Weng, Q. editor. 2014. *Scale issues in Remote Sensing*. John Wiley & Sons, Ltd, Hoboken, USA.
- Weng, Q. 2020. *Techniques and Methods in Urban Remote Sensing*. IEEE Press.
- Weng, Q. and D. Lu. 2008. A sub-pixel analysis of urbanization effect on land surface temperature and its interplay with impervious surface and vegetation coverage in Indianapolis, United States. *International Journal of Applied Earth Observation and Geoinformation*. 10:68–83.
- Wenhui, K. C. Wenfeng and S. Wenjiao. 2014. Spatio-temporal characteristics of intra-urban land cover in the cities of China and USA from 1978 to 2010. *Acta Geographica Sinica* . 69:883–895.
- Wessolek, G. 2008. Sealing of soils. 161–179 *In* J. M. Marzluff, E. Shulenberg, W. Endlicher, M. Alberti, G. Bradley, C. Ryan, U. Simon, and C. ZumBrunnen, editors. *Urban Ecology: An International Perspective on the Interaction Between Humans and Nature*. Springer, New York, USA.
- Whelan, B. and J. Taylor. 2013. Precision agriculture for grain production systems. *International Journal of Digital Earth*. CSIRO Publishing, Collingwood, Australia.
- Wiig, A. 2016. The empty rhetoric of the smart city: from digital inclusion to economic promotion in Philadelphia. *Urban Geography*. 37:535–553.
- WOCAT. 2014. WOCAT. Retrieved from <https://www.wocat.net/en/>. Accessed March 2021.
- Woodhouse, P. 2010. Beyond Industrial Agriculture? Some Questions about Farm Size, Productivity and Sustainability. *Journal of Agrarian Change*. 10:437–453.
- World Bank. 2020. Urban Development. Retrieved from <https://www.worldbank.org/en/topic/urbandevelopment/overview>. Accessed.
- World Health Organization. 2005. *Ecosystems and Human Well-Being*. Geneva, Switzerland.

- World Health Organization. 2017. Urban green spaces: a brief for action. Copenhagen, Denmark.
- Wu, D. and G. Lindasay. 2020. How to design a smart city that's built on empowerment - not corporate surveillance. Retrieved from <https://www.fastcompany.com/90469838/how-to-design-a-smart-city-thats-built-on-empowerment-not-corporate-surveillance>. Accessed March 2020.
- Wu, J. Wei-Ning Xiang and J. Zhao. 2014. Urban ecology in China: Historical developments and future directions. *Landscape and Urban Planning*. 125:222–233.
- Wüstemann, H. D. Kalisch and J. Kolbe. 2016. Towards a national indicator for urban green space provision and environmental inequalities in Germany: Method and findings. Berlin: Humboldt University of Berlin, Collaborative Research Center 649 - Economic Risk, Berlin, Germany. Retrieved from <https://www.econstor.eu/handle/10419/146191>. Accessed January 2022.
- Xiao, R. Y. Tian and G. Xu. 2020. Spatial gradient of urban green field influenced by soil sealing. *Science of The Total Environment*. 735:139490.
- Xie, L. and H. Bulkeley. 2020. Nature-based solutions for urban biodiversity governance. *Environmental Science & Policy*. 110:77–87.
- Xu, H. 2010. Analysis of impervious surface and its impact on Urban heat environment using the normalized difference impervious surface index (NDISI). *Photogrammetric Engineering and Remote Sensing*. 76:557–565.
- Xue, J. and B. Su. 2017. Significant remote sensing vegetation indices: A review of developments and applications. *Journal of Sensors*. 2017.
- Zhang, B. Z. Chen D. Peng J. A. Benediktsson B. Liu L. Zou J. Li and A. Plaza. 2019. Remotely sensed big data: Evolution in model development for information extraction [point of view]. *Proceedings of the IEEE*. 107:2294–2301.
- Zhang, L. and Q. Weng. 2016. Annual dynamics of impervious surface in the Pearl River Delta, China, from 1988 to 2013, using time series Landsat imagery. *ISPRS Journal of Photogrammetry and Remote Sensing*. 113:86–96.
- Zhang, N. M. Wang and N. Wang. 2002. Precision agriculture - A worldwide overview. *Computers and Electronics in Agriculture*. 36:113–132.
- Zhao, S. D. Zhou C. Zhu Y. Sun W. Wu and S. Liu. 2015. Spatial and Temporal Dimensions of Urban Expansion in China. *Environmental Science and Technology*. 49:9600–9609.
- Zhong, Q. J. Ma B. Zhao X. Wang J. Zong and X. Xiao. 2019. Assessing spatial-temporal dynamics of urban expansion, vegetation greenness and photosynthesis in megacity Shanghai, China during 2000–2016. *Remote Sensing of Environment*. 233:111374.

BIOTOPE AREA FACTOR: AN ECOLOGICAL URBAN INDEX TO GEOVISUALIZE SOIL SEALING IN PADUA, ITALY

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Abstract

Over the last few years, soil sealing has been recognized as one of the major threats in terms of soil degradation and loss of ecosystem services. Although many efforts have been promoted to increase the awareness of safeguarding soil for stakeholders, its value as a non-renewable resource as well as soil-related services in urban ecosystems is not implemented enough in urban planning and policies. Due to the spatially explicit component and the geographical scale of soil sealing, mapping and quantifying the number of sealed surfaces is crucial. The aim of this paper was to estimate and geovisualize the soil sealed in the city of Padua (Italy) at a very detailed scale, testing the use of the Biotope Area Factor (BAF) index. Moreover, the paper aimed to simulate an alternative mitigation scenario in a specific study area of the city. Spatial analysis was performed testing the BAF index in a Geographic Information System (GIS) environment and using aerial ortho-photos at very high resolution. The results show different values of the BAF index for all four neighborhoods from 0.35 to 0.69. In the mitigation scenario, the value of the BAF index was improved using a measure of green roofs. In conclusion, the paper provides an insightful case study for enriching the debate about soil sealing and gives scientific support for sustainable urban planning.

1. Soil Sealing in Europe and Italy

Soil sealing is one of the main forms of land take that affects urban and rural areas. It is considered the most intense form of land take by the increase of new artificial surfaces or settlement areas, for instance, residential, commercial, green urban areas, and transport areas (Prokop et al. 2011). As a result, agricultural lands, grasslands, and semi-natural lands are completely transformed (Naumann et al. 2019). Nevertheless, when the process of urbanization covers natural or semi-natural areas with artificial and impermeable materials, for example, asphalt or concrete, it is defined as soil sealing (European Commission 2012a; Artmann and Breuste 2015).

It has been observed that in wealthier countries, land take and soil sealing are not directly proportional to the growth of population as well as the expansion of urbanization as it usually occurs in developing countries (Seto et al. 2011). It has been estimated by the European Environment Agency (EEA) that since the mid-1950s, the total surface area of cities in the European Union (EU) has increased by 78%, whereas the population has grown by only 33% (Commission 2019). Academic research and the EU Commission in 2002 began to focus on the soil sealing phenomenon as defined above, as it was recognized as one of the major threats in terms of the degradation of soil and the ecosystem services it provides (Commission of the European Communities (CEC) 2002). In fact, the sealing of natural and semi-natural surfaces drastically reduces soil system processes and functions, affecting all the goods and services that soil provides to human well-being and ecosystems: carbon sequestration, microclimate regulation, groundwater reserves, biodiversity, and food production (Wessolek 2008; Scalenghe and Marsan 2009; Gardi 2017b). The process of sealing covers almost permanently natural or semi-natural soil, isolating other ecosystem compartments (Gardi 2017b). Thus, exchanges of energy, water, and gases are reduced or totally impeded (Scalenghe and Marsan 2009). Effects of soil sealing are exerted not only on the surfaces that are converted into artificial areas, but also on neighboring unsealed surfaces. Since soil is sealed and anthropic activities begin, full or partial restoration of ecosystem functions is a long and costly process (Siebielec et al. 2010; Opolot et al. 2015). For instance, recent studies have shown that for restored agricultural soil, biophysical processes are re-activated in about 15 years (Tobias et al. 2018). Moreover, urbanization processes and increases in built-up areas usually trigger the detriment of rural areas, which are critically affected by a decrease in arable lands and increase in the degradation of the most fertile soils

(Ceccarelli et al. 2014; Gardi 2017b; Aksoy et al. 2017; Naumann et al. 2019).

Even if the preservation of the soil is crucial for human well-being and for the sustainability of ecosystems, at present in the EU there is a lack of specific legislation to protect the soil. The attempt promoted by the EU Commission to design a community framework for soil protection, the Soil Framework Directive, was withdrawn in 2014 (Stankovics et al. 2018). Consequently, soil legislation was extremely fragmented across EU countries, governance levels, and policy domains (Palaia

2017; Ronchi et al. 2019). In Italy, even if there were no laws to safeguard soil enforced at the national level, some regions have written their own laws over the last few years. In 2017, the Regional Council of Veneto wrote its own legislation for all of the regional territory including the city of Padua. The main target of the Veneto Regional Law 14/2017 is to achieve 'no net land take' by 2050, in accordance with the EU Environment Action Program to 2020 (Seventh EAP) (EU Parliament and EU Council 2013; Decoville and Schneider 2016). Indeed, the law attempts to limit the construction of new buildings and infrastructures, defining a maximum net share of new sealed surfaces for each municipality in the region (Regione del Veneto 2017).

The track of European policies regarding soil sealing was released in 2012 when the EU Commission published the "Guidelines on best practice to limit, mitigate, or compensate soil sealing", illustrating some solutions to deal with the phenomenon. This document is addressed to policymakers at all levels of governance and urban planners; it shows not only practical examples, for instance, local planning tools, but also policies and legislation to be applied for all EU countries. It pinpoints three general actions defined as limitation, mitigation, and compensation of soil sealing that may be adopted at different scales, and in different contexts and urban fabric. The most important measure is the limitation of soil sealing by means of preventing the conversion of green spaces or rural areas into new buildings or infrastructure. Whereby this solution does not occur, it is possible to maintain some functions of the soil by applying mitigation measures. For example, some mitigation measures are based on highly permeable materials and surfaces (reinforced grass systems with gravel, grass grids, or permeable concrete pavers), natural water harvesting systems, and green roofs (both intensive and extensive roofs) (European Commission 2012b; Rodríguez-Rojas et al. 2018). Benefits from these practices are different and multiple: reduction of surface run-off, improvement of air quality, microclimate regulation, and increase in biodiversity (Oberndorfer et al. 2007; Alexandri and Jones 2008; Buccola and Spolek 2011). Finally, compensation measures are taken into account only in the case that it is not possible to act with limitation or mitigation measures.

Generally, the soil sealing phenomenon is investigated using statistical data on a local basis (municipalities and provinces), aerial imagery (satellites images or ortho-photos), and LiDAR (Behnisch et al. 2016; Sinha et al. 2016; Hung et al. 2018). When using remote sensed images, different vegetation-based (Normalized Difference Vegetation Index—NDVI, Soil-Adjusted Vegetation Index—SAVI, Normal Difference Built-up Index—NDBI) and ecological urban indexes (Biotope Area Factor, BAF) are adopted to assess soil sealing (Huete 1988; De Lotto et al. 2015; Congedo et al. 2016).

Due to the spatially explicit component and the geographical scale of the soil sealing phenomenon, mapping and quantifying the amount of sealed surfaces is crucial (Behnisch et al. 2016). Moreover, soil sealing monitoring through time is paramount to support decision making regarding sustainable territory planning and to assess the state of urban ecosystem services. Since 2006, soil sealing has

been monitored in all EU countries by mainly using statistical data (Land Use/Land Cover Area Frame Survey - LUCAS Program), and then, in 2015, using remotely sensed data through satellites images. In 2018, the Copernicus Land Monitoring Service performed a full reprocessing of the time series between 2006 and 2012 for comparative analyses by using an automatic derivation based on the calibrated normalized difference vegetation index (NDVI) (European Environment Agency 2018). Elaborations of updated data show that in Europe, between 2006 and 2009 and 2009 to 2012 periods, the soil sealing increased 2396 km² and 2840 km² respectively; finally, there was a decrease between the period of 2012 and 2015, with 1650 km² of new sealing.

Moreover, the Copernicus Program supplied free and open data from satellite images at a geometric resolution of 10 m pixel, which the Italian National Institute for Environmental Protection and Research (ISPRA) has adopted to analyze and quantify soil sealing for the entire country. In Italy, in 2017, the percentage of impermeable surfaces was 7.65%, which corresponds to 23,063 km² (ISPRA 2018). According to the EEA, Italy is one of the European countries with the highest amount of impervious surfaces. In the last ten years, probably due to the economic crisis, the speed of sealing has slightly decreased. On the other hand, in 2018, 54 km² were transformed into impervious surfaces. The Po valley is the most affected sector in Italy; Lombardia and Veneto with 13% and 12.4% of sealed surfaces, respectively, are the first two Italian regions most affected by the phenomenon. Apart from the Campania region (10.43%), the other Italian regions present values lower than 10% of sealed surfaces (ISPRA 2019). Today, the availability of high resolution aerial images such as ortho-photos or satellite imagery has given local institutions the chance to monitor soil sealing at a very detailed scale. In particular, municipalities could improve their sustainable territory to limit and mitigate soil sealing, paying close attention to the unique characteristics of their cities and urban fabric.

The general aim of this paper was to estimate and geovisualize the soil sealed at urban scale in Padua, one of the most sealed cities in Italy (ISPRA 2019). The specific aims were to (i) quantify the amount of soil sealing at a very detailed scale; (ii) test the use of the BAF index to quantify the amount of soil sealing; and (iii) simulate an alternative mitigated scenario by testing the use of the BAF index in a specific study area.

2. Materials and Methods

2.1. Case Study: Soil Sealing in Padua

The municipality of Padua is located in the Veneto Region (Italy) and has a total surface of 93 km² (Italian National Institute of Statistics, 2019), with 209,829 inhabitants (Italian National Institute of Statistics, 2017) (ISTAT 2019) (Figure 1).



Figure 1. Geographical framework: Veneto region and the municipality of Padua.

The city of Padua was developed within the Brenta and Bacchiglione Rivers; the ancient Venetian walls and canals surround the historical urban core (Comune di Padova 2004). The expansion and the current shape of the city are mainly the results of the urban development that occurred from 1957 to 1975 during the Italian economic boom and urbanization process. On account of the industrial growth and infrastructure development, the city was structured over the ancient walls of the city (Gullino 2009). Due to the different phases of historical urban development, together with economic drivers, the urban fabric is at present highly heterogeneous and fragmented, mixing new residential areas with green spaces, and commercial and productive districts (Figure 2) (Marzari 2008a).

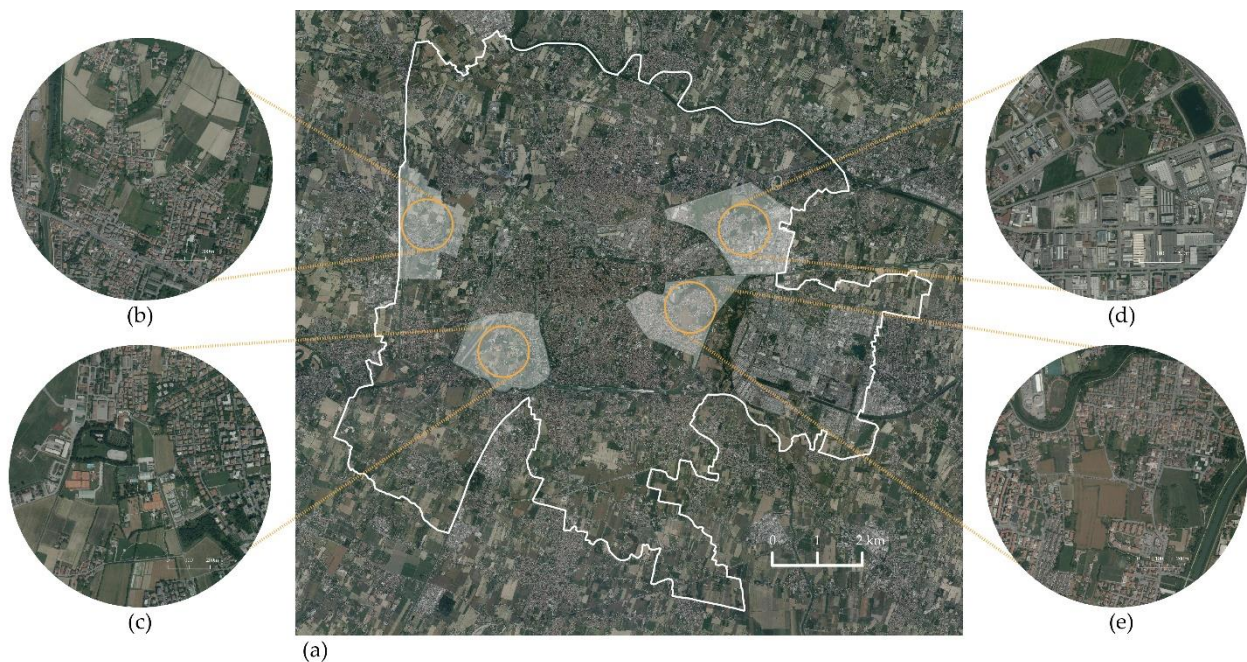


Figure 2. (a) The municipality of Padua and the boundaries of the four neighborhoods; (b) a zoom of the urban fabric of Brentelle neighborhood; (c) detail of the urban fabric of the Basso Isonzo neighborhood; (d) San Lazzaro neighborhood; (e) and Forcellini neighborhood.

According to ISPRA 2018, the municipality of Padua shows 49.4% of its territory completely sealed, with 46 km² covered by impervious surfaces (ISPRA, 2018). Moreover, in 2015, the municipality of Padua was rated as one of the 20 Italian cities with the highest values of soil sealing.

Spatial analysis of soil sealing was performed by using recent aerial ortho-photos at very high geometric resolution, provided by the Veneto Region (2015). An aerial survey was performed in the summer of 2015, and ortho-photos were processed at 20-cm pixel geometric resolution for all multispectral bands (3-bands in the visible, 1-band in the near-infrared spectrum). Thanks to the high geometric resolution, a minimum mapping unit of 6 m² was established to enable a detailed photo-interpretation of the land use and land cover surfaces. Photo-interpretation using visible (natural color composition, RGB) and near-infrared (false color composition) was performed at a variable scale from 1:2,000 to 1:500, in order to assess and extract land use features for further soil sealing analysis within the complex urban fabric of the city. Mapping at a very detailed scale allowed the identification of small permeable/impermeable surfaces such as garden units in wide residential areas, mid-size flowerbeds, boulevard, and cabin units.

Within the municipality boundaries of Padua, we identified, by a preliminary land use/land cover screening performed in GIS environment, four representative macro-areas. Boundaries of the macro-areas corresponded to four distinct neighborhoods showing geographical features of different representative urban fabrics of the city: San Lazzaro (348 ha), the industrial district of Padua located on the east border of the municipality; the Forcellini (267 ha) and Basso Isonzo (278 ha) districts,

two residential neighborhoods located near the center; and Brentelle (263 ha), an agricultural-dominant neighborhood located in the western sector of Padua (Figure 2).

2.2. The Biotope Area Factor (BAF)

The BAF is an ecological index that was developed to assess and enhance urban ecosystems, and increase the sustainability of city development. The BAF index was developed to control and regulate the construction and renovation of buildings in densely built-up areas (Climate ADAPT 2016). It has been specifically developed to be used at a very detailed scale such as building, parcel, and urban district scales (Ahern 2007; Keeley 2011). BAF values were assessed and calculated by using a basic ecological factor, namely the process of the interception of rainfall generated by a surface (Ingegnoli 2015). Alterations of this process, caused by different degrees of surface impermeability, may generate negative impacts on the ecosystem services. Therefore, the BAF index geovisualizes the level of permeability of the soil and grounds, allowing the possibility of checking the ecological status of built-up areas through this process. It was designed by the Landscape Program for West Berlin in the late 1980s (Becker and Mohren 1990). After the reunification of the capital, BAF assessment was established in the Landscape Plans (1994) and became mandatory for selected parts of the city where there is a high level of sealing. The BAF index ranges from 0 (completely impermeable surfaces or waterproof) to 1 (complete permeable surfaces) including nine classes. A BAF index equal to 1 corresponds to a green or agricultural land; on the other hand, a 0 value corresponds to buildings, streets, or parking. The intermediate classes of the BAF index also refer to the vegetation areas that have more or less connection with the underlying soil.

Since its application in Berlin, other cities have introduced the BAF index. For instance, it was adopted by Malmö in Sweden, Seattle in the USA, and in the city of Seoul in South Korea (Keeley 2011; Lakes and Kim 2012).

The BAF index is calculated using the following equation (Becker and Mohren 1990; Casella et al. 2016):

$$\text{BAF} = \frac{\sum_{i=1}^n A_i \times w_i}{\sum_{i=1}^n A_i} \quad (1)$$

where A_i corresponds to each surface of the study area that is homogeneous in terms of the BAF value multiplied by which corresponds to the BAF coefficient (Equation (1)). The result corresponds to the ecologically effective surface area (EESA). The BAF value for the considered study area equals the sum of all of the EESAs divided by the sum of the areas.

In order to test the BAF index, the methodology was based on two phases: (1) extraction of the land-use features from high resolution aerial images of 2015 and classification of the same features according to the land use classification elaborated from the Corine Land Cover database; and (2) ranking every land-use feature using the BAF index values (from 0 to 1) (Figure 3).

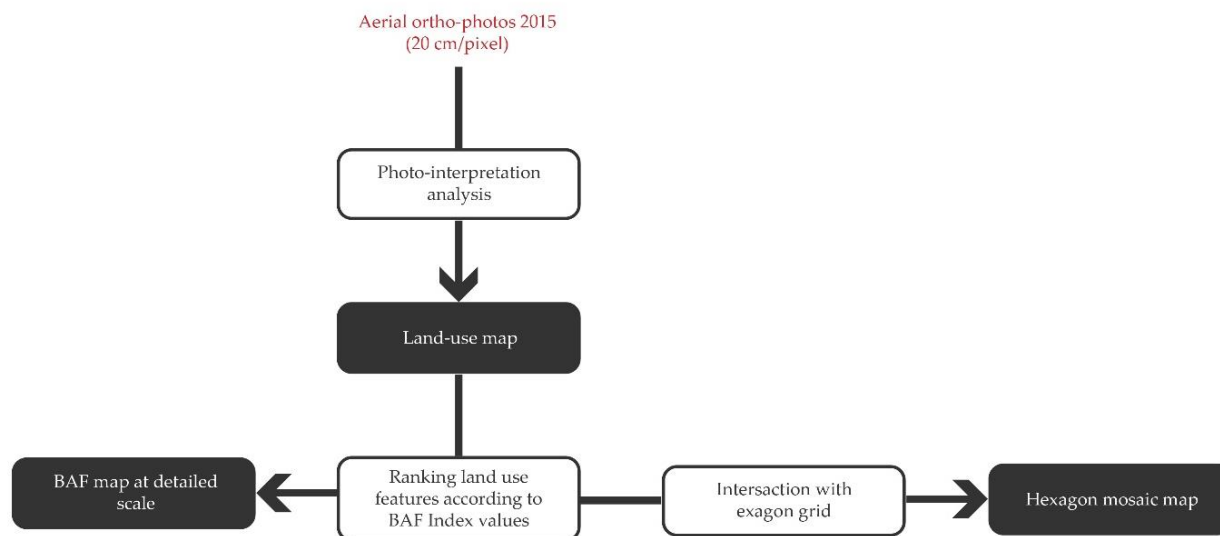


Figure 3. From the aerial ortho-photos to the BAF index calculation and representation.

Hence, by a previous display analysis of the urban fabric of the city, a regular grid model (or fishnet) of 1000 m² was set to geovisualize and represent the soil sealed and the degree of surface permeability at sub-urban scales.

Regular grids are frequently used to represent univariate geographical data for spatial analyses and geovisualization in both landscape ecology and urban planning analyses (Birch et al. 2007). According to a literature review, the hexagon grid tessellation (hexagon cells) of the area shows some advantages such as reduction of the edge effect and improvement in the geovisualization of connectivity and patterns (Carr et al. 1992; Goldblatt et al. 2018). We therefore produced hexagon mosaic maps to geovisualize the soil sealed at an urban scale and to provide simple thematic maps for urban planning.

2.3. Simulated Mitigation Scenario

To perform a simulated mitigation scenario, the San Lazzaro neighborhood was selected as it covers a sector of the industrial district of Padua, widely affected by soil sealing as well as being the most suitable area for rooftop greening. This scenario was modeled using the BAF index value (0.7), which expresses the rooftop surface permeability. According to the principles provided by the Municipality of Berlin, the value 0.7 refers to both intensively and extensively green roofs. The 0.7 value takes into account five different criteria: evapotranspiration efficiency, capacity for binding dust, infiltration ability and storage of rainwater, long-term guarantee of the conservation or development of soil functions, and availability as a habitat for plants and animals [44]. It is worth highlighting that benefits provided by intensive roofs (deep soil layers with plants and bushes) are more effective than benefits

provided by extensive roofs (thin soil layers with small plants and grass) (Czemiel Berndtsson 2010). Overall, extensive roofs are worldwide the most common category due to building weight restrictions and costs (Rowe and Getter 2006).

To perform the “rooftop greening” scenario, it was simulated that roofs of the industrial buildings could be regenerated into green roofs. In this way, the BAF index of the industrial roofs were substituted with the 0.7 value of the BAF index in place of the 0 value.

3. Results and discussion

3.1. Land Use Analysis

The analysis of land use was the first phase of the methodology. The results of the land use analysis allowed us to identify 16 classes of land use in the four neighborhoods. The results of land use classification are summarized in Figures 4 and 5. The Brentelle neighborhood presented high values of urban cropland, with 37.6% covered, which are mainly located in the northern sector of the neighborhood. Both the Basso Isonzo and Forcellini neighborhoods presented lower values of cropland, close to 15%. While these were mainly located in the southern sector of the neighborhood in Basso Isonzo, in Forcellini, they appeared to be more scattered and fragmented. Finally, the San Lazzaro neighborhood had very low values of cropland (3.9%).

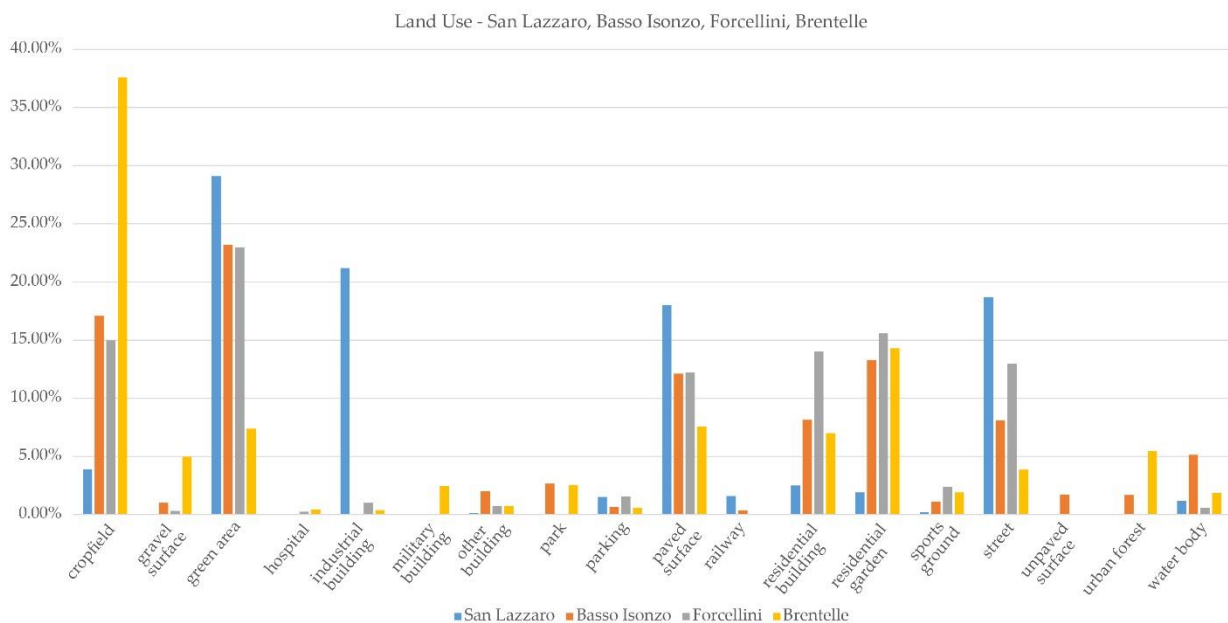


Figure 4. Land use analysis in the four neighborhoods: San Lazzaro (blue), Basso Isonzo (orange), Forcellini (gray), and Brentelle (yellow).

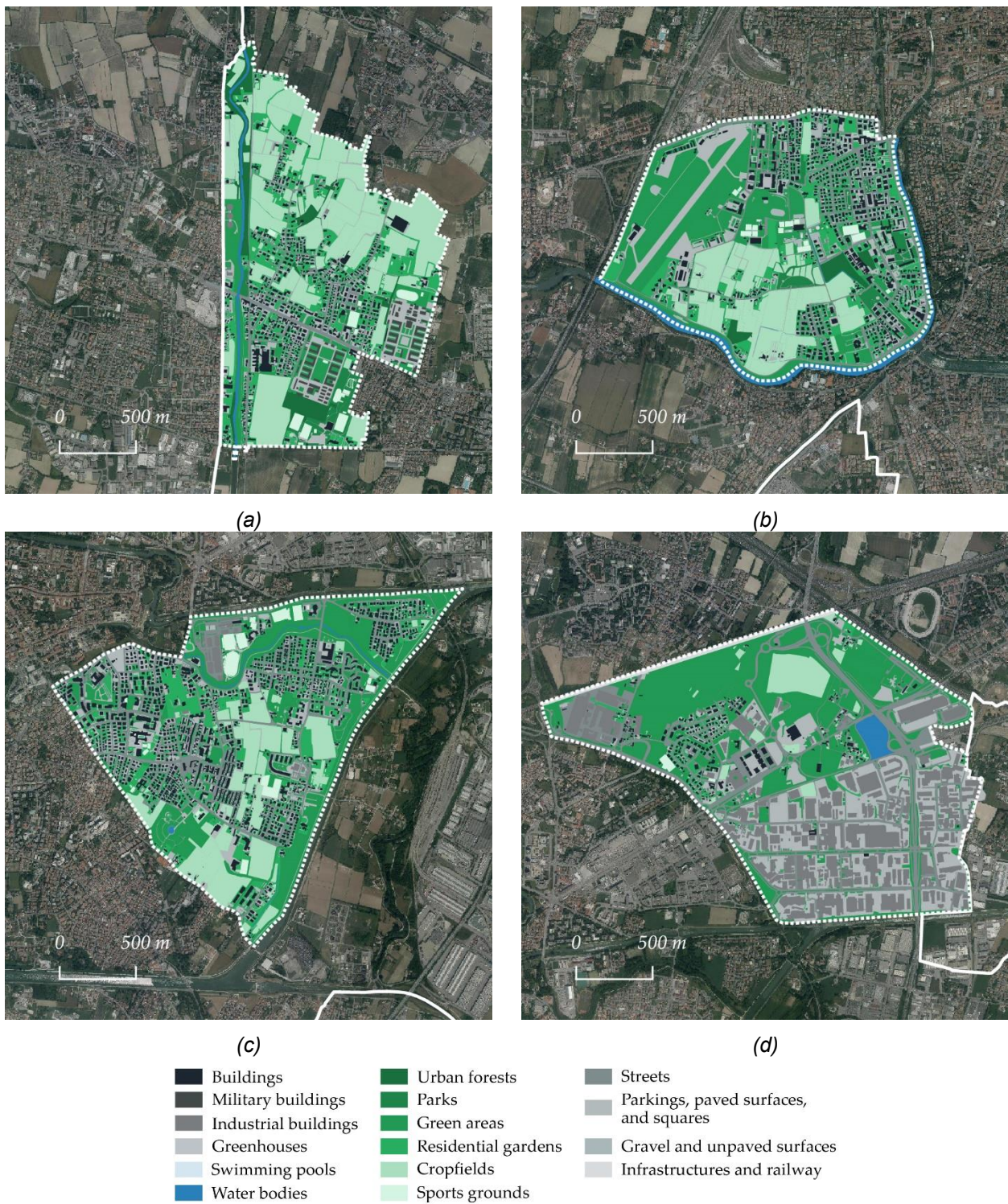


Figure 5. Land use analysis. (a) Brentelle neighborhood; (b) Basso Isonzo neighborhood; (c) Forcellini neighborhood; (d) San Lazzaro neighborhood. (e) Legend of land use analysis.

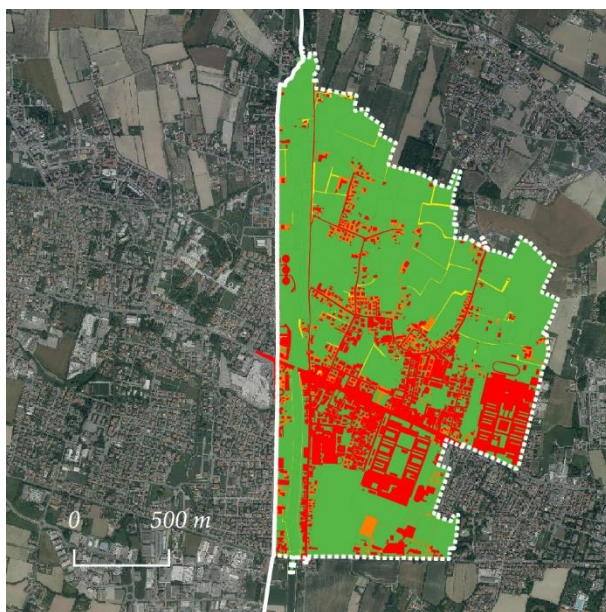
Surprisingly, San Lazzaro showed a high value of green areas, close to 30%, that were entirely located in the northern sector of the neighborhood. In contrast, the other classes that mainly covered San Lazzaro were composed of industrial buildings (21.2%), paved surfaces (18%), and streets

(18.7%). These classes were mostly pinpointed in the southern sector. It is worth noting that the sum of all these classes was almost 60% of the entire neighborhood.

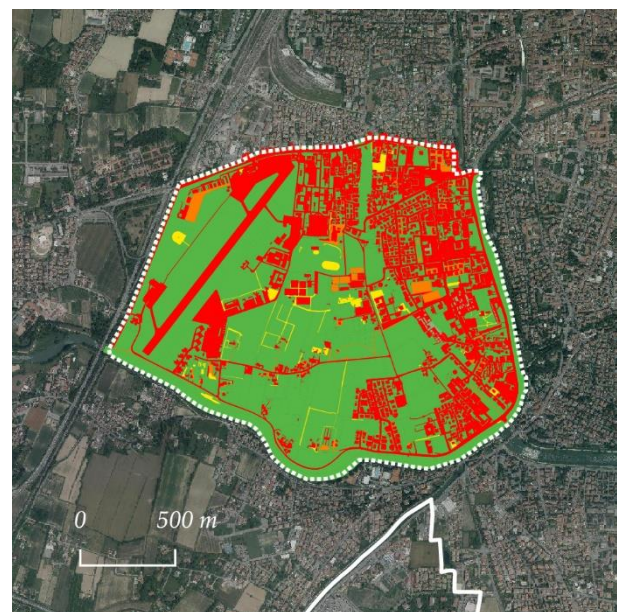
The Forcellini and Basso Isonzo neighborhoods showed high values of green areas, both 23%, while in contrast, Brentelle showed values of 10%. Concerning all classes that included buildings related to residential areas (i.e., “residential building”, “religious building”, “recreational building and “other building”), the Forcellini, Basso Isonzo, and Brentelle neighborhoods showed values of 31%, 25%, and 23%, respectively. In contrast, the San Lazzaro neighborhood presented a buildings value 4.5%. These results highlight the residential character of Forcellini, Basso Isonzo, and Brentelle, while San Lazzaro has an industrial urban fabric.

3.2. BAF Analysis

The maps in Figure 6 show the results of the BAF index for each neighborhood. San Lazzaro is the most impermeable area and shows the lowest BAF index value by only 0.35. More than 60% corresponded to impermeable surfaces, whereas 35% were completely permeable (Figure 7). The highest value of the BAF index was held by the Brentelle neighborhood at 0.69. In Brentelle, the results were completely different than that in the San Lazzaro neighborhood: approximately 70% of surfaces were permeable, whereas the impermeable surfaces were around 25%. The Basso Isonzo and Forcellini neighborhoods presented similar values of the BAF index with 0.64 and 0.56, respectively.



(a)



(b)

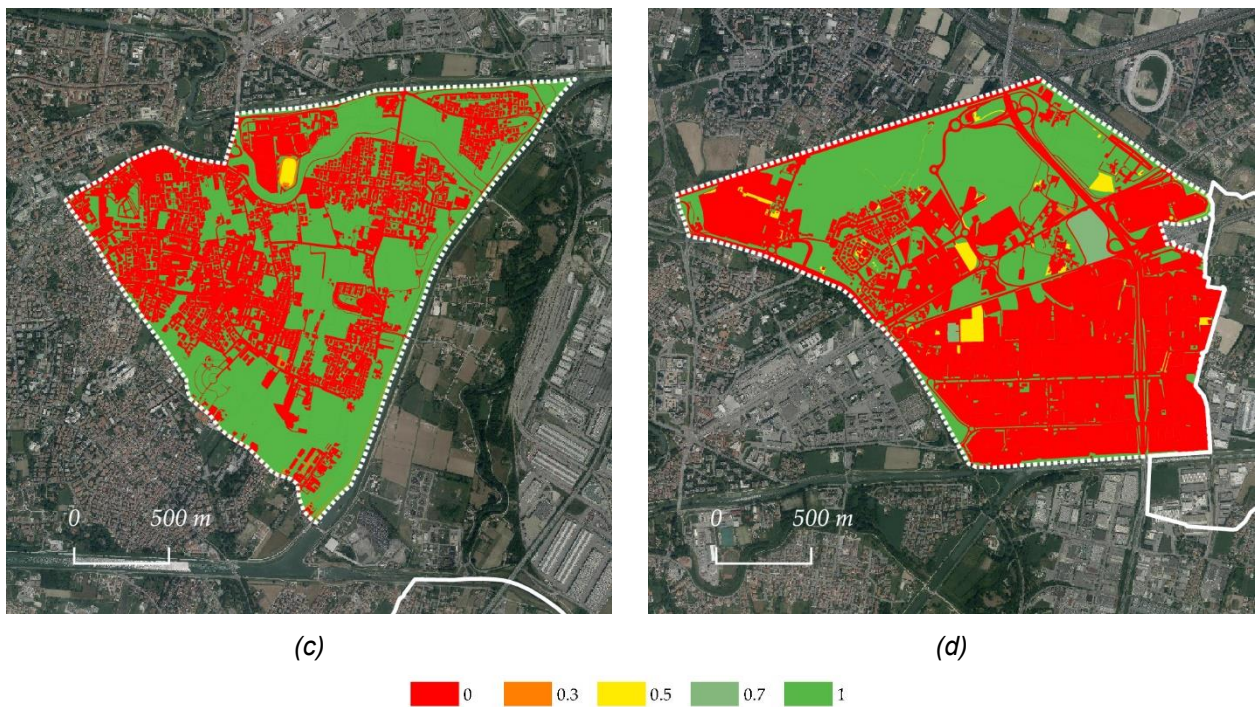


Figure 6. Biotopo area factor (BAF) analysis, showing different degrees of permeability, from 0 to 1: (a) Brentelle; (b) Basso Isonzo; (c) Forcellini; (d) San Lazzaro. (e) Legend of BAF analysis.

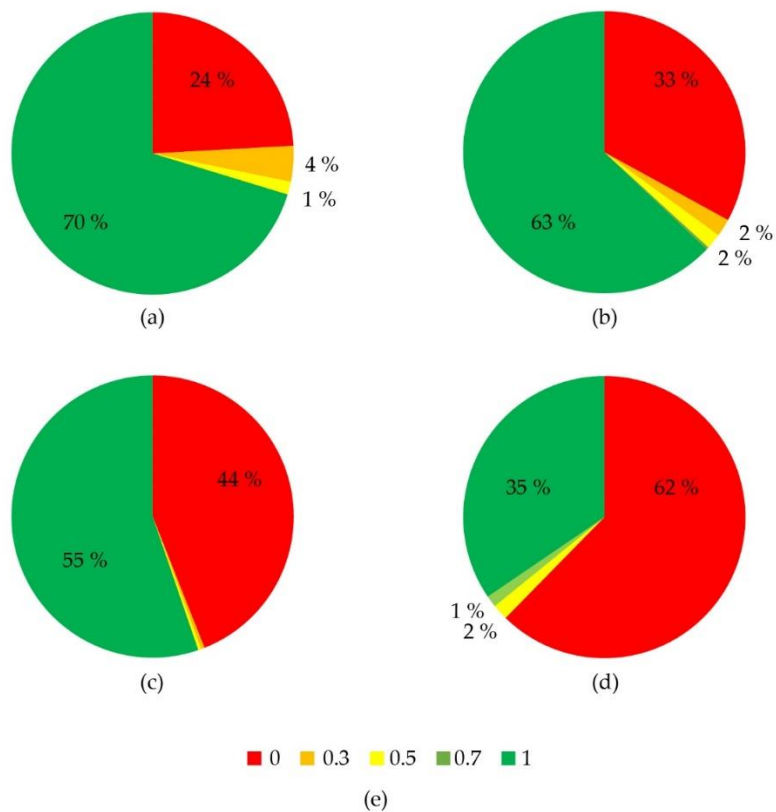


Figure 7. Percentage of BAF analysis in each neighborhood. (a) Brentelle; (b) Basso Isonzo; (c) Forcellini; (d) San Lazzaro. (e) Legend of percentage of the BAF analysis

In Basso Isonzo, more than a third of surfaces were impermeable, whereas around 60% were permeable surfaces. In Forcellini, the percentages of permeable and impermeable surfaces were quite similar, with 55% permeable surfaces and 44% impermeable surfaces.

It is noteworthy in all the four neighborhoods, the BAF classes were strongly polarized on impermeable and permeable surfaces by BAF index values of 0 and 1, respectively. Indeed, the values of the BAF index of 0.3 and 0.5 were close to 2%–4% in Brentelle and in Basso Isonzo, and corresponded to unpaved roads related to cropfield and agricultural lands. The percentages of all BAF index values are summarized in Figure 6. Moreover, the class of the 0.7 BAF index was not present in any of the four neighborhoods as it refers to rooftop greening. It is evident that the Municipality of Padua has not yet taken into account any mitigation measures to manage the soil sealing issue, especially in areas where there is a high pressure of sealed surfaces like the San Lazzaro neighborhood. Indeed, in accordance with Veneto Regional Law 14/2017, which addresses the control of the phenomenon of soil sealing, the Municipality is mainly focused on limiting the construction of new buildings and encouraging brownfield regeneration without suggesting some mitigation actions (Regione del Veneto 2017).

Further analyses showed that the amount of permeable surfaces (BAF value of 1) mainly consisted of “green areas” or “park” land use classes (Figure 8). The most striking result emerged from the comparison of the four neighborhoods highlighting San Lazzaro, which provides permeable surfaces with more than 80% of “green area” class. Although the Basso Isonzo and Forcellini neighborhoods showed high values of the “green area” land use class of 36.8% and 41.6%, respectively, they also presented mixed classes of BAF value 1. Hence, in these two neighborhoods, the BAF value of 1 also includes other relevant classes, for instance, “residential garden” and “cropfield”. The amount of “residential garden” class was rather significant both in Forcellini (28.2%), Basso Isonzo (21%), and Brentelle (20%). In addition, it is worth noting that the high rate of “cropfield” class was notable only in the Brentelle neighborhood (53.5%). In this neighborhood, other classes were less dominant.

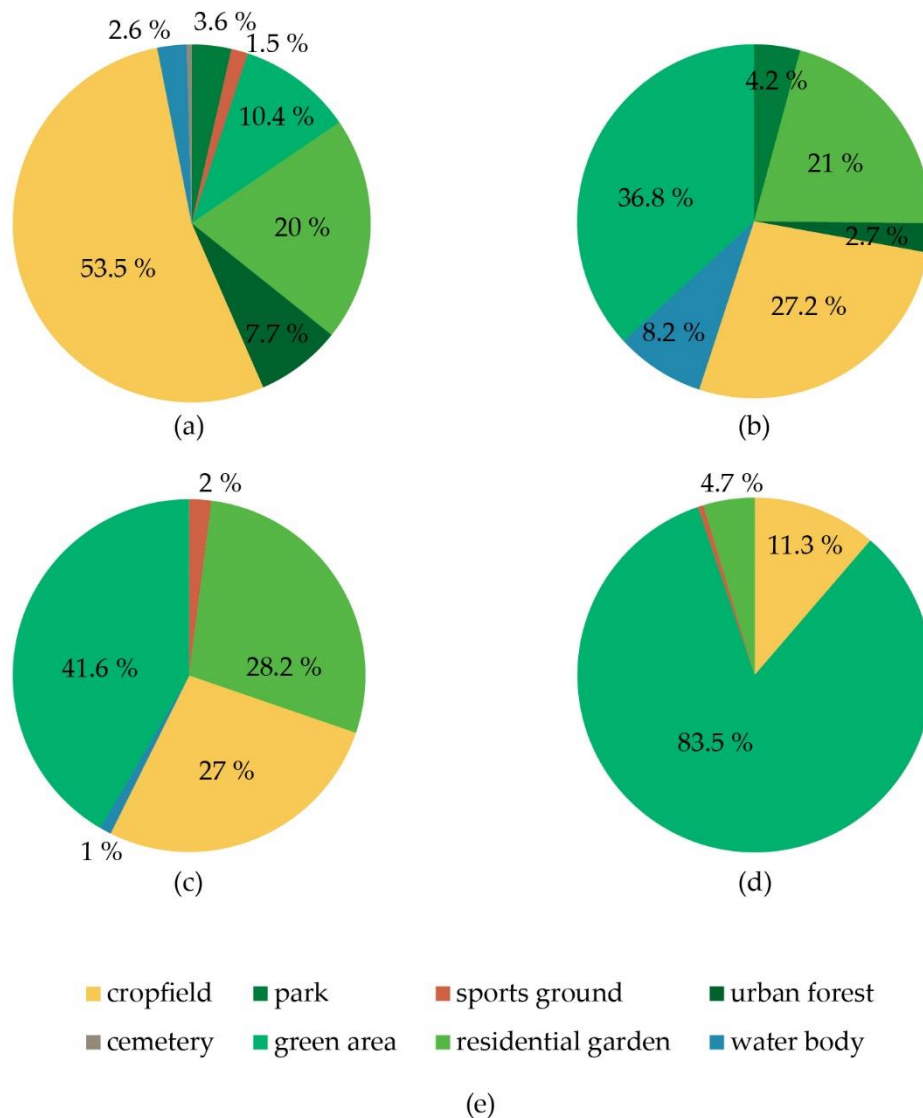


Figure 8. The pie chart with the percentage value of 1 in the BAF class in each neighborhood. (a) Brentelle neighborhood; (b) Basso Isonzo neighborhood; (c) Forcellini neighborhood; (d) San Lazzaro neighborhood

3.3. Hexagon Mosaic Map for Soil Sealing Geovisualization

Figure 9 shows the results of the hexagon tessellation and the distribution of values of the BAF index for each neighborhood. The hexagon mosaic maps show the average permeability degree from the BAF value, normalized on 1000 m² areal units.

In Brentelle, the impermeable surfaces were mainly located in the central sector of the neighborhood, while permeable surfaces were in the surrounding areas. The comparison with the land use map showed that all red hexagons corresponded to the residential pattern of the neighborhood. On the other hand, Basso Isonzo presented a different spatial distribution: the most impervious surfaces were located in the east sector and north–east, whereas the south sector was almost all permeable. The permeable surfaces in the south corresponded to “Parco Agro-Paesaggistico” of Padua, which would collect all of the contiguous cropfields remaining in the Basso Isonzo neighborhood.



Figure 9. Hexagon tessellation of the BAF analysis in each neighborhood. (a) Brentelle neighborhood; (b) Basso Isonzo neighborhood; (c) Forcellini neighborhood; (d) San Lazzaro neighborhood. (e) Legend of hexagon tessellation

In the Forcellini neighborhood, the permeable areas were also quite fragmented as the impermeable surfaces were scattered. The hexagon tessellation with a 0.3 value on the BAF index (orange) showed the presence of a mixed urban pattern of the neighborhood. In the San Lazzaro neighborhood, the overall value of the BAF index is low. Using the map, it is possible to geovisualize that the permeable surfaces were located in the central–north sector of the neighborhood,

surrounded by impermeable surfaces. It is important to note that the southern sector was overall sealed without permeable surfaces and corresponded to the industrial area of Padua.

The comparison of the maps of the BAF analysis and the hexagon tessellation (Figures 6 and 9) highlights an urban pattern of balance between impermeable surfaces such as buildings and streets, and green areas or cropfields. Particularly, this pattern emerged from the two neighborhoods of Basso Isonzo and Forcellini, in the sectors mainly covered by residential settlements. In contrast, in San Lazzaro, this balanced pattern does not occur due to the strong presence of industrial buildings that are obviously not fragmented by green areas or cropfields.

