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A Methodological Framework for Integrating Nature-Based Solutions Into Water-Sensitive Urban Planning

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Abstract

Urbanisation is one of the dominant global development processes of the 21st century and, together with climate change impacts, increasingly pressures urban ecosystems and infrastructure. These processes contribute to persistent challenges related to air, water and soil quality, as well as to the growing exposure of cities to natural risks. In this context, water-sensitive urban planning has gained importance, as it supports the integration of water-related processes and constraints into spatial planning and decision-making, using contemporary planning and spatial-analytical tools. Nature-Based Solutions (NBS) are increasingly recognised as an approach for integrating natural processes into urban water management and protection. However, their application in practice often remains fragmented and disconnected from planning procedures. This paper proposes a methodological framework for integrating NBS into water-sensitive urban planning and integrated water management, combining planning parameters, hydrological and hydrogeological criteria, and spatial information derived from risk maps, with particular emphasis on the protection of urban water resources.

Keywords: Nature-Based Solutions (NBS); water-sensitive urban planning; GIS-based planning; integrated water management.

1. Introduction

Water is an irreplaceable natural resource and a foundation of life, economic development and social well-being. Despite its central importance, water resources are often not managed rationally or protected adequately. Their spatial and temporal distribution is uneven, their quantity is limited, and their quality is increasingly under pressure. At the same time, global demand for water continues to rise, mainly as a result of population growth and rapid urbanisation. In developing countries, millions of people still become ill or die from diseases associated with the consumption of polluted water (Hrudey et al., 2006).

Urbanisation is one of the main drivers of change in water systems. At the beginning of the twentieth century, only about 5% of the world population lived in urban areas. Today, almost half of the global population lives in cities, and United Nations projections suggest that this share may reach 75% by the middle of the twenty-first century (Patrick, 2014). This trend increases pressure on water resources, while also creating opportunities for more effective management through integrated spatial planning and source-water protection.

In transition countries such as Bosnia and Herzegovina, urban development is often spontaneous and insufficiently controlled, with marked sectoral fragmentation in decision-making. As a result, urban areas expand towards zones of critical importance for water supply, including existing and potential source-water protection zones. Conflicting interests among land users, combined with the absence of integrated planning, lead to decisions that can have long-term negative effects on the environment, particularly on water resources.

The concept of sustainable development responds to the need to align economic development, social needs and environmental protection. However, its application remains limited unless it is embedded in concrete planning and management processes. Sustainable water management requires an interdisciplinary approach, coordination between sectors and close cooperation between experts and decision-makers (Đorđević et al., 2013). In this context, preventive protection of water resources is more effective and economically justified in the long term than remedial action taken after degradation has occurred.

Additional pressure on water systems arises from climate change, which affects both the availability and quality of water resources. More frequent and longer droughts, together with more intense extreme rainfall events, are expected to make urban water management increasingly complex (Sweeney et al., 2008; Coll & Sweeney, 2013). Under such conditions, conventional approaches to water management are increasingly insufficient, requiring integrated and spatially sensitive solutions.

In this context, nature-based solutions (NBS) are increasingly promoted as a way of integrating natural processes into urban water management. However, despite their broad conceptual acceptance, their practical application often remains fragmented and weakly connected to spatial planning and local hydrological and hydrogeological conditions (Kabisch et al., 2017; Raymond et al., 2017). As a result, NBS implementation may fail to achieve the expected effects and, in some cases, may even increase risk, particularly in areas of high groundwater vulnerability.

Existing approaches largely focus on the typology of measures, while giving less attention to their spatial suitability and their interaction with the specific characteristics of the urban water system. This lack of integration between spatial planning, hydrological processes and hydrogeological constraints is the key research gap addressed in this paper.

Against this background, the aim of the paper is to propose a conceptual and methodological framework for integrating nature-based solutions into water-sensitive urban planning. The framework is based on the logic of GIS-supported multicriteria analysis, through which planning parameters, hydrological processes and hydrogeological constraints are brought together within a single analytical approach (Aziz Amen & Ali, 2025; Amen et al., 2023) . Its purpose is not to offer a universal model for the spatial allocation of NBS interventions, but to establish a flexible analytical basis that can be adapted to different urban and hydrogeological contexts.

