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Editors:

Meryem Hayır Kanat

Çiğdem Coşkun Hepcan

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Cities Under Global Social Transformations: Embracing Change for a Greener Future

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KEYNOTES

Prof. Dr. Dagmar HAASE

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Dagmar Haase is a professor in Urban Ecology at the Geography Department, Humboldt-Universität zu Berlin, and a Guest Scientist at the Helmholtz Centre for Environmental Research – UFZ, Leipzig, Germany. Her core expertise is in first, modelling urban land use change and urban system dynamics and urban telecouplings. Second, Dagmar's focus is on the quantification and assessment of ecosystem services and landscape functions using statistics and earth observation data. Dagmar is the winner of the 2016 AXA Science Award and Honorary Professor of the Swedish Academy of Science. Dagmar is a member of IRI THESys since 2021.

Prof. Dr. Weiqi ZHOU

Topic: Climate change: Cities face intensified warming

Dr. Weiqi Zhou is a Professor, and deputy director of the State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences. He is also the director of the Beijing Urban Ecosystem Research Station. He is a co-leader of the Urban Ecosystem Group of the IUCN Commission on Ecosystem Management.

Prof. Dr. Charles NILON

Topic: What we know about cities and biodiversity change

He is a Professor Emeritus at the University of Missouri's School of Natural Resources. His research considers the impact of urbanization on wildlife habitats, populations, and communities.

Prof. Dr. Mikdat KADIOĞLU

Topic: Climate Risk Management

He works in Climate Change and Disaster Management. He is the Director of Istanbul Technical University's Earthquake Engineering and Disaster Management Institute and has a Ph.D. in Atmospheric Science from the University of Missouri, Columbia.

Dr. Daniela RIZZI

Topic: A Nature-Positive Economy: Thriving in Harmony with the Planet

Dr. Daniela Rizzi is a Senior Expert on Nature-based Solutions and Biodiversity at ICLEI Europe, with over 15 years of experience bridging policy, science, and practice. She is the NetworkNature Project Manager and an advocate for a nature-positive economy, emphasising that economic systems must not only operate within planetary boundaries but also actively contribute to nature restoration.

Daniela serves as a UNEP GEO-7 Expert Peer Reviewer and CEN Liaison for the Nature-based Solutions Working Group, contributing to the development of European standards for the effective implementation of NbS. She has contributed to high-level political processes, including presenting on NbS for the G7.

Prof. Ebru OZER

Topic: Green Infrastructure for Urban Resilience: Adaptive Landscapes for a Changing World

She is an associate professor at the Florida International University, Department of Landscape Architecture and Environmental and Urban Design.

Prof. Dr. Semra ATABAY

Topic: Urbanism-Ecological Commodification

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He is Head of the Department of Geography at Istanbul University, the first-ranked Turkish geography department. He is the President of the Turkish Geographical Society. He served as International Geographical Union Vice President between 2016 and 2021 and General Secretary of the International Geographical Union.

4th SURE World Conference in Istanbul, Turkey

The **4th SURE World Conference** was held in Istanbul, Turkey, between **16 and 19 July 2025**, under the theme *"Cities Under Global Social Transformations: Embracing Change for a Greener Future."* Hosted by **Yıldız Technical University**, the conference brought together scholars, practitioners, and decision-makers from around the world to exchange knowledge, build networks, and inspire future actions in the field of urban ecology.

The core thematic areas included:

- Urban biodiversity and ecosystem services
- Nature-based solutions and climate resilience
- Green infrastructure and public health
- Community engagement and environmental and multi-species justice
- Urban planning, transformation, and governance
- Interdisciplinary and transdisciplinary approaches to urban ecology
- Green and blue infrastructure in urban design
- Water and soil in urban sustainability
- Citizen participation and urban governance
- Socio-ecological approaches and equity
- Technological innovations and AI in urban planning
- Urban soundscapes and cultural perception
- Nature education and youth engagement

The conference welcomed a significant number of participants from the People's Republic of China, Germany, Türkiye, Romania, the Russian Federation, and Poland. In total, 498 individuals were listed as authors of the presented papers. Of the 134 papers included in the program, 23 were presented online. Authors from 54 different countries contributed to the conference, either individually or through collaborative work (Figure 1).