3.4. Mitigation Scenario: Rooftop Greening

Among the four study areas, the San Lazzaro neighborhood was chosen to simulate a mitigation scenario named “rooftop greening”. What stands out in this scenario is the significant outcome of results from the BAF index, showing a value of 0.59. A comparison of the two results (Figure 10) of the BAF index for San Lazzaro revealed a marked increase in the BAF index from 0.35 to 0.59 of the mitigation scenario by rooftop greening. Moreover, the result of the rooftop greening showed that the surfaces with a value of 1 on the BAF index were not modified by the increase in surfaces with a 0.7 value. In contrast, surfaces with a 0 on the BAF index were drastically reduced. Finally, surfaces with a 0.7 value on the BAF index represented 21.3% of the neighborhood, while a 0 BAF index value constituted 41.2%; surfaces with a value of 1 on the BAF index represented 31.7%. The map of the BAF index showed that the 0.7 value of the BAF index was mainly localized in the southern sector. Interestingly, the hexagon tessellation showed the positive effects that were generated by the 0.7 BAF index value, especially in the southern sector of the neighborhood. Indeed, the 0.7 BAF index value is able to balance the 0 value that already exists in the area, which is related to streets and parking. Hence, the results show that there are many hexagons in the range from 0.40–0.60 values and from 0.60–0.80. This is evidence that the pressure exerted nowadays by the industrial area could be mitigated and reduced by rooftop greening.

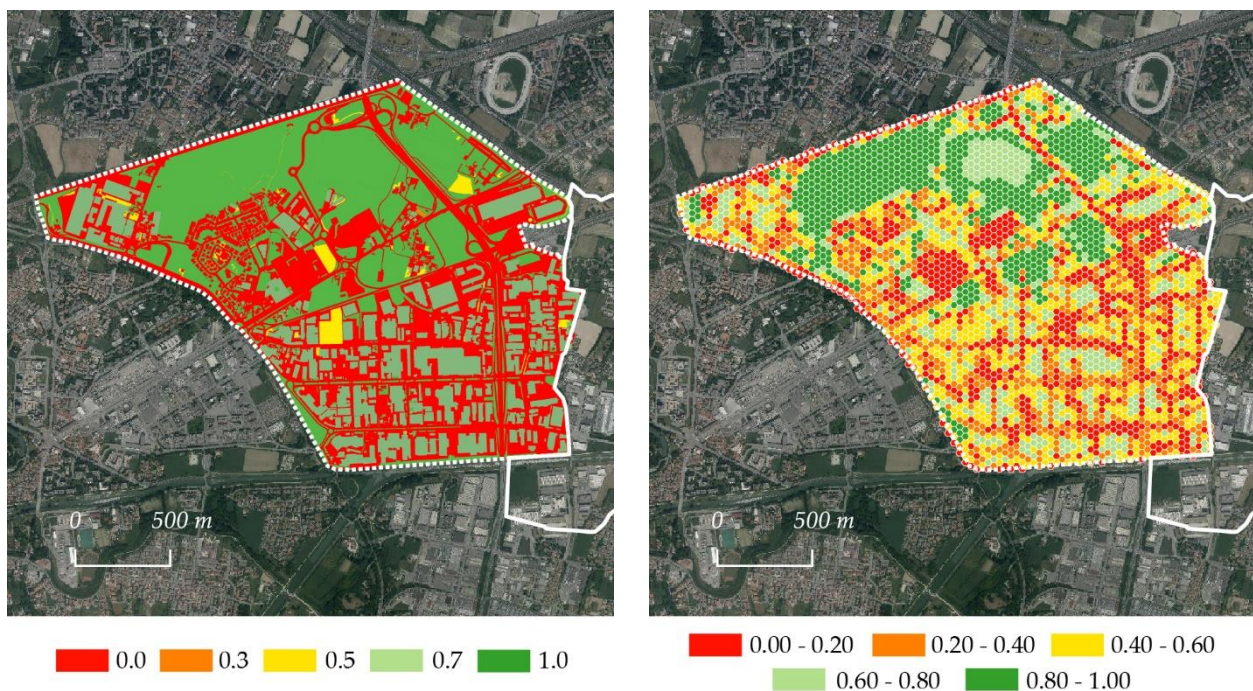


Figure 10. Mitigation scenario in the San Lazzaro neighborhood: rooftop greening. (a) BAF analysis showing different degrees of permeability (from 0 to 1); (b) Hexagon tessellation of the BAF analysis.

3.5. Towards More Sustainable Cities: BAF as Tool for Urban Planning

In light of the EU guidelines on the best practice to limit, mitigate, or compensate soil sealing, this study suggests some elements to support urban soil sealing management, especially in densely built-up areas. In particular, a high-resolution analysis could suggest the implementation of mitigation measures to policymakers and urban planners to achieve a more sustainable urban development. The BAF index is a notable and successful tool to calculate soil sealing at urban scale and to geovisualize the degree of soil permeability (Ahern 2007). A known example is the Municipality of Berlin, which at present, maintains the mandatory use of the BAF index for urban planning within the inner city. Over the last few years, other cities have followed the example of Berlin, for instance, Malmö, Seattle, and Seoul. In Italy, only the city of Bolzano (Alto Adige/Südtirol Autonomous Province) has introduced a similar tool (De Lotto; E. M. Venco 2013). The examples reveal that the application of the BAF index is an important tool in urban planning, not only for the regeneration of buildings, but also for new construction. In fact, it could be a support to reduce sealed surfaces via green areas, green roofs, and permeable surfaces (CRCS 2018). Hence, in the study, the index successfully identified and geovisualized areas and sectors of the neighborhoods of high soil sealing. Moreover, BAF maps with the exact land use features expressing the permeability degree and the hexagon tessellation maps at 1000 m² areal unit represent, together, an important tool for mitigating and compensating soil sealing: the former is useful for specific interventions such as urban greening and hydraulic adjustments, the latter geovisualizes soil sealing and highlights critical hotspots for urban drainage management and important permeable areas to preserve. Hence, the use of BAF

maps in urban planning clearly show in which neighborhoods it is fundamental to act (Becker and Mohren 1990). Moreover, it is important to highlight that a systemic urban strategy for soil sealing management could be more powerful and far-sighted. This means that at all levels of governance, stakeholders should act, taking into account all three measures proposed by the guidelines of the EU Commission. In this context, the Veneto Regional Law 14/2017 may be considered not only as the limitation of soil sealing, but also the adoption of mitigation measures in areas where it is impossible to restore a natural or semi-natural soil. Overall, strategies to contrast soil sealing should achieve the conservation, maintenance, or restoration of ecosystem services related to soil in all sectors of a city.

Finally, it is worth noting that if aerial images at very high resolution are available and updated, BAF analysis from photo-interpretation is a very powerful tool to quantify and monitor soil sealing at a very detailed scale. Hence, it allows for the identification and mapping of soil sealing in critical areas, representing a baseline to achieve and plan local and region-specific solutions to face the issue. However, the photo-interpretation method of extracting land uses features at a very detailed scale is time-consuming, especially for wide areas such as big cities. Moreover, different expert operators are often required for photo-interpretation and features extraction from aerial images. In this case, if land use and/or topographic databases at the municipal scale are available, comparisons with the photo-interpretation of macro sample areas may be used for validation and scaling-up soil sealing analysis at an urban level.

4. Conclusions

Over the last few decades, soil sealing has been recognized as one of the major threats to soil degradation and the ecosystem services that it provides. Although many efforts have been promoted to increase the awareness of stakeholders and citizens for soil conservation, as asserted by the International Year of Soils (2015) and the United Nations within the Sustainable Development Goals framework, the issue of soil sealing is currently scarcely considered. Frequently, the value of soil as non-renewable resource as well as soil-related services in urban ecosystems are not implemented in territory planning and territorial sustainability policies (Naumann et al. 2019). The methodology adopted in this research could provide an insightful case study for enriching the debate about the soil sealing phenomenon and provide scientific support for sustainable urban planning. Indeed, the study provides a relevant example of how significant it is to geovisualize and quantify the amount of soil sealing at a very detailed scale. This was performed using the BAF index in four different neighborhoods of Padua, which has the highest rate of sealing among Italian cities (ISPRA 2019). Moreover, the mitigation simulated scenario of “rooftop greening” shows how it could be interesting to push toward a mitigation approach as an alternative measure in a dense and industrial urban fabric. Indeed, according to the principles of the Municipality of Berlin, roof greening should be taken

into consideration, even considering its costly technological set-up. However, they could be suitable in particularly problematic areas with limited on-site qualification options, for example, industrial areas (Becker and Mohren 1990). The measure proposed has the potential to enhance some of the ecosystem services related to soil, for instance, decreasing the runoff and enhancing the urban microclimate through evapotranspiration (Köhler et al. 2001; Gao et al. 2018). However, it is worth noting that the study does not provide any differences between intensive and extensive green roofs, even if, according to the Urban SMS-Soil Management Strategy, a minimum depth of 10 cm of soil is recommended to achieve benefits in ecosystem services (Siebielec et al. 2010). Further research is necessary to better investigate the equivalent contribution of each solution and to reflect into the BAF index.

The study highlights that there is not one unique solution to steer soil sealing, but there is a need for a strategy that is able to take into account not only the spatial, but also the social and ecological dimensions (Artmann 2015,2016).

In conclusion, this study strengthens the idea that to study the phenomenon of soil sealing locally, it is necessary to work at a very detailed scale. For this reason, the study should be implemented using the BAF index for the whole city of Padua to better understand in which areas it is fundamental to act.

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REFERENCES

- Adams, D. and M. Hardman. 2014. Observing Guerrillas in the Wild: Reinterpreting Practices of Urban Guerrilla Gardening. *Urban Studies*. 51:1103–1119.
- Ahern, J. 2007. Green infrastructure for cities: the spatial dimension. 267–283 *In* V. Novotny and P. Brown, editors. *Cities of the Future: Towards Integrated Sustainable Water and Landscape Management*. IWA Publishing, London, UK.
- Aksoy, E. M. Gregor C. Schröder M. Löhnertz and G. Louwagie. 2017. Assessing and analysing the impact of land take pressures on arable land. *Solid Earth*. 8:683–695.
- Al-Kodmany, K. 2018. The Vertical Farm: A Review of Developments and Implications for the Vertical City. *Buildings*. 8:24.
- Albino, V. U. Berardi and R. M. Dangelico. 2015. Smart Cities: Definitions, Dimensions, Performance, and Initiatives. *Journal of Urban Technology*. 22:3–21.
- Alexandri, E. and P. Jones. 2008. Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates. *Building and Environment*. 43:480–493.
- Allwinkle, S. and P. Cruickshank. 2011. Creating smart-er cities: An overview. *Journal of Urban Technology*. 18:1–16.
- Altieri, M. A. 1995. *Agroecology. The science of sustainable agriculture*. CRC Press, Boca Raton, USA.
- Altieri, M. A. and F. R. F. Funes-Monzote. 2012. The Paradox of Cuban Agriculture. *Monthly Review*. Retrieved from <https://monthlyreview.org/2012/01/01/the-paradox-of-cuban-agriculture/>. Accessed February 2020.
- Altieri, M. A. and C. I. Nicholls. 2019. Urban agroecology. *AgroSur*. 46:46–60.
- Álvarez, D. G. 2017. Cartographic scale and minimum mapping unit influence on LULC modelling. 327–334 *In* L. Ragia, J. G. Rocha, and R. Laurini, editors. *Proceedings of the 3rd International Conference on Geographical Information Systems Theory, Applications and Management - GAMOLCS*. SciTePress, Porto.
- Amato, F. F. Martellozzo G. Nolè and B. Murgante. 2017. Preserving cultural heritage by supporting landscape planning with quantitative predictions of soil consumption. *Journal of Cultural Heritage*. 23:44–54.
- de Amorim, W. S. A. Borchardt Deggau G. do Livramento Gonçalves S. da Silva Neiva A. R. Prasath and J. B. Sagueirinho Osório de Andrade Guerra. 2019. Urban challenges and opportunities to promote sustainable food security through smart cities and the 4th industrial revolution. *Land Use Policy*. 87:104065.
- Andersson-Sköld, Y. J. Klingberg B. Gunnarsson K. Cullinane I. Gustafsson M. Hedblom I. Knez F. Lindberg Å. Ode Sang H. Pleijel P. Thorsson and S. Thorsson. 2018. A framework for assessing urban greenery's effects and valuing its ecosystem services. *Journal of Environmental Management*. 205:274–285.
- Angelidou, M. 2015. Smart cities: A conjuncture of four forces. *Cities*. 47:95–106.
- Aragón-Durand, F. J. Corfee-Morlot R. B. R. Kiunsi M. Pelling D. C. Roberts and W. Solecki. 2014. Urban Areas. 535–612 *In* V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. . Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, N. Levy, S. MacCracken, P. R. Mastrandrea, and L. L. White, editors. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom

and New York, NY, USA.

- Arcidiacono, A. S. Ronchi and S. Salata. 2016. Managing Multiple Ecosystem Services for Landscape Conservation: A Green Infrastructure in Lombardy Region. *Procedia Engineering*. 161:2297–2303.
- Arnold, C. L. and C. J. Gibbons. 1996. Impervious Surface Coverage: The Emergence of a Key Environmental Indicator. *Journal of the American Planning Association*. 62:243–258.
- Artmann, M. 2015. Managing urban soil sealing in Munich and Leipzig (Germany)-From a wicked problem to clumsy solutions. *Land Use Policy*. 46:21–37.
- Artmann, M. 2016. Urban gray vs. urban green vs. soil protection — Development of a systemic solution to soil sealing management on the example of Germany. *Environmental Impact Assessment Review*. 59:27–42.
- Artmann, M. and J. Breuste. 2015. Cities Built for and by Residents: Soil Sealing Management in the Eyes of Urban Dwellers in Germany. *Journal of Urban Planning and Development*. 141:1–13.
- Artmann, M. L. Inostroza and P. Fan. 2019. Urban sprawl, compact urban development and green cities. How much do we know, how much do we agree? *Ecological Indicators*. 96:3–9.
- Artmann, M. and K. Sartison. 2018. The Role of Urban Agriculture as a Nature-Based Solution: A Review for Developing a Systemic Assessment Framework. *Sustainability*. 10:1937.
- Arun, M. and M. Teng Yap. 2000. Singapore : The Development of an Intelligent Island and Social Dividends of Information Technology. *Urban Studies*. 37:1749–1756.
- Asad, M. S. Rashid Ahmad F. Ali R. Mehmoo M. A. Butt and S. Rathore. 2017. Use Of Remote Sensing For Urban Impervious Surfaces: A Case Study Of Lahore . *International Journal of Engineering and Applied Sciences*. 4.
- Atasoy, M. 2018. Monitoring the urban green spaces and landscape fragmentation using remote sensing: a case study in Osmaniye, Turkey. *Environmental Monitoring and Assessment*. 190:1–8.
- Babí Almenar, J. T. Elliot B. Rugani B. Philippe T. Navarrete Gutierrez G. Sonnemann and D. Geneletti. 2021. Nexus between nature-based solutions, ecosystem services and urban challenges. *Land Use Policy*. 100:104898.
- Badiu, D. L. C. I. Iojă M. PĂtroescu J. Breuste M. Artmann M. R. NițĂ S. R. GrĂdinaru C. A. Hossu and D. A. Onose. 2016. Is urban green space per capita a valuable target to achieve cities' sustainability goals? Romania as a case study. *Ecological Indicators*. 70:53–66.
- Bagan, H. and Y. Yamagata. 2014. Land-cover change analysis in 50 global cities by using a combination of Landsat data and analysis of grid cells. *Environmental Research Letters*. 9.
- Ballin, M. G. Barcaroli M. Masselli and M. Scarnó. 2018. Redesign sample for Land Use/Cover Area frame Survey (LUCAS) 2018. Luxembourg. Retrieved from <https://ec.europa.eu/eurostat/documents/3888793/9347564/KS-TC-18-006-EN-N.pdf/26cbdb1a-c418-4dfa-bc24-a27d1bc5599c?t=1540804305000>. Accessed July 2021.
- Baltimore Sun. 2018. Urban Farm Coming to Former Sparrows Point Steel Mill Site in Baltimore County. Retrieved from <http://www.baltimoresun.com/business/bs-md-sparrows-point-farm-20180508-story.html>. Accessed March 2020.
- Bates, J. 2012. “This is what modern deregulation looks like” : co-optation and contestation in the shaping of the UK’s Open Government Data Initiative . Retrieved from <http://www.ci->

journal.net/index.php/ciej/article/view/845/916. Accessed March 2020.

- Becker, G. and R. Mohren. 1990. The Biotope Area Factor as an Ecological Parameter. *Landschaft: Planen & Bauen*, Berlin, Germany.
- Beddington, J. M. Asaduzzaman A. Fernandez M. Clark M. Guillou L. Jahn M. van Erda T. Mamo N. Van Bo C. A. Nobre R. Scholes R. Sharma and J. Wakhungu. 2011. Achieving food security in the face of climate change. Copenhagen. Retrieved from www.ccafs.cgiar.org/commission. Accessed February 2020.
- Behnisch, M. H. Poglitsch and T. Krüger. 2016. Soil sealing and the complex bundle of influential factors: Germany as a case study. *ISPRS International Journal of Geo-Information*. 5:1–23.
- Bian Li Zuo Lei Zhang and Nan. 2019. Estimating 2009–2017 Impervious Surface Change in Gwadar, Pakistan Using the HJ-1A/B Constellation, GF-1/2 Data, and the Random Forest Algorithm. *ISPRS International Journal of Geo-Information*. 8:443.
- Birch, C. P. D. S. P. Oom and J. A. Beecham. 2007. Rectangular and hexagonal grids used for observation, experiment and simulation in ecology. *Ecological Modelling*. 206:347–359.
- Birk, R. J. T. Stanley G. I. Snyder T. A. Hennig M. M. Fladeland and F. Policelli. 2003. Government programs for research and operational uses of commercial remote sensing data. *Remote Sensing of Environment*. 88:3–16.
- Boschetto, P. and A. Schiavon. 2011. The Image of Metropolitan Territory. The Metropolitan City of Padua (in Italian: L'immagine del Territorio Metropolitano. La Città Metropolitana di Padova. (P. Boschetto and A. Schiavon, Eds.). Cleup, Padova, Italy.
- Brown, G. 2004. Mapping Spatial Attributes in Survey Research for Natural Resource Management: Methods and Applications. <http://dx.doi.org/10.1080/08941920590881853>. 18:17–39.
- Brown, K. H. M. Bailkey A. Meares-Choen J. Nasr J. Smit T. Buchanan and Mann Peter. 2003. Urban Agriculture and Community Food Security in the United States: Farming from the City Center to Urban Fring. Retrieved from <https://community-wealth.org/content/urban-agriculture-and-community-food-security-united-states-farming-city-center-urban-fringe>. Accessed February 2020.
- Buccola, N. and G. Spolek. 2011. A Pilot-Scale Evaluation of Greenroof Runoff Retention, Detention, and Quality. *Water, Air, & Soil Pollution*. 216:83–92.
- Burghardt, W. 2006. Soil sealing and soil properties related to sealing. *Geological Society, London, Special Publications*. 266:117–124.
- Bush, J. and A. Doyon. 2019. Building urban resilience with nature-based solutions: How can urban planning contribute? *Cities*. 95:102483.
- Calzolari, C. P. Tarocco N. Lombardo N. Marchi and F. Ungaro. 2020. Assessing soil ecosystem services in urban and peri-urban areas: From urban soils survey to providing support tool for urban planning. *Land Use Policy*. 99:105037.
- Cameron, R. W. F. T. Blanuša J. E. Taylor A. Salisbury A. J. Halstead B. Henricot and K. Thompson. 2012. The domestic garden – Its contribution to urban green infrastructure. *Urban Forestry & Urban Greening*. 11:129–137.
- Cao, S. D. Hu Z. Hu W. Zhao S. Chen and C. Yu. 2018. Comparison of spatial structures of urban agglomerations between the Beijing-Tianjin-Hebei and Boswash based on the subpixel-level impervious surface coverage product. *Journal of Geographical Sciences* 2018 28:3. 28:306–322.

- Caputo, P. F. Zagarella M. A. Cusenza M. Mistretta and M. Cellura. 2020. Energy-environmental assessment of the UIA-OpenAgri case study as urban regeneration project through agriculture. *Science of The Total Environment*. 729:138819.
- Cardullo, P. and R. Kitchin. 2019. Being a 'citizen' in the smart city: up and down the scaffold of smart citizen participation in Dublin, Ireland. *GeoJournal*. 84:1–13.
- Carr, D. B. A. R. Olsen and D. White. 1992. Hexagon Mosaic Maps for Display of Univariate and Bivariate Geographical Data. *Cartography and Geographic Information Systems*. 19:228–236.
- Carvalho, L. 2015. Smart cities from scratch? A socio-technical perspective. *Cambridge Journal of Regions, Economy and Society*. 8:43–60.
- Casella, V. M. Franzini and R. De Lotto. 2016. Geomatics for smart cities: obtaining the urban planning baf index from existing digital maps. 689–694 *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. Prague, Czech Republic.
- Casti, E. 2014. Aree dismesse e obsolete in Lombardia, Rapporto I fase di ricerca del progetto Rifo/It. Bergamo. Retrieved from www.unibg.it/diathesis. Accessed January 2022.
- Ceccarelli, T. S. Bajocco L. Salvati and L. Perini. 2014. Investigating syndromes of agricultural land degradation through past trajectories and future scenarios. *Soil Science and Plant Nutrition*. 60:60–70.
- Cervinka, R. M. Schwab R. Schönbauer I. Hämmerle L. Pirgie and J. Sudkamp. 2016. My garden – my mate? Perceived restorativeness of private gardens and its predictors. *Urban Forestry & Urban Greening*. 16:182–187.
- Chen, Y. and S. Yu. 2016. Assessment of urban growth in Guangzhou using multi-temporal, multi-sensor Landsat data to quantify and map impervious surfaces. *International Journal of Remote Sensing*. 37:5936–5952.
- Choptiany, J. M. B. E. Graeub S. Hatik D. Conversa and S. T. Ledermann. 2019. Participatory Assessment and Adaptation for Resilience to Climate Change. *Consilience*. 21:17–31.
- Clark, C. C. Ordóñez and S. J. Livesley. 2020. Private tree removal, public loss: Valuing and enforcing existing tree protection mechanisms is the key to retaining urban trees on private land. *Landscape and Urban Planning*. 203:103899.
- Climate ADAPT. 2016. Berlin Biotope Area Factor - Implementation of guidelines helping to control temperature and runoff - Climate ADAPT. Retrieved from https://climate-adapt.eea.europa.eu/metadata/case-studies/berlin-biotope-area-factor-2013-implementation-of-guidelines-helping-to-control-temperature-and-runoff/#challenges_anchor. Accessed November 2019.
- Colding, J. 2011. The Role of Ecosystem Services in Contemporary Urban Planning. 228–237 *In* J. Niemelä, J. H. Breuste, T. Elmqvist, G. Guntenspergen, P. James, and N. E. McIntyre, editors. *Urban Ecology: patterns, processes and applications*. Oxford University Press, Oxford, UK.
- Commission, E. 2019. Soil - Soil Sealing. Retrieved from https://ec.europa.eu/environment/soil/sealing_guidelines.htm. Accessed November 2019.
- Commission of the European Communities. 2002. Towards a Thematic Strategy for Soil Protection. CEC, Brussels, Belgium.
- Commission of the European Communities (CEC). 2002. Communication "Towards a Thematic Strategy for Soil Protection" COM(2002) 179 final. Brussels. Retrieved from <https://eur-lex.europa.eu/legal->

content/EN/TXT/PDF/?uri=CELEX:52002DC0179&from=EN. Accessed January 2019.

- Commissione Europea. 2007. Direttiva 2007/2/CE del Parlamento europeo e del Consiglio, del 14 marzo 2007, che istituisce un'Infrastruttura per l'informazione territoriale nella Comunità europea (Inspire). Gazzetta ufficiale dell'Unione Europea.
- Comune di Padova. 2004. Padova, città d'acque. Un modo diverso per conoscere la città. Ufficio Turismo Settore Comunicazioni ai Cittadini, Padova, Italia.
- Comune di Padova. 2014. Territorial Management Plan. Technical Implementation Standards (in Italian: Piano di Assetto del Territorio. Norme Tecniche di Attuazione. Padua, Italy.
- Comune di Padova. 2018. Plan of Interventions. Technical Implementation Standards (in Italian: Piano Degli Interventi. Norme Tecniche di Attuazione. Padua, Italy.
- Comune di Padova. 2019. Padua Bici Masterplan 2018-2022. Relation (in Italian: Bici Masterplan di Padova 2018–2022. Relazione). Padua, Italy.
- Comune di Padova. 2020. 2019 Statistical Yearbook (in Italian: Annuario Statistico 2019). Padova, Italy.
- Congedo, L. L. Sallustio M. Munafò M. Ottaviano D. Tonti and M. Marchetti. 2016. Copernicus high-resolution layers for land cover classification in Italy. *Journal of Maps*. 12:1195–1205.
- Contesse, M. B. J. M. van Vliet and J. Lenhart. 2018. Is urban agriculture urban green space? A comparison of policy arrangements for urban green space and urban agriculture in Santiago de Chile. *Land Use Policy*. 71:566–577.
- Cortijo, A. A. and M. E. P. González. 2017. Soil sealing in Madrid (Spain), study case of Colmenar Viejo. *Earth Sciences Research Journal*. 21:111–116.
- Cortinovis, C. and D. Geneletti. 2019. A framework to explore the effects of urban planning decisions on regulating ecosystem services in cities. *Ecosystem Services*. 38:100946.
- Coseo, P. and L. Larsen. 2019. Accurate Characterization of Land Cover in Urban Environments: Determining the Importance of Including Obscured Impervious Surfaces in Urban Heat Island Models. *Atmosphere* 2019, Vol. 10, Page 347. 10:347.
- CRCS. 2018. CRCS 2018: consumo di suolo, servizi ecosistemici e green infrastructures. (A. Arcidiacono, D. Di Simine, S. Ronchi, and S. Salata, Eds.). INU Edizioni, Roma, Italia.
- Crescini Di Montevecchio Benedetti, E. 2018. Consumo di suolo a Padova: analisi GIS del quartiere Forcellini (PD) e calcolo dell'indice Biotope Area Factor. Università degli Studi di Padova.
- Czemieli Berndtsson, J. 2010, April. Green roof performance towards management of runoff water quantity and quality: A review.
- Davies, C. and R. Laforteza. 2019. Transitional path to the adoption of nature-based solutions. *Land Use Policy*. 80:406–409.
- Decoville, A. and M. Schneider. 2016. Can the 2050 zero land take objective of the EU be reliably monitored? A comparative study. *Journal of Land Use Science*. 11:331–349.
- Department of Economic and Social Affairs of United Nations. 2015. Goal 11 . Retrieved from <https://sdgs.un.org/goals/goal11>. Accessed October 2021.
- Despommier, D. and E. Ellingsen. 2008. The Vertical Farm: The sky-scraper as vehicle for a sustainable urban agriculture. In A. Wood, editor. CTBUH 8th World Congress 2008. Dubai, United Arab Emirates.
- Dewaelheyns, V. E. Rogge and H. Gulinck. 2014. Putting domestic gardens on the agenda using empirical

- spatial data: The case of Flanders. *Applied Geography*. 50:132–143.
- Dobermann, A. B. S. Backmore S. E. Cook and V. Adamchuk. 2004. Precision farming: Challenges and future directions. *In* T. Fischer, N. Turner, J. Angus, L. McIntyre, M. Robertson, A. Borrell, and D. Lloyd, editors. *Proceedings of the 4th International Crop Science Congress*. Brisbane, Australia.
- Duru, M. O. Therond and M. Fares. 2015. Designing agroecological transitions; A review. *Agronomy for Sustainable Development*. 35:1237–1257.
- Eigenbrod, F. V. A. Bell H. N. Davies A. Heinemeyer P. R. Armsworth and K. J. Gaston. 2011. The impact of projected increases in urbanization on ecosystem services. 3201–3208 *In* M. P. Hassell, S. H. Alonzo, G. R. Carvalho, I. C. Cuthill, H. A. P. Heesterbee, and M. T. Siva-Jothy, editors. *Proc. R. Soc. B. London, UK*.
- Elvidge, C. D. B. T. Tuttle P. S. Sutton K. E. Baugh A. T. Howard C. Milesi B. L. Bhaduri and R. Nemani. 2007. Global Distribution and Density of Constructed Impervious Surfaces. *Sensors (Basel, Switzerland)*. 7:1962.
- Estellés Arolas, E. and F. González Ladrón-de-Guevara. 2012. Towards an integrating crowdsourcing definition. *Journal of Information Science* . 32:189–200.
- EU Commission. 2016. Mapping and Assessment of Ecosystems and their Services Urban ecosystems 4th Report Final. Retrieved from <http://ec.europa.eu>. Accessed November 2019.
- EU Parliament and EU Council. 2013. General Union Environment Action Programme to 2020 ‘Living well, within the limits of our planet.’ 171–200.
- European Commission. 2011. Roadmap to a Resource Efficient Europe. Communication from the Commission to the European Parliament, the Council, the European economic and social committee and the committee of the regions. Brussels. Retrieved from <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0571&from=EN>. Accessed April 2019.
- European Commission. 2012a. Soil Sealing. *Science for Environment Policy*.:1–41.
- European Commission. 2012b. Guidelines on best practice to limit, soil sealing mitigate or compensate. EC, Belgium.
- European Commission. 2020. Mapping Guide v6.2 for a European Urban Atlas Regional Policy. Retrieved from http://www.stadtentwicklung.berlin.de/umwelt/umweltatlas/ed610_03.htm. Accessed October 2021.
- European Environment Agency. 2016. The direct and indirect impacts of EU policies on land. Luxembourg. Retrieved from <https://www.eea.europa.eu/publications/impacts-of-eu-policies-on-land>. Accessed October 2021.
- European Environment Agency. 2018. Copernicus Land Monitoring Service – High Resolution Layer Imperviousness. Copernicus team at EEA. Retrieved from <https://land.copernicus.eu/user-corner/technical-library/hrl-imperviousness-technical-document-prod-2015>. Accessed January 2019.
- European Parliament. 2014. Precision agriculture: an opportunity for EU farmers - potential support with the CAP 2014-2020. Retrieved from https://www.europarl.europa.eu/thinktank/it/document.html?reference=IPOL-AGRI_NT%282014%29529049. Accessed February 2020.
- Fadini, U. 2013. Walls of Padua. A guide to the Renaissance Fortification System (in Italian: Mura di Padova. Guida al Sistema Bastionato Rinascimentale. (U. Fadini, Ed.). Edibus, Vicenza, Italy.

- Faivre, N. M. Fritz T. Freitas B. de Boissezon and S. Vandewoestijne. 2017. Nature-Based Solutions in the EU: Innovating with nature to address social, economic and environmental challenges. *Environmental Research*. 159:509–518.
- FAO. 2015. Status of the World's Soil Resources: Main Report. Retrieved from <http://www.fao.org/documents/card/en/c/c6814873-efc3-41db-b7d3-2081a10ede50/>. Accessed February 2020.
- FAO Food and Agriculture Organization of the United Nations. 2010. Fighting Poverty and Hunger. What Role for Urban Agriculture? Retrieved from www.fao.org/fcit. Accessed March 2021.
- FAO Food and Agriculture Organization of the United Nations. 2018a. RIMA | Resilience Index Measurement and Analysis (RIMA). Retrieved from <http://www.fao.org/resilience/background/tools/rima/en/>. Accessed March 2020.
- FAO Food and Agriculture Organization of the United Nations. 2018b. Self-evaluation and Holistic Assessment of climate Resilience of farmers and Pastoralists (SHARP) | Food and Agriculture Organization of the United Nations.
- Feltynowski, M. and J. Kronenberg. 2020. Urban Green Spaces—An Underestimated Resource in Third-Tier Towns in Poland. *Land* 2020, Vol. 9, Page 453. 9:453.
- Feng, D. Y. Zhao L. Yu C. Li J. Wang N. Clinton Y. Bai A. Belward Z. Zhu and P. Gong. 2016. Circa 2014 African land-cover maps compatible with FROM-GLC and GLC2000 classification schemes based on multi-seasonal Landsat data. <http://dx.doi.org/10.1080/01431161.2016.1218090>. 37:4648–4664.
- Fernandez, M. 2017. Urban Agriculture in Cuba: 30 years of policy and practice. *Urban Agroecology*. Retrieved from <https://ruaf.org/document/urban-agriculture-magazine-no-33-urban-agroecology/>. Accessed.
- Fini, A. P. Frangi J. Mori D. Donzelli and F. Ferrini. 2017. Nature based solutions to mitigate soil sealing in urban areas: Results from a 4-year study comparing permeable, porous, and impermeable pavements. *Environmental Research*. 156:443–454.
- Food Tank. 2016. Twelve Organizations Promoting Urban Agriculture around the World. Retrieved from <http://www.fao.org/family-farming/detail/en/c/461898/>. Accessed February 2020.
- Fouilleux, E. N. Bricas and A. Alpha. 2017. 'Feeding 9 billion people': global food security debates and the productionist trap. *Journal of European Public Policy*. 24:1658–1677.
- Franke, J. D. A. Roberts K. Halligan and G. Menz. 2009. Hierarchical Multiple Endmember Spectral Mixture Analysis (MESMA) of hyperspectral imagery for urban environments. *Remote Sensing of Environment*. 113:1712–1723.
- Franklin, J. J. Rogan S. R. Phinn and C. E. Woodcock. 2003. Rationale and Conceptual Framework for Classification Approaches to Assess Forest Resources and Properties. 279–300 *In* M. A. Wulder and S. E. Franklin, editors. *Remote Sensing of Forest Environments*. Springer, Boston.
- Frew, T. D. Baker and P. Donehue. 2016. Performance based planning in Queensland: A case of unintended plan-making outcomes. *Land Use Policy*. 50:239–251.
- Frew, T. G. 2011. The implementation of performance based planning in Queensland under the integrated planning act 1997: an evaluation of perceptions and planning schemes. Queensland University of Technology.
- Fu, Y. J. Li Q. Weng Q. Zheng L. Li S. Dai and B. Guo. 2019. Characterizing the spatial pattern of annual

- urban growth by using time series Landsat imagery. *Science of The Total Environment*. 666:274–284.
- Gabrys, J. 2014. Programming environments: environmentality and citizen sensing in the smart city. *Environment and Planning D: Society and Space*. 32:30–48.
- Gao, Y. D. Wang A. Schmidt and Y. Tang. 2018. Exploring the Response of Combined Urban Sewer System to the Implementation of Green Roof. 1–7 4th International Conference on Environmental Systems Research. IOP Publishing Ltd.
- García, P. and E. Pérez. 2016. Mapping of soil sealing by vegetation indexes and built-up index: A case study in Madrid (Spain). *Geoderma*. 268:100–107.
- Gardi, C. 2017a. Impact of land take on global food security. 146–156 *In* C. Gardi, editor. *Urban Expansion, Land Cover and Soil Ecosystem Services*. Routledge.
- Gardi, C. 2017b. *Urban Expansion, Land Cover and Soil Ecosystem Services*. (C. Gardi, Ed.) Urban Expansion, Land Cover and Soil Ecosystem Services. 1st ed. Routledge, New York, USA.
- Gebbers, R. and V. I. Adamchuk. 2010. Precision agriculture and food security. *Science*. 327:828–831.
- Giachino, C. G. Pattanaro B. Bertoldi L. Bollani and A. Bonadonna. 2021. Nature-based solutions and their potential to attract the young generations. *Land Use Policy*. 101:105176.
- Glavan, M. U. Schmutz S. Williams S. Corsi F. Monaco M. Kneafsey P. A. Guzman Rodriguez M. Čenič-Istenič and M. Pintar. 2018. The economic performance of urban gardening in three European cities – examples from Ljubljana, Milan and London. *Urban Forestry & Urban Greening*. 36:100–122.
- Gliessman, S. R. 2015. *Agroecology: The Ecology of Sustainable Food Systems*. CRC Press, Boca Raton, USA.
- Goldblatt, R. M. F. Stuhmacher B. Tellman N. Clinton G. Hanson M. Georgescu C. Wang F. Serrano-Candela A. K. Khandelwal W. H. Cheng and R. C. Balling Jr. 2018. Using Landsat and nighttime lights for supervised pixel-based image classification of urban land cover. *Remote Sensing of Environment*. 205:253–275.
- Gomes, V. C. F. G. R. Queiroz and K. R. Ferreira. 2020. An Overview of Platforms for Big Earth Observation Data Management and Analysis. *Remote Sensing 2020*, Vol. 12, Page 1253. 12:1253.
- Gómez-Baggethun, E. and D. N. Barton. 2013. Classifying and valuing ecosystem services for urban planning. *Ecological Economics*. 86:235–245.
- Gong, P. X. Li and W. Zhang. 2019. 40-Year (1978–2017) human settlement changes in China reflected by impervious surfaces from satellite remote sensing. *Science Bulletin*. 64:756–763.
- Goodchild, M. F. 2007. Citizens as sensors: the world of volunteered geography. *GeoJournal*. 69:211–221.
- Goucher, L. R. Bruce D. D. Cameron S. C. Lenny Koh and P. Horton. 2017. The environmental impact of fertilizer embodied in a wheat-to-bread supply chain. *Nature Plants*. 3:1–5.
- Grewal, S. S. and P. S. Grewal. 2012. Can cities become self-reliant in food? *Cities*. 29:1–11.
- Griffin, T. W. and J. Lowenberg-Deboer. 2005. Worldwide adoption and profitability of precision agriculture Implications for Brazil. Retrieved from <http://www.ers.usda.gov/Briefing/ARMS/>. Accessed February 2020.
- Gu, C. L. Wu and I. Cook. 2012. Progress in research on Chinese urbanization. *Frontiers of Architectural Research*. 1:101–149.
- Gullino, G. 2009. *Storia di Padova. Dall'antichità all'età contemporanea*. (G. Gullino, Ed.). Cierre Edizioni,

Verona.

- Güneralp, B. M. Reba B. U. Hales E. A. Wentz and K. C. Seto. 2020. Trends in urban land expansion, density, and land transitions from 1970 to 2010: A global synthesis. *Environmental Research Letters*. 15:044015.
- Guthman, J. 2004. *Agrarian Dreams: The Paradox of Organic Farming in California*. Geographical Review of Japan, Series A. University of California Press, Oakland, USA.
- Haines-Young, R. and M. Potschin. 2013. Common International Classification of Ecosystem Services (CICES): Consultation on Version 4, August-December 2012. Copenhagen, Denmark. Retrieved from https://cices.eu/content/uploads/sites/8/2012/07/CICES-V43_Revised-Final_Report_29012013.pdf. Accessed January 2022.
- Haklay, M. 2016. Why is participation inequality important? . 35–44 *In* C. Capineri, M. Haklay, H. Huang, V. Antoniou, J. . Kettunen, F. . Ostermann, and R. Purves, editors. *European Handbook of Crowdsourced Geographic Information*. Ubiquity Press, Londra.
- Hartcher, M. G. and R. K. Chowdhury. 2017. An alternative method for estimating total impervious area in catchments using high-resolution colour aerial photography. *Water Practice and Technology*. 12:478–486.
- Hatan, S. A. Fleischer and A. Tchetchik. 2021. Economic valuation of cultural ecosystem services: The case of landscape aesthetics in the agritourism market. *Ecological Economics*. 184:107005.
- Heitlinger, S. N. Bryan-Kinns and R. Comber. 2019. The right to the sustainable smart city. 1–13 *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. Glasgow, UK.
- Hendrickson, M. K. and M. Porth. 2012. *Urban Agriculture-Best Practices and Possibilities*. Retrieved from <http://extension.missouri.edu/foodsystems/urbanagriculture.aspx>,. Accessed March 2021.
- Hill, D. 2013. On the smart city. Or, a ‘manifesto’ for smart citizens instead. Retrieved from <https://medium.com/butwhatwasthequestion/on-the-smart-city-or-a-manifesto-for-smart-citizens-instead-7e0c6425f909>. Accessed March 2020.
- Hollands, R. G. 2008. Will the real smart city please stand up? *City*. 12:303–320.
- Holt-Giménez, E. and M. A. Altieri. 2013. Agroecology, food sovereignty, and the new green revolution. *Agroecology and Sustainable Food Systems*. 37:90–102.
- Horton, P. 2017. We need radical change in how we produce and consume food. *Food Security*. 9:1323–1327.
- Huete, A. R. 1988. A soil-adjusted vegetation index (SAVI). *Remote Sensing of Environment*. 25:295–309.
- Hung, C.-L. J. L. A. James and M. E. Hodgson. 2018. An automated algorithm for mapping building impervious areas from airborne LiDAR point-cloud data for flood hydrology. *GIScience & Remote Sensing*. 55:793–816.
- Im, J. Z. Lu J. Rhee and L. J. Quackenbush. 2012. Impervious surface quantification using a synthesis of artificial immune networks and decision/regression trees from multi-sensor data. *Remote Sensing of Environment*. 117:102–113.
- Ingegnoli, V. 2015. *Landscape Bionomics Biological-Integrated Landscape Ecology*. Springer, Milan, Italy.
- IPCC. 2021. *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Retrieved from https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf. Accessed October 2021.

- ISPRA. 2017. Consumo di suolo, dinamiche territoriali e servizi ecosistemici - Edizione 2016. Roma.
- ISPRA. 2018. Consumo di suolo, dinamiche territoriali e servizi ecosistemici. Edizione 2018. (M. Munafò, Ed.). 1st ed. ISPRA, Roma, Italia.
- ISPRA. 2019. Consumo di suolo. Dinamiche territoriali e servizi ecosistemici. Edizione 2019. (M. Michele, Ed.). 1st ed. ISPRA, Roma, Italia.
- ISPRA. 2020. Consumo di suolo, dinamiche territoriali e servizi ecosistemici. Edizione 2020. (M. Munafó, Ed.). Roma.
- ISPRA. 2021. Consumo di suolo, dinamiche territoriali e servizi ecosistemici Edizione 2021 Rapporto ISPRA SNPA. Roma.
- ISTAT. 2019. ASC - Atlante Statistico dei Comuni. Retrieved from http://asc.istat.it/asc_BL/. Accessed November 2019.
- Jennings, D. B. S. T. Jarnagin and D. W. Ebert. 2004. A modeling approach for estimating watershed impervious surface area from national land cover data 92. *Photogrammetric Engineering & Remote Sensing*. 70:1295–1307.
- Jensen, J. R. and D. C. Cowen. 1999. Remote Sensing of Urban/Suburban Infrastructure and Socio-Economic Attributes*. *Photogrammetric Engineering & Remote Sensing*. 65:611–622.
- Kabisch, N. M. Strohbach D. Haase and J. Kronenberg. 2016. Urban green space availability in European cities. *Ecological Indicators*. 70:586–596.
- Kago, J. S. Loose and R. Sietchiping. 2019. Implementing the New Urban Agenda: Urban and Territorial Integration Approaches in Support of Urban Food Systems. 27–293 *In* H. Ginzky, E. Dooley, I. L. Heuser, E. Kasimbazi, T. Markus, and T. Qin, editors. *International Yearbook of Soil Law and Policy 2018*. Springer, Cham, Switzerland.
- Karimi, A. H. Yazdandad and N. Fagerholm. 2020. Evaluating social perceptions of ecosystem services, biodiversity, and land management: Trade-offs, synergies and implications for landscape planning and management. *Ecosystem Services*. 45:101188.
- Keeley, M. 2011. The Green Area Ratio: an urban site sustainability metric. *Journal of Environmental Planning and Management*. 54:937–958.
- Kendig, L. 1980. *Performance zoning*. Planners Press American Planning Association, Washington D.C.
- Kennard, N. J. and R. H. Bamford. 2020. Urban Agriculture: Opportunities and Challenges for Sustainable Development. 1–14 *In* W. Leal Filho, A. Azul, L. Brandli, P. Özuyar, and T. Wall, editors. *Zero Hunger. Encyclopedia of the UN Sustainable Development Goals*. Springer, Cham, Switzerland.
- Koch, A. A. McBratney M. Adams D. Field R. Hill J. Crawford B. Minasny R. Lal L. Abbott A. O'Donnell D. Angers J. Baldock E. Barbier D. Binkley W. Parton D. H. Wall M. Bird J. Bouma C. Chenu C. B. Flora K. Goulding S. Grunwald J. Hempel J. Jastrow J. Lehmann K. Lorenz C. L. Morgan C. W. Rice D. Whitehead I. Young and M. Zimmermann. 2013. Soil Security: Solving the Global Soil Crisis. *Global Policy*. 4:434–441.
- Köhler, M. M. Schmidt F. W. Grimme M. Laar and F. Gusmão. 2001. Urban water retention by greened roofs in temperate and tropical climate. 151–162 38th IFLA World Congress (International Federation of Landscape Architects). Singapore.
- Kuang, W. 2019. Mapping global impervious surface area and green space within urban environments.

