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On the Reason to Implement a Sustainable Urban Drainage Nature-Based Solution to Decrease Flood Threat: A Survey

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Abstract: Systematic interviews to technicians in charge of urban drainage were undertaken to assess the distribution of nature-based solutions (NBSs) for hydraulic risk mitigation in the Veneto region (Italy) and to investigate interventions that are priorities to address the challenges of urban growth and hydraulic risk. Specifically, this paper investigated stakeholders' preference for green and gray infrastructure and for some NBSs in particular among those more frequently adopted, where they are predominantly implemented, and why. The results were interpreted in the context of significant geomorphological, socioeconomic, and regulatory parameters and how they relate to NBS implementation. The survey demonstrated that, among technical experts in one of Italy's most developed regions, there may be a certain skepticism about the effectiveness of NBSs in counteracting the hydraulic risk of flooding, the close interrelation between political decisions in favour of NBS and the constrains of national and regional legislation, and the willingness to involve the population in the decision-making process. Further investigation showed that what (de)motivates the use of NBSs may be a partial disconnection between the academic, technical, and administrative sectors.

Keywords: infiltration systems; water resources; trenches; hydraulic risk; urban drainage; survey

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1. Introduction

Urbanization has increased in recent decades, causing an unrelenting progressive alteration of the water cycle and rising flood risk [1] that is expected to be exacerbated by climate change. Therefore, climate change and urbanization require appropriate adaptation strategies [2,3]. Nature-based solutions (NBS) are the latest vision of how sustainable urban drainage can be achieved [4]. The European Commission promotes NBSs to address multiple social, economic, and environmental challenges [5], including reducing the hydraulic risk of flooding. Ruangpan [6] provided a review on hydrometeorological risk reduction with NBSs. Interest in these solutions has contributed to their diffusion and there is currently a large body of the literature presenting case studies and cost-benefit analyses on NBSs and the growing effort to create public awareness of NBSs and the co-benefits related to their implementation through surveys of the opinions of stakeholders involved [7,8].

However, due to the lack of financial incentives and institutional promotions of NBSs, the limited amount of suitable and available land and the lack of knowledge about the benefits of NBSs may hinder their implementation [9]. The lack of suitable locations may also represent a challenge for implementing NBSs in urban areas [10].

The implementation of NBSs requires an available surface area, a gentle slope, a suitable soil type, a sufficient groundwater depth, and a proper arrangement of underground infrastructure [11].

Although NBSs have been integrated into national and local regulations in many countries and are becoming a common paradigm among scientists, practitioners, and policymakers, they still remain vague or unknown to the general public [12,13]. In many countries there are political, institutional, and knowledge barriers to the implementation of NBSs; for example, policy makers tend to be more interested in projects that generate short-term results for re-election purposes [14] that may not include NBSs, while inflexible hierarchical organizational structure and lack of public awareness are among the main barriers to NBSs [15]. The interviews highlighted that socioeconomic and cultural elements, as well as technical constraints and regulation, pose significant challenges [16].

An increasing number of scientists have begun to examine how communities perceive NBSs beyond traditional decision-making patterns [17], trusting that human-related aspects can have the potential to transition to sustainable and resilient communities through solutions that are supported by popular consensus and, by so doing, bringing together environmental and socioeconomic aspects [18].

Knowledge of NBSs has spread mostly among scientists [19]; it is not clear whether this has left an information gap regarding the benefits of NBSs that may push unaware stakeholders toward traditional gray solutions [16].

Baur [20] found that stakeholders agreed that more green space and more natural habitats were indicators of successful management (confirming the work of Buijs [21] and Evans [22]), although they believed that managers need to improve information on tangible benefits and also believed that risk perception influences NBS implementation [23–25]. Finally, NBS providers (e.g., engineering companies) may not have a clear designation and this is an obstacle to the development of a designated market [26]; they also may not have complete knowledge about green facilities [12]. Peri-urban areas that underwent rapid land-use change linked to commercial and industrial area expansion increased hydraulic and pollution risk (see, e.g., the case study presented by Todeschini (2016) [27]). Chui and Ngai [28] showed that only a few NBSs have been implemented in the most urbanized and populated cities (e.g., New York City, Tokyo, or Hong Kong), which could be attributed to historical development conditions or spatial constraints that pose particular technical or social challenges. Therefore, researchers have assessed the perceptions of city dwellers through structured interviews to identify possible pathways for sustainable drainage development; NBS projects may be influenced by socioeconomic conditions [29], aesthetic value [21], and risk reduction [30].

In order to reduce the hydraulic flood risk related to the increasing urbanization of the territory, the Italian government entrusted the regional authorities with the power to regulate on the restoration of a predevelopment runoff regime [31]. Therefore, the laws promoting the use of NBSs are multiple and have regional validity. This means that, across the country, regulation is fragmented and inconsistent, as different regions can adopt more or less restrictive rules.