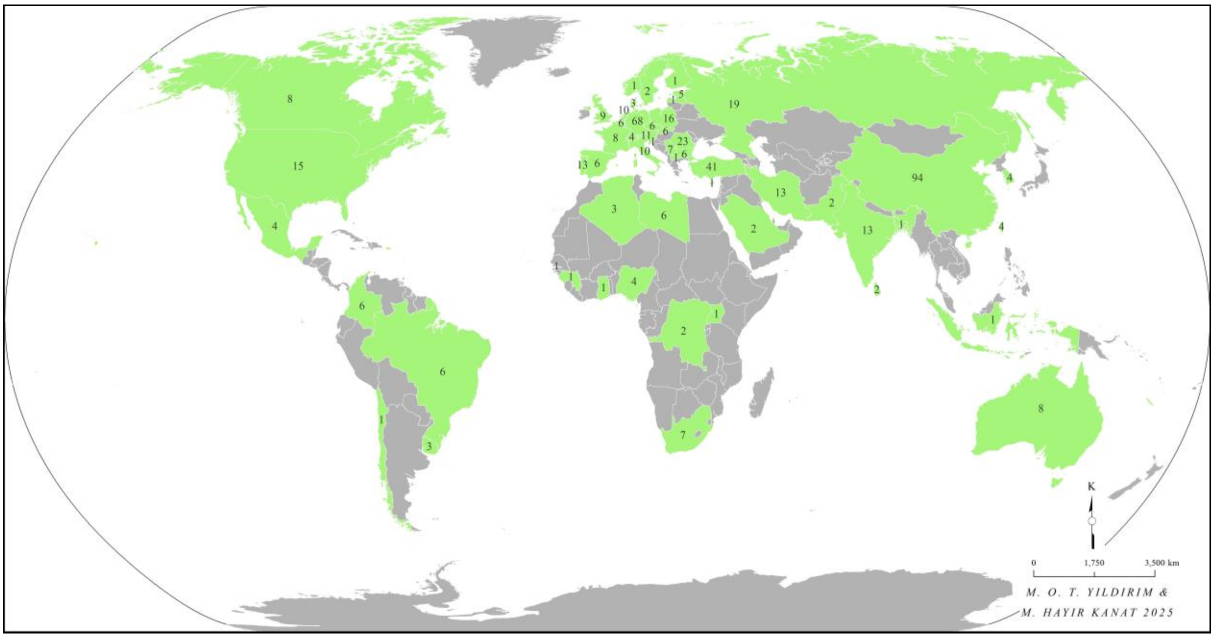

Figure 1. Geographic Distribution of the 498 Scholars Listed as Authors of Papers Presented at the Conference (from 54 Countries)

More than 200 participants from over 31 countries attended the event to explore inter- and transdisciplinary approaches to sustainable urban development, nature-based solutions, and the role of urban nature in climate adaptation and social well-being. The program featured inspiring keynote speeches, thematic sessions, interactive workshops, and field excursions across Istanbul's diverse urban landscape.

In total, the conference welcomed 133 paid participants, including 114 paper presenters and 19 listeners, representing 31 countries (Figure 2). Thanks to its hybrid format, the event was also accessible to a wider audience: individuals who wished to follow the sessions as passive participants were able to join free of charge via links shared in the program.