- Science China Earth Sciences 2019 62:10. 62:1591–1606.
- Lakes, T. and H. O. Kim. 2012. The urban environmental indicator “biotope Area Ratio” - An enhanced approach to assess and manage the urban ecosystem services using high resolution remote-sensing. *Ecological Indicators*. 13:93–103.
- Lam, S. T. and T. M. Conway. 2018. Ecosystem services in urban land use planning policies: A case study of Ontario municipalities. *Land Use Policy*. 77:641–651.
- Langella, G. A. Basile S. Giannecchini F. D. Moccia F. A. Mileti M. Munafó F. Pinto and F. Terribile. 2020. Soil Monitor: an internet platform to challenge soil sealing in Italy. *Land Degradation & Development*. 31:2883–2900.
- Li, J. Y. Wang Z. Ni S. Chen and B. Xia. 2020. An integrated strategy to improve the microclimate regulation of green-blue-grey infrastructures in specific urban forms. *Journal of Cleaner Production*. 271:122555.
- Li, W. and C. Wu. 2015. A geostatistical temporal mixture analysis approach to address endmember variability for estimating regional impervious surface distributions. *GIScience & Remote Sensing*. 53:102–121.
- Liang, S. and J. Wang. 2019. *Advanced remote sensing: terrestrial information extraction and applications*. (S. Liang and J. Wang, Eds.).
- Lillesand, T. M. and R. W. Kiefer. 1994. *Remote sensing and image interpretation*. 3rd Edition. Wiley & Sons.
- Lin, Y. H. Zhang G. Li T. Wang L. Wan and H. Lin. 2019. Improving Impervious Surface Extraction with Shadow-Based Sparse Representation from Optical, SAR, and LiDAR Data. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*. 12:2417–2428.
- Liu, O. Y. and A. Russo. 2021. Assessing the contribution of urban green spaces in green infrastructure strategy planning for urban ecosystem conditions and services. *Sustainable Cities and Society*. 68:102772.
- Lotter, D. W. 2003. Organic agriculture. *J. Sustain. Agric.* 21:59–128.
- De Lotto; E. M. Venco. 2013. Efficacia e attuabilità di indici ecologico ambientali nella pratica urbanistica. *In* F. Sbetti, F. Rossi, M. Talia, and C. Trillo, editors. *XXVIII Congresso dell'INU: Il governo della città nella contemporaneità. La città come motore di sviluppo*. INU Edizioni, Salerno, Italia.
- De Lotto, R. V. Casella M. Franzini V. Gazzola C. Morelli di Popolo S. Sturla and E. M. Venco. 2015. Estimating the Biotope Area Factor (BAF) by Means of Existing Digital Maps and GIS Technology. 617–632 *In* O. Gervasi, B. Murgante, S. Misra, M. L. Gavriloca, A. M. Alves Coutinho Rocha, C. Torre, D. Taniar, and B. O. Apduhan, editors. *Computational Science and Its Applications – ICCSA 2015*. Springer International Publishing AG Switzerland, Basel, Switzerland.
- Lozano, A. V. C. A. Vidal and J. S. Díaz. 2019. Urban growth (1956-2012) and soil sealing in the metropolitan area of Valencia (Eastern Spain). *Spanish Journal of Soil Science*. 9:88–104.
- Lu, D. E. Moran and S. Hetrick. 2011. Detection of impervious surface change with multitemporal Landsat images in an urban–rural frontier. *ISPRS Journal of Photogrammetry and Remote Sensing*. 66:298–306.
- Lu, D. and Q. Weng. 2006. Use of impervious surface in urban land-use classification. *Remote Sensing of Environment*. 102:146–160.
- Ma, Q. C. He and J. Wu. 2016. Behind the rapid expansion of urban impervious surfaces in China: Major influencing factors revealed by a hierarchical multiscale analysis. *Land Use Policy*. 59:434–445.
- MADRE. 2018. *Urban and Peri-Urban Agriculture. Best practice catalogue*. Retrieved from

- https://anima.coop/sites/default/files/madre_catalogue_web_light.pdf. Accessed.
- Maes, J. G. Zulian S. Guenther M. Thijssen and J. Raynal. 2019. Enhancing Resilience Of Urban Ecosystems through Green Infrastructure (EnRoute). Luxembourg. Retrieved from <https://publications.jrc.ec.europa.eu/repository/handle/JRC115375>. Accessed.
- Marquard, E. S. Bartke J. Gifreu i Font A. Humer A. Jonkman E. Jürgenson N. Marot L. Poelmans B. Repe R. Rybski C. Schröter-Schlaack J. Sobocká M. Tophøj Sørensen E. Vejchodská A. Yiannakou and J. Bovet. 2020. Land Consumption and Land Take: Enhancing Conceptual Clarity for Evaluating Spatial Governance in the EU Context. *Sustainability*. 12:8269.
- Martellozzo, F. J. S. Landry D. Plouffe V. Seufert P. Rowhani and N. Ramankutty. 2014. Urban agriculture: A global analysis of the space constraint to meet urban vegetable demand. *Environmental Research Letters*. 9:064025 (8pp).
- Marzari, S. 2008a. Padova e la città metropolitana. 1807-2007 la metamorfosi del paesaggio urbano. (S. Marzari, Ed.). I Antichi Editori, Venezia, Italia.
- Marzari, S. 2008b. Padua and Metropolitan City. 1807-2007 Metamorphosis of the Urban Landscape (in Italian: Padova e la Città Metropolitana. 1807-2007 la Metamorfosi del Paesaggio Urbano. (S. Marzari, Ed.). I Antichi Editori Venezia, Venezia, Italy.
- Masek, J. G. M. A. Wulder B. Markham J. McCorkel C. J. Crawford J. Storey and D. T. Jenstrom. 2020. Landsat 9: Empowering open science and applications through continuity. *Remote Sensing of Environment*. 248:111968.
- Maxwell, D. C. Levin and J. Csete. 1998. Does urban agriculture help prevent malnutrition? Evidence from Kampala. *Food Policy*. 23:411-424.
- Maye, D. 2019. 'Smart food city': Conceptual relations between smart city planning, urban food systems and innovation theory. *City, Culture and Society*. 16:18-24.
- Milan Urban Food Policy Pact. 2015. Milan Urban Food Policy Pact. Retrieved from <https://www.milanurbanfoodpolicypact.org/the-milan-pact/>. Accessed March 2020.
- Mimet, A. C. Kerbirou L. Simon J. F. Julien and R. Raymond. 2020. Contribution of private gardens to habitat availability, connectivity and conservation of the common pipistrelle in Paris. *Landscape and Urban Planning*. 193:103671.
- Misra, M. D. Kumar and S. Shekhar. 2020. Assessing Machine Learning Based Supervised Classifiers For Built-Up Impervious Surface Area Extraction From Sentinel-2 Images. *Urban Forestry & Urban Greening*. 53:126714.
- Mok, H. F. V. G. Williamson J. R. Grove K. Burry S. F. Barker and A. J. Hamilton. 2014. Strawberry fields forever? Urban agriculture in developed countries: A review. *Agronomy for Sustainable Development*. 34:21-43.
- Montgomery, D. R. 2012. *Dirt: the erosion of civilizations*. University of California Press.
- Moreno, A. A. Bhattacharyya L. Jansen Y. Arkeman R. Hartanto and M. Kleinke. 2019. Environmental engineering and sustainability for smart agriculture: The application of UAV-based remote sensing to detect biodiversity in oil palm plantations. 012008 *In* A. G. Niam, I. Yusliana, and H. Imantho, editors. International Conference on Digital Agriculture from Land to Consumers. Bogor, Indonesia.
- Mougeot, L. J. A. 2000. *Urban Agriculture: Definition, Presence, Potentials and Risks, and Policy Challenges*

- Cities Feeding People Series. Retrieved from <http://www.idrc.ca/cfp>. Accessed February 2020.
- Moustier, P. and G. Danso. 2006. Local Economic Development and Marketing of Urban Produced Food. 174–195 *In* R. van Veenhuizen, editor. *Cities Farming for the Future: Urban Agriculture for Green and Productive Cities*. RUAF Foundation, IDRC and IIRR, Philippines.
- Mullins, P. D. 2017. The ubiquitous-eco-city of Songdo: An urban systems perspective on South Korea's Green city approach. *Urban Planning*. 2:4–12.
- Munafò, M. C. Norero A. Sabbi and L. Salvati. 2010. Soil sealing in the growing city: A survey in Rome, Italy. *Scottish Geographical Journal*. 126:153–161.
- Murata, T. and N. Kawai. 2018. Degradation of the urban ecosystem function due to soil sealing: involvement in the heat island phenomenon and hydrologic cycle in the Tokyo metropolitan area. <https://doi.org/10.1080/00380768.2018.1439342>. 64:145–155.
- Naumann, S. A. Frelih-Larsen G. Prokop S. Ittner M. Reed J. Mills F. Morari S. Verzandvoort, Simone Albrecht A. Bjuréus G. Siebielec and T. Miturski. 2019. Land Take and Soil Sealing—Drivers, Trends and Policy (Legal) Instruments: Insights from European Cities. 84–112 *International Yearbook of Soil Law and Policy 2018*.
- Nin, M. A. Soutullo L. Rodríguez-Gallego and E. Di Minin. 2016. Ecosystem services-based land planning for environmental impact avoidance. *Ecosystem Services*. 17:172–184.
- Norton, G. W. and S. M. Swinton. 2000. Precision Agriculture: Global Prospects and Environmental Implications. *Proceedings of the 24th International Conference of Agricultural Economists*:269–286.
- Norton, J. 2019. *Information Systems for Grassroots Sustainable Agriculture*. PhD Thesis. University of California, Irvine, USA.
- Norton, J. B. J. Pan S. Nayeabaziz B. Tomlinson and S. Burke. 2014. Plant guild composer: An interactive online system to support back yard food production. 523–526 *Conference on Human Factors in Computing Systems - Proceedings*. Association for Computing Machinery, New York, USA.
- Norton, J. B. Tomlinson B. Penzenstadler S. McDonald E. Kang N. Koirala R. Konishi G. P. Carmona J. Shah and S. Troncoso. 2019. The SAGE Community Coordinator: A Demonstration. 1–10 *In* S. Easterbrook, editor. *Proceedings of the Fifth Workshop on Computing within Limits*. Association for Computing Machinery, Lappeenranta, Finland.
- Nowak, D. J. and E. J. Greenfield. 2020. The increase of impervious cover and decrease of tree cover within urban areas globally (2012–2017). *Urban Forestry and Urban Greening*. 49:126638.
- Oberndorfer, E. J. Lundholm B. Bass R. R. Coffman H. Doshi N. Dunnett S. Gaffin M. Köhler K. K. Y. Liu and B. Rowe. 2007. Green Roofs as Urban Ecosystems: Ecological Structures, Functions, and Services. *BioScience*. 57:823–833.
- Van Oijstaeijen, W. S. Van Passel and J. Cools. 2020. Urban green infrastructure: A review on valuation toolkits from an urban planning perspective. *Journal of Environmental Management*. 267:110603.
- Opolot, E. Y. Y. Yu and P. A. Finke. 2015. Modeling soil genesis at pedon and landscape scales: Achievements and problems. *Quaternary International*. 376:34–46.
- Orsini, F. R. Kahane R. Nono-Womdim and G. Gianquinto. 2013. Urban agriculture in the developing world: A review. *Agronomy for Sustainable Development*. 33:695–720.
- Pafi, M. A. Siragusa S. Ferri and S. Halkia. 2016. *Measuring the Accessibility of Urban Green Areas: A*

- comparison of the Green ESM with other datasets in four European cities. Luxembourg (Luxembourg). Retrieved from <http://publications.jrc.ec.europa.eu/repository/handle/JRC102525>. Accessed January 2022.
- Paleari, S. 2017. Is the European Union protecting soil? A critical analysis of Community environmental policy and law. *Land Use Policy*. 64:163–173.
- Paskaleva, K. A. 2011. The smart city: A nexus for open innovation? *Intelligent Buildings International*. 3:153–171.
- Pearsall, H. and J. K. Eller. 2020. Locating the green space paradox: A study of gentrification and public green space accessibility in Philadelphia, Pennsylvania. *Landscape and Urban Planning*. 195:103708.
- Pearson, L. J. L. Pearson and C. J. Pearson. 2010. Sustainable urban agriculture: Stocktake and opportunities. *International Journal of Agricultural Sustainability*. 8:7–19.
- Peroni, F. G. Pristeri D. Codato S. E. Pappalardo and M. De Marchi. 2019. Biotope Area Factor: An Ecological Urban Index to Geovisualize Soil Sealing in Padua, Italy. *Sustainability 2020*, Vol. 12, Page 150. 12:150.
- Phinn, S. M. Stanford P. Scarth A. T. Murray and P. T. Shyy. 2002. Monitoring the composition of urban environments based on the vegetation-impervious surface-soil (VIS) model by subpixel analysis techniques. *International Journal of Remote Sensing*. 23:4131–4153.
- Pistocchi, A. C. Calzolari F. Malucelli and F. Ungaro. 2015. Soil sealing and flood risks in the plains of Emilia-Romagna, Italy. *Journal of Hydrology: Regional Studies*. 4:398–409.
- Poulsen, M. N. 2017. Cultivating citizenship, equity, and social inclusion? Putting civic agriculture into practice through urban farming. *Agriculture and Human Values*. 34:135–148.
- Pretty, J. N. A. D. Noble D. Bossio J. Dixon R. E. Hine F. W. T. P. De Vries and J. I. L. Morison. 2006. Resource-conserving agriculture increases yields in developing countries. *Environmental Science and Technology*. 40:1114–1119.
- Pristeri, G. F. Peroni S. E. Pappalardo D. Codato A. G. Castaldo A. Masi and M. De Marchi. 2020. Mapping and Assessing Soil Sealing in Padua Municipality through Biotope Area Factor Index. *Sustainability 2020*, Vol. 12, Page 5167. 12:5167.
- Prokop, G. H. Jobstmann and A. Schönbauer. 2011. Report on best practices for limiting soil sealing and mitigating its effects. European Commission.
- Quattrocchi, D. A. and M. F. Goodchild. 1997. *Scale in Remote Sensing and GIS*. (D. A. Quattrocchi and M. F. Goodchild, Eds.). CRC Press.
- Radočaj, D. J. Obhodaš M. Jurišić and M. Gašparović. 2020. Global Open Data Remote Sensing Satellite Missions for Land Monitoring and Conservation: A Review. *Land 2020*, Vol. 9, Page 402. 9:402.
- Raghavan, B. B. Nardi S. T. Lovell J. Norton B. Tomlinson and D. J. Patterson. 2016. Computational Agroecology. 423–435 *In* J. Kaye and A. Druin, editors. *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. ACM Press, San Jose, USA.
- Regione del Veneto. 2004. Legge regionale 23 aprile 2004, n. 11 (BUR n. 45/2004) - Norme per il Governo del Territorio e in materia di Paesaggio.
- Regione del Veneto. 2017. Disposizioni per il contenimento del consumo di suolo e modifiche della legge regionale 23 aprile 2004, n. 11 “Norme per il governo del territorio e in materia di paesaggio.” 1–22. Italy.
- Regione del Veneto. 2019a. Legge Regionale n. 14 del 04 aprile 2019. Veneto 2050: politiche per la

- riqualificazione urbana e la rinaturalizzazione del territorio e modifiche alla legge regionale 23 aprile 2004, n. 11 “Norme per il governo del territorio e in materia di paesaggio”. Venezia, Italy.
- Regione del Veneto. 2019b. Deliberazione della Giunta Regionale n. 64 del 29 gennaio 2019. Venezia, Italy.
- Repubblica Italiana. 1968. Repubblica Italiana. Interministerial Decree, April 2, 1968, n. 1444 (in Italian: Decreto Interministeriale 2 Aprile 1968, n. 1444). Roma, Italy.
- RNDT. 2020. Metadata for Topographic DataBase of Padua Municipality. Retrieved from <https://geodati.gov.it/geoportale/>. Accessed January 2022.
- Rodríguez-Rojas, M. I. F. Huertas-Fernández B. Moreno G. Martínez and A. L. Grindlay. 2018. A study of the application of permeable pavements as a sustainable technique for the mitigation of soil sealing in cities: A case study in the south of Spain. *Journal of environmental management*. 205:151–162.
- Rogan, J. and D. M. Chen. 2004. Remote sensing technology for mapping and monitoring land-cover and land-use change. *Progress in Planning*. 61:301–325.
- Ronchi, S. A. Arcidiacono and L. Pogliani. 2020. Integrating green infrastructure into spatial planning regulations to improve the performance of urban ecosystems. Insights from an Italian case study. *Sustainable Cities and Society*. 53:101907.
- Ronchi, S. S. Salata A. Arcidiacono E. Piroli and L. Montanarella. 2019. Policy instruments for soil protection among the EU member states: A comparative analysis. *Land Use Policy*. 82:763–780.
- Rondeaux, G. M. Steven and F. Baret. 1996. Optimization of soil-adjusted vegetation indices. *Remote Sensing of Environment*. 55:95–107.
- Rosset, P. M. and M. A. Altieri. 1997. Agroecology versus input substitution: A fundamental contradiction of sustainable agriculture. *Society and Natural Resources*. 10:283–295.
- Rowe, D. B. and K. L. Getter. 2006. The role of extensive green roofs in sustainable development. *HortScience*. 41:1276–1285.
- Russo, A. and G. T. Cirella. 2018. Modern Compact Cities: How Much Greenery Do We Need? *International Journal of Environmental Research and Public Health* 2018, Vol. 15, Page 2180. 15:2180.
- Sam Navin, M. and L. Agilandeewari. 2020. Comprehensive review on land use/land cover change classification in remote sensing. *J. Spectral Imaging*. 9:8.
- Sánchez-Bayo, F. and K. A. G. Wyckhuys. 2019. Worldwide decline of the entomofauna: A review of its drivers. *Biological Conservation*. 232:8–27.
- dos Santos, A. R. F. S. de Oliveira A. G. da Silva J. M. Gleriani W. Gonçalves G. L. Moreira F. G. Silva E. R. F. Branco M. M. Moura R. G. da Silva R. S. Juvanhol K. B. de Souza C. A. A. S. Ribeiro V. T. de Queiroz A. V. Costa A. S. Lorenzon G. F. Domingues G. E. Marcatti N. L. M. de Castro R. T. Resende D. E. Gonzales L. A. de Almeida Telles T. R. Teixeira G. M. A. D. A. dos Santos and P. H. S. Mota. 2017. Spatial and temporal distribution of urban heat islands. *Science of the Total Environment*. 605–606:946–956.
- Saura, S. 2010. Effects of minimum mapping unit on land cover data spatial configuration and composition. <https://doi.org/10.1080/01431160110114493>. 23:4853–4880.
- Scalenghe, R. and F. A. Marsan. 2009. The anthropogenic sealing of soils in urban areas. *Landscape and Urban Planning*. 90:1–10.
- Scheuer, C. E. Boot N. Carse A. Clardy J. Gallagher S. Heck S. Marron L. Martinez-Alvarez D. Masarykova

- P. Mcmillan F. Murphy E. Steel H. Van Ekdom and H. Vecchione. 2015. Integration of ecosystem services into decision-making. *Physical Education and Sport for Children and Youth with Special Needs Researches – Best Practices – Situation.*:73–80.
- Schmutz, U. 2017. Urban Agriculture or Urban Agroecology? RUAFA. Retrieved from <https://ruaf.org/document/urban-agriculture-magazine-no-33-urban-agroecology/>. Accessed March 2021.
- Schneider, A. M. A. Friedl and D. Potere. 2010. Mapping global urban areas using MODIS 500-m data: New methods and datasets based on 'urban ecoregions.' *Remote Sensing of Environment*. 114:1733–1746.
- Scopus. 2021. How do Author / Indexed keywords work? - Scopus: Access and use Support Center. Retrieved from https://service.elsevier.com/app/answers/detail/a_id/21730/supporthub/scopus/. Accessed April 2021.
- See, L. P. Mooney G. Foody L. Bastin A. Comber J. Estima S. Fritz N. Kerle B. Jiang M. Laakso H.-Y. Liu G. Milčinski M. Nikšič M. Painho A. Pődör A.-M. Olteanu-Raimond M. Rutzinger L. See P. Mooney G. Foody L. Bastin A. Comber J. Estima S. Fritz N. Kerle B. Jiang M. Laakso H.-Y. Liu G. Milčinski M. Nikšič M. Painho A. Pődör A.-M. Olteanu-Raimond and M. Rutzinger. 2016. Crowdsourcing, Citizen Science or Volunteered Geographic Information? The Current State of Crowdsourced Geographic Information. *ISPRS International Journal of Geo-Information*. 5:55.
- Seiwert, A. and S. Rößler. 2020. Understanding the term green infrastructure: origins, rationales, semantic content and purposes as well as its relevance for application in spatial planning. *Land Use Policy*. 97:104785.
- Serbulova, N. S. Kanurny A. Gorodnyanskaya and A. Persiyanova. 2019. Sustainable food systems and agriculture: the role of information and communication technologies. 12127 *In* M. Pasetti and V. Murgul, editors. IOP Conf. Ser.: Earth Environ. Sci. Rostov-on-Don, Russia.
- Seto, K. C. M. Fragkias B. Güneralp and M. K. Reilly. 2011. A Meta-Analysis of Global Urban Land Expansion. *PLoS ONE*. 6:1–9.
- Seto, K. C. B. Güneralp and L. R. Hutyrá. 2012. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences of the United States of America*. 109:16083–16088.
- Shahtahmassebi, A. R. J. Song Q. Zheng G. A. Blackburn K. Wang L. Y. Huang Y. Pan N. Moore G. Shahtahmassebi R. Sadrabadi Haghghi J. S. Deng A. R. Shahtahmassebi J. Song Q. Zheng G. A. Blackburn K. Wang L. Y. Huang Y. Pan N. Moore G. Shahtahmassebi R. Sadrabadi Haghghi and J. S. Deng. 2016. Remote sensing of impervious surface growth: A framework for quantifying urban expansion and re-densification mechanisms. *IJAEO*. 46:94–112.
- Shi, L. Ü. Halik A. Abliz Z. Mamat and M. Welp. 2020. Urban Green Space Accessibility and Distribution Equity in an Arid Oasis City: Urumqi, China. *Forests* 2020, Vol. 11, Page 690. 11:690.
- Shuster, W. D. J. Bonta H. Thurston E. Warnemuende and D. R. Smith. 2005. Impacts of impervious surface on watershed hydrology: A review. *Urban Water Journal*. 2:263–275.
- Siddiqui, A. G. Kushwaha A. Raoof P. A. Verma and Y. Kant. 2021. Bangalore: Urban heating or urban cooling? *The Egyptian Journal of Remote Sensing and Space Science*. 24:265–272.
- Siebielec, G. S. Lazar C. Kaufmann and S. Jaensch. 2010. Handbook for measures enhancing soil function

performance and compensating soil loss during urbanization process. Urban SMS-Soil Management Strategy project. Urban SMS project, Stuttgart, Germany.

- Siegner, A. J. Sowerwine and C. Acey. 2018. Does Urban Agriculture Improve Food Security? Examining the Nexus of Food Access and Distribution of Urban Produced Foods in the United States: A Systematic Review. *Sustainability*. 10:2988.
- Sinha, P. N. K. Verma and E. Ayele. 2016. Urban Built-up Area Extraction and Change Detection of Adama Municipal Area using Time-Series Landsat Images. *International Journal of Advanced Remote Sensing and GIS*. 5:1886–1895.
- Slonecker, E. T. D. B. Jennings and D. Garofalo. 2001. Remote sensing of impervious surfaces: A review. *Remote Sensing Reviews*. 20:227–255.
- Socientize. 2014. White Paper on Citizen Science for Europe. Zaragoza, Spain.
- Söderström, O. T. Paasche and F. Klauser. 2014. Smart cities as corporate storytelling. *City*. 18:307–320.
- Sonnino, R. 2009. Feeding the city: Towards a new research and planning agenda. *International Planning Studies*. 14:425–435.
- Spadoni, G. L. A. Cavalli L. Congedo and M. Munafò. 2020. Analysis of Normalized Difference Vegetation Index (NDVI) multi-temporal series for the production of forest cartography. *Remote Sensing Applications: Society and Environment*. 20:100419.
- Specht, K. R. Siebert I. Hartmann U. B. Freisinger M. Sawicka A. Werner S. Thomaier D. Henckel H. Walk and A. Dierich. 2014. Urban agriculture of the future: An overview of sustainability aspects of food production in and on buildings. *Agriculture and Human Values*. 31:33–51.
- Stankovics, P. G. Tóth Z. Tóth P. Stankovics G. Tóth and Z. Tóth. 2018. Identifying Gaps between the Legislative Tools of Soil Protection in the EU Member States for a Common European Soil Protection Legislation. *Sustainability*. 10:1–17.
- Strollo, A. D. Smiraglia R. Bruno F. Assennato L. Congedo P. De Fioravante C. Giuliani I. Marinosci N. Riitano and M. Munafò. 2020. Land consumption in Italy. *Journal of Maps*. 16:113–123.
- Sun, Z. C. Wang H. Guo and R. Shang. 2017. A modified normalized difference impervious surface index (MNDISI) for automatic urban mapping from landsat imagery. *Remote Sensing*. 9:1–18.
- Sutton, P. C. S. J. Anderson C. D. Elvidge B. T. Tuttle and T. Ghosh. 2009. Paving the planet: impervious surface as proxy measure of the human ecological footprint. *Progress in Physical Geography*. 33:510–527.
- Swyngedouw, E. 2016. The mirage of the sustainable ‘smart city’: planetary urbanization and the spectre of combined and uneven apocalypse. 134–143 *In* O. Nel-lo and R. Mele, editors. *Cities in the 21st Century*. Routledge, New York, USA.
- Tahvonen, O. and M. Airaksinen. 2018. Low-density housing in sustainable urban planning – Scaling down to private gardens by using the green infrastructure concept. *Land Use Policy*. 75:478–485.
- Taylor, J. R. and S. T. Lovell. 2012. Mapping public and private spaces of urban agriculture in Chicago through the analysis of high-resolution aerial images in Google Earth. *Landscape and Urban Planning*. 108:57–70.
- Teixeira da Silva, R. L. Fleskens H. van Delden and M. van der Ploeg. 2018. Incorporating soil ecosystem services into urban planning: status, challenges and opportunities. *Landscape Ecology* 2018 33:7.

33:1087–1102.

- Theobald, D. M. S. J. Goetz J. B. Norman and P. Jantz. 2009. Watersheds at Risk to Increased Impervious Surface Cover in the Conterminous United States. *Journal of Hydrologic Engineering*. 14:362–368.
- Tobias, S. F. Conen A. Duss L. M. Wenzel C. Buser and C. Alewell. 2018. Soil sealing and unsealing: State of the art and examples. *Land Degradation & Development*. 29:2015–2024.
- Torres, A. V. C. Tiwari and S. F. Atkinson. 2021. Progress in ecosystem services research: A guide for scholars and practitioners. *Ecosystem Services*. 49:101267.
- Townsend, A. 2014. *Smart Cities-Big Data, Civic hackers and the question for a new utopia*. (W. W. Norton & Company, Ed.). New York, USA.
- UN-Habitat. 2021. UN Habitat Metadata sheet on SDG indicator 11.3.1. Retrieved from <https://unstats.un.org/sdgs/metadata/files/Metadata-11-03-01.pdf>. Accessed April 2021.
- UN Department of Economic and Social Affairs. 2019. *World Population Prospects 2019 Highlights*. Retrieved from www.population.un.org. Accessed February 2020.
- UNDP United Nations Development Programme. 2018. *Community-Based Resilience Analysis (CoBRA) Conceptual Framework and Methodology*. Retrieved from www.undp.org. Accessed March 2020.
- UNFPA United Nations Population Found. 2007. *State of world population 2007: unleashing the potential of urban growth*. New York. Retrieved from www.unfpa.org. Accessed February 2020.
- United States Department of Agriculture. 2016. *Urban Agriculture Toolkit*. Retrieved from <https://www.usda.gov/sites/default/files/documents/urban-agriculture-toolkit.pdf>. Accessed.
- University of Southampton. 2021. *WorldPop*. Retrieved from <https://www.worldpop.org/about>. Accessed January 2022.
- Vanolo, A. 2014. Smartmentality: The Smart City as Disciplinary Strategy. *Urban Studies*. 51:883–898.
- Vanolo, A. 2016. Is there anybody out there? The place and role of citizens in tomorrow's smart cities. *Futures*. 82:26–36.
- Vázquez Moreno, L. L. and F. Funes Aguilar. 2016. *Avances de la agroecología en Cuba Avances de la agroecología en Cuba*. Editora Estación Experimental de Pastos y Forrajes Indio Hatuey, La Habana, Cuba.
- Veolia Institute. 2019. *Urban Agriculture: another way to feed cities*. Retrieved from www.institut.veolia.org. Accessed.
- Vermeulen, S. J. B. M. Campbell and J. S. I. Ingram. 2012. Climate Change and Food Systems. *Annual Review of Environment and Resources*. 37:195–222.
- Walter, A. R. Finger R. Huber and N. Buchmann. 2017. Smart farming is key to developing sustainable agriculture. *Proceedings of the National Academy of Sciences of the United States of America*. 114:6148–6150.
- Wang, Y. and M. Li. 2019. Urban Impervious Surface Detection From Remote Sensing Images: A review of the methods and challenges. *IEEE Geoscience and Remote Sensing Magazine*. 7:64–93.
- Weng, Q. 2012. Remote sensing of impervious surfaces in the urban areas: Requirements, methods, and trends. *Remote Sensing of Environment*. 117:34–49.
- Weng, Q. editor. 2014. *Scale issues in Remote Sensing*. John Wiley & Sons, Ltd, Hoboken, USA.
- Weng, Q. 2020. *Techniques and Methods in Urban Remote Sensing*. IEEE Press.

- Weng, Q. and D. Lu. 2008. A sub-pixel analysis of urbanization effect on land surface temperature and its interplay with impervious surface and vegetation coverage in Indianapolis, United States. *International Journal of Applied Earth Observation and Geoinformation*. 10:68–83.
- Wenhui, K. C. Wenfeng and S. Wenjiao. 2014. Spatio-temporal characteristics of intra-urban land cover in the cities of China and USA from 1978 to 2010. *Acta Geographica Sinica* . 69:883–895.
- Wessolek, G. 2008. Sealing of soils. 161–179 *In* J. M. Marzluff, E. Shulenberger, W. Endlicher, M. Alberti, G. Bradley, C. Ryan, U. Simon, and C. ZumBrunnen, editors. *Urban Ecology: An International Perspective on the Interaction Between Humans and Nature*. Springer, New York, USA.
- Whelan, B. and J. Taylor. 2013. Precision agriculture for grain production systems. *International Journal of Digital Earth*. CSIRO Publishing, Collingwood, Australia.
- Wiig, A. 2016. The empty rhetoric of the smart city: from digital inclusion to economic promotion in Philadelphia. *Urban Geography*. 37:535–553.
- WOCAT. 2014. WOCAT. Retrieved from <https://www.wocat.net/en/>. Accessed March 2021.
- Woodhouse, P. 2010. Beyond Industrial Agriculture? Some Questions about Farm Size, Productivity and Sustainability. *Journal of Agrarian Change*. 10:437–453.
- World Bank. 2020. Urban Development. Retrieved from <https://www.worldbank.org/en/topic/urbandevelopment/overview>. Accessed.
- World Health Organization. 2005. *Ecosystems and Human Well-Being*. Geneva, Switzerland.
- World Health Organization. 2017. *Urban green spaces: a brief for action*. Copenhagen, Denmark.
- Wu, D. and G. Lindasay. 2020. How to design a smart city that's built on empowerment - not corporate surveillance. Retrieved from <https://www.fastcompany.com/90469838/how-to-design-a-smart-city-thats-built-on-empowerment-not-corporate-surveillance>. Accessed March 2020.
- Wu, J. Wei-Ning Xiang and J. Zhao. 2014. Urban ecology in China: Historical developments and future directions. *Landscape and Urban Planning*. 125:222–233.
- Wüstemann, H. D. Kalisch and J. Kolbe. 2016. Towards a national indicator for urban green space provision and environmental inequalities in Germany: Method and findings. Berlin: Humboldt University of Berlin, Collaborative Research Center 649 - Economic Risk, Berlin, Germany. Retrieved from <https://www.econstor.eu/handle/10419/146191>. Accessed January 2022.
- Xiao, R. Y. Tian and G. Xu. 2020. Spatial gradient of urban green field influenced by soil sealing. *Science of The Total Environment*. 735:139490.
- Xie, L. and H. Bulkeley. 2020. Nature-based solutions for urban biodiversity governance. *Environmental Science & Policy*. 110:77–87.
- Xu, H. 2010. Analysis of impervious surface and its impact on Urban heat environment using the normalized difference impervious surface index (NDISI). *Photogrammetric Engineering and Remote Sensing*. 76:557–565.
- Xue, J. and B. Su. 2017. Significant remote sensing vegetation indices: A review of developments and applications. *Journal of Sensors*. 2017.
- Zhang, B. Z. Chen D. Peng J. A. Benediktsson B. Liu L. Zou J. Li and A. Plaza. 2019. Remotely sensed big data: Evolution in model development for information extraction [point of view]. *Proceedings of the IEEE*. 107:2294–2301.

- Zhang, L. and Q. Weng. 2016. Annual dynamics of impervious surface in the Pearl River Delta, China, from 1988 to 2013, using time series Landsat imagery. *ISPRS Journal of Photogrammetry and Remote Sensing*. 113:86–96.
- Zhang, N. M. Wang and N. Wang. 2002. Precision agriculture - A worldwide overview. *Computers and Electronics in Agriculture*. 36:113–132.
- Zhao, S. D. Zhou C. Zhu Y. Sun W. Wu and S. Liu. 2015. Spatial and Temporal Dimensions of Urban Expansion in China. *Environmental Science and Technology*. 49:9600–9609.
- Zhong, Q. J. Ma B. Zhao X. Wang J. Zong and X. Xiao. 2019. Assessing spatial-temporal dynamics of urban expansion, vegetation greenness and photosynthesis in megacity Shanghai, China during 2000–2016. *Remote Sensing of Environment*. 233:111374.

WHOSE URBAN GREEN? MAPPING AND CLASSIFYING PUBLIC AND PRIVATE GREEN SPACES IN PADUA FOR SPATIAL PLANNING POLICIES

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Abstract

The rising environmental issues on contemporary cities urgently calls for sustainable planning policies. Implementation of nature-based solutions, ecosystem services, and green infrastructures associated to green spaces management is at present of paramount importance. In contrast to policies mainly focused on public greenery, the inclusion of private green in planning strategies might be a promising pathway. The general aim is mapping and classifying urban green spaces in Padua, a city of 93.3 km² (Northeast Italy). Specific aims are (i) testing an NDVI-derived extraction from very high-resolution orthophotos; (ii) classifying property status; (iii) highlighting multilevel relationships and strategies for urban green spaces implementation and management; (iv) assessing greenery in relation to per capita population. By performing remote sensing and GIS analyses, a first detailed global map of urban green spaces in Padua was created; then, binary classification and thematic maps for rural/non-rural, public/private, municipal/non-municipal greenery were produced for all urban units. Results show that, among total green spaces (52.23 km²), more than half are rural. Moreover, private green spaces represent 80%, while within public areas (20%) less than 10% are municipal (5 km²). We therefore highlight scenarios for planning policies in Padua by providing tools

to policymakers for an integrated management of green spaces, where private greenery might also contribute to ecosystem services implementation for common urban well-being.

1. Introduction

1.1. Green Spaces Management in Contemporary Urban Planning

In contemporary territorial and urban planning, nature-based policies and practices to improve the health and social life of citizens are growing and becoming even more relevant. Two terms largely used to encompass planning principles and initiatives related to this framework are ecosystem services and nature-based solutions (NBS) (Colding 2011; Scheuer et al. 2015; Faivre et al. 2017; Davies and Laforteza 2019; Cortinovia and Geneletti 2019).

Ecosystem services are inclusive approaches for natural resources management (World Health Organization 2005; Haines-Young and Potschin 2013; Torres et al. 2021), orienting environmental protection measures and biodiversity conservation to preserve nature and recognise social and economic benefits provided by ecosystems to human societies (Karimi et al. 2020; Hatan et al. 2021). In particular, urban ecosystem services (UES) are the benefits provided to people living in cities by the environmental and nature-related urban elements (EU Commission 2016; Andersson-Sköld et al. 2018; Maes et al. 2019).

NBS is an umbrella term including all planning and management strategies trying to cope with climatic, environmental, and socioeconomic issues, including adaptation dynamics (Bush and Doyon 2019; Xie and Bulkeley 2020). In this conceptual framework, the development of policies and initiatives is driven and inspired by ecological processes and functions. In fact, NBS are well recognised within the innovation policies by the European Union (EU) as a supporting tool to foster the goals of the European Green Deal, EU Biodiversity Strategy, and EU Adaptation Strategy (Giachino et al. 2021).

A concept strictly related to UES and NBS is green infrastructure (GI): it can be defined as a network of natural or semi-natural areas preserving biodiversity and providing several types of benefits and services to people (Seiwert and Rößler 2020). GI typically presents a multiscale dimension, connecting urban and non-urban landscapes as well as supporting sustainable mobility networks; since water bodies such as rivers and streams are often part of the core of such infrastructures, they are also referred to with the expression 'green-and-blue infrastructure' (Li et al. 2020).

Including UES and NBS in urban planning strategies is a relevant topic in current planning studies, especially those related to performance-based planning (Kendig 1980; Frew 2011; Nin et al. 2016; Babí Almenar et al. 2021). This research area aims to cope with the complexity of contemporary cities and territories by integrating land use zoning and metric standards for public services with a broader consideration for spatial and environmental resources and their performance in achieving collective health and equality goals. Adopting such a framework, a quantitative assessment of UES

may be used to drive qualitative maps of territorial values in support of a local GI strategy (Ronchi et al. 2020).

In all the above-mentioned frameworks, urban green spaces (UGS) play an important role in addressing and supporting urban planning policies and actions. They provide relevant UES, especially by the contribution of vegetation systems, permeable soils, and city farmlands. Therefore, they may represent a supporting basis to implement integrated NBS able to mitigate air and water pollution, hydrogeological/hydraulic risk, and urban heat islands; improving their spatial continuity and connections leads to the creation of an effective urban GI (Van Oijstaeijen et al. 2020). Moreover, UGS play a widely recognised role in improving public health (World Health Organization 2017). Traditionally, urban planners and policymakers focused on the development and management of public green spaces [26]. In recent years, the rise of new planning strategies involving a wider role for private actors, together with new approaches such as UES, led to take into consideration the role of private green spaces as a crucial issue of sustainable urban management (Cameron et al. 2012; Cervinka et al. 2016; Glavan et al. 2018; Clark et al. 2020).

Current literature highlights the important role of private gardens for network connectivity and biodiversity conservation, as well as their role as hubs in the urban GI and their contribution in providing regulating and supporting UES such as carbon storage and sequestration, urban heat island mitigation, stormwater attenuation, and noise reduction (Cameron et al. 2012; Mimet et al. 2020; Liu and Russo 2021). For these reasons, low-density housing with private green spaces is considered by some scholars as a form of sustainable urban planning (Tahvonen and Airaksinen 2018). However, other studies warn about economic and social issues related to the proliferation and prevalence of private green spaces, especially in situations of lacking or inadequate public UGS (Pearsall and Eller 2020). In addition, it is still debated whether urban and peri-urban agricultural plots should be considered as a part of urban GI (Contesse et al. 2018; Feltynowski and Kronenberg 2020). Indeed, from both GI and UES perspectives, they appear to play a remarkable role (Caputo et al. 2020): rural greenery is responsible for provisioning regulatory ecosystem services to citizens and may be included, together with other green-and-blue urban features, in urban GI supplied with sustainable mobility networks connecting cities to their natural or semi-natural surroundings.

In this context, accurate localisation and quantification of UGS and mapping their property status become paramount for GI/NBS implementation and sustainable spatial planning.

Detecting locations, extension, and use of green spaces within a city, together with their spatial relationships with urban fabric and infrastructures, is indeed pivotal to the development of GI and to the implementation of site-specific NBS (Liu and Russo 2021); moreover, data about land property applied to UGS are necessary to urban planners in order to elaborate feasible, effective strategies to enhance benefits provided by the urban environment. For example, it is possible to integrate the role of private or public soils and vegetation in contributing to the provision of some regulation UES by creating environmental corridors or buffer zones (Tahvonen and Airaksinen 2018; Mimet et al.

2020), while focusing on soft mobility connections between public and accessible UGS in implementing GI for public fruition.

1.2. Spatial Planning in Padua: Between Soil Sealing and Urban Greening

Padua is a medium-sized city located in Veneto, northeast of Italy, approximately 35 km west of Venice (Figure 1). The municipal territory spans 93.3 km² with a population of about 211,000 inhabitants (2020). The city lies on an almost completely plain surface, south of the first pre-alpine reliefs. It is an ancient city, playing an important cultural and economic role in Italy since the Middle Ages and characterized by a wall system realized in the 16th century, when the city was under Venetian rule (Fadini 2013).

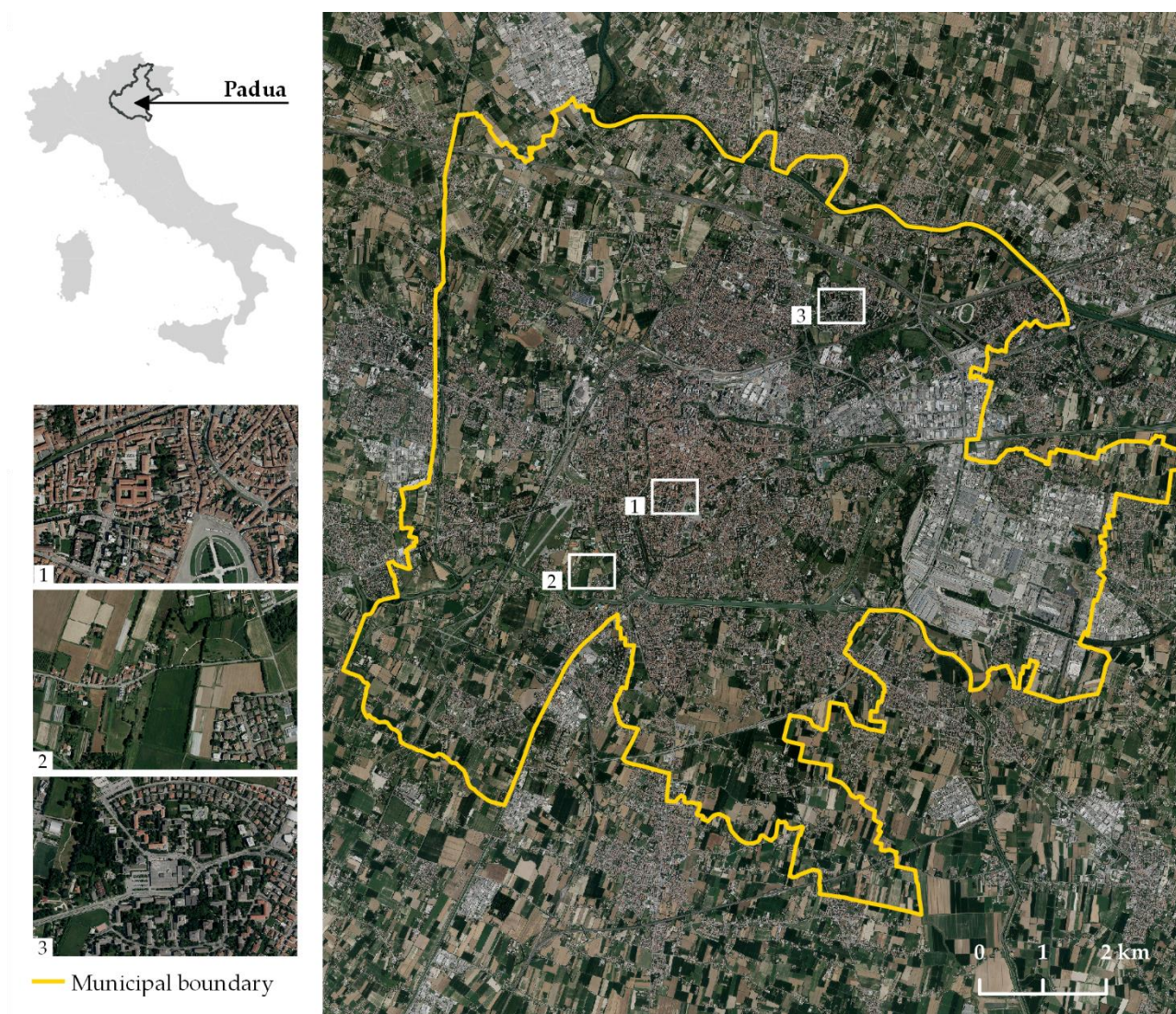


Figure 1. Geographical framework of Padua (Italy) and a zoomed-in image on different types of urban fabric of the city.

As in other European cities, in recent decades, Padua experimented with urban development consisting of medium-density residential districts around the city centre and sparse new buildings or

complexes spreading on the urban fringes between the core city and the surrounding countryside (Marzari 2008b). This phenomenon and the resulting growth of grey mobility infrastructures led to a relevant fragmentation of peri-urban natural and rural areas in Padua (Boschetto and Schiavon 2011).

Regarding administrative units, Padua is currently divided into 6 neighbourhoods and 40 sub-neighbourhood urban units (Comune di Padova 2020).

In this urban development context, the latest National Report from the Italian Institute for Environmental Protection and Research ISPRA (2020) ranked Veneto as the second region in Italy affected by soil sealing phenomenon, with 217,619 ha completely covered by sealed surfaces (11.87%). In addition, with 45–50% of sealed surfaces Padua is one of the most affected cities in Italy, ranked as fifth by ISPRA assessment and showing a remarkable rate increase of about 20–25 ha per year (Peroni et al. 2019; ISPRA 2020; Pristeri et al. 2020). To limit soil sealing and its impacts on UES, different regional rules and regulations are currently issued for a more sustainable territory planning agenda, involving public institutions, policymakers, and stakeholders. In fact, within the ‘no net land take by 2050,’ European Commission’s Roadmap to a Resource Efficient Europe (European Commission 2011), recent revisions of the Veneto regional planning law issued strict limitations to new buildings.

The regional planning law of Veneto, known as ‘Regulations for territorial and landscape management’, approved in 2004 (Regione del Veneto 2004) and lastly revised in 2017 and 2019, rules that every municipality must adopt an urban development plan consisting of two parts: (i) a ‘Territorial Management Plan’ (‘Piano di Assetto del Territorio’, PAT) which includes strategies and policies and (ii) a ‘Plan of Interventions’ (‘Piano degli Interventi’, PI) which is based on operational provisions for the implementation of planning decisions (Comune di Padova 2014,2018).

By revisions and integrations of the regional planning law (Regione del Veneto 2017,2019a), new regulations and incentives to limit and mitigate soil sealing are issued for all the municipalities of Veneto Region, by promoting regeneration and renaturalisation practices. They designate and allocate the total amount of soil sealing for all the municipalities of the Veneto Region and by implementing GI, renaturalisation and urban regeneration processes (Regione del Veneto 2017). In 2019, a regional decree reallocated for the whole municipal territory of Padua a maximum amount of 262.48 ha of soil sealing (Regione del Veneto 2019b), fuelling the debate about the protection of existing green spaces, implementation of GIs, and increase of UES.

Lamentably, detailed estimation of the spatial dimension of UGS at the urban scale is disaggregated and incomplete, making spatial planning at present critical and inconsistent. Moreover, identification of suitable areas for soil sealing mitigation/compensation and integration of GI into UES management require urban professionals to also map the property status by classifying public and private UGS.

1.3. Aims of the Study

The general aim of this study is to map and classify all UGS within the municipal territory of Padua by integrating NDVI-based analyses with ancillary and ground data.

The specific aims are (i) to test the integration of NDVI extraction from very high-resolution orthophotos, together with a municipal geodatabase, to accurately estimate the spatial dimension of UGS; (ii) to classify property status and land use of UGS; (iii) to highlight multilevel relationships and possible strategies for UGS implementation and management; (iv) to assess the distribution and the amount of U in relation to per capita population.

Coherently with our purposes, in this paper, we use a definition of UGS which includes all the pervious surfaces able to host some kind of vegetation and to play a role in green management policies by local authorities. In particular, given the conformation of the municipality territory and the importance of rural land plots in a site-specific analysis focused on Padua, we chose to include peri-urban agricultural areas in our UGS mapping, as proposed in the scientific literature focusing on UGS assessment for urban planning purposes (Contesse et al. 2018; Feltynowski and Kronenberg 2020; Liu and Russo 2021).

2. Data and Methods

2.1. Data Sources

For the first screening and detection of UGS, we adopted the Normalised Difference Vegetation Index (NDVI) to perform a multispectral analysis on very high-resolution aerial images. This vegetation index, based on spectral signature (Xue and Su 2017) is largely used in vegetation mapping (Rondeaux et al. 1996; Spadoni et al. 2020).

NDVI analysis was performed on public orthophotos dating to the early summer of 2015, provided by AGEA/Veneto Region. Orthophotos were structured in two multiband, image datasets at very high spatial resolution (20 cm pixel⁻¹): one with red, green, and blue bands in the visible range and the other one with near-infrared (NIR), red, and blue bands.

In order to integrate the results, we used ancillary data from the Topographic Database (DB) of Padua Municipality, part of a series of digital land use/land cover maps implemented by Veneto Region in collaboration with municipalities involved.

For data validation, we used UGS maps of four sample urban units in Padua that had been carried out in the framework of a study aiming to calculate the Biotope Area Factor ecological index (Peroni et al. 2019). This study was developed by adopting a methodology based on highly detailed photointerpretation performed by skilled researchers, supervised and checked by the authors of the study. The source dataset was AGEA/Regione Veneto 2015 orthoimagery, and the same was used for NDVI extraction. Therefore, in our work, we adopted results of the abovementioned paper (Peroni et al. 2019) as macro-area data validation for our results.

The classification of UGS by property was realised by means of a query on cadastral codes of public institutions performed on the cadastral database of Padua Municipality.

Finally, tables and analyses concerning population in the urban units in which the city is subdivided were based on data from Padua 2019 statistical yearbook, released by the municipality (Comune di Padova 2020).

All spatial and spectral analyses were performed by using the open source GIS software QGIS (version 3.x).

Table 1 shows the main input spatial data used in the workflow, schematising their use and sources.

Table 1. Main input spatial data used and their sources

Name	Description	Use	Source
Orthophotos	20 cm/pixel resolution, multiband (RGB-NIR), June-July 2015	NDVI calculation	AGEA/Veneto Region (2015)
Topographic database (DB)	Digital land use/land cover map	Integration and refinement of UGS from NDVI, rural-urban classification	Padua Municipality
UGS map of 4 sample areas	UGS mapped by expert photointerpretation on orthophotos (ground truth) of 4 areas of Padua	UGS from NDVI + Topographic DB result validation	Peroni et al., 2020
Cadastral database (DB)	Cadastral DB of public and municipal properties	Property (public, municipal, private) classification	Padua Municipality

2.2. Urban Green Spaces Detection

Firstly, orthophotos were merged and clipped on the boundary of the Padua municipality. Then, the NDVI value was calculated for each image pixel, by performing the standard normalised band ratio as follows:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

Afterwards, different tests on NDVI threshold values were performed in order to extract green areas. As reported in scientific literature, due to different factors, NDVI threshold values to detect vegetation are not univocal, although a value below 0.1 generally represents the absence of greenness (Atasoy 2018). As the NDVI analysis is able to extract only vegetated surfaces we performed different tests in the range of 0.1–0.3 to identify a suitable threshold value according to the aim of the study.

Visual analysis was performed with the help of updated aerial imagery on different spots in the city and carried out for the different thresholds tested, the results of which confirmed that the value of 0.15 was the most suitable for UGS extraction in this case study. In fact, values more than 0.15 allowed the extraction of very low vegetated areas, avoiding the presence of artificially sealed soils from surfaces detected as UGS.

The NDVI-derived raster image was then vectorised into a shapefile. The adoption of multispectral indexes derived from remote sensing to map urban vegetation, indeed, may produce flaws consisting in the underrepresentation of ploughed or fallow land but also in the overrepresentation of tree canopies spreading on streets or other artificial features.

Basing on topographic DB classes, we performed an integration function and a subtraction on the NDVI-derived vector map. In the first case, we gathered topographic DB classes representing potentially vegetated land, such as 'green area', 'agricultural area', 'pasture and fallow', 'vegetation-free area', 'river banks' and added to the map the areas not already detected by NDVI. In the second case, we gathered DB classes related to sealed or permanently non-vegetated land, such as 'street area', 'pedestrian paths area', 'railway', 'building', 'water body' and subtracted the features overlapping our vegetation map. In this way, we fixed the most common misrepresentations. It should be said that such corrections are useful to improve quantitative mapping results but may cause little flaws in detailed visualisation.

At the end of the process, we obtained a polygonal shapefile representing actually or potentially vegetated land (UGS) within the borders of Padua Municipality.

Later, in order to verify correlations between the size of green areas and their distance from the centre of the city, we extracted centroids of polygons representing UGS and created a scatterplot matching UGS extent and distance from the city centre. Since our goal was to analyse UGS dimensions with respect to Padua spatial development, we calculated distances starting from 'Piazza delle Erbe', the main square in Padua and centre of the historical city since the Middle Ages.

2.3. Data Validation

To validate data derived from NDVI extraction and topographic DB integrations, we performed a spatial linear regression with the results of detailed mapping of green surfaces in four macro-sample areas of the city (Figure 2), derived from the study described in Section 2.1. The regression was calculated using the GRASS GIS function 'r.regression.line' in QGIS.