Sarajevsko polje is considered in this paper as an illustrative example of a complex urban hydrogeological system in which groundwater protection requirements overlap with the need to manage surface runoff. In this way, the proposed framework supports context-specific planning of NBS interventions in areas where their application must be aligned with hydrogeological vulnerability, source-water protection zones and existing patterns of urban development.

Accordingly, the paper addresses three research questions: (i) how the logic of GIS-based multicriteria analysis can support the spatially differentiated integration of NBS into urban planning; (ii) how hydrogeological vulnerability can be incorporated as a constraining factor in the spatial allocation of NBS interventions; (iii) how functional zones for protection-oriented, retention-oriented and mixed strategies of NBS implementation can be conceptually distinguished on the basis of the relationship between hydrological needs and hydrogeological constraints.

This paper proposes an integrated GIS-based analytical framework for assessing the suitability of implementing nature-based solutions (NBS), with the aim of linking urban hydrological needs with hydrogeological constraints related to groundwater protection. On this basis, conceptual zoning is introduced as a planning-support tool to guide the spatial implementation of NBS in complex urban systems, where the protection of groundwater quality and function represents a key planning and management requirement.

Previous research on groundwater vulnerability in Sarajevsko polje has demonstrated the pronounced sensitivity of the aquifer to pollution and confirmed the relevance of vulnerability maps as tools for source-water protection (Hadžić et al., 2015). Earlier work on source-water protection in urban areas, with a particular focus on Sarajevsko polje, further indicated that urban expansion, weakly coordinated sectoral policies and the delayed implementation of protective measures contribute to the progressive degradation of protection zones and increased risks to groundwater (Hadžić & Milišić, 2017). Building on these findings, this paper develops a spatially explicit methodological framework that links planning parameters, hydrological processes and hydrogeological constraints to support the context-sensitive application of nature-based solutions.

2. Research Context and Conceptual Basis

2.1. Sarajevsko polje as an Illustrative Hydrogeological and Urban Planning Context

The proposed methodological framework is considered in relation to Sarajevsko polje, the main drinking-water source for the city of Sarajevo. Sarajevsko polje is the largest groundwater source in Bosnia and Herzegovina and supplies water to almost 400 000 inhabitants. More than 80% of the total drinking-water demand, approximately 2.5 m3/s, is abstracted from the Sokolovići, Bačevo, Konaci and Stup sources, as well as from the Bosna I and Bosna II water intakes (Hadžić et al., 2015).

The area is a highly sensitive urban hydrogeological system, characterised by highly permeable alluvial deposits, strong hydraulic connectivity between surface watercourses and groundwater, and considerable pressures from urban development (Hadžić et al., 2015). The vulnerability of the source area is further increased by the short residence time of water in the field and by the fact that the existing first, second and third protection zones are located within the urban area of Sarajevo, where numerous potential sources of pollution are present (Hadžić & Milišić, 2017).

Studies carried out in this area indicate that naturally renewable groundwater quantities are estimated at approximately 800-1250 l/s, while abstracted quantities in some periods substantially exceed this range. This further underlines the need for careful and long-term sustainable management of the resource (Hadžić & Milišić, 2017). Previous studies also show that a significant part of Sarajevsko polje is classified as an area of high or very high intrinsic vulnerability, confirming the need for stricter protection regimes and careful selection of intervention types in these areas (Hadžić et al., 2015). These characteristics make Sarajevsko polje a suitable example for examining how NBS planning must simultaneously address groundwater protection and surface runoff control within the same urban space. The historical development of sanitary protection zones in Sarajevsko polje, including decisions from 1961, 1967 and 1987, the more recent 2013 proposal for protection zones, and the implications of changes to the regulation on sanitary protection zones, have been analysed in detail in previous work (Hadžić & Milišić, 2017). This paper builds on those findings but shifts the focus from the normative framework to the spatial integration of hydrogeological constraints and NBS planning.