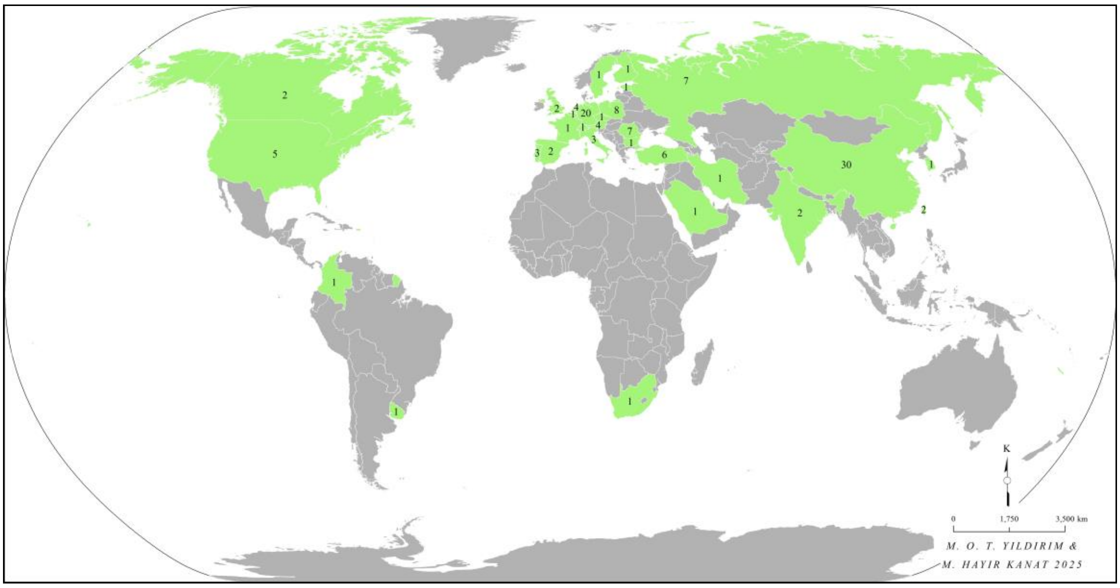

Figure 2. Country breakdown of registered participants who delivered presentations at the conference (paid paper presenters).

Opening Reception

On the evening of the first day, the opening reception was held with a large and enthusiastic turnout. Scientists from various countries gathered in a friendly and dynamic atmosphere, engaging in both social and scientific exchanges. The event provided an excellent opportunity for networking, with many participants discussing potential future collaborations and brainstorming project ideas shaped by interdisciplinary perspectives (Photo 1).

Prof. Dr. Meryem Hayır Kanat, Chair of the Organizing Committee
Yildiz Technical University, Istanbul-Turkiye

Photo 1: From the Opening Reception of the 4th SURE World Conference (©Gizem Anayol)

SURE General Assembly Meeting

At the end of the second day, the SURE General Assembly Meeting was held. During the meeting, Prof. Dr. Juergen Breuste (President), Prof. Dr. Martina Artmann (Secretary General), and Prof. Dr. Cristian Ioja (Treasurer) presented recent activities of the association and provided an overview of the work carried out over the past four years.

It was emphasized that SURE actively encourages youth participation by offering free membership for students and supporting their involvement in conferences.

Regional representatives reported that SURE sections in China, Iran, Southeastern Europe, and Central Europe are highly active in various initiatives. Regional conferences and summer schools were highlighted as key activities within these sections.

Photo 2: Participants of the SURE General Assembly (©Gizem Anayol)

Dinner with Conference Members and Volunteers

On the third day of the conference, the leading members of the 4th SURE World Conference and the dedicated volunteers who worked diligently throughout the organisation came together for a dinner at **AĞA Restaurant**, located on the Yıldız Technical University campus (Photo 3).

Photo 3: Dinner attended by professors including SURE Honorary Member Prof. Dr. Andrzej Mizgajski, Keynote Speaker Prof. Dr. Ebru Ozer, SURE President Prof. Dr. Jürgen Breuste, Prof. Dr. Jing Gan, and Prof. Dr. Martin Sauerwein (©Hayır Kanat)

Photo 4: A group of professors and conference volunteers, including Prof. Dr. Çiğdem Coşkun Hepcan, Prof. Dr. Şerif Hepcan, Prof. Dr. Iwona Zwierzchowska, Prof. Dr. Angela Hof, Prof. Dr. Cristian Ioja, Prof. Dr. Aslı Görgülü, and Prof. Dr. Hakan Akçay (©Hayır Kanat)

Excurtion Day

On the fourth day of the conference, participants had the opportunity to experience one of the world's most significant straits—the Bosphorus—which separates Asia and Europe. As part of the technical tour, they observed the city's skyline and patterns of urban development along the route from Eminönü to Anadolu Kavağı.