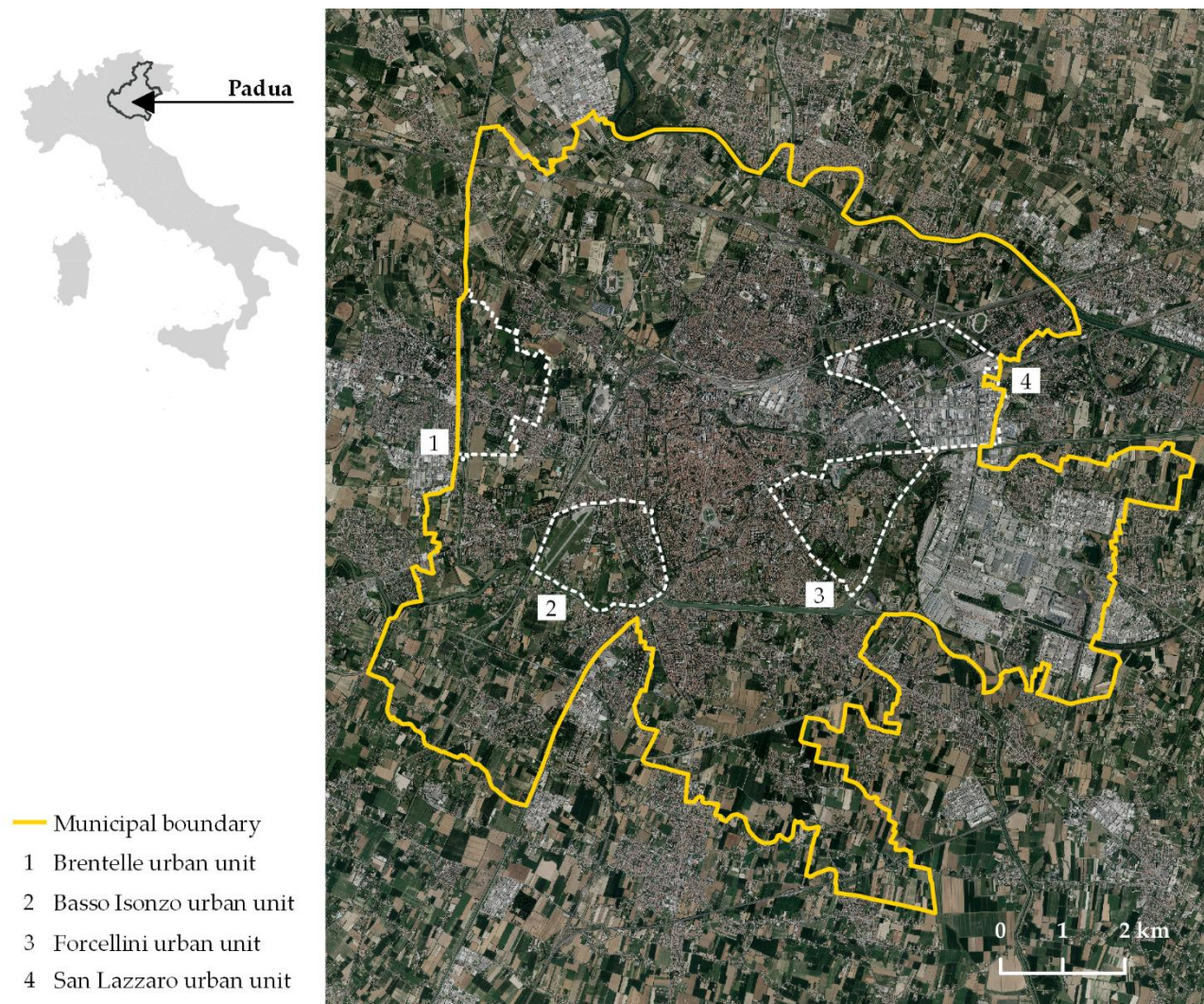


Figure 2. Location of the macro-sample areas within the municipality borders of Padua adopted as data validation

The validation process was strengthened by calculating a confusion matrix for each sample area with QGIS semi-automatic classification plugin, to determine how many pixels resulted as 'green' or 'not green' according to the two datasets. Then, we calculated user's and producer's accuracy and kappa coefficients to measure global accordance.

The macro-areas used for our comparison are four urban units such as Brentelle (macro-area 1, 2.60 km²), Forcellini (macro-area 2, 2.66 km²), Sacra Famiglia (macro-area 3, 2.77 km²), and San Lazzaro (macro-area 4, 3.44 km²). In their diversity, they represent a good sample of the relationships between green spaces and urban fabric in Padua.

2.4. Urban Green Spaces Definition and Classification

Once obtained a map of the distribution of green areas in Padua, we chose to organise and classify our data by adopting three binary categories, with the purpose of achieving more structured

information and coping with the needs of spatial planners and local policymakers. The binary categories of UGS adopted in our classification are the following:

- *Rural–non-rural*. It allows defining urban and peri-urban UGS associated with agricultural land use, which may serve as a basis for community gardens projects and provide both regulating and provisioning UES;
- *Public–private*. It is a key categorisation, as it identifies areas that, thanks to their public property status, may be included in mobility or leisure urban GI and, in opposition, private UGS suitable to contribute to the creation of urban ecological corridors and the enhancement of regulating UES;
- *Municipal–non-municipal*. It defines UGS owned by the Municipality, that is, the primary features of urban green spatial planning and management oriented to improve green accessibility and reduce inequalities in UGS fruition by citizens.

Firstly, we classified rural and non-rural green areas. We used once again the topographic DB, gathering the class representing agricultural areas with a selection of farmlands belonging to other classes of the DB (e.g., ‘green areas’, ‘fallow’, ‘non-vegetated areas’) detected by visual analysis on orthoimagery and then intersecting the aggregated features with the overall UGS map derived from NDVI. The sum of the resulting features corresponds to the share of rural green areas in Padua. The remaining percentage of total green areas is therefore non-rural.

Then, we classified UGS according to their property status, in order to obtain a map of public and private green areas. For this purpose, we had to perform an overlay between cadastral maps of land parcels owned by public institutions in Padua and green surfaces derived by our mapping. This task was conducted in cooperation with Padua Municipality, which provided a table of Italian public institutions that we filtered to select the ones that were likely to own land plots in Padua (for instance, public parks and gardens are mostly the property of Padua Municipality; the University of Padua holds several studies and research facilities equipped with green spaces; Province of Padua is the owner of some secondary schools building complexes surrounded by green areas; Veneto Region owns branch offices of regional agencies provided with inner gardens; vegetated embankments of streams and rivers are usually state property; the Italian Ministry of Defence still owns several unused barracks and military complexes often equipped with vegetation). This selection was then used to query the cadastral database of Padua in order to extract publicly owned land parcels.

The following step was to overlay such parcels with our map of green areas: in this way, we obtained a map of the spatial distribution of public green areas in Padua. The remaining share of total green represents private green areas.

Starting from the public–private green classification, since our spatial data on public green areas were equipped with information about the owner institutions, with a further selection we were able to map municipality-owned green areas. This classification allows detecting the green spaces that can be directly managed by the local city planning office and the ones that require a change of ownership

or an agreement to undergo changes such as the development of urban gardens or the planting of new trees.

Finally, in order to examine the relationships between the location of green areas and the distribution of population in the city, by clipping our maps, we calculated amounts and per capita values of each UGS category in the 40 urban units in which the municipality is officially divided.

2.5. Data Quality and Update Assessment

The main dataset used for green areas detection is the 2015 series of orthophotos released by AGEA/Veneto Region. Such orthophotos are updated every three years but at the time this work was performed the 2018 series was still not available. The overall image quality is very good; it was not possible to determine the exact data of the survey, but the amount of vegetation in the images suggests placing the photographic campaign in the spring–summer period.

For future developments, a good suggestion may be to repeat the workflow of the study on the subsequent series of orthophotos in order to detect changes in overall green areas and in their classification.

The dataset used to integrate NDVI results is the Topographic DataBase of Padua: it is gradually updated to cope with changes in land cover, but its official date of update is 2013 (RNDT 2020). This potential lack of update was balanced out with supervised checks and corrections on surfaces that underwent recent changes in land cover.

Green spaces mapping of the four sample areas used for data validation are based on the same orthoimagery used for NDVI detection. These data were generated from a strongly supervised and detailed visual analysis, and therefore, they are highly reliable.

For the classification based on property, we operated a selection starting from an overall table of Italian public administrations and institutions provided by Padua Municipality, which can be considered thorough enough for the purposes of this study. The matching with Padua cadastral database was based upon codes designating land-owning institutions. Since Italian cadastral data suffer from flaws regarding the update of codes, the query and overlay that resulted in the map of public green areas may not have identified all the required surfaces. After performing sample checks of the location and structure of known public and private green spaces in Padua, nevertheless, we can state that our results appear to fit well with the actual property layout.

2.6. Overall Workflow

In order to facilitate the comprehension of the workflow carried out for the investigation, the main steps presented in the previous paragraphs are schematised in the flowchart in Figure 3. Data input, as well as intermediate and final output, are inserted in parallelepipeds with yellow, blue, and red borders, respectively. Processes are enclosed in rectangles. A green rectangle comprises the two result validation processes carried out to validate the final overall map of Padua UGS.

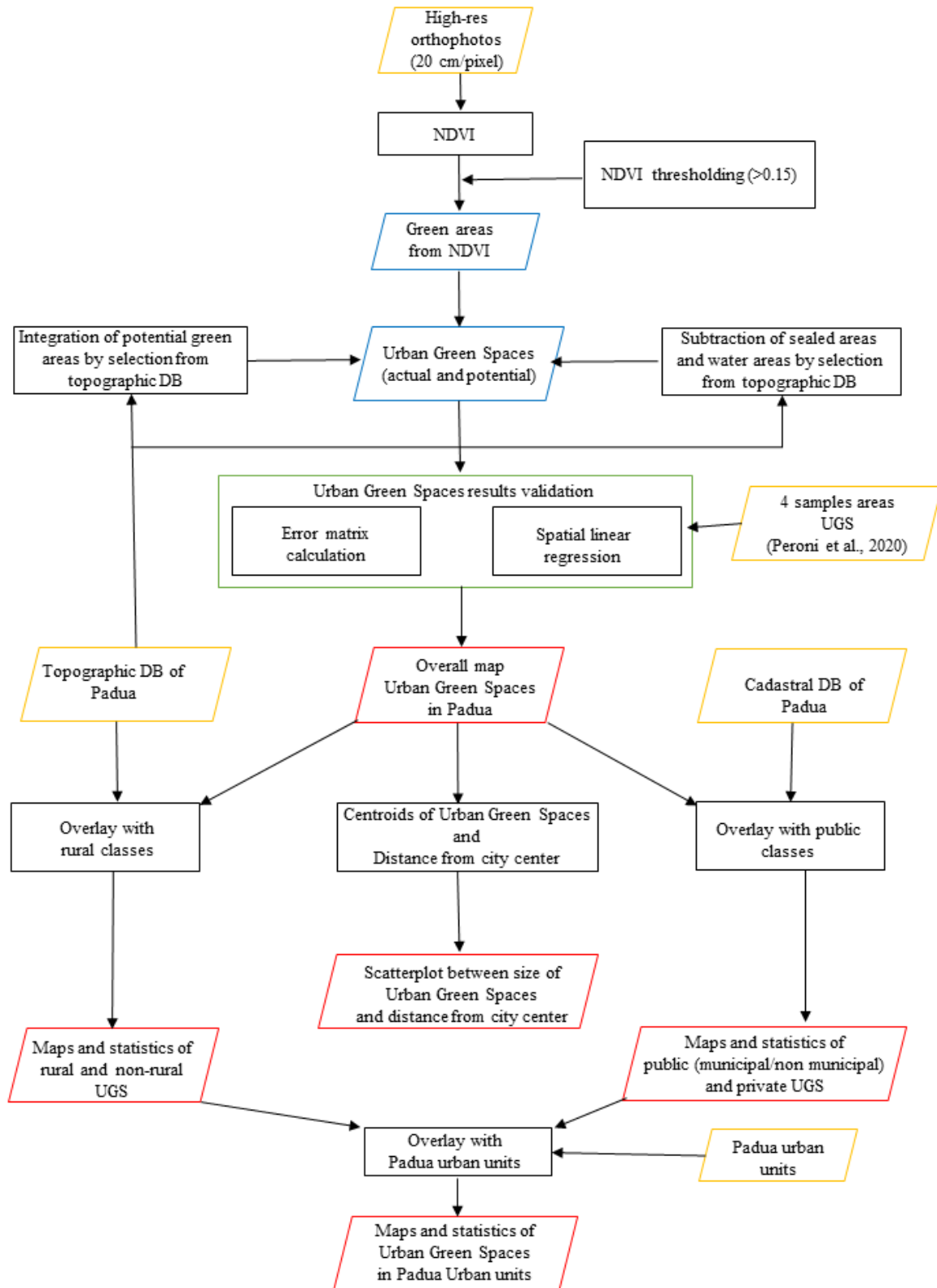


Figure 3. Overall flowchart showing the main methodologies (black boxes), data inputs (yellow boxes), urban green spaces validation (green box), and outputs (red boxes).

3. Results and Discussion

3.1. Urban Green Space Extraction (NDVI), Integration, and Cross Validation

UGS location after NDVI extraction and before integration based on the topographic DB is shown in Figure 4. The chromatic value scale adopted for representation, based on a linear interpolation of NDVI values, allows locating areas where vegetation is most flourishing, often coincident with the tree canopy. Moreover, the pattern of peri-urban agricultural fields and the state of cultivations can be distinguished in a yellow-light-green range of colours.

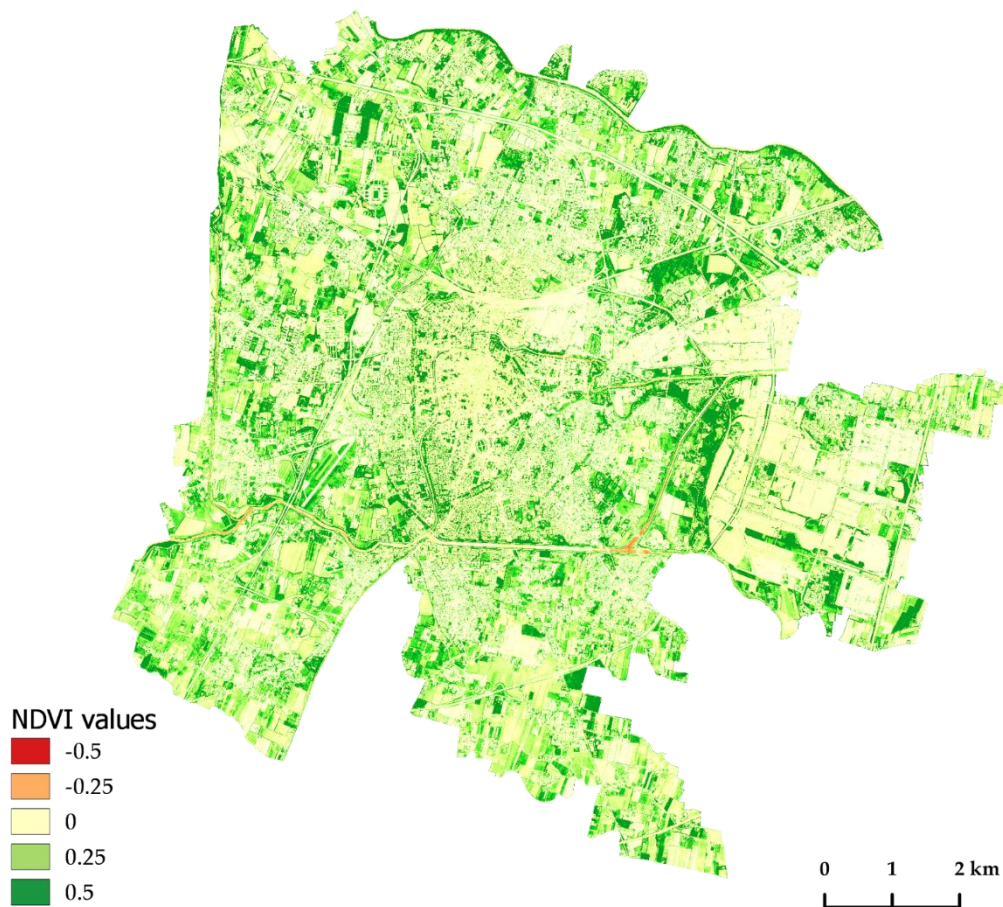


Figure 4. Urban green spaces in Padua by NDVI extraction, before integration with municipal topographic database.

Results of validation performed in the four sample areas after extracting UGS by a proper NDVI threshold and integrating them with topographic DB classes are presented in Table 2, Table 3, Table 4, Table 5, Table 6, Table 7 and Table 8. Table 2 shows the number of green areas in the four macro-sample units of Brentelle (macro-area 1), Forcellini (macro-area 2), Sacra Famiglia (macro-area 3), and San Lazzaro (macro-area 4), according to NDVI and visual analysis (see also Figure 5). Comparative spatial analyses between NDVI and classification by expert photo interpretation are very similar for each neighbourhood.

Table 2. Green surfaces from NDVI and from visual analysis in the four sample areas.

Macro-sample area	Green areas from NDVI/topo DB (km²)	Green areas from visual analysis (km²)
Brentelle (1)	1.84	1.80
Forcellini (2)	1.59	1.64
Sacra Famiglia (3)	1.73	1.71
San Lazzaro (4)	1.23	1.24

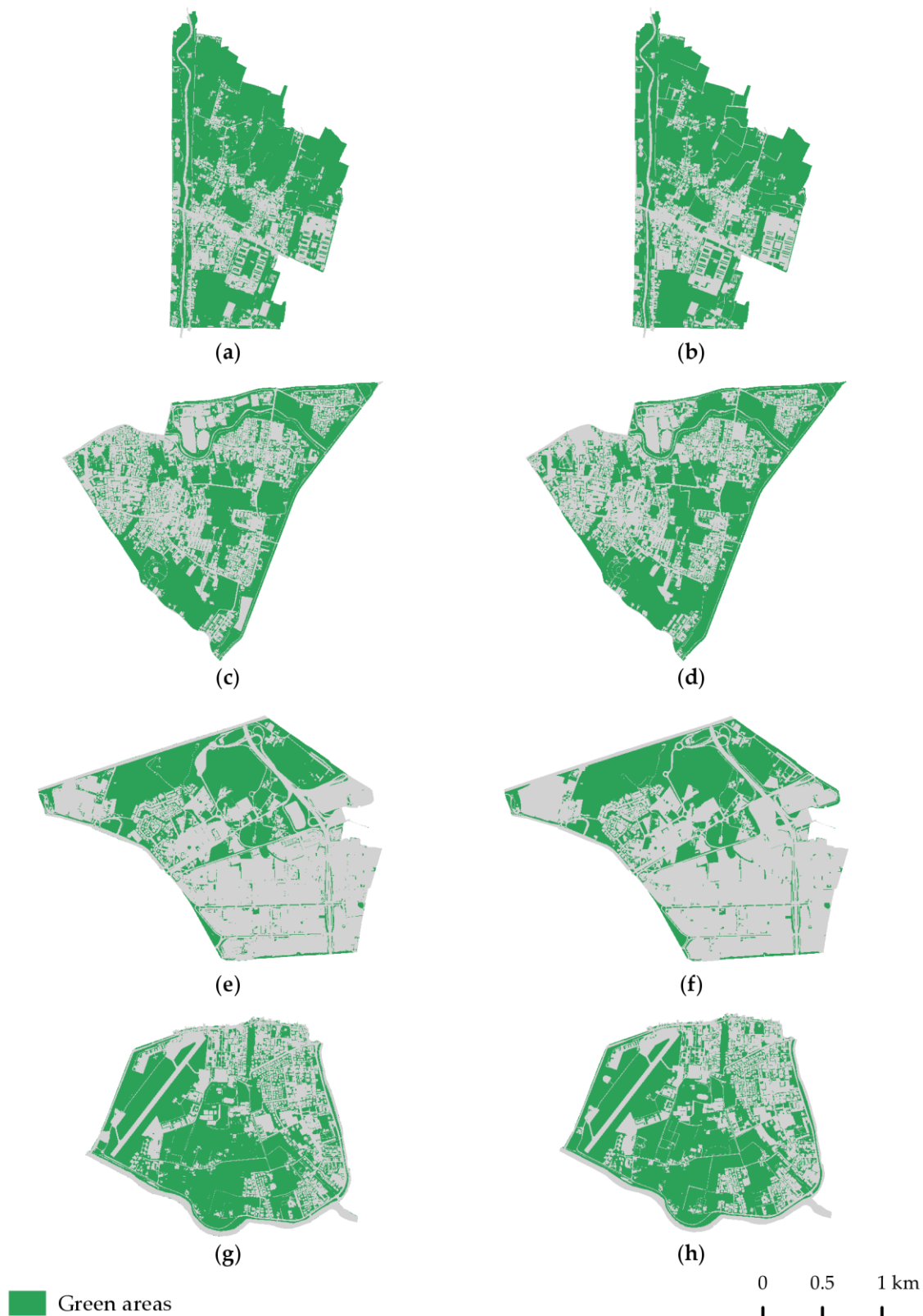


Figure 5. Comparison of green surfaces obtained from NDVI and from previous results in the four sample macro-areas (Peroni et al. 2019; Pristeri et al. 2020): (a) Brentelle neighbourhood resulted by NDVI analysis (macro-area 1); (b) Brentelle neighbourhood resulted by visual analysis (macro-area 1); (c) Forcellini neighbourhood resulted by NDVI analysis (macro-area 2); (d) Forcellini neighbourhood resulted by visual analysis (macro-area 2); (e) San Lazzaro neighbourhood resulted by NDVI analysis (macro-area 3); (f) San Lazzaro neighbourhood resulted by visual analysis (macro-area 3); (g) Basso Isonzo

neighbourhood resulted by NDVI analysis (macro-area 4); (h) Basso Isonzo neighbourhood resulted by visual analysis (macro-area 1).

Results of the spatial linear regressions calculated on the sample areas between NDVI-derived data, combined with the topographic DB, and data from visual analysis (Peroni et al. 2019; Pristeri et al. 2020) (Table 3), show that R values range from 0.80 and 0.84, indicating a high efficiency of the adopted methodology.

Table 3. Results of spatial linear regressions in the four sample areas.

Sample area	R value
Brentelle	0.80
Forcellini	0.81
Sacra Famiglia	0.84
San Lazzaro	0.84

Results of the error matrices calculated on the sample macro-areas (Table 4, Table 5, Table 6 and Table 7) show that both user's and producer's accuracy values range from 84% to 95%, indicating a high correspondence between the two datasets.

Table 4. Error matrix for Brentelle. 0 = not green; 1 = green. Rows = visual analysis; columns = NDVI + Topographic DB. UA = user's accuracy; PA = producer's accuracy.

	0	1	TOTAL	PA (%)
0	2785201	351455	3136656	84.15
1	524780	6870427	7395207	95.13
TOTAL	3309981	7221882	10531863	
UA (%)	88.80	92.90		

Table 5. Error matrix for Forcellini. 0 = not green; 1 = green. Rows = visual analysis; columns = NDVI + Topographic DB. UA = user's accuracy; PA = producer's accuracy.

	0	1	TOTAL	PA (%)
0	4899198	646442	5545640	91.01
1	484267	5864363	6348630	90.07
TOTAL	5383465	6510805	11894270	
UA (%)	88.34	92.37		

Table 6. Error matrix for Sacra Famiglia. 0 = not green; 1 = green. Rows = visual analysis; columns = NDVI + Topographic DB. UA = user's accuracy; PA = producer's accuracy.

	0	1	TOTAL	PA (%)
0	4382170	390491	4772661	89.31
1	524717	6323181	6847898	94.18
TOTAL	4906887	6713672	11620559	

UA (%) 91.82 92.34

Table 7. Error matrix for San Lazzaro. 0 = not green; 1 = green. Rows = visual analysis; columns = NDVI + Topographic DB. UA = user's accuracy; PA = producer's accuracy

	0	1	TOTAL	PA (%)
0	8320253	403748	8724001	93.54
1	574417	4359710	4934127	91.52
TOTAL	8894670	4763458	13658128	
UA (%)	95.37	88.36		

Overall accuracy and kappa coefficient for the sample macro-areas are shown in Table 8. Overall accuracy ranks above 90% in all the four areas; kappa coefficients, which measures overall agreement in classification, range from 0.80 to 0.84 with a pattern similar to R values. In conclusion, we can state that results of comparative spatial analyses in the four macro-areas allow us to validate the UGS detection operated at the city level.

Table 8. Overall accuracy and kappa coefficient in the four sample areas.

Sample area	Overall accuracy (%)	Kappa coefficient
Brentelle	91.68	0.80
Forcellini	90.49	0.81
Sacra Famiglia	92.12	0.84
San Lazzaro	92.84	0.84

3.2. Urban Green Spaces: Estimation and Binary Classification

According to NDVI-based classification and validation, the total area of UGS is 52.23 km², which represents 56% of the municipal territory of Padua. Rural green areas are 28.8 km² (55.14% of total UGS), while non-rural green areas are 23.43 km² (44.86% of total UGS).

Results about property-based UGS classification show a large preponderance of private green spaces (41.98 km², 80.38% of total UGS); on the contrary, public UGS sums up to 10.25 km² which is less than 20% of total UGS (Table 9).

Table 9. Classification of green areas in Padua.

Green area category	Area	Percentage of total green areas
Total	52.23 km ²	100 %
Rural	28.80 km ²	55.14 %
Non-rural	23.43 km ²	44.86 %
Public	10.25 km ²	19.62 %
Private	41.98 km ²	80.38 %
Municipal	5.02 km ²	9.61 %
Non-municipal	47.21 km ²	90.39 %

Finally, Padua Municipality owns about 50% of public UGS, for an amount of about 5 km² (less than 10% of the total green amount). UGS not owned by the Municipality represent about 47.21 km² which represents about 90% of the overall mapped green spaces (Table 9).

The visual analysis highlights a general pattern in the spatial distribution of UGS, from the city centre towards the borders: the urban core consists mostly of built-up surfaces, with a minority of sparse, small, or medium-sized green plots. Moreover, outward from the historical city, UGS become denser and broader so that their relationship with built-up areas changes (Figure 6). One exception is represented by the industrial area of Padua, which spreads on the eastern sector of the city.

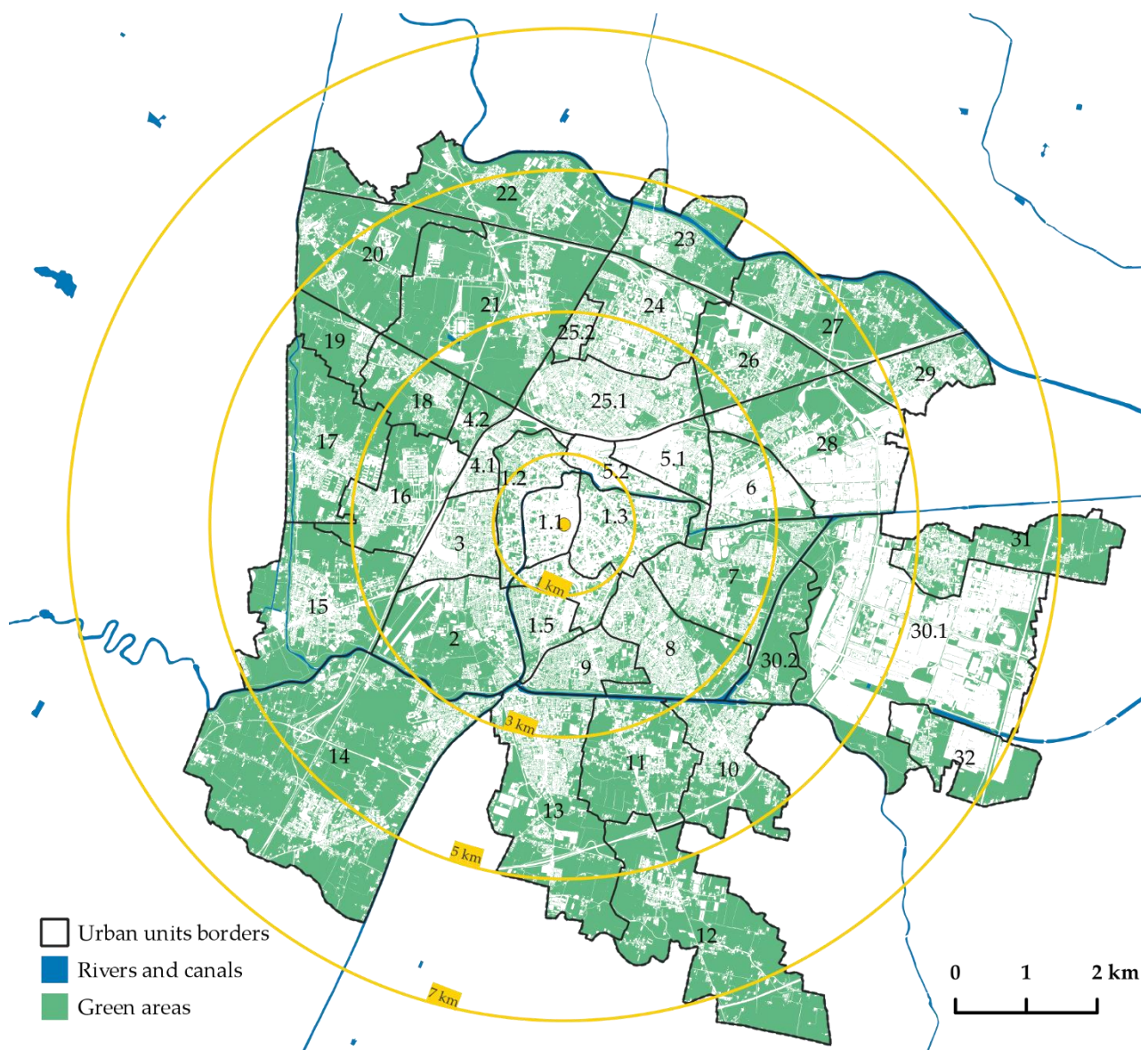


Figure 6. Spatial distribution of all urban green spaces (for definition UGS see paragraph 1.3) in the city of Padua, divided by urban units (municipal codes; see Table 11 for corresponding urban unit names). In yellow are the distances at 1 km, 3 km, 5 km, and 7 km from the city centre (yellow dot).

Figure 7 (see Section 2.2) shows the distribution of UGS feature dimensions and their distance from the city centre. The scatter diagram confirms that wider green areas are mostly located in a 3–7 km distance range from the urban centre, with a peak near a 5 km distance.

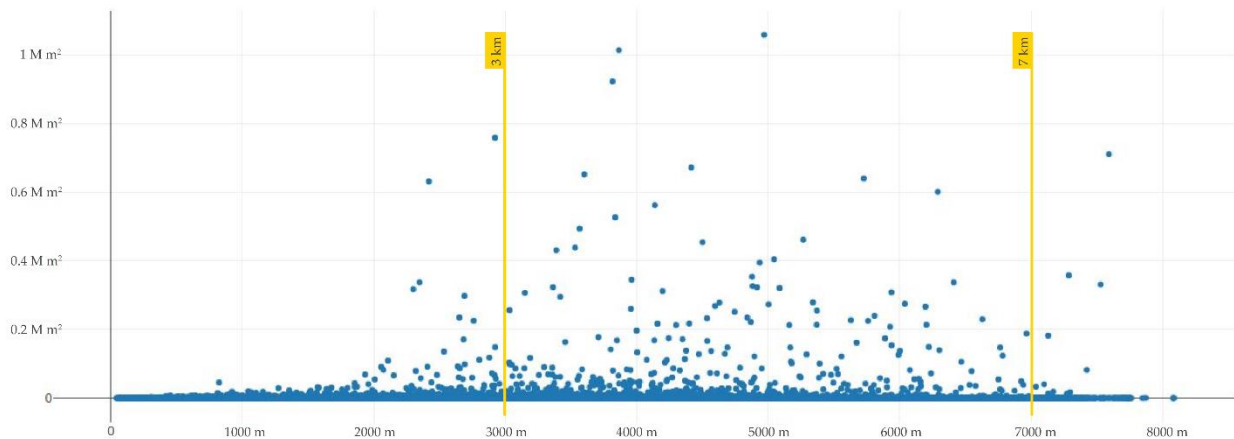


Figure 7. Scatterplot of the distribution of urban green spaces feature dimensions (y axis, m²) and distance from city centre (x axis, m).

Visual analysis of the map of rural and non-rural UGS (Figure 8) points out a centre–borders pattern similar to the one highlighted in Figure 6, with a clear prevalence of crops in the transition belt between the city and the surrounding countryside. This map also displays a size opposition, because non-rural green appears to be located in multiple, small land parcels, while agricultural areas mainly cover wide, compact land plots.

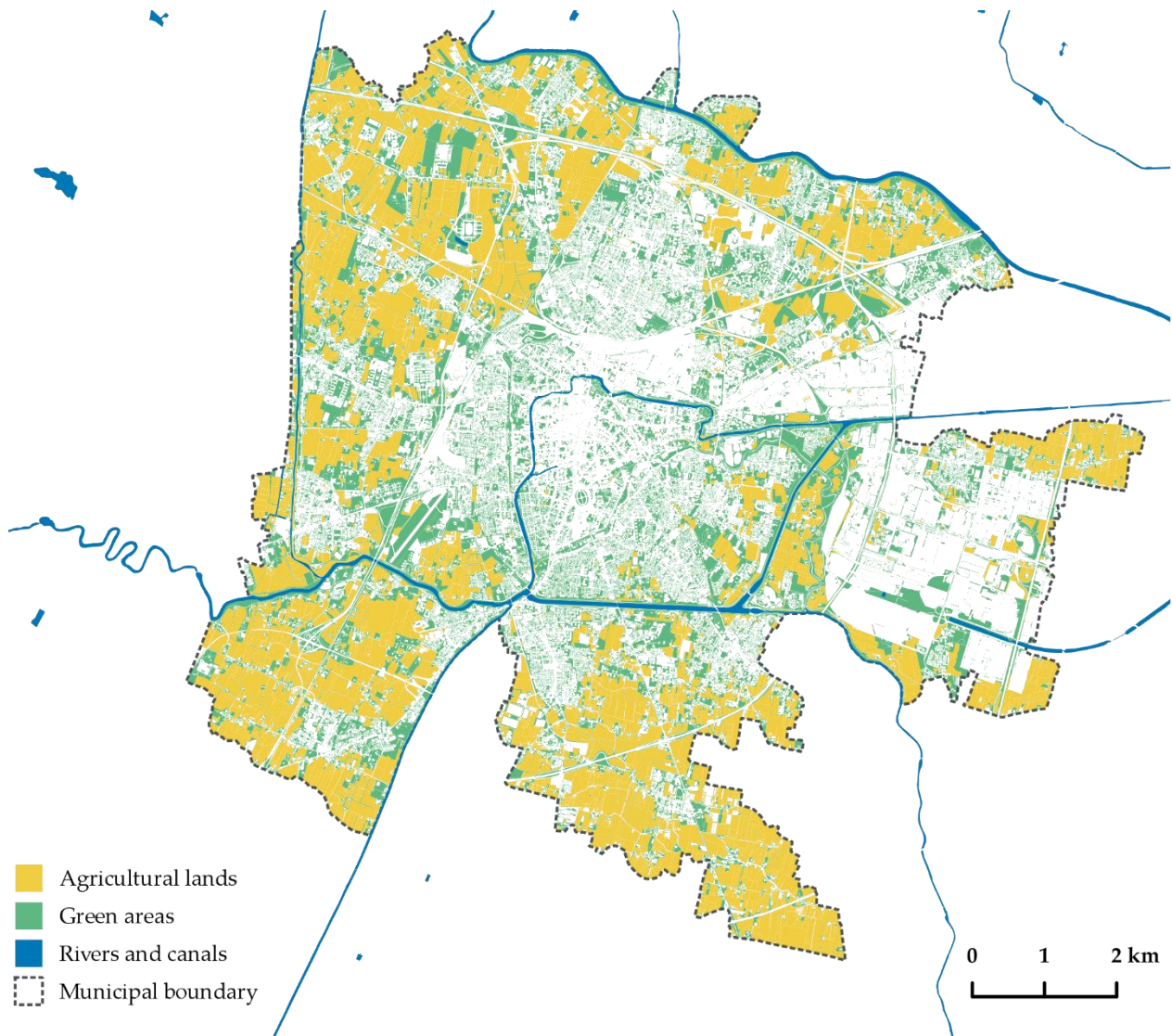


Figure 8. Map of rural and non-rural urban green spaces in Padua.

Classification of public and private UGS (Figure 9) shows a predominance of privately owned greenery: it includes both a vast majority of crops and cultivated areas towards the city edges and a lot of small-sized courts, gardens, and backyards located in the old town or beside low-rise houses spreading beyond the city walls. Most of large public green areas correspond to major city public parks.

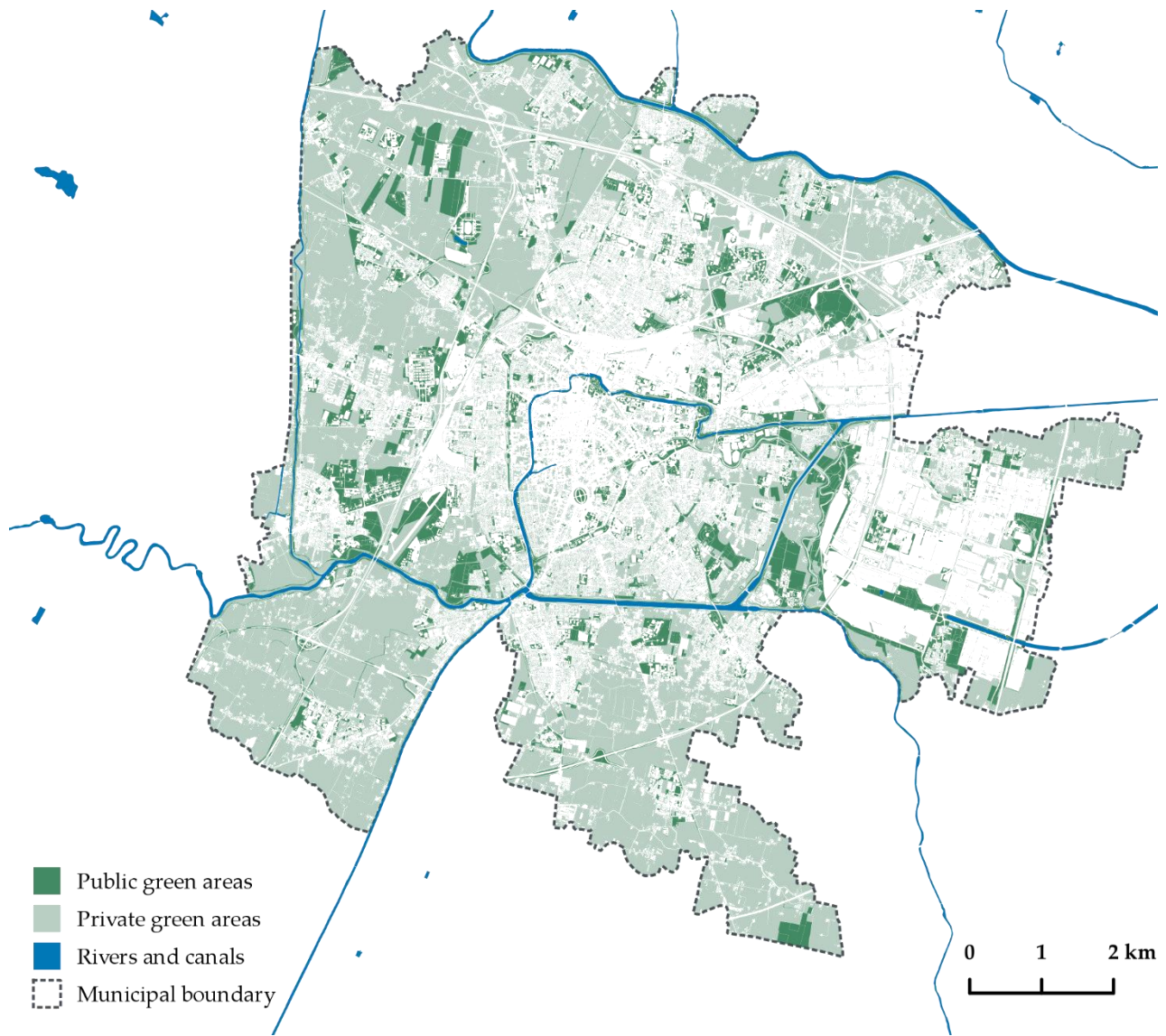


Figure 9. Map of public and private urban green spaces in Padua.

Finally, municipal UGS appear to be discontinuous, scattered subsets of municipal greenery; most recognisable areas are located outside of the core of the city (Figure 10).

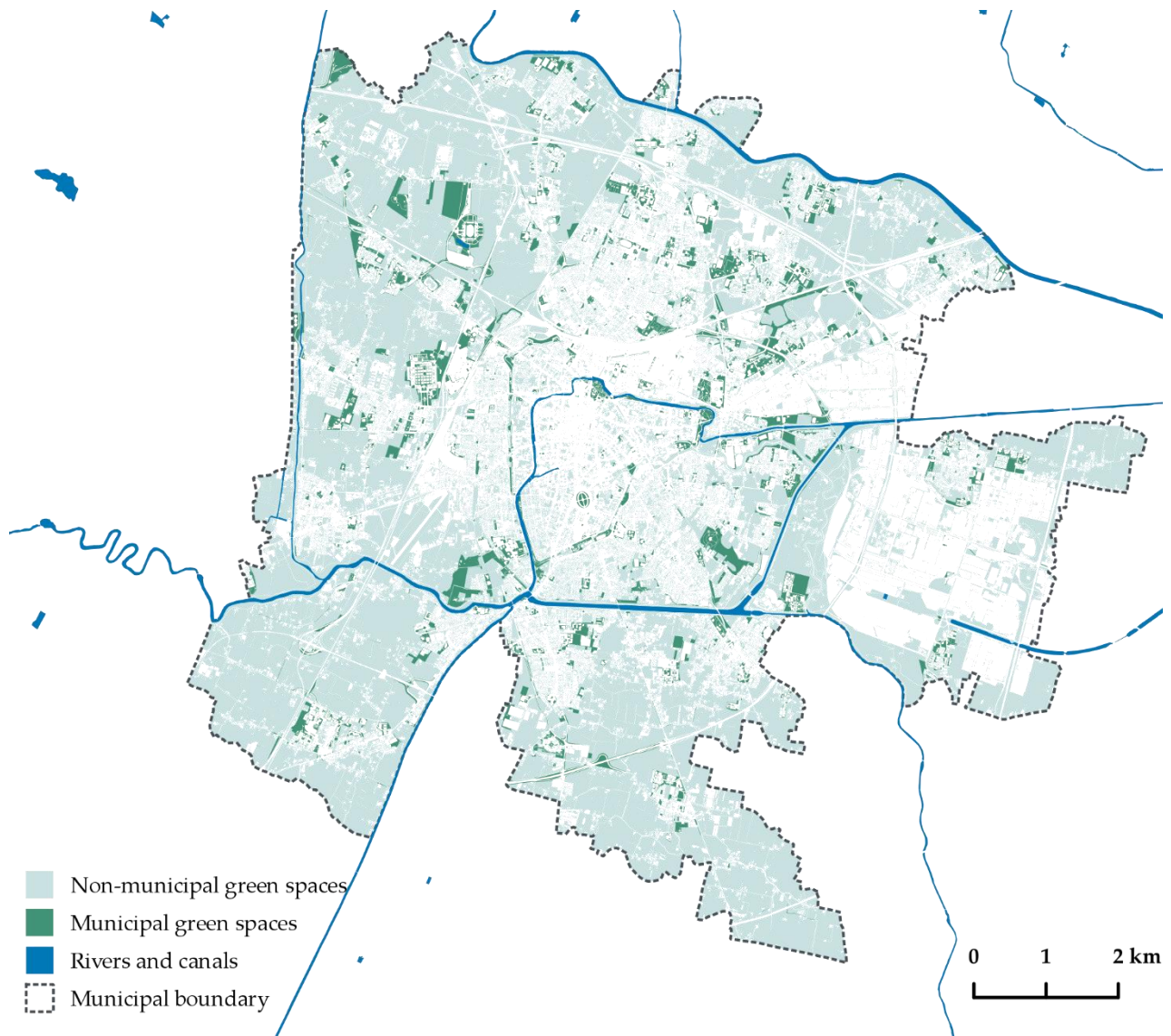


Figure 10. Map of public urban green spaces: municipal green spaces (light green), non-municipal green spaces (green).

As UES are provided by all ecosystems, it is interesting to intersect the individual contribution of public (municipal–non-municipal) and private greening with rural–non-rural UGS. This matrix suggests the possibility to focus on policies aiming to enhance ecosystem services provided by private rural areas in Padua, which represent more than 60% of total private green (Table 10).

Table 10. Matrix of public–private and rural–non-rural green areas.

Property	Total (km ²)	Rural green (km ²)	Non-rural green (km ²)	Percentage of rural green	Percentage of non-rural green
Municipal	5.03	1.22	3.81	24.25	75.75
Public, non-municipal	5.22	1.71	3.51	32.76	67.24
Private	41.98	25.89	16.09	61.67	38.33

3.3. Urban Green Spaces and Population in Padua Urban Units

In the current literature, UGS per capita is widely used as an indicator to assess environmental quality and availability of green spaces by citizens (Pafi et al. 2016; Wüstemann et al. 2016; Kabisch et al. 2016; Russo and Cirella 2018). On average, European citizens have access to about 18 m² of public green space within the boundary of their city, with a benchmarking of 20 m² per person (Maes et al. 2019). In Italy, standards fixed at a national level in 1968 and still in force set a minimum of 9 m² of accessible public green areas per capita (Repubblica Italiana 1968).

Several local case studies have been performed on this topic (Badiu et al. 2016; Kabisch et al. 2016; Shi et al. 2020); however, comparative analyses of results might be misleading due to the differences in the definition of green spaces, extraction methodology, and classification criteria. Moreover, the results of municipality-level research are widely influenced by the extent of administrative boundaries and land use patterns of study areas.

Therefore, in our study, we focused on a comparative assessment of UGS categories in Padua urban units in order to highlight variability and imbalances in their spatial distribution.

As illustrated in Section 2.5, we calculated extents and per capita rates of the different types of classified UGS for each one of the urban units in Padua (Table 11). Population in urban units is represented in Figure 11.

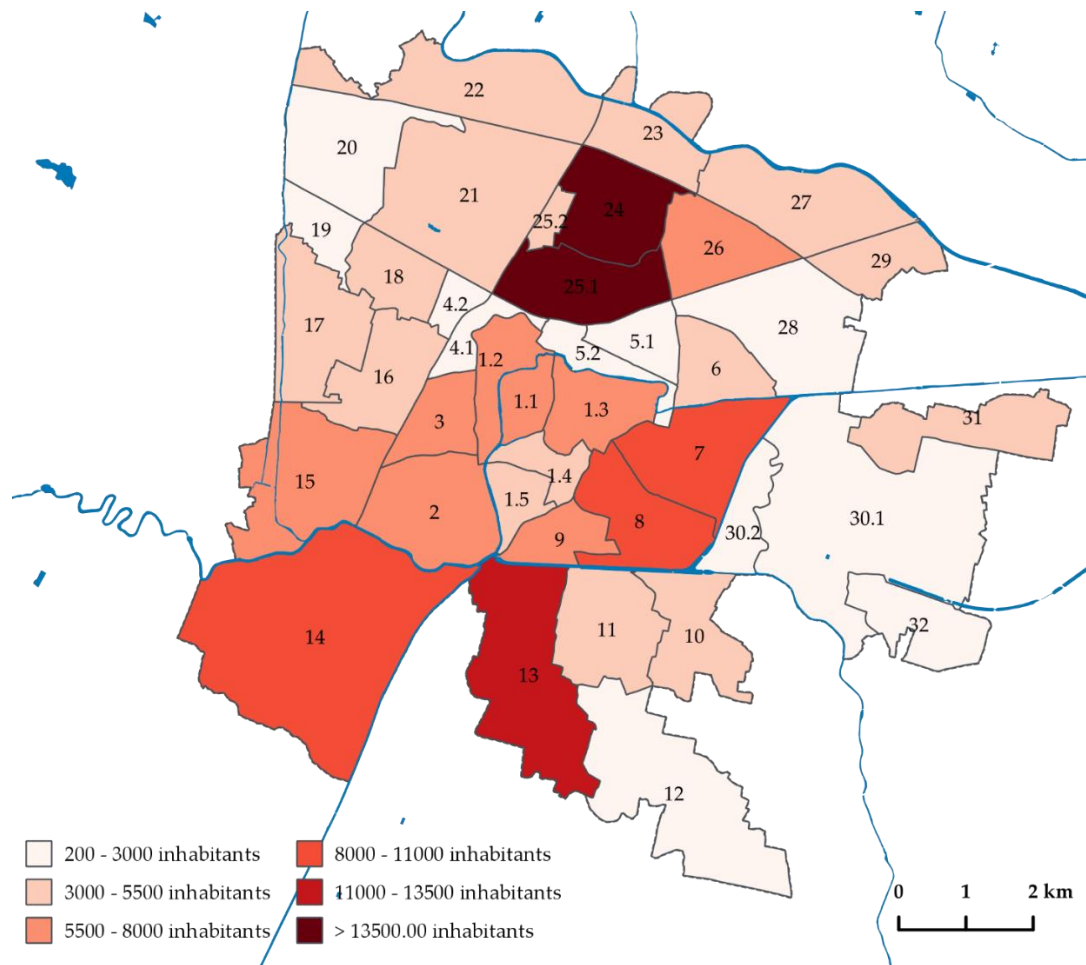


Figure 11. Population in Padua urban units. Urban units are represented in the map by their municipal codes (see Table 11 for the corresponding urban units).

Table 11. Areas and per capita (PC) values of green space categories in the urban units of Padua.