2.2. Nature-Based Solutions within Integrated Water Management and Spatial Planning

Although urbanisation is a major driver of economic development, it also generates substantial pressure on water resources. In urban areas, it increases impervious surfaces, alters the microclimate, increases wastewater volumes and reduces green and agricultural areas. These processes lead to the deterioration of the qualitative characteristics of both surface water and groundwater (Hadžić, 2013; Hadžić, Srna, & Milišić, 2015). A particularly important problem in urban environments is groundwater degradation, which is often associated with insufficiently defined or inadequately protected source-water protection zones, as well as with the high natural vulnerability of aquifers (Institut za hidrotehniku d.d. Sarajevo, 2013; Avdagić et al., 1999).

Spatial planning is a key tool for managing land use and balancing development and environmental objectives. Since land use is directly linked to sectors such as water management, infrastructure, agriculture and environmental protection, its role in preserving water resources is fundamental. However, coordination between spatial planning and water resources management remains a major challenge, particularly because administrative and hydrological logics of management often do not coincide. In this context, integrated water resources management provides an important theoretical and operational basis for overcoming sectoral approaches (Global Water Partnership (GWP), 2004).

Nature-based solutions can play an important operational role in implementing the principles of integrated water management, but only if they are spatially differentiated and aligned with local hydrological and hydrogeological conditions. Contemporary approaches to stormwater management have evolved through concepts such as Low Impact Development (LID), Sustainable Urban Drainage Systems (SUDS) and Water Sensitive Urban Design (WSUD), which gradually introduced the principles of decentralised water management, multifunctionality and the integration of blue-green solutions into spatial planning. The NBS concept further develops these approaches, but its effective application depends on local context and cannot be based on a universal typology of measures.

3. Methodological Framework for the Spatial Suitability Assessment of NBS Interventions

3.1. Selection and Role of Criteria in the Suitability Assessment

The proposed framework integrates several categories of input data that capture the characteristics of the natural system, anthropogenic pressures and planning conditions within the considered urban area. The area is of particular importance, as it overlies the main groundwater source used for supplying Sarajevo with drinking water. In this sense, criteria are conceptually divided into primary criteria, which have a direct role in assessing spatial suitability for NBS implementation, and secondary, or modifying, criteria, which influence the type, priority and design of individual interventions.

In the operational application of the framework, primary criteria are grouped into four main categories: (i) spatial planning criteria, including land use, degree of urbanisation, urban density, existing and planned infrastructure networks and planned development zones; (ii) hydrological criteria, including surface runoff patterns, areas prone to pluvial flooding, the capacity of the existing drainage system and microtopography that influences water retention; (iii) hydrogeological criteria, including aquifer type, depth to groundwater, infiltration capacity, groundwater flow dynamics and intrinsic groundwater vulnerability maps; and (iv) risk criteria, including flood hazard maps, source-water protection zones and locations of potential pollution sources.

In a GIS environment, each of these criterion groups is represented as a separate spatial layer, which can be further classified into categories of low, medium and high suitability, or into categories of constraint for NBS implementation. Hydrogeological criteria have particular importance among the primary criteria, as they make it possible to include groundwater vulnerability as a spatially explicit component of the suitability assessment. Vulnerability indicators may be based on previous studies that produced intrinsic vulnerability maps of Sarajevsko polje using an index-based approach and GIS (Hadžić et al., 2015). In this way, existing vulnerability maps are not used in isolation, but are integrated with other criteria within a broader multicriteria approach to assessing the suitability of NBS implementation.

Secondary criteria are treated as modifying layers. They do not act as strict constraints, but they influence the priority, type and design of interventions. This group includes indicators related to urban heat island intensity, air quality, soil condition and potential contamination, imperviousness, existing green infrastructure and ecological connectivity. In operational terms, these criteria help identify areas where NBS interventions may provide additional co-benefits, such as urban cooling, improved air quality or strengthened green infrastructure. They are therefore usually applied in the multicriteria procedure by increasing or decreasing suitability within already defined primary categories.

Within the proposed methodological approach, groundwater vulnerability has a particularly important role in areas characterised by high permeability and rapid groundwater flow, where the risk of contamination is considerably increased (Krešić et al., 2006; Hadžić, 2013). Under such conditions, hydrogeological criteria are not merely one set of input layers; they may have a dominant role in defining constraints on certain types of NBS interventions, especially those involving direct or intensive stormwater infiltration.