More than 1.101 article publications in the last 38 years have dealt with NBSs, focusing mainly on environmental sciences and green sustainable science technology; 101 are published review articles concerning NBSs (www.webofscience.com, accessed on 1 June 2023). Academic initiatives, such as the third mission project of the University of Padova (www.unipd.it/terza-missione-impegno-societa, accessed on 1 June 2023), aimed at bridging the gap between academia and the real world. To realize this scope, we attempted an estimate of the width of the gap between academia and technical administrations on the ground concerning NBS realization in the Veneto region. Assuming that technical offices could be keepers of the NBS census, we investigated the diffusion of NBSs in relation to the type of geomorphological and urban context, i.e., which NBSs are most frequently implemented, whether or not NBSs are preferred to the grey solution, and why.

Only a few articles have been published reporting the results of surveys on the perception of hydrogeological risks in Italy [32–36]; none involved technicians. Bernello et al. [37] interviewed, via Google Modules, a sample of 120 common people living in the Veneto region to test their willingness and knowledge perception of NBSs in order to demonstrate a general lack of knowledge among the people. People are influenced by past and recent experience [37] and, as we remark here, they do not have a duty to manage and protect the land from extreme events; rather, they choose local solutions confined to their private areas of influence. Aware that regulatory fragmentation may be an obstacle to the implementation of NBSs [12] and in view of the fragmentation of technical regulatory assessments nationwide, in order to investigate the link between NBS diffusion, information disseminated, and regulation, it was necessary to restrict the survey to an area with a homogeneous regulatory framework, i.e., one region, the Veneto region, one of the richest and most developed regions in north-eastern Italy, where the location, technical characteristics, and efficiency of NBSs have not been systematically documented. Therefore, we proposed a survey to the 563 local authorities' technical offices to address state of the art and willingness to implement further NBS solutions over the local territory; 57 municipalities, out of 563, agreed to respond to the survey through their technical offices.

We believe that local authority awareness and action, as well as dissemination and promotion of participation, may trigger NBS diffusion and that popular consensus is just part of the prerequisite for NBS implementation. The elements that strongly motivate a survey among potential decision makers and NBS promoters are the fragmentation and inconsistency of regulation nationwide and the lack of a formal registry of NBS, both suggesting that no systematic change in drainage management paradigm is promoted and that interest toward NBS may lack incentive. Therefore, we tested operators' awareness of their potential benefits when integrated into traditional urban drainage systems and what the perceived obstacles were to their implementation because they can make decisions on NBS implementation and have the instruments to judge whether green solution may be preferred to grey and when. We examined whether there was an interrelationship between the cultural and geomorphological attributes of the area and the political will to implement NBSs in urban drainage systems as flood frequency mitigation tools.

2. Materials and Methods

The state-of-the-art mitigation measures reflect a number of facts relevant to the spread of NBSs, namely political consensus, technical knowledge, and trust. Experienced urban drainage officers, responding to our online survey, provided a map of the distribution and density of NBSs and other interventions to mitigate flood risk, as well as a picture of the political impediment to their diffusion at the level of decision makers.

2.1. Study Area and Sample

Veneto represents an area where technical regulatory framework on hydraulic risk mitigation is homogeneous and where 563 municipalities, belonging to seven provinces, are distributed over a geomorphologically very heterogeneous territory. The geomorphology of this small region (the total area is 18,345 km^2) ranges from the Alps to the plains towards the Adriatic Sea, through the Venice lagoon and several river estuaries.

We submitted the survey to the technical offices of the municipalities that are responsible for issuing the approval to the hydraulic invariance projects according to the current regulations; only 57 municipalities out of 563 agreed to respond to the survey through their technical offices; they are flagged in Figure 1 and can be considered representative of geomorphologically diverse areas.