Urban unit code	Urban unit	Pop.	Area (km ²)	Pop. density per km ²	Total UGS (m ² PC)	Rural UGS (m ² PC)	Public UGS (m ² PC)	Private UGS (m ² PC)	Municipal UGS (m ² PC)
1.1	Piazze	6893	0.80	8616.25	13.88	0.19	2.44	11.45	1.11
1.2	Savonarola	6560	1.19	5535.86	63.28	1.03	24.80	38.48	13.14
1.3	Santo - Portello	6975	1.63	4292.31	65.11	0.69	31.76	33.35	17.05
1.4	Prato della Valle	3272	0.76	4305.26	68.01	1.30	27.85	40.16	15.51
1.5	Città Giardino	4168	0.78	5371.13	64.86	2.99	16.63	48.22	12.89
2	Sacra Famiglia	7327	2.77	2640.36	231.83	83.74	90.61	141.22	38.14
3	San Giuseppe	7463	1.24	6023.41	40.76	0.30	6.24	34.52	3.83
4.1	Porta Trento Sud	2468	0.63	3936.20	59.34	0.00	6.02	53.32	4.77
4.2	Porta Trento Nord	625	0.46	1346.98	457.83	184.84	123.97	333.86	123.24
5.1	Fiera	2094	1.02	2061.02	96.86	13.77	46.31	50.55	43.55
5.2	Stazione	2274	0.83	2749.70	77.24	11.12	37.09	40.15	9.98
6	Stanga	3751	1.40	2671.65	117.39	19.13	58.08	59.31	48.55
7	Forcellini	9836	2.66	3697.74	132.63	31.70	41.30	91.33	23.10
8	Madonna Pellegrina	10964	2.23	4909.99	91.02	22.45	26.52	64.51	18.50

9	Sant'Osvaldo	6646	1.08	6148.01	68.36	10.77	9.75	58.61	7.03
10	Voltabarozzo	5272	2.07	2549.32	227.63	130.88	20.90	206.73	14.85
11	SS. Crocefisso	4612	2.44	1887.07	365.24	221.59	46.17	319.07	13.80
12	Salboro	2596	4.71	551.40	1503.08	1274.32	94.64	1408.44	32.94
13	Guizza	12770	4.25	3007.54	203.04	135.60	23.96	179.07	23.02
14	Mandria	10248	8.92	1149.27	662.69	461.45	48.45	614.24	25.39
15	Brusegana	7292	3.57	2041.43	319.30	176.99	95.66	223.75	6.49
16	Cave	4210	2.07	2030.87	255.52	126.39	75.43	180.09	72.55
17	Brentelle	4274	2.60	1645.11	425.47	236.57	45.74	379.84	25.76
18	Sant'ignazio	3791	1.37	2775.26	242.66	156.46	33.00	209.66	31.21
19	Montà	1196	0.91	1309.97	613.94	416.81	75.28	538.66	68.88
20	Ponterotto	2768	2.82	982.95	801.02	607.42	119.33	681.70	53.08
21	Sacro Cuore	4903	4.96	988.71	767.44	520.22	133.60	633.84	83.24
22	Altichiero	4111	3.54	1162.94	625.81	388.66	73.02	552.80	52.34
23	Pontevigodarzere	5302	1.91	2771.56	205.12	108.11	31.42	173.70	13.98
24	San Carlo	15044	2.23	6761.35	53.69	10.29	16.75	36.94	15.11
25.1	Arcella	15944	2.25	7092.53	40.99	2.56	8.71	32.28	7.60
25.2	San Bellino	3460	0.34	10267.06	31.79	0.30	3.18	28.61	2.74
26	Mortise	6503	1.89	3438.92	153.63	72.90	45.68	107.95	30.95
27	Torre	4496	3.07	1466.41	467.90	288.98	40.02	427.88	27.17
28	San Lazzaro	1838	3.44	534.61	669.18	270.77	311.46	357.72	108.09
29	Ponte di Brenta	3470	1.27	2727.99	150.88	21.23	17.74	133.14	13.22
30.1	Zona Industriale	575	8.07	71.29	4096.68	1464.42	1888.52	2208.17	55.48
30.2	Terranegra	242	1.18	205.61	3541.26	1941.74	1749.26	1792.00	472.61
31	Camin	4052	2.25	1800.09	377.63	261.16	44.56	333.07	31.92
32	Granze	877	1.73	505.77	1023.89	647.74	311.21	712.69	50.32
PADUA		211162	93.31	2263.09	247.35	136.39	48.54	198.80	23.77

With respect to Table 11, we focus on overall, public, and municipal UGS, since these categories are, respectively, relevant for their contribution to ES provisioning, for their potential public accessibility, and for their actual public fruition managed by Padua Municipality. Values for the aforementioned UGS are graphically represented in Figure 12; density maps concerning public and municipal UGS are displayed in Figure 13.

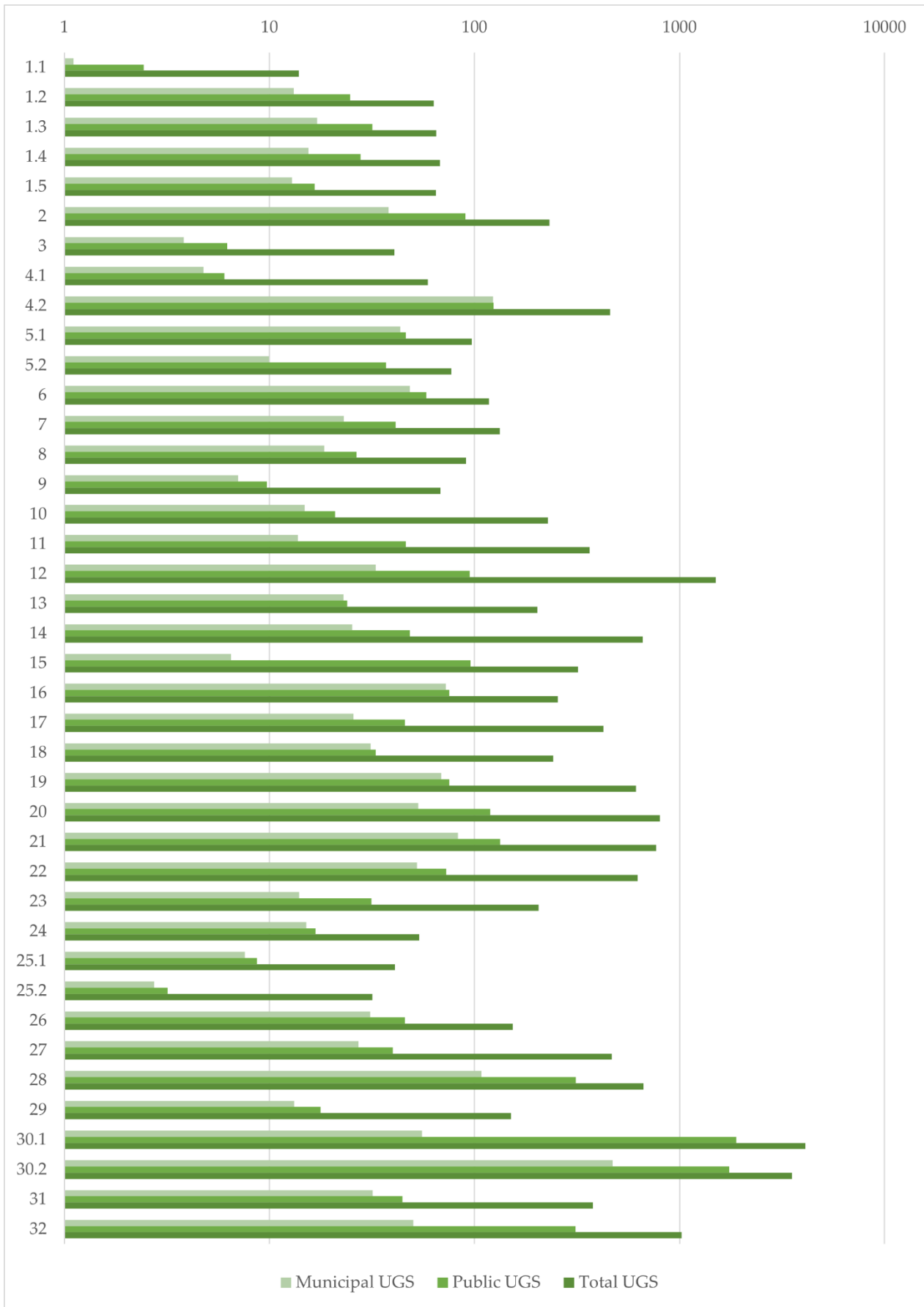


Figure 12. Total, public, and municipal UGS (x axis per capita m²) in Padua urban units (y axis).

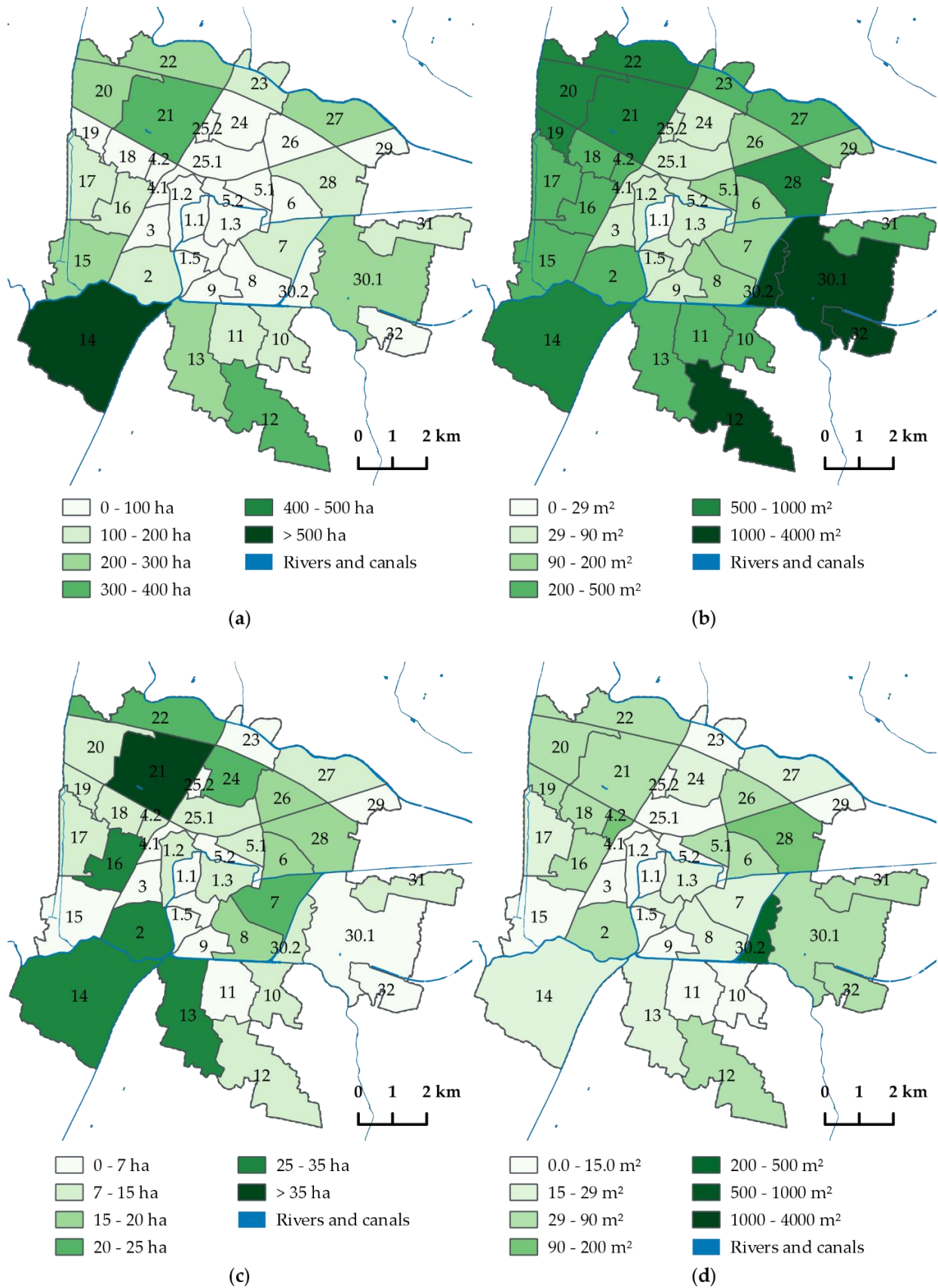


Figure 13. Spatial analyses of urban green space and population at sub-neighbourhood urban unit levels: (a) map of total urban green spaces; (b) map of urban green spaces per capita; (c) map of municipal urban green spaces; (d) map of municipal urban green spaces per capita.

Regarding municipality-scale UGS, in Padua, there is quite a remarkable total of 247.35 m² of per capita UGS; among them, public UGS areas amount to 48.54 m² per capita, and municipal UGS areas are 23.77 m² per capita.

Analysis of values in urban units shows that those included in the core city or in the densely populated northern district show the lowest rates of total UGS (e.g., 13.88 m² per capita in unit 1.1), due to the remarkable share of built-up spaces. The highest rates belong to scarcely populated, mostly agricultural peripheral urban units (e.g., 1503.08 m² per capita in unit 12); unit 30.1 (4096.68 m² per capita) is a special case because it corresponds to the industrial area of the city with a very low population density. A similar pattern applies to public UGS, for example, urban parks, where, nevertheless, there is a difference between unit 1.1 (where the city Hall, the city cathedral, and some of the main squares belong), which shows the lowest rate with 2.44 m² per capita, and the remaining urban units in the historical centre, showing slightly higher rates (up to 31.76 m² per capita in unit 1.3); other critical urban units are the dense residential districts located immediately outside the city wall system (e.g., 6.24 m² per capita in unit 3, 8.71 m² per capita in unit 25.1), implying that, in some cases, the city development outside its ancient core did not adequately consider the need for public green spaces.

As regards municipal UGS areas, their distribution in the compact city is comparable to public UGS, with the lowest rate in unit 1.1 (1.11 m² per capita) and remarkably low values for units located north and west of the historical centre and adjacent to the wall system (e.g., 3.83 m² per capita in unit 3). A special case is unit 15 on the western municipality border (6.49 m² per capita), where a compact residential suburb developed in a formerly rural area crossed by two water streams: the area is therefore quite valuable from a landscape and environmental perspective but currently lacks municipal green facilities.

Then, we briefly focus on the five most densely populated urban units (1.1; 9; 24; 25.1; 25.2), hosting almost 23% of the city population. In these units, UGS values rank far below municipality average values: total UGS areas range from 13.88 to 68.36 m² per capita (247.35 m² per capita in Padua); public UGS areas range from 2.44 to 16.75 m² per capita (48.54 m² per capita in Padua); municipal UGS areas range from 1.11 to 15.11 m² per capita (23.77 m² per capita in Padua). These values show how issues related to UGS availability are particularly relevant in the compact city and require an overall vision to be tackled.

Finally, we gathered together results on different UGS categories in a general scheme (Figure 14), where values of every UGS category assessed are divided into five equally numerous subsets or quintiles.

Urban unit	Population density	Total PC UGS density	Rural PC UGS density	Public PC UGS density	Private PC UGS density	Municipal PC UGS density	
25.2 San Bellino	P1	T5	R5	Pu5	Pr5	M5	
1.1 Piazze	P1	T5	R5	Pu5	Pr5	M5	
25.1 Arcella	P1	T5	R5	Pu5	Pr5	M5	
24 San Carlo	P1	T5	R4	Pu5	Pr5	M4	(a)
9 Sant'Osvaldo	P1	T4	R4	Pu5	Pr4	M5	(b)
3 San Giuseppe	P1	T5	R5	Pu5	Pr5	M5	
1.2 Savonarola	P1	T5	R5	Pu4	Pr5	M4	
1.5 Città Giardino	P1	T5	R4	Pu5	Pr4	M4	
8 Madonna Pellegrina	P2	T4	R4	Pu4	Pr4	M3	
1.4 Prato della Valle	P2	T4	R5	Pu4	Pr4	M4	
1.3 Santo - Portello	P2	T4	R5	Pu4	Pr5	M3	(c)
4.1 Porta Trento Sud	P2	T5	R5	Pu5	Pr4	M5	
7 Forcellini	P2	T4	R3	Pu3	Pr4	M3	
26 Mortise	P2	T3	R3	Pu3	Pr3	M3	
13 Guizza	P2	T3	R3	Pu4	Pr3	M3	
18 Sant'ignazio	P2	T3	R3	Pu3	Pr3	M2	
23 Pontevigodarzere	P3	T3	R3	Pu4	Pr3	M4	
5.2 Stazione	P3	T4	R4	Pu3	Pr5	M5	
29 Ponte di Brenta	P3	T3	R4	Pu4	Pr3	M4	
6 Stanga	P3	T4	R4	Pu2	Pr4	M2	
2 Sacra Famiglia	P3	T3	R3	Pu2	Pr3	M2	
10 Voltabarozzo	P3	T3	R3	Pu4	Pr3	M4	
5.1 Fiera	P3	T4	R4	Pu2	Pr4	M2	
15 Brusegana	P3	T2	R2	Pu1	Pr2	M5	(d)
16 Cave	P4	T3	R3	Pu2	Pr3	M1	
11 SS. Crocefisso	P4	T2	R2	Pu3	Pr2	M4	
31 Camin	P4	T2	R2	Pu3	Pr2	M2	
17 Brentelle	P4	T2	R2	Pu3	Pr2	M3	
27 Torre	P4	T2	R2	Pu3	Pr2	M3	
4.2 Porta Trento Nord	P4	T2	R2	Pu1	Pr2	M1	
19 Montà	P4	T2	R1	Pu2	Pr2	M1	
22 Altichiero	P4	T2	R2	Pu2	Pr1	M2	
14 Mandria	P5	T1	R1	Pu2	Pr1	M3	
21 Sacro Cuore	P5	T1	R1	Pu1	Pr1	M1	
20 Ponterotto	P5	T1	R1	Pu1	Pr1	M1	
12 Salboro	P5	T1	R1	Pu2	Pr1	M2	
28 San Lazzaro	P5	T1	R2	Pu1	Pr2	M1	
32 Granze	P5	T1	R1	Pu1	Pr1	M2	
30.2 Terranegra	P5	T1	R1	Pu1	Pr1	M1	
30.1 Zona Industriale	P5	T1	R1	Pu1	Pr1	M1	

Higher population density

Lower population density

Higher green areas density

Lower green areas density

Figure 14. Density classes for population and urban green space categories in the urban units of Padua, based on per capita (PC) values displayed in Table 11 and subdivided into quintiles. Units a–d are quoted as samples for outlining UGS management strategies in Section 3.4.

The scheme in Figure 14 enables an aggregate assessment for every urban unit and may help to direct policies and strategies at the municipality level, as discussed in Section 3.4. Predictably, urban units with higher population density prove less adequate in UGS per capita equipment. Moreover, a comparative analysis of density variations for different categories in critical urban units may serve as an indicator of strengths and weaknesses to start building green areas management and development strategies, thus reinforcing the link between quantitative assessments and a planning perspective.

3.4. Urban Green Spaces: From Mapping and Classifying to Spatial Planning

The study presented in this paper and, in particular, the results of green areas classifications, endows urban planning with useful geospatial data and applicative tools for UGS management and implementation.

Performance-based urban planning focuses on the environmental performance of natural and artificial features in planned areas. Although studies and publications concerning the inclusion of UES in urban plans are more and more increasing (Gómez-Baggethun and Barton 2013; Pristeri et al. 2020), to this day, they still find limited applications in planning activities by local administrators (Arcidiacono et al. 2016; Frew et al. 2016; Ronchi et al. 2020).

In our target area, the current urban development plan is the Territorial Management Plan of Padua (Comune di Padova 2014), which outlines a thematic spatial framework for the implementation of a green-and-blue infrastructure leaning upon recognisable urban features such as the wall system, the network of streams, and rivers, the major public parks and the peri-urban rural areas. However, it does not embrace UES as an analytical or planning approach. Accurate data and thematic maps about the distribution and property status of UGS, together with an assessment of related UES, could help planners in designing a site-specific, citizen-oriented urban GI.

More generally, issues concerning inequalities in access and fruition of UGS caused by built-up density in some districts would require multiple solutions, ranging from the increase of vegetation and equipped areas in municipal UGS to a focus on designing public green areas within reuse or regeneration projects for neglected sites. As an example from our case study, from Figure 14, it can be inferred that more densely populated districts show a general lack of green spaces; among them, we chose four urban units (marked with letters a–d in Figure 14) as an example of different possible general UGS management approaches:

- Unit 24 (a) is a very densely populated district with low levels of per capita UGS; however, it relies on a certain amount of municipal green spaces. UGS management may lean on improving accessibility, connectivity, and vegetation equipment of municipal green areas;
- Unit 9 (b) is also densely populated, has a higher overall UGS equipment than unit 24 but inadequate public and municipal green areas; at the same time, it is endowed with some private green areas. UGS management will be primarily based on maintaining adequate

- vegetation amounts in private green areas and fostering public accessibility, especially by walking on cycling, among these areas, also considering the proximity to a water body;
- Unit 1.3 (c) is a quite densely populated district where municipal UGS equipment stands out on the other UGS categories, due to the presence of city parks. It may serve as a green hub for the city centre and as a soft mobility gateway to the stream network, in the framework of implementing an urban GI;
 - Unit 15 (d) is an outer district with medium population density, and good overall public UGS equipment but lack municipal UGS (see also Section 3.3): it would be strategic to develop green facilities by agreements among local administrators and public institutions which own the green areas, enhancing their accessibility and soft mobility connections.

A further action, to be undertaken especially in core cities and surrounding districts, is improving connections between built-up areas and urban GI or peri-urban open spaces.

In Padua, for example, a potentially useful planning tool may be the project of the new city cycling network (Comune di Padova 2019), which could be integrated with the design of green-and-blue infrastructure, thus encouraging and easing soft mobility for leisure and health.

Furthermore, the location of non-municipal public green areas may help municipalities in developing urban GI strategies in collaboration with other public institutions. Additionally, we noted how domestic gardens and other private UGS are able to provide a fair amount of regulating and supporting UES (Dewaelheyns et al. 2014) and should be considered, together with public and accessible UGS, as components of urban GI networks. For these reasons, spatial planners should include private UGS in ecosystem services mapping in support of urban design scenarios. It would also be useful for municipalities to involve private citizens that own significant land plots in some form of sharing of green spaces with citizens. Finally, to increase continuity of public, accessible UGS, trade-ins between private and municipal green areas may be promoted by local authorities, within multilevel governance of urban land use and land cover.

To sum up, it can be stated that spatial distribution of categorised green spaces suggests some possible guidelines for managing these spaces, partially derived from our case study but provided with general validity.

In Table 12, we present a simple layout of planning strategies related to the UGS categories discussed in our case study and to the main UES they can provide.

Table 12. Possible planning strategies for the UGS categories classified in the study.

Property	Strategies for rural UGS	Strategies for non-rural UGS
Private	Undertake initiatives to prevent the abandonment of cropfields and allow accessibility of their borders Incentive peri-urban social farming, agroecology and short chains to supply city consumers [69]	Protect and incentive private vegetation development [27] Consider the location and distribution of relevant private green spaces for environmentally-centered plans and initiatives [31]
Public, non-municipal	Foster connectivity and accessibility by pedestrian and cycle paths connected to urban GI Encourage teaching and educational activities involving children and students [70]	Promote public accessibility through agreements between Municipalities and other public institutions Create and enhance urban GI leaning on existing city network systems
Municipal	Promote their use as allotments or community gardens [71] Consider the reuse of uncultivated fields as semi-natural peri-urban buffer zones connected to urban GI	Increase accessibility to public uses with pocket parks or small public urban green spaces [72] Promote trade-ins of land plots with other public or private actors to enhance green spaces continuity

4. Conclusions

Urban green space management is a crucial topic in current urban planning, and it will presumably gain further importance in the near future, especially by considering relationships with climate change and other urgent environmental issues. Classification of green spaces by type and property can help planners and authorities to develop site-specific policies and initiatives in order to enhance the environmental and social benefits provided by vegetated and pervious areas to the urban population.

In this framework, we analysed the case study of Padua, a middle-sized historical city in the northeast of Italy. We mapped urban green spaces in Padua municipality by adopting the NDVI vegetation index; then, we classified them into three binary categories: rural–non-rural, public–private, municipal–non-municipal. Finally, we calculated statistics on the distribution of green areas by urban units and on their relationship with the city population. Results indicate that rural green areas are predominant over non-rural, especially in the peripheral neighbourhoods, by a prevalence of private green areas over public. Finally, municipally owned green spaces represent less than 10% of total UGS. Then, we focused on imbalances in green space distribution within the municipality, finding that most of the densely populated urban units display values for public and municipal greenery that are definitely below the city average.

Using our results, we attempted to link quantitative assessments with a planning perspective and outline for local spatial planners and administrators aiming to foster environmental benefits for each green space category and reduce spatial inequalities, in a performance-based planning framework which considers the contribution of private green spaces for UES provision, also considering that in the city of Padua private UGS are by far predominant over public ones.

Our work could serve as a basis for further analysis on urban green connectivity and accessibility for citizens, involving an assessment of green spaces by their reachable range by walking or bike; other possible analyses may include mapping selected ecosystem services at the municipality level, with focuses on strategic districts. Future uses and developments of this study would require periodic updates of results and thematic maps to cope with changes in land cover, land use, or property.

Author Contributions

Conceptualisation, Guglielmo Pristeri, Francesca Peroni, and Salvatore Eugenio Pappalardo; Methodology, Guglielmo Pristeri, Daniele Codato, and Salvatore Eugenio Pappalardo; Analysis, Guglielmo Pristeri and Francesca Peroni; Writing—original draft preparation, Guglielmo Pristeri, Francesca Peroni, and Salvatore Eugenio Pappalardo; Writing—review and editing, Salvatore Eugenio Pappalardo, Antonio Masi, and Massimo De Marchi; Validation, Daniele Codato; Visualisation, Francesca Peroni and Guglielmo Pristeri; Project administration, Massimo De Marchi; Funding acquisition, Massimo De Marchi; Supervision, Massimo De Marchi and Antonio Masi. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

No ethical approval was required due to the use of publically available and/or aggregate secondary data.

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Conflicts of Interest

The authors declare no conflict of interest.

REFERENCES

- Adams, D. and M. Hardman. 2014. Observing Guerrillas in the Wild: Reinterpreting Practices of Urban Guerrilla Gardening. *Urban Studies*. 51:1103–1119.
- Ahern, J. 2007. Green infrastructure for cities: the spatial dimension. 267–283 *In* V. Novotny and P. Brown, editors. *Cities of the Future: Towards Integrated Sustainable Water and Landscape Management*. IWA Publishing, London, UK.
- Aksoy, E. M. Gregor C. Schröder M. Löhnertz and G. Louwagie. 2017. Assessing and analysing the impact of land take pressures on arable land. *Solid Earth*. 8:683–695.
- Al-Kodmany, K. 2018. The Vertical Farm: A Review of Developments and Implications for the Vertical City. *Buildings*. 8:24.
- Albino, V. U. Berardi and R. M. Dangelico. 2015. Smart Cities: Definitions, Dimensions, Performance, and Initiatives. *Journal of Urban Technology*. 22:3–21.
- Alexandri, E. and P. Jones. 2008. Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates. *Building and Environment*. 43:480–493.
- Allwinkle, S. and P. Cruickshank. 2011. Creating smart-er cities: An overview. *Journal of Urban Technology*. 18:1–16.
- Altieri, M. A. 1995. *Agroecology. The science of sustainable agriculture*. CRC Press, Boca Raton, USA.
- Altieri, M. A. and F. R. F. Funes-Monzote. 2012. The Paradox of Cuban Agriculture. *Monthly Review*. Retrieved from <https://monthlyreview.org/2012/01/01/the-paradox-of-cuban-agriculture/>. Accessed February 2020.
- Altieri, M. A. and C. I. Nicholls. 2019. Urban agroecology. *AgroSur*. 46:46–60.
- Álvarez, D. G. 2017. Cartographic scale and minimum mapping unit influence on LULC modelling. 327–334 *In* L. Ragia, J. G. Rocha, and R. Laurini, editors. *Proceedings of the 3rd International Conference on Geographical Information Systems Theory, Applications and Management - GAMOLCS*. SciTePress, Porto.
- Amato, F. F. Martellozzo G. Nolè and B. Murgante. 2017. Preserving cultural heritage by supporting landscape planning with quantitative predictions of soil consumption. *Journal of Cultural Heritage*. 23:44–54.
- de Amorim, W. S. A. Borchardt Deggau G. do Livramento Gonçalves S. da Silva Neiva A. R. Prasath and J. B. Salgueirinho Osório de Andrade Guerra. 2019. Urban challenges and opportunities to promote sustainable food security through smart cities and the 4th industrial revolution. *Land Use Policy*. 87:104065.
- Andersson-Sköld, Y. J. Klingberg B. Gunnarsson K. Cullinane I. Gustafsson M. Hedblom I. Knez F. Lindberg Å. Ode Sang H. Pleijel P. Thorsson and S. Thorsson. 2018. A framework for assessing urban greenery's effects and valuing its ecosystem services. *Journal of Environmental Management*. 205:274–285.
- Angelidou, M. 2015. Smart cities: A conjuncture of four forces. *Cities*. 47:95–106.
- Aragón-Durand, F. J. Corfee-Morlot R. B. R. Kiunsi M. Pelling D. C. Roberts and W. Solecki. 2014. Urban Areas. 535–612 *In* V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. . Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, N. Levy, S. MacCracken, P. R. Mastrandrea, and L. L. White, editors. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom

and New York, NY, USA.

- Arcidiacono, A. S. Ronchi and S. Salata. 2016. Managing Multiple Ecosystem Services for Landscape Conservation: A Green Infrastructure in Lombardy Region. *Procedia Engineering*. 161:2297–2303.
- Arnold, C. L. and C. J. Gibbons. 1996. Impervious Surface Coverage: The Emergence of a Key Environmental Indicator. *Journal of the American Planning Association*. 62:243–258.
- Artmann, M. 2015. Managing urban soil sealing in Munich and Leipzig (Germany)-From a wicked problem to clumsy solutions. *Land Use Policy*. 46:21–37.
- Artmann, M. 2016. Urban gray vs. urban green vs. soil protection — Development of a systemic solution to soil sealing management on the example of Germany. *Environmental Impact Assessment Review*. 59:27–42.
- Artmann, M. and J. Breuste. 2015. Cities Built for and by Residents: Soil Sealing Management in the Eyes of Urban Dwellers in Germany. *Journal of Urban Planning and Development*. 141:1–13.
- Artmann, M. L. Inostroza and P. Fan. 2019. Urban sprawl, compact urban development and green cities. How much do we know, how much do we agree? *Ecological Indicators*. 96:3–9.
- Artmann, M. and K. Sartison. 2018. The Role of Urban Agriculture as a Nature-Based Solution: A Review for Developing a Systemic Assessment Framework. *Sustainability*. 10:1937.
- Arun, M. and M. Teng Yap. 2000. Singapore : The Development of an Intelligent Island and Social Dividends of Information Technology. *Urban Studies*. 37:1749–1756.
- Asad, M. S. Rashid Ahmad F. Ali R. Mehmoo M. A. Butt and S. Rathore. 2017. Use Of Remote Sensing For Urban Impervious Surfaces: A Case Study Of Lahore . *International Journal of Engineering and Applied Sciences*. 4.
- Atasoy, M. 2018. Monitoring the urban green spaces and landscape fragmentation using remote sensing: a case study in Osmaniye, Turkey. *Environmental Monitoring and Assessment*. 190:1–8.
- Babí Almenar, J. T. Elliot B. Rugani B. Philippe T. Navarrete Gutierrez G. Sonnemann and D. Geneletti. 2021. Nexus between nature-based solutions, ecosystem services and urban challenges. *Land Use Policy*. 100:104898.
- Badiu, D. L. C. I. Iojă M. PĂtroescu J. Breuste M. Artmann M. R. NițĂ S. R. GrĂdinaru C. A. Hossu and D. A. Onose. 2016. Is urban green space per capita a valuable target to achieve cities' sustainability goals? Romania as a case study. *Ecological Indicators*. 70:53–66.
- Bagan, H. and Y. Yamagata. 2014. Land-cover change analysis in 50 global cities by using a combination of Landsat data and analysis of grid cells. *Environmental Research Letters*. 9.
- Ballin, M. G. Barcaroli M. Masselli and M. Scarnó. 2018. Redesign sample for Land Use/Cover Area frame Survey (LUCAS) 2018. Luxembourg. Retrieved from <https://ec.europa.eu/eurostat/documents/3888793/9347564/KS-TC-18-006-EN-N.pdf/26cbdb1a-c418-4dfa-bc24-a27d1bc5599c?t=1540804305000>. Accessed July 2021.
- Baltimore Sun. 2018. Urban Farm Coming to Former Sparrows Point Steel Mill Site in Baltimore County. Retrieved from <http://www.baltimoresun.com/business/bs-md-sparrows-point-farm-20180508-story.html>. Accessed March 2020.
- Bates, J. 2012. “This is what modern deregulation looks like” : co-optation and contestation in the shaping of the UK’s Open Government Data Initiative . Retrieved from <http://www.ci-journal.net/index.php/ciej/article/view/845/916>. Accessed March 2020.

- Becker, G. and R. Mohren. 1990. The Biotope Area Factor as an Ecological Parameter. *Landschaft: Planen & Bauen*, Berlin, Germany.
- Beddington, J. M. Asaduzzaman A. Fernandez M. Clark M. Guillou L. Jahn M. van Erda T. Mamo N. Van Bo C. A. Nobre R. Scholes R. Sharma and J. Wakhungu. 2011. Achieving food security in the face of climate change. Copenhagen. Retrieved from www.ccafs.cgiar.org/commission. Accessed February 2020.
- Behnisch, M. H. Poglitsch and T. Krüger. 2016. Soil sealing and the complex bundle of influential factors: Germany as a case study. *ISPRS International Journal of Geo-Information*. 5:1–23.
- Bian Li Zuo Lei Zhang and Nan. 2019. Estimating 2009–2017 Impervious Surface Change in Gwadar, Pakistan Using the HJ-1A/B Constellation, GF-1/2 Data, and the Random Forest Algorithm. *ISPRS International Journal of Geo-Information*. 8:443.
- Birch, C. P. D. S. P. Oom and J. A. Beecham. 2007. Rectangular and hexagonal grids used for observation, experiment and simulation in ecology. *Ecological Modelling*. 206:347–359.
- Birk, R. J. T. Stanley G. I. Snyder T. A. Hennig M. M. Fladeland and F. Policelli. 2003. Government programs for research and operational uses of commercial remote sensing data. *Remote Sensing of Environment*. 88:3–16.
- Boschetto, P. and A. Schiavon. 2011. The Image of Metropolitan Territory. The Metropolitan City of Padua (in Italian: *L'immagine del Territorio Metropolitano*. La Città Metropolitana di Padova. (P. Boschetto and A. Schiavon, Eds.). Cleup, Padova, Italy.
- Brown, G. 2004. Mapping Spatial Attributes in Survey Research for Natural Resource Management: Methods and Applications. <http://dx.doi.org/10.1080/08941920590881853>. 18:17–39.
- Brown, K. H. M. Bailkey A. Meares-Choen J. Nasr J. Smit T. Buchanan and Mann Peter. 2003. Urban Agriculture and Community Food Security in the United States: Farming from the City Center to Urban Fring. Retrieved from <https://community-wealth.org/content/urban-agriculture-and-community-food-security-united-states-farming-city-center-urban-fringe>. Accessed February 2020.
- Buccola, N. and G. Spolek. 2011. A Pilot-Scale Evaluation of Greenroof Runoff Retention, Detention, and Quality. *Water, Air, & Soil Pollution*. 216:83–92.
- Burghardt, W. 2006. Soil sealing and soil properties related to sealing. Geological Society, London, Special Publications. 266:117–124.
- Bush, J. and A. Doyon. 2019. Building urban resilience with nature-based solutions: How can urban planning contribute? *Cities*. 95:102483.
- Calzolari, C. P. Tarocco N. Lombardo N. Marchi and F. Ungaro. 2020. Assessing soil ecosystem services in urban and peri-urban areas: From urban soils survey to providing support tool for urban planning. *Land Use Policy*. 99:105037.
- Cameron, R. W. F. T. Blanuša J. E. Taylor A. Salisbury A. J. Halstead B. Henricot and K. Thompson. 2012. The domestic garden – Its contribution to urban green infrastructure. *Urban Forestry & Urban Greening*. 11:129–137.
- Cao, S. D. Hu Z. Hu W. Zhao S. Chen and C. Yu. 2018. Comparison of spatial structures of urban agglomerations between the Beijing-Tianjin-Hebei and Boswash based on the subpixel-level impervious surface coverage product. *Journal of Geographical Sciences* 2018 28:3. 28:306–322.
- Caputo, P. F. Zagarella M. A. Cusenza M. Mistretta and M. Cellura. 2020. Energy-environmental assessment of the UIA-OpenAgri case study as urban regeneration project through agriculture. *Science of The Total*

Environment. 729:138819.

- Cardullo, P. and R. Kitchin. 2019. Being a 'citizen' in the smart city: up and down the scaffold of smart citizen participation in Dublin, Ireland. *GeoJournal*. 84:1–13.
- Carr, D. B. A. R. Olsen and D. White. 1992. Hexagon Mosaic Maps for Display of Univariate and Bivariate Geographical Data. *Cartography and Geographic Information Systems*. 19:228–236.
- Carvalho, L. 2015. Smart cities from scratch? A socio-technical perspective. *Cambridge Journal of Regions, Economy and Society*. 8:43–60.
- Casella, V. M. Franzini and R. De Lotto. 2016. Geomatics for smart cities: obtaining the urban planning baf index from existing digital maps. 689–694 *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. Prague, Czech Republic.
- Casti, E. 2014. Aree dismesse e obsolete in Lombardia, Rapporto I fase di ricerca del progetto Rifo/It. Bergamo. Retrieved from www.unibg.it/diathesis. Accessed January 2022.
- Ceccarelli, T. S. Bajocco L. Salvati and L. Perini. 2014. Investigating syndromes of agricultural land degradation through past trajectories and future scenarios. *Soil Science and Plant Nutrition*. 60:60–70.
- Cervinka, R. M. Schwab R. Schönbauer I. Hämmerle L. Pirgie and J. Sudkamp. 2016. My garden – my mate? Perceived restorativeness of private gardens and its predictors. *Urban Forestry & Urban Greening*. 16:182–187.
- Chen, Y. and S. Yu. 2016. Assessment of urban growth in Guangzhou using multi-temporal, multi-sensor Landsat data to quantify and map impervious surfaces. *International Journal of Remote Sensing*. 37:5936–5952.
- Choptiany, J. M. B. E. Graeub S. Hatik D. Conversa and S. T. Ledermann. 2019. Participatory Assessment and Adaptation for Resilience to Climate Change. *Consilience*. 21:17–31.
- Clark, C. C. Ordóñez and S. J. Livesley. 2020. Private tree removal, public loss: Valuing and enforcing existing tree protection mechanisms is the key to retaining urban trees on private land. *Landscape and Urban Planning*. 203:103899.
- Climate ADAPT. 2016. Berlin Biotope Area Factor - Implementation of guidelines helping to control temperature and runoff - Climate ADAPT. Retrieved from https://climate-adapt.eea.europa.eu/metadata/case-studies/berlin-biotope-area-factor-2013-implementation-of-guidelines-helping-to-control-temperature-and-runoff/#challenges_anchor. Accessed November 2019.
- Colding, J. 2011. The Role of Ecosystem Services in Contemporary Urban Planning. 228–237 *In* J. Niemelä, J. H. Breuste, T. Elmqvist, G. Guntenspergen, P. James, and N. E. McIntyre, editors. *Urban Ecology: patterns, processes and applications*. Oxford University Press, Oxford, UK.
- Commission, E. 2019. Soil - Soil Sealing. Retrieved from https://ec.europa.eu/environment/soil/sealing_guidelines.htm. Accessed November 2019.
- Commission of the European Communities. 2002. Towards a Thematic Strategy for Soil Protection. CEC, Brussels, Belgium.
- Commission of the European Communities (CEC). 2002. Communication "Towards a Thematic Strategy for Soil Protection" COM(2002) 179 final. Brussels. Retrieved from <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52002DC0179&from=EN>. Accessed January 2019.
- Commissione Europea. 2007. Direttiva 2007/2/CE del Parlamento europeo e del Consiglio, del 14 marzo 2007, che istituisce un'Infrastruttura per l'informazione territoriale nella Comunità europea (Inspire). *Gazzetta* 229

ufficiale dell'Unione Europea.

- Comune di Padova. 2004. Padova, città d'acque. Un modo diverso per conoscere la città. Ufficio Turismo Settore Comunicazioni ai Cittadini, Padova, Italia.
- Comune di Padova. 2014. Territorial Management Plan. Technical Implementation Standards (in Italian: Piano di Assetto del Territorio. Norme Tecniche di Attuazione. Padua, Italy.
- Comune di Padova. 2018. Plan of Interventions. Technical Implementation Standards (in Italian: Piano Degli Interventi. Norme Tecniche di Attuazione. Padua, Italy.
- Comune di Padova. 2019. Padua Bici Masterplan 2018–2022. Relation (in Italian: Bici Masterplan di Padova 2018–2022. Relazione). Padua, Italy.
- Comune di Padova. 2020. 2019 Statistical Yearbook (in Italian: Annuario Statistico 2019). Padova, Italy.
- Congedo, L. L. Sallustio M. Munafò M. Ottaviano D. Tonti and M. Marchetti. 2016. Copernicus high-resolution layers for land cover classification in Italy. *Journal of Maps*. 12:1195–1205.
- Contesse, M. B. J. M. van Vliet and J. Lenhart. 2018. Is urban agriculture urban green space? A comparison of policy arrangements for urban green space and urban agriculture in Santiago de Chile. *Land Use Policy*. 71:566–577.
- Cortijo, A. A. and M. E. P. González. 2017. Soil sealing in Madrid (Spain), study case of Colmenar Viejo. *Earth Sciences Research Journal*. 21:111–116.
- Cortinovis, C. and D. Geneletti. 2019. A framework to explore the effects of urban planning decisions on regulating ecosystem services in cities. *Ecosystem Services*. 38:100946.
- Coseo, P. and L. Larsen. 2019. Accurate Characterization of Land Cover in Urban Environments: Determining the Importance of Including Obscured Impervious Surfaces in Urban Heat Island Models. *Atmosphere* 2019, Vol. 10, Page 347. 10:347.
- CRCS. 2018. CRCS 2018: consumo di suolo, servizi ecosistemici e green infrastructures. (A. Arcidiacono, D. Di Simine, S. Ronchi, and S. Salata, Eds.). INU Edizioni, Roma, Italia.
- Crescini Di Montevecchio Benedetti, E. 2018. Consumo di suolo a Padova: analisi GIS del quartiere Forcellini (PD) e calcolo dell'indice Biotopo Area Factor. Università degli Studi di Padova.
- Czemieli Berndtsson, J. 2010, April. Green roof performance towards management of runoff water quantity and quality: A review.
- Davies, C. and R. Laforteza. 2019. Transitional path to the adoption of nature-based solutions. *Land Use Policy*. 80:406–409.
- Decoville, A. and M. Schneider. 2016. Can the 2050 zero land take objective of the EU be reliably monitored? A comparative study. *Journal of Land Use Science*. 11:331–349.
- Department of Economic and Social Affairs of United Nations. 2015. Goal 11 . Retrieved from <https://sdgs.un.org/goals/goal11>. Accessed October 2021.
- Despommier, D. and E. Ellingsen. 2008. The Vertical Farm: The sky-scraper as vehicle for a sustainable urban agriculture. *In* A. Wood, editor. CTBUH 8th World Congress 2008. Dubai, United Arab Emirates.
- Dewaelheyns, V. E. Rogge and H. Gulinck. 2014. Putting domestic gardens on the agenda using empirical spatial data: The case of Flanders. *Applied Geography*. 50:132–143.
- Dobermann, A. B. S. Backmore S. E. Cook and V. Adamchuk. 2004. Precision farming: Challenges and future directions. *In* T. Fischer, N. Turner, J. Angus, L. McIntyre, M. Robertson, A. Borrell, and D. Lloyd, editors. Proceedings of the 4th International Crop Science Congress. Brisbane, Australia.

- Duru, M. O. Therond and M. Fares. 2015. Designing agroecological transitions; A review. *Agronomy for Sustainable Development*. 35:1237–1257.
- Eigenbrod, F. V. A. Bell H. N. Davies A. Heinemeyer P. R. Armsworth and K. J. Gaston. 2011. The impact of projected increases in urbanization on ecosystem services. 3201–3208 *In* M. P. Hassell, S. H. Alonzo, G. R. Carvalho, I. C. Cuthill, H. A. P. Heesterbee, and M. T. Siva-Jothy, editors. *Proc. R. Soc. B. London, UK*.
- Elvidge, C. D. B. T. Tuttle P. S. Sutton K. E. Baugh A. T. Howard C. Milesi B. L. Bhaduri and R. Nemani. 2007. Global Distribution and Density of Constructed Impervious Surfaces. *Sensors (Basel, Switzerland)*. 7:1962.
- Estellés Arolas, E. and F. González Ladrón-de-Guevara. 2012. Towards an integrating crowdsourcing definition. *Journal of Information Science* . 32:189–200.
- EU Commission. 2016. Mapping and Assessment of Ecosystems and their Services Urban ecosystems 4th Report Final. Retrieved from <http://ec.europa.eu>. Accessed November 2019.
- EU Parliament and EU Council. 2013. General Union Environment Action Programme to 2020 'Living well, within the limits of our planet.' 171–200.
- European Commission. 2011. Roadmap to a Resource Efficient Europe. Communication from the Commission to the European Parliament, the Council, the European economic and social committee and the committee of the regions. Brussels. Retrieved from <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0571&from=EN>. Accessed April 2019.
- European Commission. 2012a. Soil Sealing. *Science for Environment Policy*.:1–41.
- European Commission. 2012b. Guidelines on best practice to limit, soil sealing mitigate or compensate. EC, Belgium.
- European Commission. 2020. Mapping Guide v6.2 for a European Urban Atlas Regional Policy. Retrieved from http://www.stadtentwicklung.berlin.de/umwelt/umweltatlas/ed610_03.htm. Accessed October 2021.
- European Environment Agency. 2016. The direct and indirect impacts of EU policies on land. Luxembourg. Retrieved from <https://www.eea.europa.eu/publications/impacts-of-eu-policies-on-land>. Accessed October 2021.
- European Environment Agency. 2018. Copernicus Land Monitoring Service – High Resolution Layer Imperviousness. Copernicus team at EEA. Retrieved from <https://land.copernicus.eu/user-corner/technical-library/hrl-imperviousness-technical-document-prod-2015>. Accessed January 2019.
- European Parliament. 2014. Precision agriculture: an opportunity for EU farmers - potential support with the CAP 2014-2020. Retrieved from https://www.europarl.europa.eu/thinktank/it/document.html?reference=IPOL-AGRI_NT%282014%29529049. Accessed February 2020.
- Fadini, U. 2013. Walls of Padua. A guide to the Renaissance Fortification System (in Italian: Mura di Padova. Guida al Sistema Bastionato Rinascimentale. (U. Fadini, Ed.). Edibus, Vicenza, Italy.
- Faivre, N. M. Fritz T. Freitas B. de Boissezon and S. Vandewoestijne. 2017. Nature-Based Solutions in the EU: Innovating with nature to address social, economic and environmental challenges. *Environmental Research*. 159:509–518.
- FAO. 2015. Status of the World's Soil Resources: Main Report. Retrieved from <http://www.fao.org/documents/card/en/c/c6814873-efc3-41db-b7d3-2081a10ede50/>. Accessed

February 2020.

- FAO Food and Agriculture Organization of the United Nations. 2010. Fighting Poverty and Hunger. What Role for Urban Agriculture? Retrieved from www.fao.org/fcit. Accessed March 2021.
- FAO Food and Agriculture Organization of the United Nations. 2018a. RIMA | Resilience Index Measurement and Analysis (RIMA). Retrieved from <http://www.fao.org/resilience/background/tools/rima/en/>. Accessed March 2020.
- FAO Food and Agriculture Organization of the United Nations. 2018b. Self-evaluation and Holistic Assessment of climate Resilience of farmers and Pastoralists (SHARP) | Food and Agriculture Organization of the United Nations.
- Feltynowski, M. and J. Kronenberg. 2020. Urban Green Spaces—An Underestimated Resource in Third-Tier Towns in Poland. *Land* 2020, Vol. 9, Page 453. 9:453.
- Feng, D. Y. Zhao L. Yu C. Li J. Wang N. Clinton Y. Bai A. Belward Z. Zhu and P. Gong. 2016. Circa 2014 African land-cover maps compatible with FROM-GLC and GLC2000 classification schemes based on multi-seasonal Landsat data. <http://dx.doi.org/10.1080/01431161.2016.1218090>. 37:4648–4664.
- Fernandez, M. 2017. Urban Agriculture in Cuba: 30 years of policy and practice. *Urban Agroecology*. Retrieved from <https://ruaf.org/document/urban-agriculture-magazine-no-33-urban-agroecology/>. Accessed.
- Fini, A. P. Frangi J. Mori D. Donzelli and F. Ferrini. 2017. Nature based solutions to mitigate soil sealing in urban areas: Results from a 4-year study comparing permeable, porous, and impermeable pavements. *Environmental Research*. 156:443–454.
- Food Tank. 2016. Twelve Organizations Promoting Urban Agriculture around the World. Retrieved from <http://www.fao.org/family-farming/detail/en/c/461898/>. Accessed February 2020.
- Fouilleux, E. N. Bricas and A. Alpha. 2017. 'Feeding 9 billion people': global food security debates and the productionist trap. *Journal of European Public Policy*. 24:1658–1677.
- Franke, J. D. A. Roberts K. Halligan and G. Menz. 2009. Hierarchical Multiple Endmember Spectral Mixture Analysis (MESMA) of hyperspectral imagery for urban environments. *Remote Sensing of Environment*. 113:1712–1723.
- Franklin, J. J. Rogan S. R. Phinn and C. E. Woodcock. 2003. Rationale and Conceptual Framework for Classification Approaches to Assess Forest Resources and Properties. 279–300 *In* M. A. Wulder and S. E. Franklin, editors. *Remote Sensing of Forest Environments*. Springer, Boston.
- Frew, T. D. Baker and P. Donehue. 2016. Performance based planning in Queensland: A case of unintended plan-making outcomes. *Land Use Policy*. 50:239–251.
- Frew, T. G. 2011. The implementation of performance based planning in Queensland under the integrated planning act 1997: an evaluation of perceptions and planning schemes. Queensland University of Technology.
- Fu, Y. J. Li Q. Weng Q. Zheng L. Li S. Dai and B. Guo. 2019. Characterizing the spatial pattern of annual urban growth by using time series Landsat imagery. *Science of The Total Environment*. 666:274–284.
- Gabrys, J. 2014. Programming environments: environmentality and citizen sensing in the smart city. *Environment and Planning D: Society and Space*. 32:30–48.
- Gao, Y. D. Wang A. Schmidt and Y. Tang. 2018. Exploring the Response of Combined Urban Sewer System to the Implementation of Green Roof. 1–7 4th International Conference on Environmental Systems Research. IOP Publishing Ltd.