3.2. GIS-Supported Multicriteria Assessment

The methodological approach is conceived as a GIS-supported multicriteria assessment of spatial suitability for NBS interventions. In this framework, the use of GIS is not only a technical choice, but an important methodological element because urban water systems are spatially heterogeneous. GIS enables hydrological, hydrogeological, planning and environmental criteria to be integrated within a single analytical space, while also allowing constraints and potential suitability zones for different types of NBS interventions to be defined explicitly. In this sense, GIS-supported multicriteria assessment functions as a decision-support tool rather than as a universal model that can be applied without adaptation to local context.

The proposed procedure consists of five interrelated steps.

Step 1 - data preparation. The collection and harmonisation of spatial data includes the identification of relevant sources, such as spatial plans, hydrometeorological data, hydrogeological studies, vulnerability maps, flood hazard maps and land-use data. The collected data are harmonised within a common coordinate system and an appropriate spatial resolution. At this stage, each selected criterion, including planning, hydrological, hydrogeological and risk-related criteria, is translated into a corresponding vector or raster layer, with the required reprojection, generalisation and data-quality checks.

Step 2 - classification and standardisation of criteria. The classification of criteria into primary and secondary groups follows their role in decision-making, distinguishing suitability and constraint layers from modifying layers. Operational classes are defined for each primary criterion, such as low, medium and high degree of urbanisation; low, medium and high groundwater vulnerability; or low, medium and high exposure to pluvial flooding. These classes are then standardised on a common ordinal suitability scale, for example from 1 to 3 or from 1 to 5, which enables different types of spatial data to be compared and combined within the same analytical framework.

Step 3 - definition of constraint layers. Constraint layers are used to identify areas where the application of certain types of NBS interventions, especially infiltration measures, should be restricted, made conditional on additional treatment or excluded altogether. These layers commonly include zones of high and very high groundwater vulnerability, source-water protection zones and areas with a pronounced risk of rapid contaminant transport towards the aquifer. Operationally, constraint layers may be applied as binary masks, permitted/not permitted, or as strong negative weights in the aggregation of suitability.

Step 4 - aggregation through weighted decision-making. Standardised criteria are integrated through GIS overlay analysis using a weighted decision-making logic. Relative weights are assigned to each group of criteria, including planning, hydrological, hydrogeological and risk criteria, on the basis of the literature, available data and expert judgement. In this framework, hydrogeological criteria are recognised as a potentially dominant regulatory factor, as they may restrict or condition the use of infiltration-based NBS measures. The result of this step is a set of suitability layers that expresses, for each spatial element, such as a pixel or polygon, the relative potential for NBS implementation, while explicitly taking constraints into account.

Step 5 - functional zoning. The final step interprets the results of the multicriteria assessment through functional zoning. Aggregated suitability and constraint indices are translated into three conceptual categories: protection-oriented zones, retention-oriented zones and mixed-function zones. Operationally, this can be achieved by defining suitability thresholds for retention interventions and thresholds for hydrogeological constraints, and then identifying areas where these categories overlap. In this way, the proposed procedure provides a basis for developing a map of functional zones that may inform planning and management decisions.

A schematic representation of the proposed GIS-supported procedure for multicriteria suitability assessment and functional zoning of NBS interventions is shown in Figure 1.

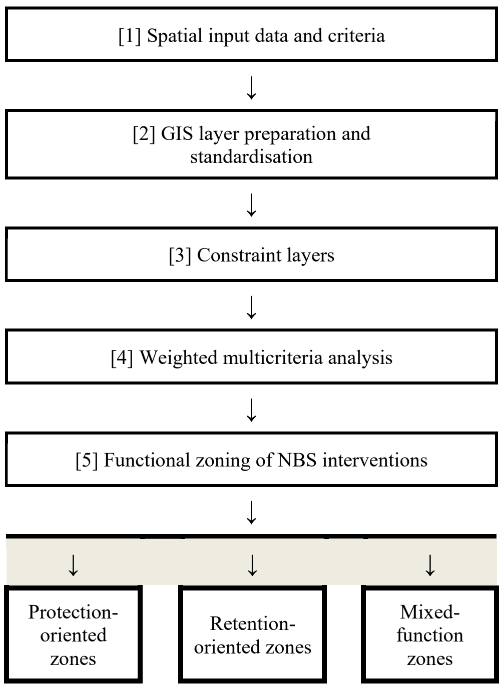

Figure 1. Schematic representation of the GIS-supported procedure for multicriteria suitability assessment and functional zoning of NBS interventions.