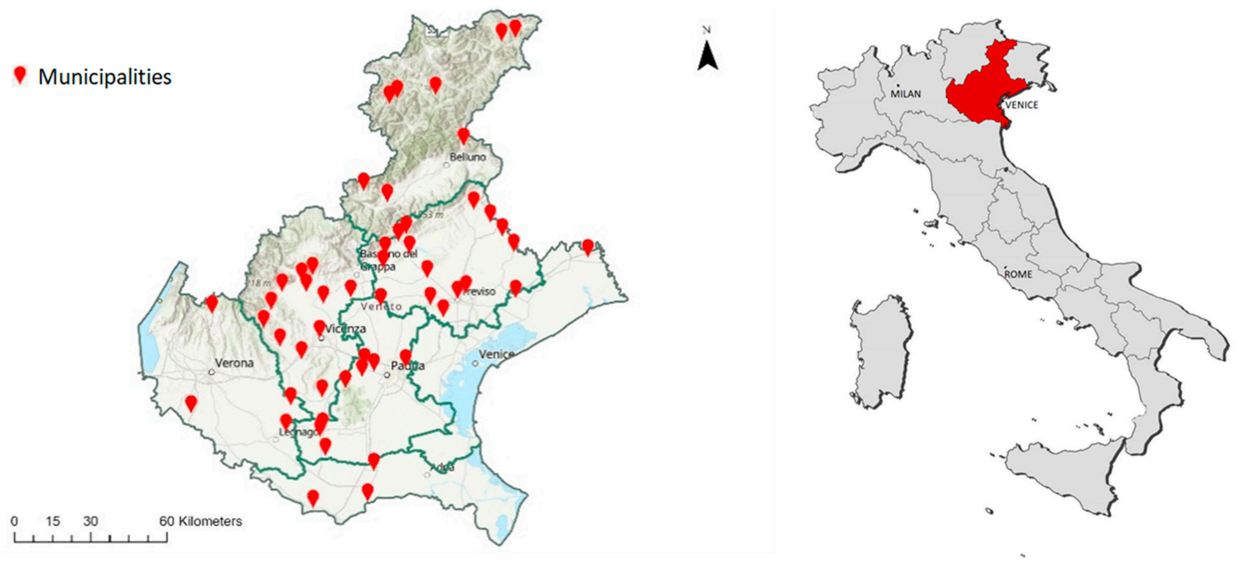

Figure 1. Municipalities that agreed to respond to the survey.

2.2. Climate

Veneto's climate is sub-continental, overall temperate, and mitigated by the sea. The Alps' range protects it from the northern winds. The climatic zones of the alpine region have cool summers and cold temperatures in winter, with frequent snowfall. The hilly belt and part of the plain has a milder climate. Finally, the rest of the plain has a more continental climate.

2.3. Research Method and Procedures

A descriptive research criterion and survey approach was used in this study. The actions taken are summarized in Figure 2.

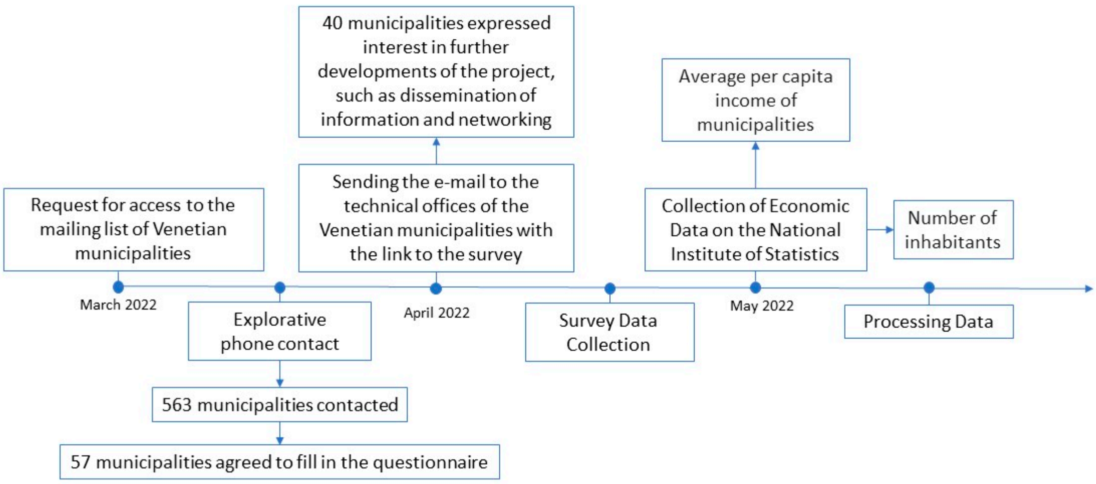

Figure 2. Sequence of actions taken.

There is no registry of NBSs at the municipal level, nor at the regional or national level, so data on the number, type, and location of NBSs were collected through an online survey to determine the degree of acceptance and whether NBS implementation was limited by geomorphological, economic, or cultural factors. Data were acquired through a synergy of questionnaires, structural interviews, and observations.

At the beginning of the questionnaire, there was a brief explanation indicating the title, motivation, and purpose of the survey; the questionnaires were anonymous; the questions were short and clear; both multiple-choice and close-ended questions were asked.

The research was relativist in design because of the technicians' individual perceptions of flood risk and the causes of drought; the epistemology was positively constructivist in that the participants were actively involved in giving meaning to their knowledge of the socioeconomic and environmental world and in constructing their own opinions on the topic.

2.4. Variables and Measurements

The survey was structured to collect as much information as possible regarding the application and disposition of NBSs. The questionnaire was divided according to several study variables.

Geographic variables: variables measuring the respondents' qualification and geographical location of the municipality.

Data collection: the number, location, and period of NBS construction was investigated.

Attitudinal variables: We hypothesized that the use of NBSs is influenced by the attitude of the technicians who choose them. We used the five-item Likert scale to measure the perceived usefulness of nature-based solutions. In this way, technicians rated the choice of NBSs on the need for hydraulic risk reduction (in relation to the protection of water resources), how much they considered NBSs to be a practicable solution, and on the importance of involving the population in the planning stage of land protection interventions.