- García, P. and E. Pérez. 2016. Mapping of soil sealing by vegetation indexes and built-up index: A case study in Madrid (Spain). *Geoderma*. 268:100–107.
- Gardi, C. 2017a. Impact of land take on global food security. 146–156 *In* C. Gardi, editor. *Urban Expansion, Land Cover and Soil Ecosystem Services*. Routledge.
- Gardi, C. 2017b. *Urban Expansion, Land Cover and Soil Ecosystem Services*. (C. Gardi, Ed.) *Urban Expansion, Land Cover and Soil Ecosystem Services*. 1st ed. Routledge, New York, USA.
- Gebbers, R. and V. I. Adamchuk. 2010. Precision agriculture and food security. *Science*. 327:828–831.
- Giachino, C. G. Pattanaro B. Bertoldi L. Bollani and A. Bonadonna. 2021. Nature-based solutions and their potential to attract the young generations. *Land Use Policy*. 101:105176.
- Glavan, M. U. Schmutz S. Williams S. Corsi F. Monaco M. Kneafsey P. A. Guzman Rodriguez M. Čenič-Istenič and M. Pintar. 2018. The economic performance of urban gardening in three European cities – examples from Ljubljana, Milan and London. *Urban Forestry & Urban Greening*. 36:100–122.
- Gliessman, S. R. 2015. *Agroecology: The Ecology of Sustainable Food Systems*. CRC Press, Boca Raton, USA.
- Goldblatt, R. M. F. Stuhlmacher B. Tellman N. Clinton G. Hanson M. Georgescu C. Wang F. Serrano-Candela A. K. Khandelwal W. H. Cheng and R. C. Balling Jr. 2018. Using Landsat and nighttime lights for supervised pixel-based image classification of urban land cover. *Remote Sensing of Environment*. 205:253–275.
- Gomes, V. C. F. G. R. Queiroz and K. R. Ferreira. 2020. An Overview of Platforms for Big Earth Observation Data Management and Analysis. *Remote Sensing 2020*, Vol. 12, Page 1253. 12:1253.
- Gómez-Baggethun, E. and D. N. Barton. 2013. Classifying and valuing ecosystem services for urban planning. *Ecological Economics*. 86:235–245.
- Gong, P. X. Li and W. Zhang. 2019. 40-Year (1978–2017) human settlement changes in China reflected by impervious surfaces from satellite remote sensing. *Science Bulletin*. 64:756–763.
- Goodchild, M. F. 2007. Citizens as sensors: the world of volunteered geography. *GeoJournal*. 69:211–221.
- Goucher, L. R. Bruce D. D. Cameron S. C. Lenny Koh and P. Horton. 2017. The environmental impact of fertilizer embodied in a wheat-to-bread supply chain. *Nature Plants*. 3:1–5.
- Grewal, S. S. and P. S. Grewal. 2012. Can cities become self-reliant in food? *Cities*. 29:1–11.
- Griffin, T. W. and J. Lowenberg-Deboer. 2005. Worldwide adoption and profitability of precision agriculture Implications for Brazil. Retrieved from <http://www.ers.usda.gov/Briefing/ARMS/>. Accessed February 2020.
- Gu, C. L. Wu and I. Cook. 2012. Progress in research on Chinese urbanization. *Frontiers of Architectural Research*. 1:101–149.
- Gullino, G. 2009. *Storia di Padova. Dall'antichità all'età contemporanea*. (G. Gullino, Ed.). Cierre Edizioni, Verona.
- Güneralp, B. M. Reba B. U. Hales E. A. Wentz and K. C. Seto. 2020. Trends in urban land expansion, density, and land transitions from 1970 to 2010: A global synthesis. *Environmental Research Letters*. 15:044015.
- Guthman, J. 2004. *Agrarian Dreams: The Paradox of Organic Farming in California*. *Geographical Review of Japan, Series A*. University of California Press, Oakland, USA.
- Haines-Young, R. and M. Potschin. 2013. *Common International Classification of Ecosystem Services (CICES): Consultation on Version 4, August-December 2012*. Copenhagen, Denmark. Retrieved from

https://cices.eu/content/uploads/sites/8/2012/07/CICES-V43_Revised-Final_Report_29012013.pdf.

Accessed January 2022.

- Haklay, M. 2016. Why is participation inequality important? . 35–44 *In* C. Capineri, M. Haklay, H. Huang, V. Antoniou, J. . Kettunen, F. . Ostermann, and R. Purves, editors. *European Handbook of Crowdsourced Geographic Information*. Ubiquity Press, Londra.
- Hartcher, M. G. and R. K. Chowdhury. 2017. An alternative method for estimating total impervious area in catchments using high-resolution colour aerial photography. *Water Practice and Technology*. 12:478–486.
- Hatan, S. A. Fleischer and A. Tchetchik. 2021. Economic valuation of cultural ecosystem services: The case of landscape aesthetics in the agritourism market. *Ecological Economics*. 184:107005.
- Heitlinger, S. N. Bryan-Kinns and R. Comber. 2019. The right to the sustainable smart city. 1–13 *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. Glasgow, UK.
- Hendrickson, M. K. and M. Porth. 2012. *Urban Agriculture-Best Practices and Possibilities*. Retrieved from <http://extension.missouri.edu/foodsystems/urbanagriculture.aspx>,. Accessed March 2021.
- Hill, D. 2013. On the smart city. Or, a ‘manifesto’ for smart citizens instead. Retrieved from <https://medium.com/butwhatwasthequestion/on-the-smart-city-or-a-manifesto-for-smart-citizens-instead-7e0c6425f909>. Accessed March 2020.
- Hollands, R. G. 2008. Will the real smart city please stand up? *City*. 12:303–320.
- Holt-Giménez, E. and M. A. Altieri. 2013. Agroecology, food sovereignty, and the new green revolution. *Agroecology and Sustainable Food Systems*. 37:90–102.
- Horton, P. 2017. We need radical change in how we produce and consume food. *Food Security*. 9:1323–1327.
- Huete, A. R. 1988. A soil-adjusted vegetation index (SAVI). *Remote Sensing of Environment*. 25:295–309.
- Hung, C.-L. J. L. A. James and M. E. Hodgson. 2018. An automated algorithm for mapping building impervious areas from airborne LiDAR point-cloud data for flood hydrology. *GIScience & Remote Sensing*. 55:793–816.
- Im, J. Z. Lu J. Rhee and L. J. Quackenbush. 2012. Impervious surface quantification using a synthesis of artificial immune networks and decision/regression trees from multi-sensor data. *Remote Sensing of Environment*. 117:102–113.
- Ingegnoli, V. 2015. *Landscape Bionomics Biological-Integrated Landscape Ecology*. Springer, Milan, Italy.
- IPCC. 2021. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Retrieved from https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf. Accessed October 2021.
- ISPRA. 2017. *Consumo di suolo, dinamiche territoriali e servizi ecosistemici - Edizione 2016*. Roma.
- ISPRA. 2018. *Consumo di suolo, dinamiche territoriali e servizi ecosistemici. Edizione 2018. (M. Munafò, Ed.)*. 1st ed. ISPRA, Roma, Italia.
- ISPRA. 2019. *Consumo di suolo. Dinamiche territoriali e servizi ecosistemici. Edizione 2019. (M. Michele, Ed.)*. 1st ed. ISPRA, Roma, Italia.
- ISPRA. 2020. *Consumo di suolo, dinamiche territoriali e servizi ecosistemici. Edizione 2020. (M. Munafó, Ed.)*. Roma.
- ISPRA. 2021. *Consumo di suolo, dinamiche territoriali e servizi ecosistemici Edizione 2021 Rapporto ISPRA*

SNPA. Roma.

- ISTAT. 2019. ASC - Atlante Statistico dei Comuni. Retrieved from http://asc.istat.it/asc_BL/. Accessed November 2019.
- Jennings, D. B. S. T. Jarnagin and D. W. Ebert. 2004. A modeling approach for estimating watershed impervious surface area from national land cover data 92. *Photogrammetric Engineering & Remote Sensing*. 70:1295–1307.
- Jensen, J. R. and D. C. Cowen. 1999. Remote Sensing of Urban/Suburban Infrastructure and Socio-Economic Attributes*. *Photogrammetric Engineering & Remote Sensing*. 65:611–622.
- Kabisch, N. M. Strohbach D. Haase and J. Kronenberg. 2016. Urban green space availability in European cities. *Ecological Indicators*. 70:586–596.
- Kago, J. S. Loose and R. Sietchiping. 2019. Implementing the New Urban Agenda: Urban and Territorial Integration Approaches in Support of Urban Food Systems. 27–293 *In* H. Ginzky, E. Dooley, I. L. Heuser, E. Kasimbazi, T. Markus, and T. Qin, editors. *International Yearbook of Soil Law and Policy 2018*. Springer, Cham, Switzerland.
- Karimi, A. H. Yazdandad and N. Fagerholm. 2020. Evaluating social perceptions of ecosystem services, biodiversity, and land management: Trade-offs, synergies and implications for landscape planning and management. *Ecosystem Services*. 45:101188.
- Keeley, M. 2011. The Green Area Ratio: an urban site sustainability metric. *Journal of Environmental Planning and Management*. 54:937–958.
- Kendig, L. 1980. *Performance zoning*. Planners Press American Planning Association, Washington D.C.
- Kennard, N. J. and R. H. Bamford. 2020. Urban Agriculture: Opportunities and Challenges for Sustainable Development. 1–14 *In* W. Leal Filho, A. Azul, L. Brandli, P. Özuyar, and T. Wall, editors. *Zero Hunger. Encyclopedia of the UN Sustainable Development Goals*. Springer, Cham, Switzerland.
- Koch, A. A. McBratney M. Adams D. Field R. Hill J. Crawford B. Minasny R. Lal L. Abbott A. O'Donnell D. Angers J. Baldock E. Barbier D. Binkley W. Parton D. H. Wall M. Bird J. Bouma C. Chenu C. B. Flora K. Goulding S. Grunwald J. Hempel J. Jastrow J. Lehmann K. Lorenz C. L. Morgan C. W. Rice D. Whitehead I. Young and M. Zimmermann. 2013. Soil Security: Solving the Global Soil Crisis. *Global Policy*. 4:434–441.
- Köhler, M. M. Schmidt F. W. Grimme M. Laar and F. Gusmão. 2001. Urban water retention by greened roofs in temperate and tropical climate. 151–162 38th IFLA World Congress (International Federation of Landscape Architects). Singapore.
- Kuang, W. 2019. Mapping global impervious surface area and green space within urban environments. *Science China Earth Sciences* 2019 62:10. 62:1591–1606.
- Lakes, T. and H. O. Kim. 2012. The urban environmental indicator “biotope Area Ratio” - An enhanced approach to assess and manage the urban ecosystem services using high resolution remote-sensing. *Ecological Indicators*. 13:93–103.
- Lam, S. T. and T. M. Conway. 2018. Ecosystem services in urban land use planning policies: A case study of Ontario municipalities. *Land Use Policy*. 77:641–651.
- Langella, G. A. Basile S. Giannecchini F. D. Moccia F. A. Mileti M. Munafó F. Pinto and F. Terribile. 2020. Soil Monitor: an internet platform to challenge soil sealing in Italy. *Land Degradation & Development*. 31:2883–2900.

- Li, J. Y. Wang Z. Ni S. Chen and B. Xia. 2020. An integrated strategy to improve the microclimate regulation of green-blue-grey infrastructures in specific urban forms. *Journal of Cleaner Production*. 271:122555.
- Li, W. and C. Wu. 2015. A geostatistical temporal mixture analysis approach to address endmember variability for estimating regional impervious surface distributions. *GIScience & Remote Sensing*. 53:102–121.
- Liang, S. and J. Wang. 2019. *Advanced remote sensing: terrestrial information extraction and applications*. (S. Liang and J. Wang, Eds.).
- Lillesand, T. M. and R. W. Kiefer. 1994. *Remote sensing and image interpretation*. 3rd Edition. Wiley & Sons.
- Lin, Y. H. Zhang G. Li T. Wang L. Wan and H. Lin. 2019. Improving Impervious Surface Extraction with Shadow-Based Sparse Representation from Optical, SAR, and LiDAR Data. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*. 12:2417–2428.
- Liu, O. Y. and A. Russo. 2021. Assessing the contribution of urban green spaces in green infrastructure strategy planning for urban ecosystem conditions and services. *Sustainable Cities and Society*. 68:102772.
- Lotter, D. W. 2003. Organic agriculture. *J. Sustain. Agric.* 21:59–128.
- De Lotto; E. M. Venco. 2013. Efficacia e attuabilità di indici ecologico ambientali nella pratica urbanistica. *In* F. Sbetti, F. Rossi, M. Talia, and C. Trillo, editors. XXVIII Congresso dell'INU: Il governo della città nella contemporaneità. La città come motore di sviluppo. INU Edizioni, Salerno, Italia.
- De Lotto, R. V. Casella M. Franzini V. Gazzola C. Morelli di Popolo S. Sturla and E. M. Venco. 2015. Estimating the Biotope Area Factor (BAF) by Means of Existing Digital Maps and GIS Technology. 617–632 *In* O. Gervasi, B. Murgante, S. Misra, M. L. Gavriloca, A. M. Alves Coutinho Rocha, C. Torre, D. Taniar, and B. O. Apduhan, editors. *Computational Science and Its Applications – ICCSA 2015*. Springer International Publishing AG Switzerland, Basel, Switzerland.
- Lozano, A. V. C. A. Vidal and J. S. Díaz. 2019. Urban growth (1956-2012) and soil sealing in the metropolitan area of Valencia (Eastern Spain). *Spanish Journal of Soil Science*. 9:88–104.
- Lu, D. E. Moran and S. Hetrick. 2011. Detection of impervious surface change with multitemporal Landsat images in an urban–rural frontier. *ISPRS Journal of Photogrammetry and Remote Sensing*. 66:298–306.
- Lu, D. and Q. Weng. 2006. Use of impervious surface in urban land-use classification. *Remote Sensing of Environment*. 102:146–160.
- Ma, Q. C. He and J. Wu. 2016. Behind the rapid expansion of urban impervious surfaces in China: Major influencing factors revealed by a hierarchical multiscale analysis. *Land Use Policy*. 59:434–445.
- MADRE. 2018. *Urban and Peri-Urban Agriculture. Best practice catalogue*. Retrieved from https://anima.coop/sites/default/files/madre_catalogue_web_light.pdf. Accessed.
- Maes, J. G. Zulian S. Guenther M. Thijssen and J. Raynal. 2019. *Enhancing Resilience Of Urban Ecosystems through Green Infrastructure (EnRoute)*. Luxembourg. Retrieved from <https://publications.jrc.ec.europa.eu/repository/handle/JRC115375>. Accessed.
- Marquard, E. S. Bartke J. Gifreu i Font A. Humer A. Jonkman E. Jürgenson N. Marot L. Poelmans B. Repe R. Rybski C. Schröter-Schlaack J. Sobocká M. Tophøj Sørensen E. Vejchodská A. Yiannakou and J. Bovet. 2020. Land Consumption and Land Take: Enhancing Conceptual Clarity for Evaluating Spatial Governance in the EU Context. *Sustainability*. 12:8269.
- Martellozzo, F. J. S. Landry D. Plouffe V. Seufert P. Rowhani and N. Ramankutty. 2014. Urban agriculture: A global analysis of the space constraint to meet urban vegetable demand. *Environmental Research*

Letters. 9:064025 (8pp).

- Marzari, S. 2008a. Padova e la città metropolitana. 1807-2007 la metamorfosi del paesaggio urbano. (S. Marzari, Ed.). I Antichi Editori, Venezia, Italia.
- Marzari, S. 2008b. Padua and Metropolitan City. 1807-2007 Metamorphosis of the Urban Landscape (in Italian: Padova e la Città Metropolitana. 1807–2007 la Metamorfosi del Paesaggio Urbano. (S. Marzari, Ed.). I Antichi Editori Venezia, Venezia, Italy.
- Masek, J. G. M. A. Wulder B. Markham J. McCorkel C. J. Crawford J. Storey and D. T. Jenstrom. 2020. Landsat 9: Empowering open science and applications through continuity. *Remote Sensing of Environment*. 248:111968.
- Maxwell, D. C. Levin and J. Csete. 1998. Does urban agriculture help prevent malnutrition? Evidence from Kampala. *Food Policy*. 23:411–424.
- Maye, D. 2019. 'Smart food city': Conceptual relations between smart city planning, urban food systems and innovation theory. *City, Culture and Society*. 16:18–24.
- Milan Urban Food Policy Pact. 2015. Milan Urban Food Policy Pact. Retrieved from <https://www.milanurbanfoodpolicypact.org/the-milan-pact/>. Accessed March 2020.
- Mimet, A. C. Kerbirou L. Simon J. F. Julien and R. Raymond. 2020. Contribution of private gardens to habitat availability, connectivity and conservation of the common pipistrelle in Paris. *Landscape and Urban Planning*. 193:103671.
- Misra, M. D. Kumar and S. Shekhar. 2020. Assessing Machine Learning Based Supervised Classifiers For Built-Up Impervious Surface Area Extraction From Sentinel-2 Images. *Urban Forestry & Urban Greening*. 53:126714.
- Mok, H. F. V. G. Williamson J. R. Grove K. Burry S. F. Barker and A. J. Hamilton. 2014. Strawberry fields forever? Urban agriculture in developed countries: A review. *Agronomy for Sustainable Development*. 34:21–43.
- Montgomery, D. R. 2012. *Dirt: the erosion of civilizations*. University of California Press.
- Moreno, A. A. Bhattacharyya L. Jansen Y. Arkeman R. Hartanto and M. Kleinke. 2019. Environmental engineering and sustainability for smart agriculture: The application of UAV-based remote sensing to detect biodiversity in oil palm plantations. 012008 *In* A. G. Niam, I. Yusliana, and H. Imantho, editors. International Conference on Digital Agriculture from Land to Consumers. Bogor, Indonesia.
- Mougeot, L. J. A. 2000. Urban Agriculture: Definition, Presence, Potentials and Risks, and Policy Challenges Cities Feeding People Series. Retrieved from <http://www.idrc.ca/cfp>. Accessed February 2020.
- Moustier, P. and G. Danso. 2006. Local Economic Development and Marketing of Urban Produced Food. 174–195 *In* R. van Veenhuizen, editor. *Cities Farming for the Future: Urban Agriculture for Green and Productive Cities*. RUA Foundation, IDRC and IIRR, Philippines.
- Mullins, P. D. 2017. The ubiquitous-eco-city of Songdo: An urban systems perspective on South Korea's Green city approach. *Urban Planning*. 2:4–12.
- Munafò, M. C. Norero A. Sabbi and L. Salvati. 2010. Soil sealing in the growing city: A survey in Rome, Italy. *Scottish Geographical Journal*. 126:153–161.
- Murata, T. and N. Kawai. 2018. Degradation of the urban ecosystem function due to soil sealing: involvement in the heat island phenomenon and hydrologic cycle in the Tokyo metropolitan area. <https://doi.org/10.1080/00380768.2018.1439342>. 64:145–155.

- Naumann, S. A. Frelih-Larsen G. Prokop S. Ittner M. Reed J. Mills F. Morari S. Verzaandvoort, Simone Albrecht A. Bjuréus G. Siebielec and T. Miturski. 2019. Land Take and Soil Sealing—Drivers, Trends and Policy (Legal) Instruments: Insights from European Cities. 84–112 *International Yearbook of Soil Law and Policy* 2018.
- Nin, M. A. Soutullo L. Rodríguez-Gallego and E. Di Minin. 2016. Ecosystem services-based land planning for environmental impact avoidance. *Ecosystem Services*. 17:172–184.
- Norton, G. W. and S. M. Swinton. 2000. Precision Agriculture: Global Prospects and Environmental Implications. *Proceedings of the 24th International Conference of Agricultural Economists*:269–286.
- Norton, J. 2019. Information Systems for Grassroots Sustainable Agriculture. PhD Thesis. University of California, Irvine, USA.
- Norton, J. B. J. Pan S. Naye baziz B. Tomlinson and S. Burke. 2014. Plant guild composer: An interactive online system to support back yard food production. 523–526 *Conference on Human Factors in Computing Systems - Proceedings*. Association for Computing Machinery, New York, USA.
- Norton, J. B. Tomlinson B. Penzenstadler S. McDonald E. Kang N. Koirala R. Konishi G. P. Carmona J. Shah and S. Troncoso. 2019. The SAGE Community Coordinator: A Demonstration. 1–10 *In* S. Easterbrook, editor. *Proceedings of the Fifth Workshop on Computing within Limits*. Association for Computing Machinery, Lappeenranta, Finland.
- Nowak, D. J. and E. J. Greenfield. 2020. The increase of impervious cover and decrease of tree cover within urban areas globally (2012–2017). *Urban Forestry and Urban Greening*. 49:126638.
- Oberndorfer, E. J. Lundholm B. Bass R. R. Coffman H. Doshi N. Dunnett S. Gaffin M. Köhler K. K. Y. Liu and B. Rowe. 2007. Green Roofs as Urban Ecosystems: Ecological Structures, Functions, and Services. *BioScience*. 57:823–833.
- Van Oijstaeijen, W. S. Van Passel and J. Cools. 2020. Urban green infrastructure: A review on valuation toolkits from an urban planning perspective. *Journal of Environmental Management*. 267:110603.
- Opolot, E. Y. Y. Yu and P. A. Finke. 2015. Modeling soil genesis at pedon and landscape scales: Achievements and problems. *Quaternary International*. 376:34–46.
- Orsini, F. R. Kahane R. Nono-Womdim and G. Gianquinto. 2013. Urban agriculture in the developing world: A review. *Agronomy for Sustainable Development*. 33:695–720.
- Pafi, M. A. Siragusa S. Ferri and S. Halkia. 2016. Measuring the Accessibility of Urban Green Areas : A comparison of the Green ESM with other datasets in four European cities. Luxembourg (Luxembourg). Retrieved from <http://publications.jrc.ec.europa.eu/repository/handle/JRC102525>. Accessed January 2022.
- Paleari, S. 2017. Is the European Union protecting soil? A critical analysis of Community environmental policy and law. *Land Use Policy*. 64:163–173.
- Paskaleva, K. A. 2011. The smart city: A nexus for open innovation? *Intelligent Buildings International*. 3:153–171.
- Pearsall, H. and J. K. Eller. 2020. Locating the green space paradox: A study of gentrification and public green space accessibility in Philadelphia, Pennsylvania. *Landscape and Urban Planning*. 195:103708.
- Pearson, L. J. L. Pearson and C. J. Pearson. 2010. Sustainable urban agriculture: Stocktake and opportunities. *International Journal of Agricultural Sustainability*. 8:7–19.
- Peroni, F. G. Pristeri D. Codato S. E. Pappalardo and M. De Marchi. 2019. Biotope Area Factor: An Ecological

- Urban Index to Geovisualize Soil Sealing in Padua, Italy. *Sustainability* 2020, Vol. 12, Page 150. 12:150.
- Phinn, S. M. Stanford P. Scarth A. T. Murray and P. T. Shyy. 2002. Monitoring the composition of urban environments based on the vegetation-impervious surface-soil (VIS) model by subpixel analysis techniques. *International Journal of Remote Sensing*. 23:4131–4153.
- Pistocchi, A. C. Calzolari F. Malucelli and F. Ungaro. 2015. Soil sealing and flood risks in the plains of Emilia-Romagna, Italy. *Journal of Hydrology: Regional Studies*. 4:398–409.
- Poulsen, M. N. 2017. Cultivating citizenship, equity, and social inclusion? Putting civic agriculture into practice through urban farming. *Agriculture and Human Values*. 34:135–148.
- Pretty, J. N. A. D. Noble D. Bossio J. Dixon R. E. Hine F. W. T. P. De Vries and J. I. L. Morison. 2006. Resource-conserving agriculture increases yields in developing countries. *Environmental Science and Technology*. 40:1114–1119.
- Pristeri, G. F. Peroni S. E. Pappalardo D. Codato A. G. Castaldo A. Masi and M. De Marchi. 2020. Mapping and Assessing Soil Sealing in Padua Municipality through Biotope Area Factor Index. *Sustainability* 2020, Vol. 12, Page 5167. 12:5167.
- Prokop, G. H. Jobstmann and A. Schönbauer. 2011. Report on best practices for limiting soil sealing and mitigating its effects. European Commission.
- Quattrocchi, D. A. and M. F. Goodchild. 1997. Scale in Remote Sensing and GIS. (D. A. Quattrocchi and M. F. Goodchild, Eds.). CRC Press.
- Radočaj, D. J. Obhodaš M. Jurišić and M. Gašparović. 2020. Global Open Data Remote Sensing Satellite Missions for Land Monitoring and Conservation: A Review. *Land* 2020, Vol. 9, Page 402. 9:402.
- Raghavan, B. B. Nardi S. T. Lovell J. Norton B. Tomlinson and D. J. Patterson. 2016. Computational Agroecology. 423–435 *In* J. Kaye and A. Druin, editors. Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems. ACM Press, San Jose, USA.
- Regione del Veneto. 2004. Legge regionale 23 aprile 2004, n. 11 (BUR n. 45/2004) - Norme per il Governo del Territorio e in materia di Paesaggio.
- Regione del Veneto. 2017. Disposizioni per il contenimento del consumo di suolo e modifiche della legge regionale 23 aprile 2004, n. 11 “Norme per il governo del territorio e in materia di paesaggio.” 1–22. Italy.
- Regione del Veneto. 2019a. Legge Regionale n. 14 del 04 aprile 2019. Veneto 2050: politiche per la riqualificazione urbana e la rinaturalizzazione del territorio e modifiche alla legge regionale 23 aprile 2004, n. 11 “Norme per il governo del territorio e in materia di paesaggio”. Venezia, Italy.
- Regione del Veneto. 2019b. Deliberazione della Giunta Regionale n. 64 del 29 gennaio 2019. Venezia, Italy.
- Repubblica Italiana. 1968. Repubblica Italiana. Interministerial Decree, April 2, 1968, n. 1444 (in Italian: Decreto Interministeriale 2 Aprile 1968, n. 1444). Roma, Italy.
- RNDT. 2020. Metadata for Topographic DataBase of Padua Municipality. Retrieved from <https://geodati.gov.it/geoportale/>. Accessed January 2022.
- Rodríguez-Rojas, M. I. F. Huertas-Fernández B. Moreno G. Martínez and A. L. Grindlay. 2018. A study of the application of permeable pavements as a sustainable technique for the mitigation of soil sealing in cities: A case study in the south of Spain. *Journal of environmental management*. 205:151–162.
- Rogan, J. and D. M. Chen. 2004. Remote sensing technology for mapping and monitoring land-cover and land-use change. *Progress in Planning*. 61:301–325.
- Ronchi, S. A. Arcidiacono and L. Pogliani. 2020. Integrating green infrastructure into spatial planning

- regulations to improve the performance of urban ecosystems. Insights from an Italian case study. *Sustainable Cities and Society*. 53:101907.
- Ronchi, S. S. Salata A. Arcidiacono E. Piroli and L. Montanarella. 2019. Policy instruments for soil protection among the EU member states: A comparative analysis. *Land Use Policy*. 82:763–780.
- Rondeaux, G. M. Steven and F. Baret. 1996. Optimization of soil-adjusted vegetation indices. *Remote Sensing of Environment*. 55:95–107.
- Rosset, P. M. and M. A. Altieri. 1997. Agroecology versus input substitution: A fundamental contradiction of sustainable agriculture. *Society and Natural Resources*. 10:283–295.
- Rowe, D. B. and K. L. Getter. 2006. The role of extensive green roofs in sustainable development. *HortScience*. 41:1276–1285.
- Russo, A. and G. T. Cirella. 2018. Modern Compact Cities: How Much Greenery Do We Need? *International Journal of Environmental Research and Public Health* 2018, Vol. 15, Page 2180. 15:2180.
- Sam Navin, M. and L. Agilandeewari. 2020. Comprehensive review on land use/land cover change classification in remote sensing. *J. Spectral Imaging*. 9:8.
- Sánchez-Bayo, F. and K. A. G. Wyckhuys. 2019. Worldwide decline of the entomofauna: A review of its drivers. *Biological Conservation*. 232:8–27.
- dos Santos, A. R. F. S. de Oliveira A. G. da Silva J. M. Gleriani W. Gonçalves G. L. Moreira F. G. Silva E. R. F. Branco M. M. Moura R. G. da Silva R. S. Juvanhol K. B. de Souza C. A. A. S. Ribeiro V. T. de Queiroz A. V. Costa A. S. Lorenzon G. F. Domingues G. E. Marcatti N. L. M. de Castro R. T. Resende D. E. Gonzales L. A. de Almeida Telles T. R. Teixeira G. M. A. D. A. dos Santos and P. H. S. Mota. 2017. Spatial and temporal distribution of urban heat islands. *Science of the Total Environment*. 605–606:946–956.
- Saura, S. 2010. Effects of minimum mapping unit on land cover data spatial configuration and composition. <https://doi.org/10.1080/01431160110114493>. 23:4853–4880.
- Scalenghe, R. and F. A. Marsan. 2009. The anthropogenic sealing of soils in urban areas. *Landscape and Urban Planning*. 90:1–10.
- Scheuer, C. E. Boot N. Carse A. Clardy J. Gallagher S. Heck S. Marron L. Martinez-Alvarez D. Masarykova P. Mcmillan F. Murphy E. Steel H. Van Ekdom and H. Vecchione. 2015. Integration of ecosystem services into decision-making. *Physical Education and Sport for Children and Youth with Special Needs Researches – Best Practices – Situation*.:73–80.
- Schmutz, U. 2017. Urban Agriculture or Urban Agroecology? RUAf. Retrieved from <https://ruaf.org/document/urban-agriculture-magazine-no-33-urban-agroecology/>. Accessed March 2021.
- Schneider, A. M. A. Friedl and D. Potere. 2010. Mapping global urban areas using MODIS 500-m data: New methods and datasets based on ‘urban ecoregions.’ *Remote Sensing of Environment*. 114:1733–1746.
- Scopus. 2021. How do Author / Indexed keywords work? - Scopus: Access and use Support Center. Retrieved from https://service.elsevier.com/app/answers/detail/a_id/21730/supporthub/scopus/. Accessed April 2021.
- See, L. P. Mooney G. Foody L. Bastin A. Comber J. Estima S. Fritz N. Kerle B. Jiang M. Laakso H.-Y. Liu G. Milčinski M. Nikšič M. Painho A. Pódör A.-M. Olteanu-Raimond M. Rutzinger L. See P. Mooney G. Foody L. Bastin A. Comber J. Estima S. Fritz N. Kerle B. Jiang M. Laakso H.-Y. Liu G. Milčinski M. Nikšič M.

- Painho A. Pődör A.-M. Olteanu-Raimond and M. Rutzinger. 2016. Crowdsourcing, Citizen Science or Volunteered Geographic Information? The Current State of Crowdsourced Geographic Information. *ISPRS International Journal of Geo-Information*. 5:55.
- Seiwert, A. and S. Rößler. 2020. Understanding the term green infrastructure: origins, rationales, semantic content and purposes as well as its relevance for application in spatial planning. *Land Use Policy*. 97:104785.
- Serbulova, N. S. Kanurny A. Gorodnyanskaya and A. Persiyanova. 2019. Sustainable food systems and agriculture: the role of information and communication technologies. 12127 *In* M. Pasetti and V. Murgul, editors. IOP Conf. Ser.: Earth Environ. Sci. Rostov-on-Don, Russia.
- Seto, K. C. M. Fragkias B. Güneralp and M. K. Reilly. 2011. A Meta-Analysis of Global Urban Land Expansion. *PLoS ONE*. 6:1–9.
- Seto, K. C. B. Güneralp and L. R. Hutyrá. 2012. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences of the United States of America*. 109:16083–16088.
- Shahtahmassebi, A. R. J. Song Q. Zheng G. A. Blackburn K. Wang L. Y. Huang Y. Pan N. Moore G. Shahtahmassebi R. Sadrabadi Haghghi J. S. Deng A. R. Shahtahmassebi J. Song Q. Zheng G. A. Blackburn K. Wang L. Y. Huang Y. Pan N. Moore G. Shahtahmassebi R. Sadrabadi Haghghi and J. S. Deng. 2016. Remote sensing of impervious surface growth: A framework for quantifying urban expansion and re-densification mechanisms. *IJAEO*. 46:94–112.
- Shi, L. Ü. Halik A. Abliz Z. Mamat and M. Welp. 2020. Urban Green Space Accessibility and Distribution Equity in an Arid Oasis City: Urumqi, China. *Forests* 2020, Vol. 11, Page 690. 11:690.
- Shuster, W. D. J. Bonta H. Thurston E. Warnemuende and D. R. Smith. 2005. Impacts of impervious surface on watershed hydrology: A review. *Urban Water Journal*. 2:263–275.
- Siddiqui, A. G. Kushwaha A. Raouf P. A. Verma and Y. Kant. 2021. Bangalore: Urban heating or urban cooling? *The Egyptian Journal of Remote Sensing and Space Science*. 24:265–272.
- Siebielec, G. S. Lazar C. Kaufmann and S. Jaensch. 2010. Handbook for measures enhancing soil function performance and compensating soil loss during urbanization process. Urban SMS-Soil Management Strategy project. Urban SMS project, Stuttgart, Germany.
- Siegner, A. J. Sowerwine and C. Acey. 2018. Does Urban Agriculture Improve Food Security? Examining the Nexus of Food Access and Distribution of Urban Produced Foods in the United States: A Systematic Review. *Sustainability*. 10:2988.
- Sinha, P. N. K. Verma and E. Ayele. 2016. Urban Built-up Area Extraction and Change Detection of Adama Municipal Area using Time-Series Landsat Images. *International Journal of Advanced Remote Sensing and GIS*. 5:1886–1895.
- Slonecker, E. T. D. B. Jennings and D. Garofalo. 2001. Remote sensing of impervious surfaces: A review. *Remote Sensing Reviews*. 20:227–255.
- Socientize. 2014. White Paper on Citizen Science for Europe. Zaragoza, Spain.
- Söderström, O. T. Paasche and F. Klauser. 2014. Smart cities as corporate storytelling. *City*. 18:307–320.
- Sonnino, R. 2009. Feeding the city: Towards a new research and planning agenda. *International Planning Studies*. 14:425–435.
- Spadoni, G. L. A. Cavalli L. Congedo and M. Munafò. 2020. Analysis of Normalized Difference Vegetation

- Index (NDVI) multi-temporal series for the production of forest cartography. *Remote Sensing Applications: Society and Environment*. 20:100419.
- Specht, K. R. Siebert I. Hartmann U. B. Freisinger M. Sawicka A. Werner S. Thomaier D. Henckel H. Walk and A. Dierich. 2014. Urban agriculture of the future: An overview of sustainability aspects of food production in and on buildings. *Agriculture and Human Values*. 31:33–51.
- Stankovics, P. G. Tóth Z. Tóth P. Stankovics G. Tóth and Z. Tóth. 2018. Identifying Gaps between the Legislative Tools of Soil Protection in the EU Member States for a Common European Soil Protection Legislation. *Sustainability*. 10:1–17.
- Strollo, A. D. Smiraglia R. Bruno F. Assennato L. Congedo P. De Fioravante C. Giuliani I. Marinosci N. Riitano and M. Munafò. 2020. Land consumption in Italy. *Journal of Maps*. 16:113–123.
- Sun, Z. C. Wang H. Guo and R. Shang. 2017. A modified normalized difference impervious surface index (MNDISI) for automatic urban mapping from landsat imagery. *Remote Sensing*. 9:1–18.
- Sutton, P. C. S. J. Anderson C. D. Elvidge B. T. Tuttle and T. Ghosh. 2009. Paving the planet: impervious surface as proxy measure of the human ecological footprint. *Progress in Physical Geography*. 33:510–527.
- Swyngedouw, E. 2016. The mirage of the sustainable ‘smart city’: planetary urbanization and the spectre of combined and uneven apocalypse. 134–143 *In* O. Nel-lo and R. Mele, editors. *Cities in the 21st Century*. Routledge, New York, USA.
- Tahvonen, O. and M. Airaksinen. 2018. Low-density housing in sustainable urban planning – Scaling down to private gardens by using the green infrastructure concept. *Land Use Policy*. 75:478–485.
- Taylor, J. R. and S. T. Lovell. 2012. Mapping public and private spaces of urban agriculture in Chicago through the analysis of high-resolution aerial images in Google Earth. *Landscape and Urban Planning*. 108:57–70.
- Teixeira da Silva, R. L. Fleskens H. van Delden and M. van der Ploeg. 2018. Incorporating soil ecosystem services into urban planning: status, challenges and opportunities. *Landscape Ecology* 2018 33:7. 33:1087–1102.
- Theobald, D. M. S. J. Goetz J. B. Norman and P. Jantz. 2009. Watersheds at Risk to Increased Impervious Surface Cover in the Conterminous United States. *Journal of Hydrologic Engineering*. 14:362–368.
- Tobias, S. F. Conen A. Duss L. M. Wenzel C. Buser and C. Alewell. 2018. Soil sealing and unsealing: State of the art and examples. *Land Degradation & Development*. 29:2015–2024.
- Torres, A. V. C. Tiwari and S. F. Atkinson. 2021. Progress in ecosystem services research: A guide for scholars and practitioners. *Ecosystem Services*. 49:101267.
- Townsend, A. 2014. *Smart Cities-Big Data, Civic hackers and the question for a new utopia*. (W. W. Norton & Company, Ed.). New York, USA.
- UN-Habitat. 2021. UN Habitat Metadata sheet on SDG indicator 11.3.1. Retrieved from <https://unstats.un.org/sdgs/metadata/files/Metadata-11-03-01.pdf>. Accessed April 2021.
- UN Department of Economic and Social Affairs. 2019. *World Population Prospects 2019 Highlights*. Retrieved from www.population.un.org. Accessed February 2020.
- UNDP United Nations Development Programme. 2018. *Community-Based Resilience Analysis (CoBRA) Conceptual Framework and Methodology*. Retrieved from www.undp.org. Accessed March 2020.
- UNFPA United Nations Population Found. 2007. *State of world population 2007: unleashing the potential of*

- urban growth. New York. Retrieved from www.unfpa.org. Accessed February 2020.
- United States Department of Agriculture. 2016. Urban Agriculture Toolkit. Retrieved from <https://www.usda.gov/sites/default/files/documents/urban-agriculture-toolkit.pdf>. Accessed.
- University of Southampton. 2021. WorldPop. Retrieved from <https://www.worldpop.org/about>. Accessed January 2022.
- Vanolo, A. 2014. Smartmentality: The Smart City as Disciplinary Strategy. *Urban Studies*. 51:883–898.
- Vanolo, A. 2016. Is there anybody out there? The place and role of citizens in tomorrow's smart cities. *Futures*. 82:26–36.
- Vázquez Moreno, L. L. and F. Funes Aguilar. 2016. Avances de la agroecología en Cuba Avances de la agroecología en Cuba. Editora Estación Experimental de Pastos y Forrajes Indio Hatuey, La Habana, Cuba.
- Veolia Institute. 2019. Urban Agriculture: another way to feed cities. Retrieved from www.institut.veolia.org. Accessed.
- Vermeulen, S. J. B. M. Campbell and J. S. I. Ingram. 2012. Climate Change and Food Systems. *Annual Review of Environment and Resources*. 37:195–222.
- Walter, A. R. Finger R. Huber and N. Buchmann. 2017. Smart farming is key to developing sustainable agriculture. *Proceedings of the National Academy of Sciences of the United States of America*. 114:6148–6150.
- Wang, Y. and M. Li. 2019. Urban Impervious Surface Detection From Remote Sensing Images: A review of the methods and challenges. *IEEE Geoscience and Remote Sensing Magazine*. 7:64–93.
- Weng, Q. 2012. Remote sensing of impervious surfaces in the urban areas: Requirements, methods, and trends. *Remote Sensing of Environment*. 117:34–49.
- Weng, Q. editor. 2014. *Scale issues in Remote Sensing*. John Wiley & Sons, Ltd, Hoboken, USA.
- Weng, Q. 2020. *Techniques and Methods in Urban Remote Sensing*. IEEE Press.
- Weng, Q. and D. Lu. 2008. A sub-pixel analysis of urbanization effect on land surface temperature and its interplay with impervious surface and vegetation coverage in Indianapolis, United States. *International Journal of Applied Earth Observation and Geoinformation*. 10:68–83.
- Wenhui, K. C. Wenfeng and S. Wenjiao. 2014. Spatio-temporal characteristics of intra-urban land cover in the cities of China and USA from 1978 to 2010. *Acta Geographica Sinica*. 69:883–895.
- Wessolek, G. 2008. Sealing of soils. 161–179 *In* J. M. Marzluff, E. Shulenberger, W. Endlicher, M. Alberti, G. Bradley, C. Ryan, U. Simon, and C. ZumBrunnen, editors. *Urban Ecology: An International Perspective on the Interaction Between Humans and Nature*. Springer, New York, USA.
- Whelan, B. and J. Taylor. 2013. Precision agriculture for grain production systems. *International Journal of Digital Earth*. CSIRO Publishing, Collingwood, Australia.
- Wiig, A. 2016. The empty rhetoric of the smart city: from digital inclusion to economic promotion in Philadelphia. *Urban Geography*. 37:535–553.
- WOCAT. 2014. WOCAT. Retrieved from <https://www.wocat.net/en/>. Accessed March 2021.
- Woodhouse, P. 2010. Beyond Industrial Agriculture? Some Questions about Farm Size, Productivity and Sustainability. *Journal of Agrarian Change*. 10:437–453.
- World Bank. 2020. Urban Development. Retrieved from <https://www.worldbank.org/en/topic/urbandevelopment/overview>. Accessed.

- World Health Organization. 2005. Ecosystems and Human Well-Being. Geneva, Switzerland.
- World Health Organization. 2017. Urban green spaces: a brief for action. Copenhagen, Denmark.
- Wu, D. and G. Lindasay. 2020. How to design a smart city that's built on empowerment - not corporate surveillance. Retrieved from <https://www.fastcompany.com/90469838/how-to-design-a-smart-city-thats-built-on-empowerment-not-corporate-surveillance>. Accessed March 2020.
- Wu, J. Wei-Ning Xiang and J. Zhao. 2014. Urban ecology in China: Historical developments and future directions. *Landscape and Urban Planning*. 125:222–233.
- Wüstemann, H. D. Kalisch and J. Kolbe. 2016. Towards a national indicator for urban green space provision and environmental inequalities in Germany: Method and findings. Berlin: Humboldt University of Berlin, Collaborative Research Center 649 - Economic Risk, Berlin, Germany. Retrieved from <https://www.econstor.eu/handle/10419/146191>. Accessed January 2022.
- Xiao, R. Y. Tian and G. Xu. 2020. Spatial gradient of urban green field influenced by soil sealing. *Science of The Total Environment*. 735:139490.
- Xie, L. and H. Bulkeley. 2020. Nature-based solutions for urban biodiversity governance. *Environmental Science & Policy*. 110:77–87.
- Xu, H. 2010. Analysis of impervious surface and its impact on Urban heat environment using the normalized difference impervious surface index (NDISI). *Photogrammetric Engineering and Remote Sensing*. 76:557–565.
- Xue, J. and B. Su. 2017. Significant remote sensing vegetation indices: A review of developments and applications. *Journal of Sensors*. 2017.
- Zhang, B. Z. Chen D. Peng J. A. Benediktsson B. Liu L. Zou J. Li and A. Plaza. 2019. Remotely sensed big data: Evolution in model development for information extraction [point of view]. *Proceedings of the IEEE*. 107:2294–2301.
- Zhang, L. and Q. Weng. 2016. Annual dynamics of impervious surface in the Pearl River Delta, China, from 1988 to 2013, using time series Landsat imagery. *ISPRS Journal of Photogrammetry and Remote Sensing*. 113:86–96.
- Zhang, N. M. Wang and N. Wang. 2002. Precision agriculture - A worldwide overview. *Computers and Electronics in Agriculture*. 36:113–132.
- Zhao, S. D. Zhou C. Zhu Y. Sun W. Wu and S. Liu. 2015. Spatial and Temporal Dimensions of Urban Expansion in China. *Environmental Science and Technology*. 49:9600–9609.
- Zhong, Q. J. Ma B. Zhao X. Wang J. Zong and X. Xiao. 2019. Assessing spatial-temporal dynamics of urban expansion, vegetation greenness and photosynthesis in megacity Shanghai, China during 2000–2016. *Remote Sensing of Environment*. 233:111374.

SMART CITIES AND AGROECOLOGY: URBAN AGRICULTURE, PROXIMITY TO FOOD AND URBAN ECOSYSTEM SERVICES

Chapter of the book De Marchi M., Diantini A., Pappalardo S. (eds.) *Drones and Geographical Information Technologies in Agroecology and Organic Farming: Contributions to Technological Sovereignty* (in press)

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Abstract

Worldwide, urban development has been increasingly influenced by the model of smart cities. However, smart cities have been criticised due to their inability to build a just and inclusive urban environment for their dwellers. One of the main topics related to smart cities is the integration of agricultural production in their ecosystems. Even if Information and Communication Technologies (ICT) has been used in agricultural development since the late decades of the past century, it is unable to guarantee a sustainable development. Moreover, agroecology is an agricultural approach that enhances the quality of ecosystem services and human well-being, including in urban areas. The introduction of this approach in urban ecosystems could be difficult due to the complexity of knowledge and principles that should be developed to design an agroecological system. In this framework, ICT could provide some useful tools to enhance the competencies of dwellers to practice agroecology within cities. In this regard, the chapter aims to analyse which role agroecology could play in smart cities. Specifically, it investigates how ICT could spread agroecological approaches in order to boost urban agriculture in cities. Finally, the chapter explores how smart urban agriculture tends to guarantee food sovereignty and the maintenance of ecosystem services.

1. Introduction: Smart Cities and Urban Agriculture

One of the most inspiring models of urban areas of the future is smart cities (Vanolo 2016). Smart cities are usually considered efficient ecosystems, where urban processes, resources, and services are optimized and ameliorated (Carvalho 2015). A unique and clear definition is already not specified; however, the concept generally refers to the integration of technology and data collection into urban context to monitor, manage, and regulate flows (Hollands 2008; Maye 2019).

Recently, the concept of smart city has evolved and it is always more frequently related to climate change issues (Angelidou 2015). Cities are ecosystems of high consumption of energy and resources and they are sources of pollution and contamination due to the high concentration of people (Seto et al. 2012). In addition, it is estimated that by 2050 almost 70 per cent of the world population will live in urban areas, resulting in increased pressure on urban ecosystems (de Amorim et al. 2019). In this regard, the concept of smart cities is at present shifting towards a focus to achieve 'greener' cities, i.e. planned to reduce greenhouse gas emissions, and to promote energy efficiency through adoption of appropriate technologies (Gabrys 2014).

It is worth noting that the components and topics usually developed in a smart-city strategy try to integrate various systems of an urban area; for instance, economy, transportation, and education. According to a literature review on smart cities provided by Albino et al.(2015), four aspects come to light: (i) political efficiency and social/cultural development; (ii) urban growth; (iii) social inclusion of citizens; and (iv) environment (Albino et al. 2015). The literature gives significant attention to topics related to the quality of life and environment; nevertheless it does not mention questions like urban food systems and food security (Maye 2019). Surprisingly, the issue of 'urban food' and how to integrate new technologies to feed a growing population is not a key topic in the smart city debate; moreover, the definition of smart cities does not include any direct references to food production.

On the other hand, academic research as well as the social demands on urban agriculture (UA) is constantly growing. Based on the literature review provided by Artmann and Sartison (2018), UA is a surging topic, especially since 2013. Over the last few years, UA has been considered a key issue in steadily increasing global populations and the ongoing expansion of cities. Indeed, it is estimated that by 2050, the world's population will be 9.7 billion and the supply of food will become a critical issue (Fouilleux et al. 2017; UN Department of Economic and Social Affairs 2019). Moreover, new urbanization and infrastructure are steadily growing and the pressure on semi-natural soil and peri-UA is drastically increasing. Hence, the lands allotted for food production are decreasing, especially near cities (Eigenbrod et al. 2011). As a consequence, policy makers and urban planners have gradually identified urban areas as a fundamental part of the food system and, especially in Western countries, food policies have been developed to relocate some areas of food production into cities (Sonnino 2009; Veolia Institute 2019). Moreover, UA provides other important benefits to citizens, especially in developed countries by increasing social inclusion and equity in the communities involved in the process, as discussed later in the chapter (Poulsen 2017).

However, a direct link already exists between smart cities, information and communication technologies (ICTs) and agriculture. For nearly twenty years, precision agriculture has been growing in prominence as a farming-management concept. Precision agriculture is related to the use of digital technologies, such as unmanned aerial vehicles (UAV), autonomous machines, global positioning systems (GPS), and geographic information systems (GIS) (Griffin and Lowenberg-Deboer 2005).