In this paper, the suitability and constraint indices are considered at a conceptual level, without assigning specific numerical weights, thresholds, or classification values. Their quantification, calibration, and testing are therefore left for future empirical research. In an operational application of the framework, the retention index would combine indicators of surface runoff, imperviousness, and pluvial flood risk, grouped into low, medium, and high categories of retention need. The hydrogeological index would integrate groundwater vulnerability, the presence of sanitary protection zones, and groundwater depth into categories of low, moderate, and high constraints for infiltration-based measures. In this sense, the indices serve as conceptual tools for organising spatial information, rather than as fully specified quantitative models. The steps described above are therefore understood as a methodological framework, while the specification of fixed weights, thresholds, and index values is left for future empirical research.

Table 1: Criterion groups, examples of input layers and their role in the analysis.

Criterion group	Examples of input layers	Role in the analysis
Planning	Land use, urban density, infrastructure network	Defines the spatial context and development constraints
Hydrological	Surface runoff, pluvial flooding, drainage	Assesses the need for retention and runoff control
Hydrogeological	Aquifer type, depth to groundwater, vulnerability	Defines constraints on infiltration measures
Risk	Flood hazard maps, source-water protection zones, pollution sources	Identifies sensitive and risk-prone areas
Secondary (modifiers)	UHI, air quality, green infrastructure	Assesses co-benefits and intervention priorities

3.3. Functional Zoning Logic for NBS Interventions

Functional zoning builds on the concepts of the retention and hydrogeological indices by translating their combined values into three types of zones relevant for planning NBS interventions. The proposed multicriteria procedure enables a spatial suitability assessment that can provide a basis for defining functional zones for the implementation of nature-based solutions. Unlike administratively defined boundaries, these zones emerge from the relationship between hydrological needs, hydrogeological constraints and planning conditions, and therefore reflect functional processes and constraints within the urban water system.

The zoning is based on a combination of assessed spatial suitability and identified constraints. It integrates different types of spatial information, including groundwater sanitary protection zones, areas exposed to flood risk, the degree of urbanisation, land-use patterns and potential sources of pollution. In this way, source-water protection zones are not treated as the only criterion, but as one of the key regulatory layers that, together with hydrological and planning factors, define the conditions for applying specific types of NBS interventions.

On the basis of this logic, three categories of functional zones can be conceptually distinguished: (1) protection-oriented zones, which correspond to areas of high groundwater vulnerability, often within sanitary protection zones, where infiltration measures are strictly restricted or excluded; (2) retention-oriented zones, which overlap with urban areas prone to pluvial flooding and increased surface runoff, where priority is given to measures that enhance retention and delay runoff; and (3) mixed-function zones, where spatial patterns indicate both high retention potential and pronounced hydrogeological constraints, requiring careful balancing between retention, water treatment and groundwater protection.

Conceptually, mixed-function zones include areas where medium to high need for surface-water retention overlaps with moderate to high hydrogeological constraints defined by aquifer vulnerability, the presence of sanitary protection zones and depth to groundwater. In practice, this corresponds to situations in which surface runoff must be reduced while infiltration is strictly controlled because of groundwater sensitivity, requiring hybrid and functionally combined NBS solutions.

4. Planning Operationalisation and Implications of the Proposed Framework

4.1. Linking Functional Zones, Planning Instruments and NBS Intervention Types

The proposed GIS-based multicriteria framework makes it possible to conceptually distinguish three functional zone types relevant to the spatial allocation of NBS in water-sensitive urban planning. These zones derive from the relationship between hydrological needs, hydrogeological constraints and existing planning conditions, translating spatial analysis into categories that are directly relevant to planning and management practice.