3. Results

Only 10% of the municipalities participated in the survey; most of them were interested in further developments of the project, such as dissemination and networking. They were diffused across the territory; this fact supported the research of correlation with socioeconomic and geomorphological data. Contextually, the faltering participation indicated that awareness and interest toward the new paradigm in water management needs promotion at the level of decision makers. The data on the presence and location of various types of NBS were analyzed first. Secondly, the time trend of the realization of various NBSs was described. Finally, the opinions of the respondents were used to give reason to quantitative evidence.

3.1. Diffusion of NBSs over the Territory

We selected four typical solutions to mitigate hydraulic flood risk (retention basins (green), detention basins (grey), NBSs (green), and levee enhancement) and asked the stakeholders whether it was often implemented in their area. The responses are summarized in Table 1.

Table 1. NBS territorial coverage according to expert answers.

	Retention Basin		Detention Tank		NBS		Riverbank Enhancement	
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
Frequently implemented	9	23.1	28	71.8	14	32.6	19	41.3
Rarely implemented	30	76.9	11	28.2	29	67.4	27	58.7

Detention tanks were ranked as the first-choice intervention for flood-risk mitigation (n = 28), followed by riverbank enhancement (n = 19), NBS (n = 14), and retention basins (n = 9) (that have rarely been adopted to achieve the purpose) (Table 1). The preference for grey solutions may be dictated by a distrust of green solutions, a lack of information, or habits or geophysical constraints that limit the effectiveness of NBSs. The main reason in our case emerged from the following questions that were part of the survey.

Among NBSs, we specified four typical solutions (vegetated swales, porous pavements, bioretention gardens, and infiltration trenches) and asked experts how many had been implemented in the municipality they represented. The results are shown in Table 2. Porous pavements were the most widely used NBS, followed by infiltration trenches.

Table 2. Percentage of vegetated swales, porous pavements, bioretention gardens, and infiltration trenches.

Type of NBS	None	Less than 5	Between 6 and 20	More than 20
Vegetated Swales	76.6%	19.1%	0.0%	4.3%
Porous Pavements	23.5%	25.5%	29.4%	21.6%
Bioretention Gardens	71.4%	24.5%	2.0%	2.0%
Infiltration Trenches	69.4%	16.3%	12.2%	2.0%

According to further stakeholder comments, porous pavements differed from those described, for example, by Eckart [38], in that they lacked a subsurface drainage system and could be likened to the permeable area where parking was allowed, thus resulting in a very simple and low-cost intervention, which could explain the survey result.

3.2. Spatial Distribution of NBSs

Figure 3 shows the numerosity and spatial distribution of NBSs in the Veneto region. The number of NBSs built varied significantly between neighbouring and distant municipalities, resulting in a highly heterogeneous distribution of NBSs, whose structure was not easy to recognize and that was attributed to geophysical, demographic, or social variables.

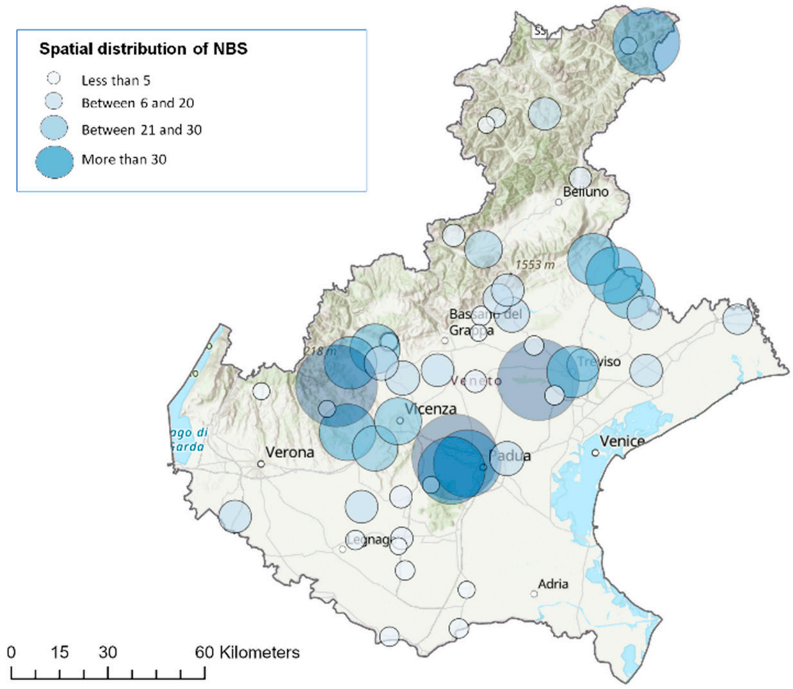

Figure 3. Spatial distribution of NBS. Symbol size is proportional to the number of realized solutions.

Porous pavements and infiltration trenches cannot be constructed where the water table is too close to the ground surface [39]. Infiltration capacity appears to be a geomorphologic parameter that influences the distribution of infiltration systems. Figure 4 shows that porous pavements and infiltration trenches were found mainly in the area at the foothills of the Alps and at some distance from the coast, where groundwater depth and soil infiltration capacity were not a barrier.