The main goals of precision agriculture are to: (i) enhance and optimize agricultural production; (ii) contribute to food security; (iii) minimize the impact of conventional agriculture on the environment and wildlife (Norton and Swinton 2000; Gebbers and Adamchuk 2010; Whelan and Taylor 2013; European Parliament 2014; Walter et al. 2017; Moreno et al. 2019; de Amorim et al. 2019). This farming system is rather common and has already been applied in different parts of the world to various sectors of agriculture, e. g. viticulture, horticulture, and livestock production (Gebbers and Adamchuk 2010). Much of the literature has considered precision agriculture more sustainable than conventional agriculture. However, ICT solutions in agriculture could cause some negative consequences (Serbulova et al. 2019). The high cost of these technologies could lead to exclusion of vulnerable people in developing countries or in low-income communities (Zhang et al. 2002; Dobermann et al. 2004). Moreover, despite the high capacity of new technologies to decrease and limit agrochemical input use, such as pesticides and fertilizers, the pressure on the environment continues. As a consequence, many researchers suggest that the turning point would be an agroecological approach, in order to achieve more sustainable ways to produce food (Duru et al. 2015).

However, compared with precision agriculture, agroecology does not usually integrate ICTs. Given this background, it is clear that there is a gap between smart cities and urban food systems, even if smart cities and agriculture already present a connection in the precision farming debate. Hence, the aim of this chapter is to investigate the two research fields (smart city and agriculture) and to analyze which possible links could be achieved between these main topics. By doing so, the purpose is to support an idea of sustainable urban agriculture that aims to reach environmental and social sustainability in cities through the integration of ICTs. In other words, the vision is to combine the debate between smart cities, food systems, and UA by adopting agroecological approaches. To develop these arguments, the chapter begins by reviewing the smart city and urban agriculture concepts respectively. Later, it analyzes some innovative examples of integration of ICTs in urban agriculture and finally, it focuses on a specific example, named 'farmbetter'.

2. Are Smart Cities Inclusive Urban Environments?

The debate around smart cities has covered more than twenty years and at present many cities could be labelled as smart cities, due to the integration of ICTs in their urban environment (Hollands 2008; Allwinkle and Cruickshank 2011). The most famous forerunners are Singapore, San Diego, San Francisco, and Amsterdam and there are also examples of smart cities built from scratch, like Songdo (South Korea), Masdar City (United Arab Emirates), and PlanIT Valley (Portugal) (Arun and Teng Yap 2000; Vanolo 2016; Mullins 2017). However, over the last few years, many critics have been moved against this urban development model. The critics are concerned with two main aspects: on one hand, there is a strong presence of companies and big societies in smart city

development projects, e.g. IBM, Cisco, Google, Sidewalk Labs, and Alphabet (Wu and Lindsay 2020); on the other hand, there is an undefined role of citizens and citizenship within smart cities (Hollands 2008).

Companies and entrepreneurs occupy a key role in the development of these technologies and, at the same time, they are producers of ICTs and amplifiers of the concept of smart city. Particularly, they become indispensable actors of smart city debate (Paskaleva 2011; Söderström et al. 2014). One of the most famous examples is IBM, which, in 2011, officially registered the trademark 'smarter cities' and began a campaign to spread the concept around the world. The campaign highlights the most critical issues that cities are facing, such as the increase in urban populations, aging infrastructure, and pollution of urban environments. The initiative suggested that these problems need more than traditional solutions to be solved. As a result, IBM proposed technological alternatives as the unique medicine of urban problems and the company gained a hegemonic position on other IT societies, animating the debate on smart cities (Söderström et al. 2014). Generally, even the more dominant role of private companies in the public debate about smart cities is causing a lot of concern. The first issue is related to the administration of public services which are managed by private companies (Hollands 2008). Second, the dependency of cities on technologies provided by companies is increasing in relation to the use of particular technological platforms or devices (Bates 2012; Hill 2013). Finally, smart solutions provided by these ICT companies do not account for the uniqueness of places, peoples, and cultures and they are similarly spread to other cities (Townsend 2014). Moreover, citizens usually occupy a defined role as part of communication systems: they are often described as sensors aimed at collecting data in continuous interactions with sensing technologies used for environmental monitoring and feedback (Gabrys 2014). ICTs enable city dwellers to track their processes, consumption, and monitoring of their life and, in this way, they feel they are an active and fundamental part of smart cities. However, the language of smart city is not always inclusive and many questions are growing on the role of citizens within these innovative urban systems. Some authors highlight that smart cities are usually not considering social inclusion strategies, participation processes, and empowerment of urban dwellers (Carvalho 2015; Wiig 2016). The management and the services of cities are directly regulated by city administrations, often in association with private companies, following a top-down approach (Cardullo and Kitchin 2019). Indeed, the debate does not include the voices, aspirations, and desires of all citizens and there is a lack of connection with society and people (Vanolo 2014). Smart cities appeared to be more addressed to solving urban issues by adopting market-led solutions rather than fostering civil, social, and political rights (Swyngedouw 2016).

3. Urban Agriculture: The Living Space of Urban Food Production and Social Inclusion

Worldwide, UA provides different benefits to humankind and their well-being. It is a complex issue that embodies various urban challenges. Indeed, UA aims not only to achieve food security, but is a multifaceted phenomenon that seeks also to enhance social cohesion, equity, education, and mitigation of extreme events (Veolia Institute 2019). In this regard, there are several definitions of UA.

According to Viraj Puri, CEO of Gotham Greens, UA is defined as 'reconnecting with the community through food, jobs and economic development' (Baltimore Sun 2018 p. 1) UA is also described as 'growing food in cities' (Taylor and Lovell 2012 p. 57) and as 'improving the economy, environment, and health of cities' (Food Tank 2016), while the FAO described UA as the 'crop and livestock production within cities and towns and surrounding areas' (FAO Food and Agriculture Organization of the United Nations 2010 p. 1).

Since the early 1990s, food produced in cities has begun to increase worldwide. In just thirteen years, from 1993 to 2005, urban food production doubled from 15 per cent to 30 per cent of all food produces and the trend has been steadily increasing (Martellozzo et al. 2014; Altieri and Nicholls 2019). Moreover, UA is increasing in parallel to urban population growth. At the global level, in 2007, the population living in urban areas overtook the rural population and, at the same time, concerns related to urban planning and fresh food supply grew (UNFPA United Nations Population Found 2007). UA is heterogeneously defined and usually refers to agriculture in areas of limited space, due to the high competition for land in cities. It can involve vertical and rooftop gardens, community and residential gardens, vacant lands or brownfields, containers on balconies, and commercial urban farms (Specht et al. 2014). The scale of urban agricultural activities is related not only to the physical dimension, but also to its categorization. For instance, UA could be practised at the individual level in privately-owned areas, in communities (community gardens or guerrilla gardening⁹), and at commercial scale (Brown et al. 2003; Pearson et al. 2010; Adams and Hardman 2014; Mok et al. 2014). What is worth noting is that UA is performed in both developed and developing countries, but there are some differences in the role and implementation of UA in both areas. Indeed, in developed countries, the debate is recognized by institutions, policymakers, and citizens for several benefits and services provided and the initiatives related to UA are particularly diffused. The spread of UA in developed countries is mainly located in Europe and the USA, as demonstrated by the majority of academic studies, while in developing countries, research is poor or is composed mainly of grey literature, e.g. technical documents and project reports (Orsini et al. 2013; Artmann and Sartison 2018). Altogether, in developed countries, the general role identified for UA is to create a more sustainable lifestyle along with social ties within communities. Many initiatives are promoted in

⁹ Guerilla gardening is an example of grassroot initiatives of UA. The term usually refers to urban dwellers occupying spaces for growing vegetables or plants (Adams and Hardman 2014)

European and North American countries, and probably the most famous is the Milan Urban Food Policy Pact in 2015. The Pact highlights the key role of cities to achieve 'sustainable food systems and promoting healthy diets' and it recognizes the important role played by urban farmers and smallholder producers through food production (Milan Urban Food Policy Pact 2015 p. 1). Hence, cities have to implement and adopt 'food policies', 'programmes and initiatives' that do not have to be the only activities related to departments of agricultural and/or rural development (Milan Urban Food Policy Pact 2015; Kago et al. 2019). The papers analyzed in Artmann and Sartison's Review (2018) focused on developed countries and they highlight how the scientific literature covers different societal challenges of urbanization, such as climate change, ecosystem services, social cohesion, and food security.

On the other hand, UA in developing countries has a different function and it is more related to food and nutrition security (Maxwell et al. 1998). However, it is important to highlight that in developed countries, UA also plays an important role in the socio-economic conditions of urban dwellers (Mougeot 2000). Indeed, it is crucial for self-consumption and it could also become a source of income as well as decreasing the costs of grocery shopping (Moustier and Danso 2006). Nevertheless, institutions and policymakers do not consider UA in agricultural policies that are usually addressed in rural areas. Hence, many dwellers and urban farmers do not have access to the capital needed to purchase services to improve their production, for instance fertilizers, chemicals, and technical advice (Veolia Institute 2019).

4. How to Grow Food in Cities?

The existing agri-food system causes between 19-29 per cent of global greenhouse gas emissions and agricultural production is responsible for 80-86 per cent of total food system emissions (Vermeulen et al. 2012). Conventional agriculture causes pollution in land and water bodies, loss of biodiversity, and degradation of important ecosystems (Goucher et al. 2017; Sánchez-Bayo and Wyckhuys 2019). Furthermore, the current agri-food scheme results in other negative environmental impacts, e. g. soil erosion, loss of nutrients, loss of organic matter, and loss of soil biodiversity (FAO 2015). The main negative drivers of industrial agriculture are the use of monoculture practices that result in low genetic diversity, intensive tillage, chemical pest control, and the excessive use of inputs, such as fertilizers and pesticides (Woodhouse 2010; Holt-Giménez and Altieri 2013; Horton 2017). In addition, these highly-mechanised crop systems tend to compromise future yields in favor of high immediate productivity (Gliessman 2015).

It is important to highlight that the term UA refers to agriculture in general and it includes different agricultural systems, for instance, organic agriculture, agroecology, permaculture, vertical farming, and also industrial agriculture. Some of them could be categorized as alternative methods of agriculture, but they present many more similarities to conventional agriculture practices. Vertical

farming could be an example of alternative methods; however, it refers to an intense production model to cultivate plants or animals within skyscrapers (Despommier and Ellingsen 2008). Compared with conventional agriculture, vertical farming is considered more sustainable, given its emphasis on reduced energy, water, and fossil fuels use. However, sustainability could be called into question, in fact, start-up costs and energy are very high, especially in the beginning (Schmutz 2017; Al-Kodmany 2018).

Organic agriculture is another case of a non-traditional form of agriculture, through biodynamic agriculture and permaculture, which are defined as alternative agriculture due to the reduction of synthetic chemical inputs, such as pesticides and fertilizers (Lotter 2003). However, even if organic farming principles are similar to agroecological ones, market forces are demanding farmers to introduce input substitutions, making their operations dependent, and more intensive, mainly to maximize agricultural production (Rosset and Altieri 1997). By doing so, environmental impacts are reduced, but farmers remain strictly dependent on companies and too high production costs. The paradox is demonstrated by Californian organic farmers who grow grapes and strawberries, using between twelve and eighteen biological inputs and simultaneously they become trapped in an 'organic treadmill'. It means that while some specific diseases are managed by the use of organic inputs, other plantation aspects may be simultaneously affected by the need of other inputs to be controlled again (Guthman 2004).

Data clearly show the high production UA could provide to a city (Kennard and Bamford 2020). In Cleveland (Ohio), a city of 400,000 inhabitants, it is estimated that the urban area should be able to achieve high levels of self-sufficiency in fresh vegetables, fruits, eggs, poultry, and honey, depending on UA and how it is managed (Grewal and Grewal 2012). Another important example of where UA has been applied is Cuba, starting thirty years ago. In 1990, due to the collapse of the Soviet Union and then of hugely subsidized fuel, the country shifted from an intensive monoculture system to a small-scale system, applying agroecological principles (Vázquez Moreno and Funes Aguilar 2016). Worldwide, it seems that no other country has achieved these objectives with a form of agriculture that uses the ecological services of biodiversity and reduces food miles, energy use, and effectively closes local production and consumption cycles (Altieri and Funes-Monzote 2012). It is estimated that in Cuba, during 2014, more than 50 per cent of fresh products were produced by urban farmers and UA has been responsible for more than 300,000 jobs (Fernandez 2017).

5. IC Technologies to Spread an Agroecological Approach in Cities

The premise of this chapter is to describe how to develop an agricultural system within smart cities that is sustainable and at the same time can guarantee food security and other social benefits to citizens, at present and in the future. As shown in the previous paragraph, the starting point could

not be conventional agriculture or other methods that use high quantities of inputs (energy, water, and agrochemicals). Thus, the origin will be agroecology approaches and principles.

Agroecology can produce higher yields than industrial agriculture without the negative environmental impacts of the latter, even if it requires more labour (Pretty et al. 2006). Indeed, the main objective of agroecology is to improve the efficiency of biological processes and to enhance biological activities above and below the soil, also in the urban environment (Altieri and Nicholls 2019). Moreover, agroecological principles are usually applied in developing countries in small parcels of land and, therefore, it could be suitable also at the urban scale (Altieri 1995).

In fact, the urban environment is a concrete place to test a transition from industrial agriculture to agroecology, especially at a small-test scale. However, there are significant bottlenecks to the diffusion of this system, not only in urban contexts but also in rural contexts. It could be possible to define three different crucial issues: (i) practitioners usually need a lot of experience before translating their knowledge into functional agroecological systems in specific contexts; (ii) there are few experts and too few new experts are being trained (Norton 2019); and (iii) although scientific knowledge on this subject is well advanced, it is very difficult to ensure its accessibility to the general public (Raghavan et al. 2016). Knowledge required to manage an agroecological system is multiple and refers to climate information, land topography, water management, local biogeochemical conditions, information about specific plants and animals, and many others. What is more, knowledge is usually site-specific, even though it could be adapted to other sites (Raghavan et al. 2016). In this framework, ICTs could play a key role in disseminating agroecological knowledge in urban environments and smart cities. They could become important in every phase of the agroecological system – from the design of the agroecosystem to the maintenance of the unit – and they could be a great support to experts, new practitioners, and citizens. The introduction of ICTs in agroecosystems could be applied through two different methods: (i) models to disseminate practices and to connect experts and citizens; and (ii) introduction and application of open-source Internet of Things (IoT) technologies. At present, these two methods are an emerging field in the agroecology discourse and only in recent years, researchers and agroecologists have joined forces to develop these applications for serving citizens. Models are very useful methods that could help experts and citizens to plan, to develop, and to maintain their agroecosystems. Moreover, they become fundamental to connect people with different knowledge and in different parts of the world to share their knowledge. Models are developed by researchers and experts and they usually present information about plants, their interactions with other plants, climate and soil models suitable for specific locations, and other information (Raghavan et al. 2016). This information is obtained by the integration of data provided by existing databases that could be satellite data and weather/climate models. Currently, there are two models that are being implemented: (i) the software for agricultural ecosystems community coordinator (SAGE-CC); and (ii) and the smartphone app farmbetter. The

first one is developed by the University of California and is specific for the urban environment (Norton 2019). At the moment, the software is a demonstration and will be further implemented. The main objective of SAGE-CC is to facilitate the design and maintenance of agroecosystems between different owners of a community garden to create community polyculture. More specifically, the SAGE-CC could help neighborhoods to create a suitable sustainable polyculture system and simplify some fundamental processes in agroecology. The software could suggest which plants take advantage of their proximity or whether their relationship could be detrimental. According to the article 'The SAGE Community Coordinator: A Demonstration', a paramount example is reported by the process of pollination: some plants have to be located near other individuals of the same species to ensure wind or animal pollination. The idea of the SAGE-CC is to develop an interface with a map of the gardens where users can design and customize their property, using the most suitable cultivars. Vegetation databases will be developed categorizing plants not only in reference to the type or species but also based on their ecosystem relationship property, e.g. bark protection, fire, and insects, and on ecosystem relationship value. In this way, owners may understand good practices and best strategies to grow their sustainable food production and local food systems. Moreover, the SAGE-CC is developed as free and open-source software. First, users could freely access the system and their plant data; second, other communities could copy and modify it to their needs and environment. The second model is executed by farmbetter and is mainly aimed at developing countries for rural communities. It is implemented for measuring and improving the resilience of farmers and pastoralists in the face of climate change, for example, providing them with the right strategies to adapt to extreme events or specific shocks, such as floods and droughts (Choptiany et al. 2019). As climate change is becoming an urgent issue, as previously mentioned, it is crucial to guarantee food security to citizens and farmers, in part by providing them with the tools to deal with this growing threat (Beddington et al. 2011). New technologies, such as mobile phones, and big data collection, that are available in real-time and are becoming ever cheaper, could certainly help in this task. Hence, the transition of an urban community to one that has long-term local food resilience is complex and faced with many organizational challenges (Norton et al. 2014). The second method presented in this chapter is the introduction of open source IoT technologies to support and implement practices of urban agroecology and to empower citizens. The 'Connected Seeds and Sensors' project was an important case study that took place between 2015 and 2017. It was a joint project between Spitalfields City Farm, a community garden operating since the 1970s in east London, and Queen Mary University of London. More specifically, the aims of the project were to support the practices of food-growing and seed-saving via the use of networked environmental sensors and data visualizations and the creation of an interactive seed library (Heitlinger et al. 2019). The purpose of researchers was to integrate IoT technologies in small-scale urban agriculture, in stark contrast to sensors used by precision farming. The project introduced

open source and custom-built IoT devices in the community garden to collect data and to verify how gardeners could respond to devices. The data collected included air temperature, humidity, and pressure, soil moisture and temperature, and ambient light. A second part of the project was to create an interactive library of seeds, where records were gathered and provided by experts, to explain the value and functions of a specific seed. More specifically, at the beginning, citizens were involved in workshops and activities to better understand best practices for food production in cities and the importance of saving seeds. Later, fifteen people of different nationalities were involved as seed guardians to grow one to two crops. In eight of these gardens, IoT devices were set up. These devices were previously designed and customized and they were based on open-source systems. Finally, the data collected from the sensors were presented on an interactive website, where citizens could also view photos and audio from the gardens. By doing so, researchers were able to increase citizens' participation in the integration of IoT technologies, generally managed in a top-down vision of the city. Moreover, the objective of the project was not only to test IoT technologies in urban agriculture, but also to create opportunities for interaction, social cohesion, and the care of common spaces.

6. Farmbetter: Building Resilience through Knowledge

In this section, we introduce a vignette of the application farmbetter and review its positioning within the current paradigm of rural development, explaining how it aims to improve farmers' access to knowledge. We subsequently outline the necessary steps to transform it into urban settings and conclude with an outlook on its applicability in contributing toward agroecology in an urban context. Existing approaches to assess the resilience of farmers (FAO Food and Agriculture Organization of the United Nations 2018a,2018b; UNDP United Nations Development Programme 2018) fail to provide farmers with actionable recommendations. Instead, they have been designed largely for project staff and monitoring and evaluation officers in order to measure project impact and to design more targeted interventions. Recognizing that climate change presents these farmers with novel challenges, farmbetter was developed in 2018, aiming to build upon the lessons learned from the above tools. This resulted in an Android app (farmbetter) launched in 2019 and provides users with tailored recommendations to empower them to make informed decisions to adapt and withstand shocks and stresses (e.g. droughts). By making the app on a smartphone aimed at farmers (rather than a tablet), it changed the emphasis away from project staff and instead empowered farmers to assess and improve their resilience themselves.

In addition to the above, the dominant approach in integrating ICT in rural areas is focused on capital-intensive solutions that include the improved adoption of high-yielding seed varieties, fertilizers and pesticides. While successful at reducing the yield gap at least in the short term, these intensification strategies are more vulnerable to shocks and stresses and are highly dependent on continuing to

produce ever greater amounts of inputs. Integrating more knowledge-intensive, agroecological approaches that have a proven track record can, not only improve agricultural productivity in the long run, but importantly, provide avenues to strengthen smallholder farmers' resilience in rural areas. Farmers in these areas tend to be less well connected with input suppliers and also receive less extension service support. The app 'farmbetter' aims to supplement existing services and value chains by leveraging peer-reviewed sustainable land-management practices from existing databases (e.g. the world overview of conservation approaches and technologies (WOCAT) is the leading database of over 1,200 sustainable land-management practices, hosted by the University of Berne (WOCAT 2014)). The app starts by asking questions about the farmers' practices, contexts, and interests in improving their livelihood (Fig. 1A). Using farmers' geolocation, global datasets are accessed to understand the local context (soil type, precipitation, altitude, agroecosystem zone, etc.). This information creates a unique profile of the farmer who can link to thousands of best practices from databases, such as WOCAT (Fig. 1B). By using global databases, farmbetter is able to access many more of the best practices (that have the same characteristics as the farmer's context) than if only accessing ones from within a specific country or region.

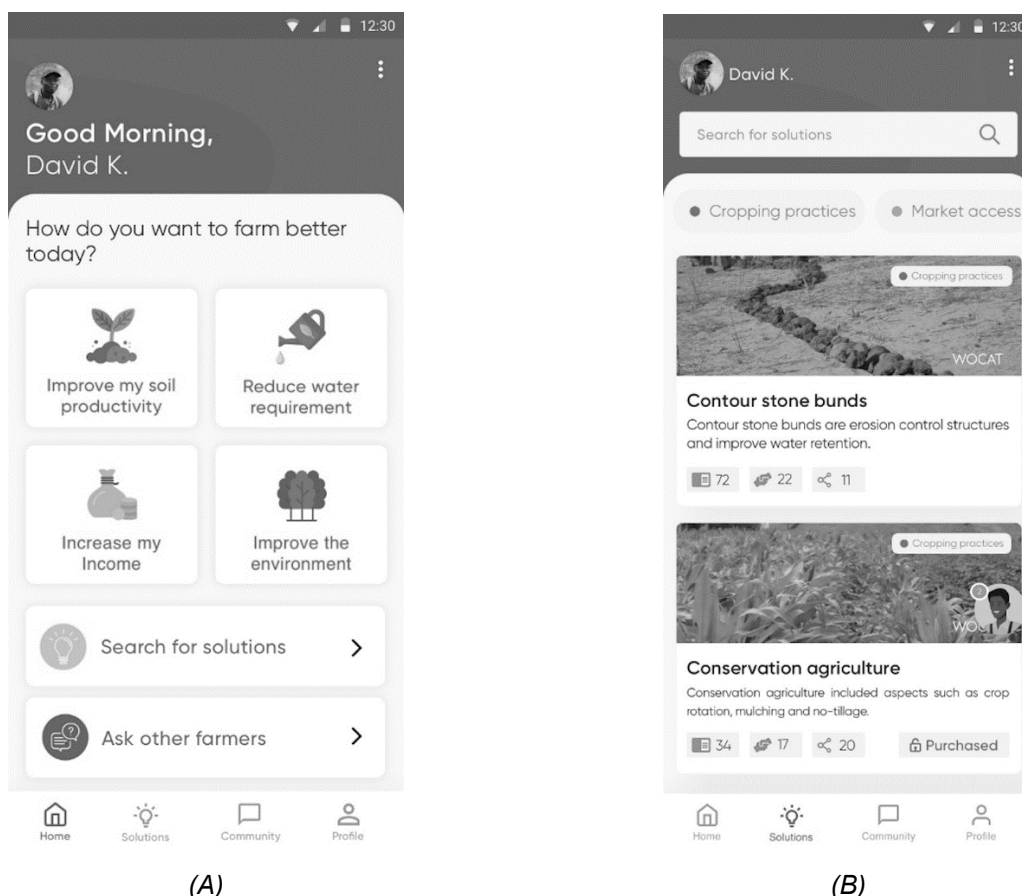


Fig. 1: Home 2 (A) and solutions 2 (B) (Source: Authors' elaboration)
 In order to adapt the farmbetter approach from rural farmers to a peri-urban or urban agricultural context, it is expected that the following five main conditions will be needed to change: (i) conditions limiting the reach of ICTs, such as lower literacy and ownership of smartphones in rural areas, will

be less prevalent; (ii) as described in the community gardens above, production will need to be intensified given the price premium placed on land in urban settings; (iii) urban production is expected to be less diverse, as high value crops or legumes are grown to offset the costs; (iv) in addition to space, a key limiting capital factor is likely labour, especially in cases where urban agriculture is undertaken as a voluntary or part-time activity to supplement a wage-earning main income; and (v) lastly, with regards to shocks and stresses, urban areas often experience the heat island effect, increasing temperatures between 1-3°C, and hence impacting viabilities of urban food production. Given the varied geography with buildings, wind tunnels, and shades, there are likely to be numerous microclimates that will be more difficult to assess from global datasets based on satellite data. However, one major benefit of using farmbetter in smart cities is that there will be more data available for improving recommendation matching and for more nuanced best practices for urban farmers to implement.

In order to adapt the application to a smart city environment, farmbetter would need the following three main changes to adapt to an urban environment: first, the current rural application focuses predominantly on the ability of farmers to receive tailored recommendations. In a context of lower population densities and lack of adequate extension services, the provisioning of new targeted knowledge subsequently can act as a key driver to empower farmers to improve their resilience. In an urban environment, where the barriers to gaining access to services or new knowledge are expected to be lower, the need for tailored recommendations might be lower. With lower expertise in urban agriculture, however, the need for having a forum for farmers to interact with experts and others to get additional advice is heightened. Second, given urban agriculture's positioning outside the field of dominant development actors, there's a need to build upon the relatively recent and limited documentation of urban agricultural practices. For the current application, the existing dataset of solutions from WOCAT will need to be complemented with specific ones that are applicable to urban areas. Examples include databases from the University of Missouri (Hendrickson and Porth 2012), Interreg Mediterranean (MADRE 2018), and the United States Department of Agriculture (United States Department of Agriculture 2016).

Third, in order to improve the matching mentioned above, a population density filter would need to complement the existing agroecological filters (e.g. University of Southampton 2021) to ensure that the matching of solutions is adequately weighted based on the dominant characteristics of working in an urban environment. Urban settings would also trigger a reduction in the ranking on select factors, such as soils, as they are usually not a pre-determinant for urban agricultural production, given that many of the sites would either bring in soil or use artificial approaches, such as hydroponics or vertical agriculture. Furthermore, given the effect of the built environment on temperatures or flooding, a higher spatial granularity is likely to improve the matching, and in the event of a lack of such data, adapting the weights would be advisable. Incorporating data from the

urban farmers themselves on microclimates, including rooftop farming, could also help identify more opportunities to implement urban agriculture and make developing the profile of the farmer's context more accurate.

Given that farmbetter has been designed as a platform that is based on matching the profiles of farmers to datasets of best practices, the app is relatively agnostic to the content of those databases (as long as the content is of a high quality). As discussed above, some changes would still be recommended to make it more appropriate and effective for urban agriculture. As with developing farmbetter in its current form required many iterations and input from users, adapting farmbetter to the urban context would require similar collaborations. Once databases of best practices are connected to the app, a pilot would be necessary to test its effectiveness and to allow for improvements, using a human-centered design approach. As urban agriculture provides a significant opportunity to reduce environmental impacts and increase food security in urban areas, it is important to realise this potential. The farmbetter app provides one means by which to connect the existing, proven best practices to urban farmers, who want advice tailored to their specific contexts.

7. The Benefits of Agroecology in Smart Cities: Ecosystem Services, Food Sovereignty, and Empowerment of Citizens

This chapter aims to investigate and analyze possible links between smart cities and UA by the integration of an agroecological approach. Hence, the chapter provides a critical viewpoint on one of the most inspiring models of the city of the future, namely smart cities, and how that form of urban, social, and political development, with its connected technologies, could be linked with UA and food systems to provide not only food sovereignty, but also, others social and environmental benefits to human well-being.

Particularly, the benefits provided by urban agroecology in cities are multiple. Like other UA systems, it increases food sovereignty in cities thanks to easier access to healthy food in developing countries, but also in underserved communities in developed countries (Kennard and Bamford 2020). Moreover, urban agroecology could be an important approach due to its educational, cultural, geographic, and economic dimensions (Siegener et al. 2018). However, the spread of this approach, not only in rural areas but also in cities, could be difficult, due to the high competencies required by citizens and farmers. Hence, ICTs could involve innovative devices and resources to support the dissemination and knowledge of this practice in urban environments (Raghavan et al. 2016). Even if the three examples above are tests or at the beginning of their experience, they are examples of how it could be possible and feasible to integrate ICTs into UA and how they could foster the introduction of agroecological practices. Indeed, all of them show how, through the use of IoT technologies, laypersons could grow their own food wherever they are and support food production in cities through the introduction of agroecological techniques. Although farmbetter is mainly

developed for rural areas, it shows how farmers could benefit from ICTs to develop the best agroecological practices to improve their resilience to climate change (Choptiany et al., 2019). At present, SAGE-CC is only a test but it already illustrates how various owners of community gardens could collaborate to implement a sustainable polyculture. Moreover, each example highlights different positive aspects provided by the integration of ICTs and urban agroecology. SAGE-CC highlights how the implementation of sustainable polyculture systems could contrast the dependency of citizens on conventional agriculture and increase plant diversity in urban ecosystems (Norton et al. 2019). Finally, these examples illustrate how ICTs are important tools in the development of cities of the future and, at the same time, how new technologies and data could be applied. In fact, many critics have been moved against the present model of smart cities, due to their inability to guarantee empowerment of citizens and citizenship and also due to the big presence of companies in the governance and administration of cities. The literature on smart cities shows how ICTs are mainly integrating, monitoring, and regulating directly by companies or in a strict partnership between private and public, without the participation of citizens, except for the sensing of data. The examples proposed in this chapter investigate how it could be possible to involve different citizens in the life of the cities of the future. For instance, the Queen Mary University of London study is an example of social inclusion in urban spaces by practicing urban agroecology and, at the same time, providing food for citizens. The project was promoted in a low-income community in the north-east of England and it showed how citizens collaborated to develop their own community garden. The project highlights how IoT technologies could be integrated, not with a top-down approach, but with a bottom-up experience that aims to empower citizens and provide them with knowledge to test and use open source IoT in UA.

In conclusion, the chapter highlights the need for further research and studies to analyze and investigate how to feed a growing population in cities of the future. Moreover, it highlights the potential to capture and integrate agroecological approaches and ICTs into the smart city debate.

REFERENCES

- Adams, D. and M. Hardman. 2014. Observing Guerrillas in the Wild: Reinterpreting Practices of Urban Guerrilla Gardening. *Urban Studies*. 51:1103–1119.
- Ahern, J. 2007. Green infrastructure for cities: the spatial dimension. 267–283 *In* V. Novotny and P. Brown, editors. *Cities of the Future: Towards Integrated Sustainable Water and Landscape Management*. IWA Publishing, London, UK.
- Aksoy, E. M. Gregor C. Schröder M. Löhnertz and G. Louwagie. 2017. Assessing and analysing the impact of land take pressures on arable land. *Solid Earth*. 8:683–695.
- Al-Kodmany, K. 2018. The Vertical Farm: A Review of Developments and Implications for the Vertical City. *Buildings*. 8:24.
- Albino, V. U. Berardi and R. M. Dangelico. 2015. Smart Cities: Definitions, Dimensions, Performance, and Initiatives. *Journal of Urban Technology*. 22:3–21.
- Alexandri, E. and P. Jones. 2008. Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates. *Building and Environment*. 43:480–493.
- Allwinkle, S. and P. Cruickshank. 2011. Creating smart-er cities: An overview. *Journal of Urban Technology*. 18:1–16.
- Altieri, M. A. 1995. *Agroecology. The science of sustainable agriculture*. CRC Press, Boca Raton, USA.
- Altieri, M. A. and F. R. F. Funes-Monzote. 2012. The Paradox of Cuban Agriculture. *Monthly Review*. Retrieved from <https://monthlyreview.org/2012/01/01/the-paradox-of-cuban-agriculture/>. Accessed February 2020.
- Altieri, M. A. and C. I. Nicholls. 2019. Urban agroecology. *AgroSur*. 46:46–60.
- Álvarez, D. G. 2017. Cartographic scale and minimum mapping unit influence on LULC modelling. 327–334 *In* L. Ragia, J. G. Rocha, and R. Laurini, editors. *Proceedings of the 3rd International Conference on Geographical Information Systems Theory, Applications and Management - GAMOLCS*. SciTePress, Porto.
- Amato, F. F. Martellozzo G. Nolè and B. Murgante. 2017. Preserving cultural heritage by supporting landscape planning with quantitative predictions of soil consumption. *Journal of Cultural Heritage*. 23:44–54.
- de Amorim, W. S. A. Borchardt Deggau G. do Livramento Gonçalves S. da Silva Neiva A. R. Prasath and J. B. Salgueirinho Osório de Andrade Guerra. 2019. Urban challenges and opportunities to promote sustainable food security through smart cities and the 4th industrial revolution. *Land Use Policy*. 87:104065.
- Andersson-Sköld, Y. J. Klingberg B. Gunnarsson K. Cullinane I. Gustafsson M. Hedblom I. Knez F. Lindberg Å. Ode Sang H. Pleijel P. Thorsson and S. Thorsson. 2018. A framework for assessing urban greenery's effects and valuing its ecosystem services. *Journal of Environmental Management*. 205:274–285.
- Angelidou, M. 2015. Smart cities: A conjuncture of four forces. *Cities*. 47:95–106.
- Aragón-Durand, F. J. Corfee-Morlot R. B. R. Kiunsi M. Pelling D. C. Roberts and W. Solecki. 2014. Urban Areas. 535–612 *In* V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. . Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, N. Levy, S. MacCracken, P. R. Mastrandrea, and L. L. White, editors. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom

and New York, NY, USA.

- Arcidiacono, A. S. Ronchi and S. Salata. 2016. Managing Multiple Ecosystem Services for Landscape Conservation: A Green Infrastructure in Lombardy Region. *Procedia Engineering*. 161:2297–2303.
- Arnold, C. L. and C. J. Gibbons. 1996. Impervious Surface Coverage: The Emergence of a Key Environmental Indicator. *Journal of the American Planning Association*. 62:243–258.
- Artmann, M. 2015. Managing urban soil sealing in Munich and Leipzig (Germany)-From a wicked problem to clumsy solutions. *Land Use Policy*. 46:21–37.
- Artmann, M. 2016. Urban gray vs. urban green vs. soil protection — Development of a systemic solution to soil sealing management on the example of Germany. *Environmental Impact Assessment Review*. 59:27–42.
- Artmann, M. and J. Breuste. 2015. Cities Built for and by Residents: Soil Sealing Management in the Eyes of Urban Dwellers in Germany. *Journal of Urban Planning and Development*. 141:1–13.
- Artmann, M. L. Inostroza and P. Fan. 2019. Urban sprawl, compact urban development and green cities. How much do we know, how much do we agree? *Ecological Indicators*. 96:3–9.
- Artmann, M. and K. Sartison. 2018. The Role of Urban Agriculture as a Nature-Based Solution: A Review for Developing a Systemic Assessment Framework. *Sustainability*. 10:1937.
- Arun, M. and M. Teng Yap. 2000. Singapore : The Development of an Intelligent Island and Social Dividends of Information Technology. *Urban Studies*. 37:1749–1756.
- Asad, M. S. Rashid Ahmad F. Ali R. Mehmoo M. A. Butt and S. Rathore. 2017. Use Of Remote Sensing For Urban Impervious Surfaces: A Case Study Of Lahore . *International Journal of Engineering and Applied Sciences*. 4.
- Atasoy, M. 2018. Monitoring the urban green spaces and landscape fragmentation using remote sensing: a case study in Osmaniye, Turkey. *Environmental Monitoring and Assessment*. 190:1–8.
- Babí Almenar, J. T. Elliot B. Rugani B. Philippe T. Navarrete Gutierrez G. Sonnemann and D. Geneletti. 2021. Nexus between nature-based solutions, ecosystem services and urban challenges. *Land Use Policy*. 100:104898.
- Badiu, D. L. C. I. Iojă M. Pătroescu J. Breuste M. Artmann M. R. Niță S. R. Grădinaru C. A. Hossu and D. A. Onose. 2016. Is urban green space per capita a valuable target to achieve cities' sustainability goals? Romania as a case study. *Ecological Indicators*. 70:53–66.
- Bagan, H. and Y. Yamagata. 2014. Land-cover change analysis in 50 global cities by using a combination of Landsat data and analysis of grid cells. *Environmental Research Letters*. 9.
- Ballin, M. G. Barcaroli M. Masselli and M. Scarnó. 2018. Redesign sample for Land Use/Cover Area frame Survey (LUCAS) 2018. Luxembourg. Retrieved from <https://ec.europa.eu/eurostat/documents/3888793/9347564/KS-TC-18-006-EN-N.pdf/26cbdb1a-c418-4dfa-bc24-a27d1bc5599c?t=1540804305000>. Accessed July 2021.
- Baltimore Sun. 2018. Urban Farm Coming to Former Sparrows Point Steel Mill Site in Baltimore County. Retrieved from <http://www.baltimoresun.com/business/bs-md-sparrows-point-farm-20180508-story.html>. Accessed March 2020.
- Bates, J. 2012. “This is what modern deregulation looks like” : co-optation and contestation in the shaping of the UK's Open Government Data Initiative . Retrieved from <http://www.ci->

journal.net/index.php/ciej/article/view/845/916. Accessed March 2020.

- Becker, G. and R. Mohren. 1990. The Biotope Area Factor as an Ecological Parameter. *Landschaft: Planen & Bauen*, Berlin, Germany.
- Beddington, J. M. Asaduzzaman A. Fernandez M. Clark M. Guillou L. Jahn M. vand Erda T. Mamo N. Van Bo C. A. Nobre R. Scholes R. Sharma and J. Wakhungu. 2011. Achieving food security in the face of climate change. Copenhagen. Retrieved from www.ccafs.cgiar.org/commission. Accessed February 2020.
- Behnisch, M. H. Poglitsch and T. Krüger. 2016. Soil sealing and the complex bundle of influential factors: Germany as a case study. *ISPRS International Journal of Geo-Information*. 5:1–23.
- Bian Li Zuo Lei Zhang and Nan. 2019. Estimating 2009–2017 Impervious Surface Change in Gwadar, Pakistan Using the HJ-1A/B Constellation, GF-1/2 Data, and the Random Forest Algorithm. *ISPRS International Journal of Geo-Information*. 8:443.
- Birch, C. P. D. S. P. Oom and J. A. Beecham. 2007. Rectangular and hexagonal grids used for observation, experiment and simulation in ecology. *Ecological Modelling*. 206:347–359.
- Birk, R. J. T. Stanley G. I. Snyder T. A. Hennig M. M. Fladeland and F. Policelli. 2003. Government programs for research and operational uses of commercial remote sensing data. *Remote Sensing of Environment*. 88:3–16.
- Boschetto, P. and A. Schiavon. 2011. The Image of Metropolitan Territory. The Metropolitan City of Padua (in Italian: *L'immagine del Territorio Metropolitano*. La Città Metropolitana di Padova. (P. Boschetto and A. Schiavon, Eds.). Cleup, Padova, Italy.
- Brown, G. 2004. Mapping Spatial Attributes in Survey Research for Natural Resource Management: Methods and Applications. <http://dx.doi.org/10.1080/08941920590881853>. 18:17–39.
- Brown, K. H. M. Bailkey A. Meares-Choen J. Nasr J. Smit T. Buchanan and Mann Peter. 2003. Urban Agriculture and Community Food Security in the United States: Farming from the City Center to Urban Fring. Retrieved from <https://community-wealth.org/content/urban-agriculture-and-community-food-security-united-states-farming-city-center-urban-fringe>. Accessed February 2020.
- Buccola, N. and G. Spolek. 2011. A Pilot-Scale Evaluation of Greenroof Runoff Retention, Detention, and Quality. *Water, Air, & Soil Pollution*. 216:83–92.
- Burghardt, W. 2006. Soil sealing and soil properties related to sealing. Geological Society, London, Special Publications. 266:117–124.
- Bush, J. and A. Doyon. 2019. Building urban resilience with nature-based solutions: How can urban planning contribute? *Cities*. 95:102483.
- Calzolari, C. P. Tarocco N. Lombardo N. Marchi and F. Ungaro. 2020. Assessing soil ecosystem services in urban and peri-urban areas: From urban soils survey to providing support tool for urban planning. *Land Use Policy*. 99:105037.
- Cameron, R. W. F. T. Blanuša J. E. Taylor A. Salisbury A. J. Halstead B. Henricot and K. Thompson. 2012. The domestic garden – Its contribution to urban green infrastructure. *Urban Forestry & Urban Greening*. 11:129–137.
- Cao, S. D. Hu Z. Hu W. Zhao S. Chen and C. Yu. 2018. Comparison of spatial structures of urban agglomerations between the Beijing-Tianjin-Hebei and Boswash based on the subpixel-level impervious surface coverage product. *Journal of Geographical Sciences* 2018 28:3. 28:306–322.

- Caputo, P. F. Zagarella M. A. Cusenza M. Mistretta and M. Cellura. 2020. Energy-environmental assessment of the UIA-OpenAgri case study as urban regeneration project through agriculture. *Science of The Total Environment*. 729:138819.
- Cardullo, P. and R. Kitchin. 2019. Being a 'citizen' in the smart city: up and down the scaffold of smart citizen participation in Dublin, Ireland. *GeoJournal*. 84:1–13.
- Carr, D. B. A. R. Olsen and D. White. 1992. Hexagon Mosaic Maps for Display of Univariate and Bivariate Geographical Data. *Cartography and Geographic Information Systems*. 19:228–236.
- Carvalho, L. 2015. Smart cities from scratch? A socio-technical perspective. *Cambridge Journal of Regions, Economy and Society*. 8:43–60.
- Casella, V. M. Franzini and R. De Lotto. 2016. Geomatics for smart cities: obtaining the urban planning baf index from existing digital maps. 689–694 *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. Prague, Czech Republic.
- Casti, E. 2014. Aree dismesse e obsolete in Lombardia, Rapporto I fase di ricerca del progetto Rifo/It. Bergamo. Retrieved from www.unibg.it/diathesis. Accessed January 2022.
- Ceccarelli, T. S. Bajocco L. Salvati and L. Perini. 2014. Investigating syndromes of agricultural land degradation through past trajectories and future scenarios. *Soil Science and Plant Nutrition*. 60:60–70.
- Cervinka, R. M. Schwab R. Schönbauer I. Hämmerle L. Pirgie and J. Sudkamp. 2016. My garden – my mate? Perceived restorativeness of private gardens and its predictors. *Urban Forestry & Urban Greening*. 16:182–187.
- Chen, Y. and S. Yu. 2016. Assessment of urban growth in Guangzhou using multi-temporal, multi-sensor Landsat data to quantify and map impervious surfaces. *International Journal of Remote Sensing*. 37:5936–5952.
- Choptiany, J. M. B. E. Graeub S. Hatik D. Conversa and S. T. Ledermann. 2019. Participatory Assessment and Adaptation for Resilience to Climate Change. *Consilience*. 21:17–31.
- Clark, C. C. Ordóñez and S. J. Livesley. 2020. Private tree removal, public loss: Valuing and enforcing existing tree protection mechanisms is the key to retaining urban trees on private land. *Landscape and Urban Planning*. 203:103899.
- Climate ADAPT. 2016. Berlin Biotope Area Factor - Implementation of guidelines helping to control temperature and runoff - Climate ADAPT. Retrieved from https://climate-adapt.eea.europa.eu/metadata/case-studies/berlin-biotope-area-factor-2013-implementation-of-guidelines-helping-to-control-temperature-and-runoff/#challenges_anchor. Accessed November 2019.
- Colding, J. 2011. The Role of Ecosystem Services in Contemporary Urban Planning. 228–237 *In* J. Niemelä, J. H. Breuste, T. Elmqvist, G. Guntenspergen, P. James, and N. E. McIntyre, editors. *Urban Ecology: patterns, processes and applications*. Oxford University Press, Oxford, UK.
- Commission, E. 2019. Soil - Soil Sealing. Retrieved from https://ec.europa.eu/environment/soil/sealing_guidelines.htm. Accessed November 2019.
- Commission of the European Communities. 2002. Towards a Thematic Strategy for Soil Protection. CEC, Brussels, Belgium.
- Commission of the European Communities (CEC). 2002. Communication "Towards a Thematic Strategy for Soil Protection" COM(2002) 179 final. Brussels. Retrieved from <https://eur-lex.europa.eu/legal->

content/EN/TXT/PDF/?uri=CELEX:52002DC0179&from=EN. Accessed January 2019.

- Commissione Europea. 2007. Direttiva 2007/2/CE del Parlamento europeo e del Consiglio, del 14 marzo 2007, che istituisce un'Infrastruttura per l'informazione territoriale nella Comunità europea (Inspire). Gazzetta ufficiale dell'Unione Europea.
- Comune di Padova. 2004. Padova, città d'acque. Un modo diverso per conoscere la città. Ufficio Turismo Settore Comunicazioni ai Cittadini, Padova, Italia.
- Comune di Padova. 2014. Territorial Management Plan. Technical Implementation Standards (in Italian: Piano di Assetto del Territorio. Norme Tecniche di Attuazione. Padua, Italy.
- Comune di Padova. 2018. Plan of Interventions. Technical Implementation Standards (in Italian: Piano Degli Interventi. Norme Tecniche di Attuazione. Padua, Italy.
- Comune di Padova. 2019. Padua Bici Masterplan 2018-2022. Relation (in Italian: Bici Masterplan di Padova 2018–2022. Relazione). Padua, Italy.
- Comune di Padova. 2020. 2019 Statistical Yearbook (in Italian: Annuario Statistico 2019). Padova, Italy.
- Congedo, L. L. Sallustio M. Munafò M. Ottaviano D. Tonti and M. Marchetti. 2016. Copernicus high-resolution layers for land cover classification in Italy. *Journal of Maps*. 12:1195–1205.
- Contesse, M. B. J. M. van Vliet and J. Lenhart. 2018. Is urban agriculture urban green space? A comparison of policy arrangements for urban green space and urban agriculture in Santiago de Chile. *Land Use Policy*. 71:566–577.
- Cortijo, A. A. and M. E. P. González. 2017. Soil sealing in Madrid (Spain), study case of Colmenar Viejo. *Earth Sciences Research Journal*. 21:111–116.
- Cortinovis, C. and D. Geneletti. 2019. A framework to explore the effects of urban planning decisions on regulating ecosystem services in cities. *Ecosystem Services*. 38:100946.
- Coseo, P. and L. Larsen. 2019. Accurate Characterization of Land Cover in Urban Environments: Determining the Importance of Including Obscured Impervious Surfaces in Urban Heat Island Models. *Atmosphere* 2019, Vol. 10, Page 347. 10:347.
- CRCS. 2018. CRCS 2018: consumo di suolo, servizi ecosistemici e green infrastructures. (A. Arcidiacono, D. Di Simine, S. Ronchi, and S. Salata, Eds.). INU Edizioni, Roma, Italia.
- Crescini Di Montevecchio Benedetti, E. 2018. Consumo di suolo a Padova: analisi GIS del quartiere Forcellini (PD) e calcolo dell'indice Biotope Area Factor. Università degli Studi di Padova.
- Czemieli Berndtsson, J. 2010, April. Green roof performance towards management of runoff water quantity and quality: A review.
- Davies, C. and R. Laforteza. 2019. Transitional path to the adoption of nature-based solutions. *Land Use Policy*. 80:406–409.
- Decoville, A. and M. Schneider. 2016. Can the 2050 zero land take objective of the EU be reliably monitored? A comparative study. *Journal of Land Use Science*. 11:331–349.
- Department of Economic and Social Affairs of United Nations. 2015. Goal 11 . Retrieved from <https://sdgs.un.org/goals/goal11>. Accessed October 2021.
- Despommier, D. and E. Ellingsen. 2008. The Vertical Farm: The sky-scraper as vehicle for a sustainable urban agriculture. In A. Wood, editor. CTBUH 8th World Congress 2008. Dubai, United Arab Emirates.
- Dewaelheyns, V. E. Rogge and H. Gulinck. 2014. Putting domestic gardens on the agenda using empirical

- spatial data: The case of Flanders. *Applied Geography*. 50:132–143.
- Dobermann, A. B. S. Backmore S. E. Cook and V. Adamchuk. 2004. Precision farming: Challenges and future directions. *In* T. Fischer, N. Turner, J. Angus, L. McIntyre, M. Robertson, A. Borrell, and D. Lloyd, editors. Proceedings of the 4th International Crop Science Congress. Brisbane, Australia.
- Duru, M. O. Therond and M. Fares. 2015. Designing agroecological transitions; A review. *Agronomy for Sustainable Development*. 35:1237–1257.
- Eigenbrod, F. V. A. Bell H. N. Davies A. Heinemeyer P. R. Armsworth and K. J. Gaston. 2011. The impact of projected increases in urbanization on ecosystem services. 3201–3208 *In* M. P. Hassell, S. H. Alonzo, G. R. Carvalho, I. C. Cuthill, H. A. P. Heesterbee, and M. T. Siva-Jothy, editors. Proc. R. Soc. B. London, UK.
- Elvidge, C. D. B. T. Tuttle P. S. Sutton K. E. Baugh A. T. Howard C. Milesi B. L. Bhaduri and R. Nemani. 2007. Global Distribution and Density of Constructed Impervious Surfaces. *Sensors (Basel, Switzerland)*. 7:1962.
- Estellés Arolas, E. and F. González Ladrón-de-Guevara. 2012. Towards an integrating crowdsourcing definition. *Journal of Information Science* . 32:189–200.
- EU Commission. 2016. Mapping and Assessment of Ecosystems and their Services Urban ecosystems 4th Report Final. Retrieved from <http://ec.europa.eu>. Accessed November 2019.
- EU Parliament and EU Council. 2013. General Union Environment Action Programme to 2020 'Living well, within the limits of our planet.' 171–200.
- European Commission. 2011. Roadmap to a Resource Efficient Europe. Communication from the Commission to the European Parliament, the Council, the European economic and social committee and the committee of the regions. Brussels. Retrieved from <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0571&from=EN>. Accessed April 2019.
- European Commission. 2012a. Soil Sealing. *Science for Environment Policy*.:1–41.
- European Commission. 2012b. Guidelines on best practice to limit, soil sealing mitigate or compensate. EC, Belgium.
- European Commission. 2020. Mapping Guide v6.2 for a European Urban Atlas Regional Policy. Retrieved from http://www.stadtentwicklung.berlin.de/umwelt/umweltatlas/ed610_03.htm. Accessed October 2021.
- European Environment Agency. 2016. The direct and indirect impacts of EU policies on land. Luxembourg. Retrieved from <https://www.eea.europa.eu/publications/impacts-of-eu-policies-on-land>. Accessed October 2021.
- European Environment Agency. 2018. Copernicus Land Monitoring Service – High Resolution Layer Imperviousness. Copernicus team at EEA. Retrieved from <https://land.copernicus.eu/user-corner/technical-library/hrl-imperviousness-technical-document-prod-2015>. Accessed January 2019.
- European Parliament. 2014. Precision agriculture: an opportunity for EU farmers - potential support with the CAP 2014-2020. Retrieved from https://www.europarl.europa.eu/thinktank/it/document.html?reference=IPOL-AGRI_NT%282014%29529049. Accessed February 2020.
- Fadini, U. 2013. Walls of Padua. A guide to the Renaissance Fortification System (in Italian: Mura di Padova. Guida al Sistema Bastionato Rinascimentale. (U. Fadini, Ed.). Edibus, Vicenza, Italy.