Protection-oriented zones refer to areas of high groundwater vulnerability, often located within sanitary protection zones, where hydrogeological criteria play a dominant role in decision-making. In these areas, the priority is to preserve groundwater quality, while measures based on direct or intensive infiltration are restricted, made conditional on additional treatment or excluded.

Retention-oriented zones refer to urban areas with increased surface runoff, a high share of impervious surfaces and pronounced pluvial flood risk. In these areas, priority is given to NBS interventions that provide temporary water storage, reduce peak flows, increase the time of concentration and relieve pressure on the existing drainage system, provided that there are no significant hydrogeological constraints.

Mixed-function zones are areas where requirements for surface runoff management overlap with constraints related to groundwater protection. In these zones, NBS implementation requires careful balancing between retention, water treatment and controlled infiltration, supported by a more detailed local assessment of hydrogeological risk.

An important contribution of the proposed framework is the operational linkage between functional zoning, planning instruments and types of NBS intervention. In this way, the conceptual results of spatial suitability assessment can be

used to identify priority areas for intervention, avoid inappropriate placement of measures in hydrogeologically sensitive zones, and integrate NBS principles into spatial, regulatory and management documents.
Table 2 presents a matrix linking functional zones, dominant management objectives, key constraints, relevant planning instruments and recommended types of NBS intervention. The matrix is not a universal model applicable independently of local context. Rather, it is an indicative decision-support tool that should be adapted to the specific hydrological, hydrogeological, urban planning and institutional conditions of the area under consideration.

Table 2: Linking functional zoning, planning instruments and types of NBS intervention.

Functional zone	Dominant management objective	Key constraints	Planning instruments	Recommended types of NBS intervention	Implementation constraints / notes
Protection-oriented zones	Protection of groundwater quality	High aquifer vulnerability; sanitary protection zones; rapid infiltration and contaminant transport	Sanitary protection zones, building conditions, land-use restrictions, regulatory plans	Green barriers, protective vegetation zones, control of pollution sources, stormwater management without direct infiltration, controlled phytoremediation	Infiltration measures should be restricted, conditioned by prior treatment or excluded; water-quality control is required; priority should be given to groundwater protection
Retention-oriented zones	Flood risk reduction and surface runoff management	High imperviousness; intense surface runoff; pressure on the drainage system	Urban plans, drainage plans, flood management plans, technical guidelines	Retention areas, rain gardens, green roofs, permeable surfaces, green corridors, urban depressions for temporary water storage	Infiltration is acceptable only where hydrogeological constraints are absent; the focus is on reducing peak flows and delaying runoff
Mixed-function zones	Balance between groundwater protection and flood risk reduction	Simultaneous presence of hydrological needs and hydrogeological constraints	Integrated plans, special building conditions, source-water protection requirements, local water management plans	Hybrid solutions, controlled infiltration, filtration before infiltration, multifunctional green spaces, combined retention, treatment and controlled discharge	Application requires prior risk assessment; infiltration should be conditioned by treatment and monitoring; design depends on local conditions