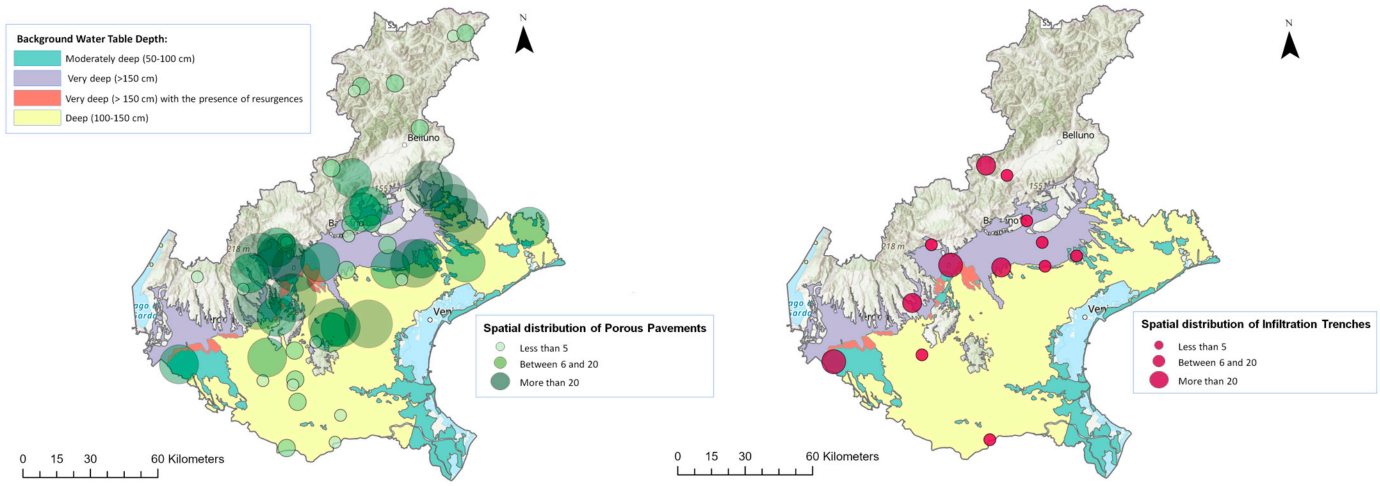

Figure 4. Spatial distribution of porous pavements (**left**) and infiltration trenches (**right**) superimposed on the groundwater depth map. The size of the symbols is proportional to the number of specific infiltration systems implemented. In the background water table depth: greater than 1.5 m (purple); between 1 and 1.5 m (yellow); between 0.5 and 1 m (green).

3.3. Dynamics of NBS Socioeconomic Characteristics

The possibility that socioeconomic factors influence policy decisions on hydraulic risk management certainly deserves consideration for truly sustainable development. The National Institute of Statistics [40] database provided the number of inhabitants and annual average per capita income of municipalities that participated in the survey (Figure 5). Although it is well known that aggregation in urban centers offers opportunities for economic growth, the per capita income of small municipalities in the Veneto region is not very different from that of large ones. To explain why, it is worth analyzing the urban structure and history of the Veneto region, which includes numerous villages and historical centers around which continuously expanding urban areas grew during the second half of the 20th century as a result of the industrial and socioeconomic development that took place in northeastern Italy. Today, Veneto is configured, from an urban planning point of view, as a large interconnected metropolitan area; people easily move from one municipality to another for reasons related to work or other personal interests. By virtue of the connections between different areas within the region, the socioeconomic characterization of the population tends to homogenize across the territory, giving reason for minimal income differences between municipalities, as the data show. The highly heterogeneous spatial distribution of NBSs across the territory (Figure 3) cannot be attributed to economic factors related to the development and income of citizens (Figure 5).

The number of NBSs varied widely for small and medium-sized centers and tended to decrease on average as the number of inhabitants increased (Figure 6). Small municipalities may have had a history of recent development and available and easily accessible space for NBS implementation or they may have been historical centers where no change in urban planning was allowed. Large urban centers often have a mixed urban structure, with a historical center and districts dating from different eras that range from the postwar period to the present. Only in the last few decades have new districts arisen based on more environmentally sustainable standards of construction.

Available urban space often limits the ability to implement certain types of NBS. We asked experts to specify what types of NBS have been implemented and where, suggesting four typical urban areas:

1. Historical centers, where heritage preservation and urban development dictated by local economic growth require adaptive practices that respect the urban layout;
2. Areas of new urbanization, specifically regulated by regional law, where post-development runoff production cannot exceed the predevelopment one and where

there is an opportunity to design new buildings and infrastructure based on sustainable development principles;
3. Industrial areas that can be hot spots of runoff and pollution production and require special attention to ensure environmental protection;
4. The suburbs, where the interconnectedness of socioeconomic development can be a limitation due to the lack of infrastructure or can be an opportunity due to the dynamic and transitional nature of the suburbs.