- Faivre, N. M. Fritz T. Freitas B. de Boissezon and S. Vandewoestijne. 2017. Nature-Based Solutions in the EU: Innovating with nature to address social, economic and environmental challenges. *Environmental Research*. 159:509–518.
- FAO. 2015. Status of the World's Soil Resources: Main Report. Retrieved from <http://www.fao.org/documents/card/en/c/c6814873-efc3-41db-b7d3-2081a10ede50/>. Accessed February 2020.
- FAO Food and Agriculture Organization of the United Nations. 2010. Fighting Poverty and Hunger. What Role for Urban Agriculture? Retrieved from www.fao.org/fcit. Accessed March 2021.
- FAO Food and Agriculture Organization of the United Nations. 2018a. RIMA | Resilience Index Measurement and Analysis (RIMA). Retrieved from <http://www.fao.org/resilience/background/tools/rima/en/>. Accessed March 2020.
- FAO Food and Agriculture Organization of the United Nations. 2018b. Self-evaluation and Holistic Assessment of climate Resilience of farmers and Pastoralists (SHARP) | Food and Agriculture Organization of the United Nations.
- Feltynowski, M. and J. Kronenberg. 2020. Urban Green Spaces—An Underestimated Resource in Third-Tier Towns in Poland. *Land* 2020, Vol. 9, Page 453. 9:453.
- Feng, D. Y. Zhao L. Yu C. Li J. Wang N. Clinton Y. Bai A. Belward Z. Zhu and P. Gong. 2016. Circa 2014 African land-cover maps compatible with FROM-GLC and GLC2000 classification schemes based on multi-seasonal Landsat data. <http://dx.doi.org/10.1080/01431161.2016.1218090>. 37:4648–4664.
- Fernandez, M. 2017. Urban Agriculture in Cuba: 30 years of policy and practice. *Urban Agroecology*. Retrieved from <https://ruaf.org/document/urban-agriculture-magazine-no-33-urban-agroecology/>. Accessed.
- Fini, A. P. Frangi J. Mori D. Donzelli and F. Ferrini. 2017. Nature based solutions to mitigate soil sealing in urban areas: Results from a 4-year study comparing permeable, porous, and impermeable pavements. *Environmental Research*. 156:443–454.
- Food Tank. 2016. Twelve Organizations Promoting Urban Agriculture around the World. Retrieved from <http://www.fao.org/family-farming/detail/en/c/461898/>. Accessed February 2020.
- Fouilleux, E. N. Bricas and A. Alpha. 2017. 'Feeding 9 billion people': global food security debates and the productionist trap. *Journal of European Public Policy*. 24:1658–1677.
- Franke, J. D. A. Roberts K. Halligan and G. Menz. 2009. Hierarchical Multiple Endmember Spectral Mixture Analysis (MESMA) of hyperspectral imagery for urban environments. *Remote Sensing of Environment*. 113:1712–1723.
- Franklin, J. J. Rogan S. R. Phinn and C. E. Woodcock. 2003. Rationale and Conceptual Framework for Classification Approaches to Assess Forest Resources and Properties. 279–300 *In* M. A. Wulder and S. E. Franklin, editors. *Remote Sensing of Forest Environments*. Springer, Boston.
- Frew, T. D. Baker and P. Donehue. 2016. Performance based planning in Queensland: A case of unintended plan-making outcomes. *Land Use Policy*. 50:239–251.
- Frew, T. G. 2011. The implementation of performance based planning in Queensland under the integrated planning act 1997: an evaluation of perceptions and planning schemes. Queensland University of Technology.
- Fu, Y. J. Li Q. Weng Q. Zheng L. Li S. Dai and B. Guo. 2019. Characterizing the spatial pattern of annual

- urban growth by using time series Landsat imagery. *Science of The Total Environment*. 666:274–284.
- Gabrys, J. 2014. Programming environments: environmentality and citizen sensing in the smart city. *Environment and Planning D: Society and Space*. 32:30–48.
- Gao, Y. D. Wang A. Schmidt and Y. Tang. 2018. Exploring the Response of Combined Urban Sewer System to the Implementation of Green Roof. 1–7 4th International Conference on Environmental Systems Research. IOP Publishing Ltd.
- García, P. and E. Pérez. 2016. Mapping of soil sealing by vegetation indexes and built-up index: A case study in Madrid (Spain). *Geoderma*. 268:100–107.
- Gardi, C. 2017a. Impact of land take on global food security. 146–156 *In* C. Gardi, editor. *Urban Expansion, Land Cover and Soil Ecosystem Services*. Routledge.
- Gardi, C. 2017b. *Urban Expansion, Land Cover and Soil Ecosystem Services*. (C. Gardi, Ed.) Urban Expansion, Land Cover and Soil Ecosystem Services. 1st ed. Routledge, New York, USA.
- Gebbers, R. and V. I. Adamchuk. 2010. Precision agriculture and food security. *Science*. 327:828–831.
- Giachino, C. G. Pattanaro B. Bertoldi L. Bollani and A. Bonadonna. 2021. Nature-based solutions and their potential to attract the young generations. *Land Use Policy*. 101:105176.
- Glavan, M. U. Schmutz S. Williams S. Corsi F. Monaco M. Kneafsey P. A. Guzman Rodriguez M. Čenič-Istenič and M. Pintar. 2018. The economic performance of urban gardening in three European cities – examples from Ljubljana, Milan and London. *Urban Forestry & Urban Greening*. 36:100–122.
- Gliessman, S. R. 2015. *Agroecology: The Ecology of Sustainable Food Systems*. CRC Press, Boca Raton, USA.
- Goldblatt, R. M. F. Stuhlmacher B. Tellman N. Clinton G. Hanson M. Georgescu C. Wang F. Serrano-Candela A. K. Khandelwal W. H. Cheng and R. C. Balling Jr. 2018. Using Landsat and nighttime lights for supervised pixel-based image classification of urban land cover. *Remote Sensing of Environment*. 205:253–275.
- Gomes, V. C. F. G. R. Queiroz and K. R. Ferreira. 2020. An Overview of Platforms for Big Earth Observation Data Management and Analysis. *Remote Sensing 2020*, Vol. 12, Page 1253. 12:1253.
- Gómez-Baggethun, E. and D. N. Barton. 2013. Classifying and valuing ecosystem services for urban planning. *Ecological Economics*. 86:235–245.
- Gong, P. X. Li and W. Zhang. 2019. 40-Year (1978–2017) human settlement changes in China reflected by impervious surfaces from satellite remote sensing. *Science Bulletin*. 64:756–763.
- Goodchild, M. F. 2007. Citizens as sensors: the world of volunteered geography. *GeoJournal*. 69:211–221.
- Goucher, L. R. Bruce D. D. Cameron S. C. Lenny Koh and P. Horton. 2017. The environmental impact of fertilizer embodied in a wheat-to-bread supply chain. *Nature Plants*. 3:1–5.
- Grewal, S. S. and P. S. Grewal. 2012. Can cities become self-reliant in food? *Cities*. 29:1–11.
- Griffin, T. W. and J. Lowenberg-Deboer. 2005. Worldwide adoption and profitability of precision agriculture Implications for Brazil. Retrieved from <http://www.ers.usda.gov/Briefing/ARMS/>. Accessed February 2020.
- Gu, C. L. Wu and I. Cook. 2012. Progress in research on Chinese urbanization. *Frontiers of Architectural Research*. 1:101–149.
- Gullino, G. 2009. *Storia di Padova. Dall'antichità all'età contemporanea*. (G. Gullino, Ed.). Cierre Edizioni,

Verona.

- Güneralp, B. M. Reba B. U. Hales E. A. Wentz and K. C. Seto. 2020. Trends in urban land expansion, density, and land transitions from 1970 to 2010: A global synthesis. *Environmental Research Letters*. 15:044015.
- Guthman, J. 2004. *Agrarian Dreams: The Paradox of Organic Farming in California*. Geographical Review of Japan, Series A. University of California Press, Oakland, USA.
- Haines-Young, R. and M. Potschin. 2013. Common International Classification of Ecosystem Services (CICES): Consultation on Version 4, August-December 2012. Copenhagen, Denmark. Retrieved from https://cices.eu/content/uploads/sites/8/2012/07/CICES-V43_Revised-Final_Report_29012013.pdf. Accessed January 2022.
- Haklay, M. 2016. Why is participation inequality important? . 35–44 *In* C. Capineri, M. Haklay, H. Huang, V. Antoniou, J. . Kettunen, F. . Ostermann, and R. Purves, editors. *European Handbook of Crowdsourced Geographic Information*. Ubiquity Press, Londra.
- Hartcher, M. G. and R. K. Chowdhury. 2017. An alternative method for estimating total impervious area in catchments using high-resolution colour aerial photography. *Water Practice and Technology*. 12:478–486.
- Hatan, S. A. Fleischer and A. Tchetchik. 2021. Economic valuation of cultural ecosystem services: The case of landscape aesthetics in the agritourism market. *Ecological Economics*. 184:107005.
- Heitlinger, S. N. Bryan-Kinns and R. Comber. 2019. The right to the sustainable smart city. 1–13 *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. Glasgow, UK.
- Hendrickson, M. K. and M. Porth. 2012. *Urban Agriculture–Best Practices and Possibilities*. Retrieved from <http://extension.missouri.edu/foodsystems/urbanagriculture.aspx>,. Accessed March 2021.
- Hill, D. 2013. On the smart city. Or, a ‘manifesto’ for smart citizens instead. Retrieved from <https://medium.com/butwhatwasthequestion/on-the-smart-city-or-a-manifesto-for-smart-citizens-instead-7e0c6425f909>. Accessed March 2020.
- Hollands, R. G. 2008. Will the real smart city please stand up? *City*. 12:303–320.
- Holt-Giménez, E. and M. A. Altieri. 2013. Agroecology, food sovereignty, and the new green revolution. *Agroecology and Sustainable Food Systems*. 37:90–102.
- Horton, P. 2017. We need radical change in how we produce and consume food. *Food Security*. 9:1323–1327.
- Huete, A. R. 1988. A soil-adjusted vegetation index (SAVI). *Remote Sensing of Environment*. 25:295–309.
- Hung, C.-L. J. L. A. James and M. E. Hodgson. 2018. An automated algorithm for mapping building impervious areas from airborne LiDAR point-cloud data for flood hydrology. *GIScience & Remote Sensing*. 55:793–816.
- Im, J. Z. Lu J. Rhee and L. J. Quackenbush. 2012. Impervious surface quantification using a synthesis of artificial immune networks and decision/regression trees from multi-sensor data. *Remote Sensing of Environment*. 117:102–113.
- Ingegnoli, V. 2015. *Landscape Bionomics Biological-Integrated Landscape Ecology*. Springer, Milan, Italy.
- IPCC. 2021. *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Retrieved from https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf. Accessed October 2021.

- ISPRA. 2017. Consumo di suolo, dinamiche territoriali e servizi ecosistemici - Edizione 2016. Roma.
- ISPRA. 2018. Consumo di suolo, dinamiche territoriali e servizi ecosistemici. Edizione 2018. (M. Munafò, Ed.). 1st ed. ISPRA, Roma, Italia.
- ISPRA. 2019. Consumo di suolo. Dinamiche territoriali e servizi ecosistemici. Edizione 2019. (M. Michele, Ed.). 1st ed. ISPRA, Roma, Italia.
- ISPRA. 2020. Consumo di suolo, dinamiche territoriali e servizi ecosistemici. Edizione 2020. (M. Munafó, Ed.). Roma.
- ISPRA. 2021. Consumo di suolo, dinamiche territoriali e servizi ecosistemici Edizione 2021 Rapporto ISPRA SNPA. Roma.
- ISTAT. 2019. ASC - Atlante Statistico dei Comuni. Retrieved from http://asc.istat.it/asc_BL/. Accessed November 2019.
- Jennings, D. B. S. T. Jarnagin and D. W. Ebert. 2004. A modeling approach for estimating watershed impervious surface area from national land cover data 92. *Photogrammetric Engineering & Remote Sensing*. 70:1295–1307.
- Jensen, J. R. and D. C. Cowen. 1999. Remote Sensing of Urban/Suburban Infrastructure and Socio-Economic Attributes*. *Photogrammetric Engineering & Remote Sensing*. 65:611–622.
- Kabisch, N. M. Strohbach D. Haase and J. Kronenberg. 2016. Urban green space availability in European cities. *Ecological Indicators*. 70:586–596.
- Kago, J. S. Loose and R. Sietchiping. 2019. Implementing the New Urban Agenda: Urban and Territorial Integration Approaches in Support of Urban Food Systems. 27–293 *In* H. Ginzky, E. Dooley, I. L. Heuser, E. Kasimbazi, T. Markus, and T. Qin, editors. *International Yearbook of Soil Law and Policy 2018*. Springer, Cham, Switzerland.
- Karimi, A. H. Yazdandad and N. Fagerholm. 2020. Evaluating social perceptions of ecosystem services, biodiversity, and land management: Trade-offs, synergies and implications for landscape planning and management. *Ecosystem Services*. 45:101188.
- Keeley, M. 2011. The Green Area Ratio: an urban site sustainability metric. *Journal of Environmental Planning and Management*. 54:937–958.
- Kendig, L. 1980. *Performance zoning*. Planners Press American Planning Association, Washington D.C.
- Kennard, N. J. and R. H. Bamford. 2020. Urban Agriculture: Opportunities and Challenges for Sustainable Development. 1–14 *In* W. Leal Filho, A. Azul, L. Brandli, P. Özuyar, and T. Wall, editors. *Zero Hunger. Encyclopedia of the UN Sustainable Development Goals*. Springer, Cham, Switzerland.
- Koch, A. A. McBratney M. Adams D. Field R. Hill J. Crawford B. Minasny R. Lal L. Abbott A. O'Donnell D. Angers J. Baldock E. Barbier D. Binkley W. Parton D. H. Wall M. Bird J. Bouma C. Chenu C. B. Flora K. Goulding S. Grunwald J. Hempel J. Jastrow J. Lehmann K. Lorenz C. L. Morgan C. W. Rice D. Whitehead I. Young and M. Zimmermann. 2013. Soil Security: Solving the Global Soil Crisis. *Global Policy*. 4:434–441.
- Köhler, M. M. Schmidt F. W. Grimme M. Laar and F. Gusmão. 2001. Urban water retention by greened roofs in temperate and tropical climate. 151–162 38th IFLA World Congress (International Federation of Landscape Architects). Singapore.
- Kuang, W. 2019. Mapping global impervious surface area and green space within urban environments.

- Science China Earth Sciences 2019 62:10. 62:1591–1606.
- Lakes, T. and H. O. Kim. 2012. The urban environmental indicator “biotope Area Ratio” - An enhanced approach to assess and manage the urban ecosystem services using high resolution remote-sensing. *Ecological Indicators*. 13:93–103.
- Lam, S. T. and T. M. Conway. 2018. Ecosystem services in urban land use planning policies: A case study of Ontario municipalities. *Land Use Policy*. 77:641–651.
- Langella, G. A. Basile S. Giannecchini F. D. Moccia F. A. Mileti M. Munafó F. Pinto and F. Terribile. 2020. Soil Monitor: an internet platform to challenge soil sealing in Italy. *Land Degradation & Development*. 31:2883–2900.
- Li, J. Y. Wang Z. Ni S. Chen and B. Xia. 2020. An integrated strategy to improve the microclimate regulation of green-blue-grey infrastructures in specific urban forms. *Journal of Cleaner Production*. 271:122555.
- Li, W. and C. Wu. 2015. A geostatistical temporal mixture analysis approach to address endmember variability for estimating regional impervious surface distributions. *GIScience & Remote Sensing*. 53:102–121.
- Liang, S. and J. Wang. 2019. *Advanced remote sensing: terrestrial information extraction and applications*. (S. Liang and J. Wang, Eds.).
- Lillesand, T. M. and R. W. Kiefer. 1994. *Remote sensing and image interpretation*. 3rd Edition. Wiley & Sons.
- Lin, Y. H. Zhang G. Li T. Wang L. Wan and H. Lin. 2019. Improving Impervious Surface Extraction with Shadow-Based Sparse Representation from Optical, SAR, and LiDAR Data. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*. 12:2417–2428.
- Liu, O. Y. and A. Russo. 2021. Assessing the contribution of urban green spaces in green infrastructure strategy planning for urban ecosystem conditions and services. *Sustainable Cities and Society*. 68:102772.
- Lotter, D. W. 2003. Organic agriculture. *J. Sustain. Agric.* 21:59–128.
- De Lotto; E. M. Venco. 2013. Efficacia e attuabilità di indici ecologico ambientali nella pratica urbanistica. *In* F. Sbetti, F. Rossi, M. Talia, and C. Trillo, editors. *XXVIII Congresso dell'INU: Il governo della città nella contemporaneità. La città come motore di sviluppo*. INU Edizioni, Salerno, Italia.
- De Lotto, R. V. Casella M. Franzini V. Gazzola C. Morelli di Popolo S. Sturla and E. M. Venco. 2015. Estimating the Biotope Area Factor (BAF) by Means of Existing Digital Maps and GIS Technology. 617–632 *In* O. Gervasi, B. Murgante, S. Misra, M. L. Gavriloca, A. M. Alves Coutinho Rocha, C. Torre, D. Taniar, and B. O. Apduhan, editors. *Computational Science and Its Applications – ICCSA 2015*. Springer International Publishing AG Switzerland, Basel, Switzerland.
- Lozano, A. V. C. A. Vidal and J. S. Díaz. 2019. Urban growth (1956-2012) and soil sealing in the metropolitan area of Valencia (Eastern Spain). *Spanish Journal of Soil Science*. 9:88–104.
- Lu, D. E. Moran and S. Hetrick. 2011. Detection of impervious surface change with multitemporal Landsat images in an urban–rural frontier. *ISPRS Journal of Photogrammetry and Remote Sensing*. 66:298–306.
- Lu, D. and Q. Weng. 2006. Use of impervious surface in urban land-use classification. *Remote Sensing of Environment*. 102:146–160.
- Ma, Q. C. He and J. Wu. 2016. Behind the rapid expansion of urban impervious surfaces in China: Major influencing factors revealed by a hierarchical multiscale analysis. *Land Use Policy*. 59:434–445.
- MADRE. 2018. *Urban and Peri-Urban Agriculture. Best practice catalogue*. Retrieved from

- https://anima.coop/sites/default/files/madre_catalogue_web_light.pdf. Accessed.
- Maes, J. G. Zulian S. Guenther M. Thijssen and J. Raynal. 2019. Enhancing Resilience Of Urban Ecosystems through Green Infrastructure (EnRoute). Luxembourg. Retrieved from <https://publications.jrc.ec.europa.eu/repository/handle/JRC115375>. Accessed.
- Marquard, E. S. Bartke J. Gifreu i Font A. Humer A. Jonkman E. Jürgenson N. Marot L. Poelmans B. Repe R. Rybski C. Schröter-Schlaack J. Sobocká M. Tophøj Sørensen E. Vejchodská A. Yiannakou and J. Bovet. 2020. Land Consumption and Land Take: Enhancing Conceptual Clarity for Evaluating Spatial Governance in the EU Context. *Sustainability*. 12:8269.
- Martellozzo, F. J. S. Landry D. Plouffe V. Seufert P. Rowhani and N. Ramankutty. 2014. Urban agriculture: A global analysis of the space constraint to meet urban vegetable demand. *Environmental Research Letters*. 9:064025 (8pp).
- Marzari, S. 2008a. Padova e la città metropolitana. 1807-2007 la metamorfosi del paesaggio urbano. (S. Marzari, Ed.). I Antichi Editori, Venezia, Italia.
- Marzari, S. 2008b. Padua and Metropolitan City. 1807-2007 Metamorphosis of the Urban Landscape (in Italian: Padova e la Città Metropolitana. 1807–2007 la Metamorfosi del Paesaggio Urbano. (S. Marzari, Ed.). I Antichi Editori Venezia, Venezia, Italy.
- Masek, J. G. M. A. Wulder B. Markham J. McCorkel C. J. Crawford J. Storey and D. T. Jenstrom. 2020. Landsat 9: Empowering open science and applications through continuity. *Remote Sensing of Environment*. 248:111968.
- Maxwell, D. C. Levin and J. Csete. 1998. Does urban agriculture help prevent malnutrition? Evidence from Kampala. *Food Policy*. 23:411–424.
- Maye, D. 2019. 'Smart food city': Conceptual relations between smart city planning, urban food systems and innovation theory. *City, Culture and Society*. 16:18–24.
- Milan Urban Food Policy Pact. 2015. Milan Urban Food Policy Pact. Retrieved from <https://www.milanurbanfoodpolicypact.org/the-milan-pact/>. Accessed March 2020.
- Mimet, A. C. Kerbirou L. Simon J. F. Julien and R. Raymond. 2020. Contribution of private gardens to habitat availability, connectivity and conservation of the common pipistrelle in Paris. *Landscape and Urban Planning*. 193:103671.
- Misra, M. D. Kumar and S. Shekhar. 2020. Assessing Machine Learning Based Supervised Classifiers For Built-Up Impervious Surface Area Extraction From Sentinel-2 Images. *Urban Forestry & Urban Greening*. 53:126714.
- Mok, H. F. V. G. Williamson J. R. Grove K. Burry S. F. Barker and A. J. Hamilton. 2014. Strawberry fields forever? Urban agriculture in developed countries: A review. *Agronomy for Sustainable Development*. 34:21–43.
- Montgomery, D. R. 2012. *Dirt: the erosion of civilizations*. University of California Press.
- Moreno, A. A. Bhattacharyya L. Jansen Y. Arkeman R. Hartanto and M. Kleinke. 2019. Environmental engineering and sustainability for smart agriculture: The application of UAV-based remote sensing to detect biodiversity in oil palm plantations. 012008 *In* A. G. Niam, I. Yusliana, and H. Imantho, editors. International Conference on Digital Agriculture from Land to Consumers. Bogor, Indonesia.
- Mougeot, L. J. A. 2000. *Urban Agriculture: Definition, Presence, Potentials and Risks, and Policy Challenges*

- Cities Feeding People Series. Retrieved from <http://www.idrc.ca/cfp>. Accessed February 2020.
- Moustier, P. and G. Danso. 2006. Local Economic Development and Marketing of Urban Produced Food. 174–195 *In* R. van Veenhuizen, editor. *Cities Farming for the Future: Urban Agriculture for Green and Productive Cities*. RUAF Foundation, IDRC and IIRR, Philippines.
- Mullins, P. D. 2017. The ubiquitous-eco-city of Songdo: An urban systems perspective on South Korea's Green city approach. *Urban Planning*. 2:4–12.
- Munafò, M. C. Norero A. Sabbi and L. Salvati. 2010. Soil sealing in the growing city: A survey in Rome, Italy. *Scottish Geographical Journal*. 126:153–161.
- Murata, T. and N. Kawai. 2018. Degradation of the urban ecosystem function due to soil sealing: involvement in the heat island phenomenon and hydrologic cycle in the Tokyo metropolitan area. <https://doi.org/10.1080/00380768.2018.1439342>. 64:145–155.
- Naumann, S. A. Frelih-Larsen G. Prokop S. Ittner M. Reed J. Mills F. Morari S. Verzaandvoort, Simone Albrecht A. Bjuréus G. Siebielec and T. Miturski. 2019. Land Take and Soil Sealing—Drivers, Trends and Policy (Legal) Instruments: Insights from European Cities. 84–112 *International Yearbook of Soil Law and Policy 2018*.
- Nin, M. A. Soutullo L. Rodríguez-Gallego and E. Di Minin. 2016. Ecosystem services-based land planning for environmental impact avoidance. *Ecosystem Services*. 17:172–184.
- Norton, G. W. and S. M. Swinton. 2000. Precision Agriculture: Global Prospects and Environmental Implications. *Proceedings of the 24th International Conference of Agricultural Economists*:269–286.
- Norton, J. 2019. *Information Systems for Grassroots Sustainable Agriculture*. PhD Thesis. University of California, Irvine, USA.
- Norton, J. B. J. Pan S. Naye baziz B. Tomlinson and S. Burke. 2014. Plant guild composer: An interactive online system to support back yard food production. 523–526 *Conference on Human Factors in Computing Systems - Proceedings*. Association for Computing Machinery, New York, USA.
- Norton, J. B. Tomlinson B. Penzenstadler S. McDonald E. Kang N. Koirala R. Konishi G. P. Carmona J. Shah and S. Troncoso. 2019. The SAGE Community Coordinator: A Demonstration. 1–10 *In* S. Easterbrook, editor. *Proceedings of the Fifth Workshop on Computing within Limits*. Association for Computing Machinery, Lappeenranta, Finland.
- Nowak, D. J. and E. J. Greenfield. 2020. The increase of impervious cover and decrease of tree cover within urban areas globally (2012–2017). *Urban Forestry and Urban Greening*. 49:126638.
- Oberndorfer, E. J. Lundholm B. Bass R. R. Coffman H. Doshi N. Dunnett S. Gaffin M. Köhler K. K. Y. Liu and B. Rowe. 2007. Green Roofs as Urban Ecosystems: Ecological Structures, Functions, and Services. *BioScience*. 57:823–833.
- Van Oijstaeijen, W. S. Van Passel and J. Cools. 2020. Urban green infrastructure: A review on valuation toolkits from an urban planning perspective. *Journal of Environmental Management*. 267:110603.
- Opolot, E. Y. Y. Yu and P. A. Finke. 2015. Modeling soil genesis at pedon and landscape scales: Achievements and problems. *Quaternary International*. 376:34–46.
- Orsini, F. R. Kahane R. Nono-Womdim and G. Gianquinto. 2013. Urban agriculture in the developing world: A review. *Agronomy for Sustainable Development*. 33:695–720.
- Pafi, M. A. Siragusa S. Ferri and S. Halkia. 2016. *Measuring the Accessibility of Urban Green Areas: A*

- comparison of the Green ESM with other datasets in four European cities. Luxembourg (Luxembourg). Retrieved from <http://publications.jrc.ec.europa.eu/repository/handle/JRC102525>. Accessed January 2022.
- Paleari, S. 2017. Is the European Union protecting soil? A critical analysis of Community environmental policy and law. *Land Use Policy*. 64:163–173.
- Paskaleva, K. A. 2011. The smart city: A nexus for open innovation? *Intelligent Buildings International*. 3:153–171.
- Pearsall, H. and J. K. Eller. 2020. Locating the green space paradox: A study of gentrification and public green space accessibility in Philadelphia, Pennsylvania. *Landscape and Urban Planning*. 195:103708.
- Pearson, L. J. L. Pearson and C. J. Pearson. 2010. Sustainable urban agriculture: Stocktake and opportunities. *International Journal of Agricultural Sustainability*. 8:7–19.
- Peroni, F. G. Pristeri D. Codato S. E. Pappalardo and M. De Marchi. 2019. Biotope Area Factor: An Ecological Urban Index to Geovisualize Soil Sealing in Padua, Italy. *Sustainability 2020*, Vol. 12, Page 150. 12:150.
- Phinn, S. M. Stanford P. Scarth A. T. Murray and P. T. Shyy. 2002. Monitoring the composition of urban environments based on the vegetation-impervious surface-soil (VIS) model by subpixel analysis techniques. *International Journal of Remote Sensing*. 23:4131–4153.
- Pistocchi, A. C. Calzolari F. Malucelli and F. Ungaro. 2015. Soil sealing and flood risks in the plains of Emilia-Romagna, Italy. *Journal of Hydrology: Regional Studies*. 4:398–409.
- Poulsen, M. N. 2017. Cultivating citizenship, equity, and social inclusion? Putting civic agriculture into practice through urban farming. *Agriculture and Human Values*. 34:135–148.
- Pretty, J. N. A. D. Noble D. Bossio J. Dixon R. E. Hine F. W. T. P. De Vries and J. I. L. Morison. 2006. Resource-conserving agriculture increases yields in developing countries. *Environmental Science and Technology*. 40:1114–1119.
- Pristeri, G. F. Peroni S. E. Pappalardo D. Codato A. G. Castaldo A. Masi and M. De Marchi. 2020. Mapping and Assessing Soil Sealing in Padua Municipality through Biotope Area Factor Index. *Sustainability 2020*, Vol. 12, Page 5167. 12:5167.
- Prokop, G. H. Jobstmann and A. Schönbauer. 2011. Report on best practices for limiting soil sealing and mitigating its effects. European Commission.
- Quattrocchi, D. A. and M. F. Goodchild. 1997. Scale in Remote Sensing and GIS. (D. A. Quattrocchi and M. F. Goodchild, Eds.). CRC Press.
- Radočaj, D. J. Obhodaš M. Jurišić and M. Gašparović. 2020. Global Open Data Remote Sensing Satellite Missions for Land Monitoring and Conservation: A Review. *Land 2020*, Vol. 9, Page 402. 9:402.
- Raghavan, B. B. Nardi S. T. Lovell J. Norton B. Tomlinson and D. J. Patterson. 2016. Computational Agroecology. 423–435 *In* J. Kaye and A. Druin, editors. Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems. ACM Press, San Jose, USA.
- Regione del Veneto. 2004. Legge regionale 23 aprile 2004, n. 11 (BUR n. 45/2004) - Norme per il Governo del Territorio e in materia di Paesaggio.
- Regione del Veneto. 2017. Disposizioni per il contenimento del consumo di suolo e modifiche della legge regionale 23 aprile 2004, n. 11 “Norme per il governo del territorio e in materia di paesaggio.” 1–22. Italy.
- Regione del Veneto. 2019a. Legge Regionale n. 14 del 04 aprile 2019. Veneto 2050: politiche per la

- riqualificazione urbana e la rinaturalizzazione del territorio e modifiche alla legge regionale 23 aprile 2004, n. 11 "Norme per il governo del territorio e in materia di paesaggio". Venezia, Italy.
- Regione del Veneto. 2019b. Deliberazione della Giunta Regionale n. 64 del 29 gennaio 2019. Venezia, Italy.
- Repubblica Italiana. 1968. Repubblica Italiana. Interministerial Decree, April 2, 1968, n. 1444 (in Italian: Decreto Interministeriale 2 Aprile 1968, n. 1444). Roma, Italy.
- RNDT. 2020. Metadata for Topographic DataBase of Padua Municipality. Retrieved from <https://geodati.gov.it/geoportale/>. Accessed January 2022.
- Rodríguez-Rojas, M. I. F. Huertas-Fernández B. Moreno G. Martínez and A. L. Grindlay. 2018. A study of the application of permeable pavements as a sustainable technique for the mitigation of soil sealing in cities: A case study in the south of Spain. *Journal of environmental management*. 205:151–162.
- Rogan, J. and D. M. Chen. 2004. Remote sensing technology for mapping and monitoring land-cover and land-use change. *Progress in Planning*. 61:301–325.
- Ronchi, S. A. Arcidiacono and L. Pogliani. 2020. Integrating green infrastructure into spatial planning regulations to improve the performance of urban ecosystems. Insights from an Italian case study. *Sustainable Cities and Society*. 53:101907.
- Ronchi, S. S. Salata A. Arcidiacono E. Piroli and L. Montanarella. 2019. Policy instruments for soil protection among the EU member states: A comparative analysis. *Land Use Policy*. 82:763–780.
- Rondeaux, G. M. Steven and F. Baret. 1996. Optimization of soil-adjusted vegetation indices. *Remote Sensing of Environment*. 55:95–107.
- Rosset, P. M. and M. A. Altieri. 1997. Agroecology versus input substitution: A fundamental contradiction of sustainable agriculture. *Society and Natural Resources*. 10:283–295.
- Rowe, D. B. and K. L. Getter. 2006. The role of extensive green roofs in sustainable development. *HortScience*. 41:1276–1285.
- Russo, A. and G. T. Cirella. 2018. Modern Compact Cities: How Much Greenery Do We Need? *International Journal of Environmental Research and Public Health* 2018, Vol. 15, Page 2180. 15:2180.
- Sam Navin, M. and L. Agilandeewari. 2020. Comprehensive review on land use/land cover change classification in remote sensing. *J. Spectral Imaging*. 9:8.
- Sánchez-Bayo, F. and K. A. G. Wyckhuys. 2019. Worldwide decline of the entomofauna: A review of its drivers. *Biological Conservation*. 232:8–27.
- dos Santos, A. R. F. S. de Oliveira A. G. da Silva J. M. Gleriani W. Gonçalves G. L. Moreira F. G. Silva E. R. F. Branco M. M. Moura R. G. da Silva R. S. Juvanhol K. B. de Souza C. A. A. S. Ribeiro V. T. de Queiroz A. V. Costa A. S. Lorenzon G. F. Domingues G. E. Marcatti N. L. M. de Castro R. T. Resende D. E. Gonzales L. A. de Almeida Telles T. R. Teixeira G. M. A. D. A. dos Santos and P. H. S. Mota. 2017. Spatial and temporal distribution of urban heat islands. *Science of the Total Environment*. 605–606:946–956.
- Saura, S. 2010. Effects of minimum mapping unit on land cover data spatial configuration and composition. <https://doi.org/10.1080/01431160110114493>. 23:4853–4880.
- Scalenghe, R. and F. A. Marsan. 2009. The anthropogenic sealing of soils in urban areas. *Landscape and Urban Planning*. 90:1–10.
- Scheuer, C. E. Boot N. Carse A. Clardy J. Gallagher S. Heck S. Marron L. Martinez-Alvarez D. Masarykova

- P. Mcmillan F. Murphy E. Steel H. Van Ekdom and H. Vecchione. 2015. Integration of ecosystem services into decision-making. *Physical Education and Sport for Children and Youth with Special Needs Researches – Best Practices – Situation.*:73–80.
- Schmutz, U. 2017. Urban Agriculture or Urban Agroecology? RUAF. Retrieved from <https://ruaf.org/document/urban-agriculture-magazine-no-33-urban-agroecology/>. Accessed March 2021.
- Schneider, A. M. A. Friedl and D. Potere. 2010. Mapping global urban areas using MODIS 500-m data: New methods and datasets based on 'urban ecoregions.' *Remote Sensing of Environment.* 114:1733–1746.
- Scopus. 2021. How do Author / Indexed keywords work? - Scopus: Access and use Support Center. Retrieved from https://service.elsevier.com/app/answers/detail/a_id/21730/supporthub/scopus/. Accessed April 2021.
- See, L. P. Mooney G. Foody L. Bastin A. Comber J. Estima S. Fritz N. Kerle B. Jiang M. Laakso H.-Y. Liu G. Milčinski M. Nikšič M. Painho A. Pődör A.-M. Olteanu-Raimond M. Rutzinger L. See P. Mooney G. Foody L. Bastin A. Comber J. Estima S. Fritz N. Kerle B. Jiang M. Laakso H.-Y. Liu G. Milčinski M. Nikšič M. Painho A. Pődör A.-M. Olteanu-Raimond and M. Rutzinger. 2016. Crowdsourcing, Citizen Science or Volunteered Geographic Information? The Current State of Crowdsourced Geographic Information. *ISPRS International Journal of Geo-Information.* 5:55.
- Seiwert, A. and S. Rößler. 2020. Understanding the term green infrastructure: origins, rationales, semantic content and purposes as well as its relevance for application in spatial planning. *Land Use Policy.* 97:104785.
- Serbulova, N. S. Kanurny A. Gorodnyanskaya and A. Persiyanova. 2019. Sustainable food systems and agriculture: the role of information and communication technologies. 12127 *In* M. Pasetti and V. Murgul, editors. IOP Conf. Ser.: Earth Environ. Sci. Rostov-on-Don, Russia.
- Seto, K. C. M. Fragkias B. Güneralp and M. K. Reilly. 2011. A Meta-Analysis of Global Urban Land Expansion. *PLoS ONE.* 6:1–9.
- Seto, K. C. B. Güneralp and L. R. Hutyrá. 2012. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences of the United States of America.* 109:16083–16088.
- Shahtahmassebi, A. R. J. Song Q. Zheng G. A. Blackburn K. Wang L. Y. Huang Y. Pan N. Moore G. Shahtahmassebi R. Sadrabadi Haghighi J. S. Deng A. R. Shahtahmassebi J. Song Q. Zheng G. A. Blackburn K. Wang L. Y. Huang Y. Pan N. Moore G. Shahtahmassebi R. Sadrabadi Haghighi and J. S. Deng. 2016. Remote sensing of impervious surface growth: A framework for quantifying urban expansion and re-densification mechanisms. *IJAEO.* 46:94–112.
- Shi, L. Ü. Halik A. Abliz Z. Mamat and M. Welp. 2020. Urban Green Space Accessibility and Distribution Equity in an Arid Oasis City: Urumqi, China. *Forests 2020, Vol. 11, Page 690.* 11:690.
- Shuster, W. D. J. Bonta H. Thurston E. Warnemuende and D. R. Smith. 2005. Impacts of impervious surface on watershed hydrology: A review. *Urban Water Journal.* 2:263–275.
- Siddiqui, A. G. Kushwaha A. Raouf P. A. Verma and Y. Kant. 2021. Bangalore: Urban heating or urban cooling? *The Egyptian Journal of Remote Sensing and Space Science.* 24:265–272.
- Siebielec, G. S. Lazar C. Kaufmann and S. Jaensch. 2010. Handbook for measures enhancing soil function

- performance and compensating soil loss during urbanization process. Urban SMS-Soil Management Strategy project. Urban SMS project, Stuttgart, Germany.
- Siegner, A. J. Sowerwine and C. Acey. 2018. Does Urban Agriculture Improve Food Security? Examining the Nexus of Food Access and Distribution of Urban Produced Foods in the United States: A Systematic Review. *Sustainability*. 10:2988.
- Sinha, P. N. K. Verma and E. Ayele. 2016. Urban Built-up Area Extraction and Change Detection of Adama Municipal Area using Time-Series Landsat Images. *International Journal of Advanced Remote Sensing and GIS*. 5:1886–1895.
- Slonecker, E. T. D. B. Jennings and D. Garofalo. 2001. Remote sensing of impervious surfaces: A review. *Remote Sensing Reviews*. 20:227–255.
- Socientize. 2014. White Paper on Citizen Science for Europe. Zaragoza, Spain.
- Söderström, O. T. Paasche and F. Klauser. 2014. Smart cities as corporate storytelling. *City*. 18:307–320.
- Sonnino, R. 2009. Feeding the city: Towards a new research and planning agenda. *International Planning Studies*. 14:425–435.
- Spadoni, G. L. A. Cavalli L. Congedo and M. Munafò. 2020. Analysis of Normalized Difference Vegetation Index (NDVI) multi-temporal series for the production of forest cartography. *Remote Sensing Applications: Society and Environment*. 20:100419.
- Specht, K. R. Siebert I. Hartmann U. B. Freisinger M. Sawicka A. Werner S. Thomaier D. Henckel H. Walk and A. Dierich. 2014. Urban agriculture of the future: An overview of sustainability aspects of food production in and on buildings. *Agriculture and Human Values*. 31:33–51.
- Stankovics, P. G. Tóth Z. Tóth P. Stankovics G. Tóth and Z. Tóth. 2018. Identifying Gaps between the Legislative Tools of Soil Protection in the EU Member States for a Common European Soil Protection Legislation. *Sustainability*. 10:1–17.
- Strollo, A. D. Smiraglia R. Bruno F. Assennato L. Congedo P. De Fioravante C. Giuliani I. Marinosci N. Riitano and M. Munafò. 2020. Land consumption in Italy. *Journal of Maps*. 16:113–123.
- Sun, Z. C. Wang H. Guo and R. Shang. 2017. A modified normalized difference impervious surface index (MNDISI) for automatic urban mapping from landsat imagery. *Remote Sensing*. 9:1–18.
- Sutton, P. C. S. J. Anderson C. D. Elvidge B. T. Tuttle and T. Ghosh. 2009. Paving the planet: impervious surface as proxy measure of the human ecological footprint. *Progress in Physical Geography*. 33:510–527.
- Swyngedouw, E. 2016. The mirage of the sustainable ‘smart city’: planetary urbanization and the spectre of combined and uneven apocalypse. 134–143 *In* O. Nel-lo and R. Mele, editors. *Cities in the 21st Century*. Routledge, New York, USA.
- Tahvonen, O. and M. Airaksinen. 2018. Low-density housing in sustainable urban planning – Scaling down to private gardens by using the green infrastructure concept. *Land Use Policy*. 75:478–485.
- Taylor, J. R. and S. T. Lovell. 2012. Mapping public and private spaces of urban agriculture in Chicago through the analysis of high-resolution aerial images in Google Earth. *Landscape and Urban Planning*. 108:57–70.
- Teixeira da Silva, R. L. Fleskens H. van Delden and M. van der Ploeg. 2018. Incorporating soil ecosystem services into urban planning: status, challenges and opportunities. *Landscape Ecology* 2018 33:7.

33:1087–1102.

- Theobald, D. M. S. J. Goetz J. B. Norman and P. Jantz. 2009. Watersheds at Risk to Increased Impervious Surface Cover in the Conterminous United States. *Journal of Hydrologic Engineering*. 14:362–368.
- Tobias, S. F. Conen A. Duss L. M. Wenzel C. Buser and C. Alewell. 2018. Soil sealing and unsealing: State of the art and examples. *Land Degradation & Development*. 29:2015–2024.
- Torres, A. V. C. Tiwari and S. F. Atkinson. 2021. Progress in ecosystem services research: A guide for scholars and practitioners. *Ecosystem Services*. 49:101267.
- Townsend, A. 2014. *Smart Cities-Big Data, Civic hackers and the question for a new utopia*. (W. W. Norton & Company, Ed.). New York, USA.
- UN-Habitat. 2021. UN Habitat Metadata sheet on SDG indicator 11.3.1. Retrieved from <https://unstats.un.org/sdgs/metadata/files/Metadata-11-03-01.pdf>. Accessed April 2021.
- UN Department of Economic and Social Affairs. 2019. *World Population Prospects 2019 Highlights*. Retrieved from www.population.un.org. Accessed February 2020.
- UNDP United Nations Development Programme. 2018. *Community-Based Resilience Analysis (CoBRA) Conceptual Framework and Methodology*. Retrieved from www.undp.org. Accessed March 2020.
- UNFPA United Nations Population Found. 2007. *State of world population 2007: unleashing the potential of urban growth*. New York. Retrieved from www.unfpa.org. Accessed February 2020.
- United States Department of Agriculture. 2016. *Urban Agriculture Toolkit*. Retrieved from <https://www.usda.gov/sites/default/files/documents/urban-agriculture-toolkit.pdf>. Accessed.
- University of Southampton. 2021. *WorldPop*. Retrieved from <https://www.worldpop.org/about>. Accessed January 2022.
- Vanolo, A. 2014. Smartmentality: The Smart City as Disciplinary Strategy. *Urban Studies*. 51:883–898.
- Vanolo, A. 2016. Is there anybody out there? The place and role of citizens in tomorrow's smart cities. *Futures*. 82:26–36.
- Vázquez Moreno, L. L. and F. Funes Aguilar. 2016. *Avances de la agroecología en Cuba Avances de la agroecología en Cuba*. Editora Estación Experimental de Pastos y Forrajes Indio Hatuey, La Habana, Cuba.
- Veolia Institute. 2019. *Urban Agriculture: another way to feed cities*. Retrieved from www.institut.veolia.org. Accessed.
- Vermeulen, S. J. B. M. Campbell and J. S. I. Ingram. 2012. Climate Change and Food Systems. *Annual Review of Environment and Resources*. 37:195–222.
- Walter, A. R. Finger R. Huber and N. Buchmann. 2017. Smart farming is key to developing sustainable agriculture. *Proceedings of the National Academy of Sciences of the United States of America*. 114:6148–6150.
- Wang, Y. and M. Li. 2019. Urban Impervious Surface Detection From Remote Sensing Images: A review of the methods and challenges. *IEEE Geoscience and Remote Sensing Magazine*. 7:64–93.
- Weng, Q. 2012. Remote sensing of impervious surfaces in the urban areas: Requirements, methods, and trends. *Remote Sensing of Environment*. 117:34–49.
- Weng, Q. editor. 2014. *Scale issues in Remote Sensing*. John Wiley & Sons, Ltd, Hoboken, USA.
- Weng, Q. 2020. *Techniques and Methods in Urban Remote Sensing*. IEEE Press.

- Weng, Q. and D. Lu. 2008. A sub-pixel analysis of urbanization effect on land surface temperature and its interplay with impervious surface and vegetation coverage in Indianapolis, United States. *International Journal of Applied Earth Observation and Geoinformation*. 10:68–83.
- Wenhui, K. C. Wenfeng and S. Wenjiao. 2014. Spatio-temporal characteristics of intra-urban land cover in the cities of China and USA from 1978 to 2010. *Acta Geographica Sinica* . 69:883–895.
- Wessolek, G. 2008. Sealing of soils. 161–179 *In* J. M. Marzluff, E. Shulenberg, W. Endlicher, M. Alberti, G. Bradley, C. Ryan, U. Simon, and C. ZumBrunnen, editors. *Urban Ecology: An International Perspective on the Interaction Between Humans and Nature*. Springer, New York, USA.
- Whelan, B. and J. Taylor. 2013. Precision agriculture for grain production systems. *International Journal of Digital Earth*. CSIRO Publishing, Collingwood, Australia.
- Wiig, A. 2016. The empty rhetoric of the smart city: from digital inclusion to economic promotion in Philadelphia. *Urban Geography*. 37:535–553.
- WOCAT. 2014. WOCAT. Retrieved from <https://www.wocat.net/en/>. Accessed March 2021.
- Woodhouse, P. 2010. Beyond Industrial Agriculture? Some Questions about Farm Size, Productivity and Sustainability. *Journal of Agrarian Change*. 10:437–453.
- World Bank. 2020. Urban Development. Retrieved from <https://www.worldbank.org/en/topic/urbandevelopment/overview>. Accessed.
- World Health Organization. 2005. *Ecosystems and Human Well-Being*. Geneva, Switzerland.
- World Health Organization. 2017. *Urban green spaces: a brief for action*. Copenhagen, Denmark.
- Wu, D. and G. Lindsay. 2020. How to design a smart city that's built on empowerment - not corporate surveillance. Retrieved from <https://www.fastcompany.com/90469838/how-to-design-a-smart-city-thats-built-on-empowerment-not-corporate-surveillance>. Accessed March 2020.
- Wu, J. Wei-Ning Xiang and J. Zhao. 2014. Urban ecology in China: Historical developments and future directions. *Landscape and Urban Planning*. 125:222–233.
- Wüstemann, H. D. Kalisch and J. Kolbe. 2016. Towards a national indicator for urban green space provision and environmental inequalities in Germany: Method and findings. Berlin: Humboldt University of Berlin, Collaborative Research Center 649 - Economic Risk, Berlin, Germany. Retrieved from <https://www.econstor.eu/handle/10419/146191>. Accessed January 2022.
- Xiao, R. Y. Tian and G. Xu. 2020. Spatial gradient of urban green field influenced by soil sealing. *Science of The Total Environment*. 735:139490.
- Xie, L. and H. Bulkeley. 2020. Nature-based solutions for urban biodiversity governance. *Environmental Science & Policy*. 110:77–87.
- Xu, H. 2010. Analysis of impervious surface and its impact on Urban heat environment using the normalized difference impervious surface index (NDISI). *Photogrammetric Engineering and Remote Sensing*. 76:557–565.
- Xue, J. and B. Su. 2017. Significant remote sensing vegetation indices: A review of developments and applications. *Journal of Sensors*. 2017.
- Zhang, B. Z. Chen D. Peng J. A. Benediktsson B. Liu L. Zou J. Li and A. Plaza. 2019. Remotely sensed big data: Evolution in model development for information extraction [point of view]. *Proceedings of the IEEE*. 107:2294–2301.

- Zhang, L. and Q. Weng. 2016. Annual dynamics of impervious surface in the Pearl River Delta, China, from 1988 to 2013, using time series Landsat imagery. *ISPRS Journal of Photogrammetry and Remote Sensing*. 113:86–96.
- Zhang, N. M. Wang and N. Wang. 2002. Precision agriculture - A worldwide overview. *Computers and Electronics in Agriculture*. 36:113–132.
- Zhao, S. D. Zhou C. Zhu Y. Sun W. Wu and S. Liu. 2015. Spatial and Temporal Dimensions of Urban Expansion in China. *Environmental Science and Technology*. 49:9600–9609.
- Zhong, Q. J. Ma B. Zhao X. Wang J. Zong and X. Xiao. 2019. Assessing spatial-temporal dynamics of urban expansion, vegetation greenness and photosynthesis in megacity Shanghai, China during 2000–2016. *Remote Sensing of Environment*. 233:111374.

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