4.2. Implications for Groundwater Protection and Stormwater Management

The findings of the paper suggest that the effectiveness of nature-based solutions in urban water management depends less on the universal applicability of predefined measures than on their spatial compatibility with local hydrological and hydrogeological conditions. This finding supports a shift from approaches centred on the typology of measures towards context-based planning and spatial differentiation of interventions.
An important contribution of the paper is that it treats hydrogeological vulnerability not as a secondary or supporting criterion, but as a regulatory factor that can substantially limit the application of certain types of NBS, especially those based on infiltration (Krešić et al., 2006; Hadžić, 2013). This highlights the need to avoid treating NBS as universally positive solutions without sufficient consideration of groundwater sensitivity and existing spatial pressures.
Sarajevsko polje is an illustrative example of a complex urban system in which the requirements of groundwater protection overlap with the management of surface processes. This hydrogeological system, formed in the highly permeable alluvial deposits of the Bosna and Željeznica rivers, plays a key role in supplying drinking water to the city of Sarajevo, while also being highly sensitive to pollution and urbanisation pressures (Hadžić et al., 2015). A particular challenge is that source-water protection cannot be considered only within the immediate abstraction zones, but must be addressed across the entire catchment area of Sarajevsko polje, including the recharge and aeration zones on the Igman and Bjelašnica plateaus and on the slopes of Treskavica, from where water reaches the aquifer through both surface and subsurface pathways. This combination of natural characteristics, catchment complexity and anthropogenic impacts requires careful alignment of measures that address groundwater protection and surface runoff management at the same time.
In the context of Sarajevsko polje, mixed-function zones would be expected to occur in peripheral urbanised areas where increased surface runoff, associated with a high share of impervious surfaces, overlaps with elevated aquifer vulnerability and proximity to sanitary protection zones. Such spatial configurations illustrate situations in which efforts to reduce pluvial flood risk cannot be considered separately from the need to strictly control infiltration and protect groundwater. The proposed index-based approach remains conceptual and does not assign fixed numerical weights, thresholds, or classification values. The detailed development, testing, and quantitative validation of the retention and hydrogeological indices, as well as the evaluation of mixed-function zones in specific planning or design contexts, remain tasks for future empirical research and are beyond the scope of this conceptually oriented paper.

4.3. Operational Value, Limitations and Further Application of the Framework

The proposed methodological framework responds to this challenge through a spatially explicit analytical logic that allows areas suitable for different types of NBS interventions to be conceptually differentiated, while also identifying zones where their application should be limited, conditioned by additional treatment, or carefully controlled. In this way, the framework supports a shift from isolated measures towards more integrated and context-sensitive water resources management, and provides a clearer link between GIS-based assessment and planning instruments. However, the proposed framework should be understood as a flexible analytical structure rather than a fixed universal model. Its applicability depends on the quality and spatial resolution of available data, the reliability of hydrogeological information, and the robustness of the weighting process based on expert judgement. Future research should include sensitivity testing of weights, scenario analyses, and empirical validation using local monitoring data.

5. Conclusions

This paper points to the need to treat nature-based solutions in urban water management as spatially conditioned interventions rather than as universally applicable measures. Their effectiveness depends largely on their alignment with the hydrological needs, hydrogeological vulnerability and planning constraints of a specific place. The proposed framework highlights that different water-related processes may occur within the same urban system, but that they require differentiated management approaches. In groundwater protection zones, the priority is to preserve water quality, while in urban areas with pronounced surface runoff the key measures are those that increase retention and delay runoff. Between these two situations are mixed-function zones, where runoff control must be carefully balanced with aquifer protection.

In relation to the research questions, the paper indicates that the logic of GIS-based multicriteria analysis can be a suitable tool for supporting the spatially differentiated integration of NBS into urban planning, as it enables planning parameters, hydrological processes and hydrogeological constraints to be brought together within a single analytical framework. The proposed framework also shows how hydrogeological vulnerability can be incorporated as a constraining factor through the definition of constraint layers and through the restriction, conditioning or exclusion of infiltration measures in sensitive zones, particularly within groundwater protection areas (Krešić et al., 2006; Hadžić, 2013). Finally, the framework enables the conceptual distinction between protection-oriented, retention-oriented and mixed-function zones, each of which requires a different set of planning instruments and NBS measure types.

By combining GIS-based multicriteria analysis with functional zoning, the proposed methodological framework offers one possible planning-relevant approach for aligning NBS implementation with the objectives of groundwater protection and stormwater management. This approach may help bridge the gap between conceptual discussions of NBS and their operational integration into urban planning practice, while taking into account the specific challenges of sustainable water resources management. Finally, the framework shows that conceptual identification of protection-oriented, retention-oriented and mixed-function zones enables differentiated planning approaches, with hybrid NBS solutions in mixed-function zones acting as a key instrument for balancing runoff control and aquifer protection.

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Institutional Review Board Statement
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CRediT Author Statement
Emina Hadžić: Conceptualisation, Methodology, Supervision, Writing – original draft, Writing – review & editing.
Alma Hadžić: Investigation, Resources, Visualisation, Writing – review & editing.
All authors have read and approved the final manuscript.

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