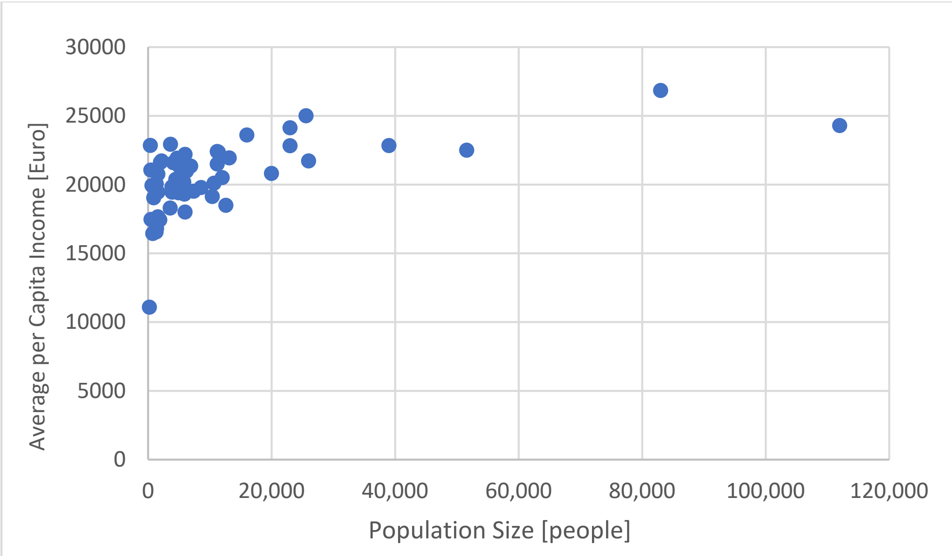

Figure 5. Average per capita income versus population size in the municipalities that participated in the interview.

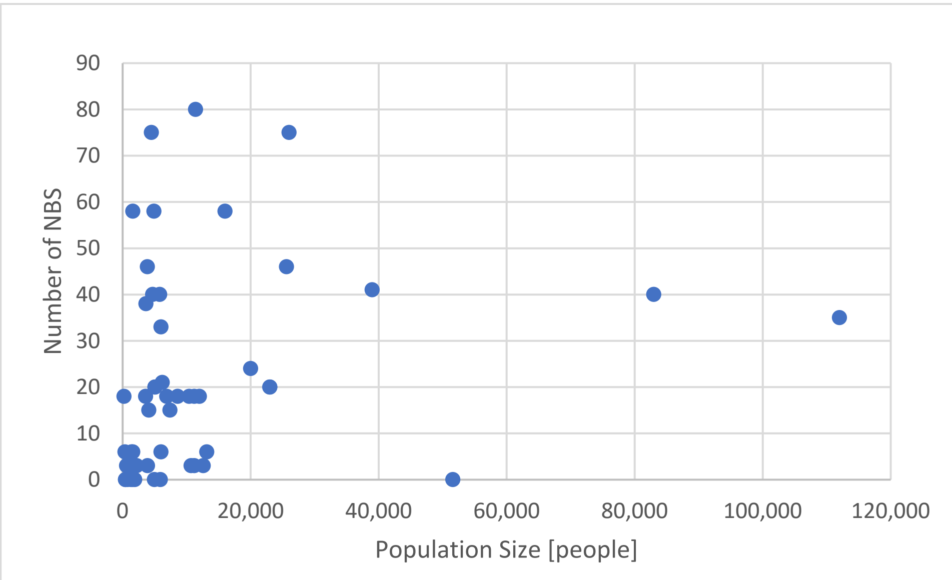

Figure 6. Number of NBSs versus population size in the municipalities that participated in the interview.

Table 3 shows that in inner cities, industrial areas, and newly urbanized areas, porous pavements were more common than other NBSs, while in the suburbs any kind of NBS had been implemented. In many cases, experts stated that no NBSs have been realized in any of the four urban regions, while the urban areas where they were most abundant were those of recent urbanization, almost certainly to satisfy the legislative constraint that the maximum flow conveyed to the drainage network should not exceed that which was conveyed to the drainage network before urbanization. This should be checked for a return time of 50 years if detention systems are present or 100 years if excess water is dispersed by infiltration systems [41].

Table 3. Percentage of NBS distribution in different urbanized areas.

	No NBS in the Municipality	Historical Centers	Suburbs	Newly Urbanized Areas	Industrial Areas
Vegetated Swales	62.9%	8.6%	17.1%	8.6%	2.9%
Porous Pavements	11.0%	19.2%	9.6%	41.1%	19.2%
Bioretention Gardens	51.4%	2.7%	8.1%	27.0%	10.8%
Infiltration Trenches	45.5%	6.8%	15.9%	18.2%	13.6%

3.4. Time Trend of NBS Development

In 2006, a national law [31] made the regions responsible for regulating the use of infiltration and detention structures for mitigating the hydraulic risk of flooding; the Veneto region's regulations came into effect in 2009 [41].

According to our survey, 36 percent of NBSs were implemented between 2000 and 2009, 52 percent after 2009, and the very small remainder were implemented before the 1990s (Figure 7), showing that legislation is one of the main driving mechanisms in the introduction of new technical solutions.

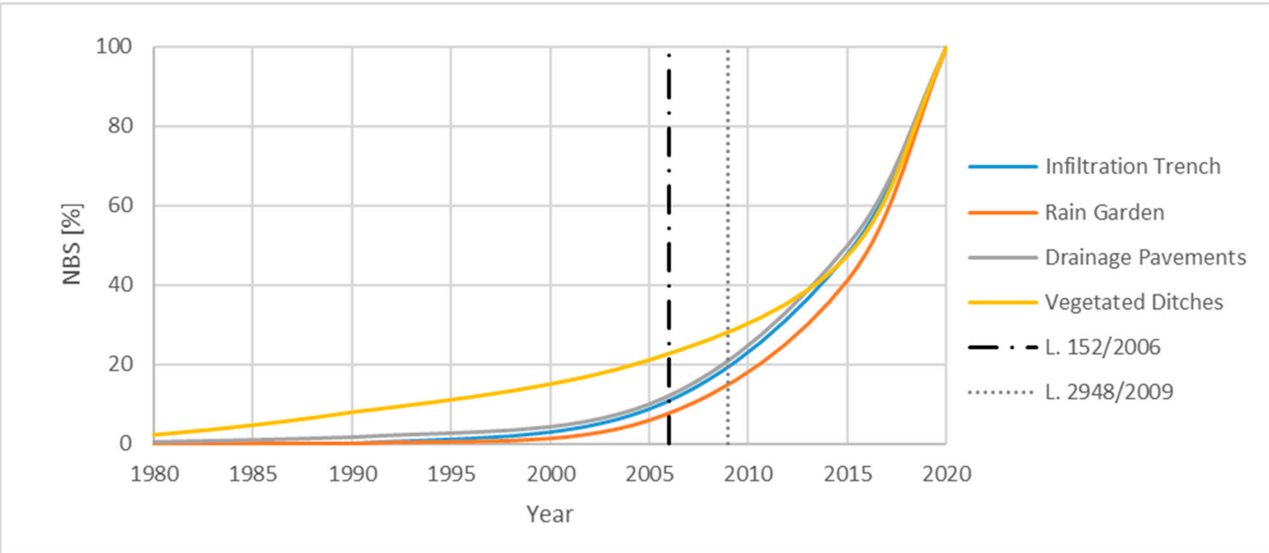

Figure 7. Percentage of NBSs implemented over time and times when new technical regulations came into effect.

3.5. Attitudinal Factors Undermining the Adoption of NBSs

Only 26.4 percent perceived NBSs as essential for flood-risk control (score 5); 39.6 percent of stakeholders rated the effectiveness of NBSs as good and gave a score of 4; a small percentage of stakeholders (2%) considered NBSs ineffective (score 2); 5.7 percent declared this type of solution useless (score 1) (Figure 8).

We asked the professional associations responsible for training technicians whether information on the effectiveness of NBSs had been disseminated through training courses and found that such systems had not been the subject of any training course in recent decades; therefore, the perceptions of the technicians surveyed were based on individually acquired elements and not through formal training channels.

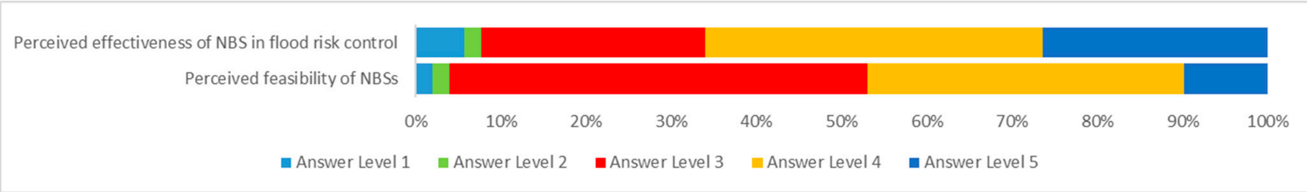

Figure 8. Perceived feasibility of NBSs and perceived effectiveness of NBSs in flood-risk control.

The rating of NBS feasibility by technical respondents on a scale of 1 to 5 produced the results shown in Figure 8. Only 9.8% felt that NBSs were easy to implement (score 5); 37.2% gave a score of 4; 49% of the experienced stakeholders gave a score of 3; 2% felt they were difficult to implement; 2% felt they were impractical (scores 1 and 2).

When we asked the reasons for their responses, stakeholders said that they were uninterested in infiltration systems, which tend to clog and threaten groundwater quality, but none mentioned the need for pretreatment. Stakeholders also mentioned that soil characteristics in many places restrict the range of possible solutions to detention systems simply because the soil does not have an adequate infiltration capacity or a sufficiently gentle slope. In their open-ended responses, they lamented the lack of a technical design and maintenance manual as well as technical regulations that could adequately restrict the scope of NBSs and define their maintenance schedule. The fact that NBSs require a certain amount of space and regular maintenance sometimes makes a systematic approach to these solutions difficult. According to the results of our survey, NBS proposals still encounter resistance from older municipal engineers and some administrators. Technicians responding to the survey said they were aware of the negative effects caused by uncontrolled urbanization, the shortcomings of traditional drainage systems, and the opportunities offered by new NBSs; some anchored on traditional solutions, others were unaware of the co-benefits associated with NBS implementation, and still others were only partially confident that NBSs can solve urban flooding problems. A total of 78.4 percent of stakeholders surveyed would like to know more about the progress of sustainable drainage and NBSs (Figure 9). This fact, and the additional comments summarized above, highlight the urgency of filling a knowledge gap caused by the rapid development of progress in the field of sustainable urban drainage and the slow process of content dissemination outside academia.

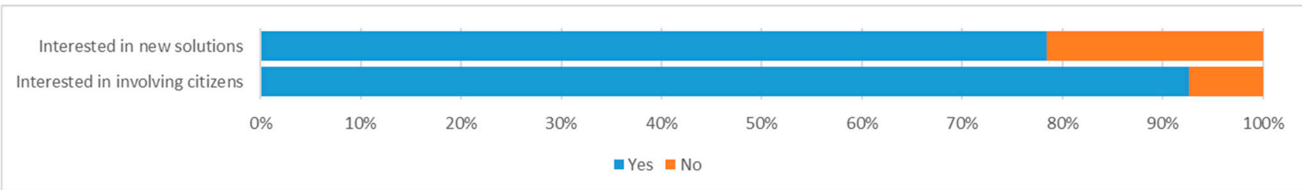

Figure 9. Willingness to advance knowledge on NBS technology and personal opinions of expert stakeholders on the importance of citizen involvement in the decision-making process surrounding NBS implementation.

We were not aware of many initiatives for citizen involvement in decision making regarding sustainable drainage and NBS implementation in the Veneto region, although 92.6 percent of experienced stakeholders agreed that citizen involvement was important (Figure 9).

4. Discussion and Conclusions

Over a territory where the legislative constraint is not fragmented (the Veneto region), we interviewed stakeholders responsible for implementing urban drainage technical solutions. The implementation of NBSs reflects political will, regulation constrains, and the consensus of stakeholders, as without them the specific technical solution might be rejected. The survey aimed to define the presence of NBSs on the territory, what promoted the implementation of NBSs, and what limited their use.

Our approach was similar to that of Ncube and Arthur [42] and, similarly, revealed that the experts' priority was flood-risk containment. In contrast to Ncube and Arthur [42], none of the experts interviewed considered the aesthetic value of NBSs as important, nor the co-benefits to the community that may result from their implementation. Different solutions for reducing hydraulic flood risk in urban areas were ranked by expert stakeholders through an online survey. Porous pavements were ranked as the solution of first choice; other vegetated NBSs, such as bioretention, were underrepresented in the area. In cases where volumes needed to be found for stormwater storage, experts often preferred the grey solution to the green one, recognizing that an infiltration system was a potential source of soil pollution and required maintenance. In this regard, no one mentioned the possibility of pretreatment.

In agreement with Ferreira [29], we found that not all institutional stakeholders may have sufficient understanding of how NBSs can assess urban hydrology challenges, suggesting that collaborative learning needs to be improved. Although social and environmental characteristics can influence decisions on NBS implementation [29], stakeholders' perceptions of hydraulic risk and their awareness of the benefits and co-benefits of NBS can foster NBS implementation.

The implementation of most existing NBSs responds to the enactment of a regional law suggesting their use. This evidence demonstrates the close interrelationship between the decisions in favor of NBSs and the constraints of national and regional legislation. Land management in urban areas can have a strong impact on the synergy of co-benefits from the use of green solutions [43]. Geophysical constraints in many cases are stated as a key issue, but the same engineers interviewed denounced the lack of technical regulations that should instead clearly define the limits of applicability of NBS in relation to the geomorphology of the territory.

Assuming that professional corporations in Italy play a role in disseminating innovation and new regulation among the members, we interviewed engineering corporations about their role in disseminating technical standards on NBSs [44]. The societies (one per province) provide learning opportunities for engineers and can influence decision makers. The dissemination of NBS design and management criteria has not taken place in recent decades, which may account for their moderate uptake and testifies to a disconnection between the academic and technical and policy sectors. On the opposite side, the engineers interviewed denounced the lack of detailed technical guidelines, in the absence of which NBSs may still be a general concept not realizing their full potential.

Technicians, aware of training shortcomings, in part perhaps attributable to a disconnection between academia, professional bodies, and the world of work, suggested the promulgation of a technical regulation that could guide them in implementing more NBSs on the ground and could advocate greater popular involvement.

In fact, NBS proposals still meet resistance from senior municipal engineers and some administrators. A limited number of technicians remain collaborative and open to initiatives such as surveys, possibly ignoring that they can bridge between stakeholders and concur in creating shared awareness. New solutions to be integrated with more traditional ones require a change of mindset; popular involvement could foster such a cultural renewal, as well as a dissemination of experience and a creation of common aims.

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