SURE Sino-European Workshop

A highlight of the conference was the SURE Sino-European Workshop and the collaborative development of the Istanbul Charter for the Conservation and Perception of Urban Nature. This workshop brought together experts from Europe and China to co-create a strategic document emphasizing collaborative, inclusive, and cross-regional approaches to protecting urban ecosystems. The Charter underlines shared responsibilities, mutual learning, and the importance of integrating ecological knowledge into urban planning and governance.

Foto: SURE Sino-European Workshop Team (©Tao Wu)

The SURE Executive Committee extends its heartfelt appreciation to Prof. Dr. Meryem Hayır Kanat, Prof. Dr. Çiğdem Coşkun Hepcan, and all members of the Organizing Committee, including the dedicated teams from Yıldız Technical University and other supporting universities. Their commitment, professionalism, and warm hospitality greatly contributed to the success of the conference. The event once again highlighted the global importance of urban ecology in shaping more just, healthy, and resilient cities.

We are already looking forward to the **5th SURE World Conference** in 2028 – stay tuned!

Istanbul Charter

For Conservation and Perception of Urban Nature

Society for Urban Ecology

Urban nature encompasses the totality of natural elements present in urban spaces, including their ecosystemic functional relationships and their use. Urban nature includes remnants of native ecosystems, patches of agricultural areas embedded within the urban fabric or around urban areas, all types and scales of designed urban green spaces, and novel wild urban ecosystems.

Importance

1. Urban nature is in a critical situation worldwide. The reduction of biodiversity loss is accelerated by climate change and multiple other factors.

2. Urban nature provides fundamental ecosystem services, with a powerful capacity for environmental risk reduction, playing a vital role in supporting human health.

3. Enhancing residents' perception and appreciation of urban nature can increase public support for conservation initiatives, further promote sustainable urban development, and improve the quality of urban life.

Targets

1. Promoting multistakeholder engagement for empowerment of urban nature issues provides a shared home for humans and nature. Enhancing stakeholders’ awareness, understanding, and sense of participation regarding the benefits of nature, actively promoting the engagement of communities for urban nature, and building better governance for a better, socio-ecologically resilient urban living environment contribute to this target.

2. An effective dialogue between professionals, citizens and decision-makers, by enriching their knowledge, understanding, and responsibility regarding the benefits of nature, and formulating better institutions for a better urban living environment is necessary.

3. Establishing and improving urban ecological monitoring and assessment systems to regularly track the efficacy of conservation efforts for urban nature.

4. Carefully reflecting dominant societal paradigms, worldviews and plural values to recognize and prioritize human-nature interconnectedness in cities and beyond.

5. Considering urban land-use teleconnection and material human-nature connections (e.g., resources, food), not strictly confined to urban boundaries, fostering social-ecological justice for human and non-human persons.

Challenges and opportunities

1. Taking effective conservation measures along urbanization gradients, particularly in high-density and socially marginalized urban sectors where natural areas are limited.

2. Promoting active public engagement in conservation activities and enhancing urban residents' awareness about the importance of the natural environment, especially for more spontaneous nature and living together with urban wildlife.

3. Coordinating interdisciplinary and cross-sectoral collaboration to strengthen comprehensive mechanisms for urban nature conservation and public perception.

4. Preserving existing natural elements in periurban areas and integrating these features into urban nature through urban design and urban reconstruction.

5. Promoting urban nature as a foundation for resilient, short food supply chains through the integration of urban agriculture and green infrastructure, with emphasis on edible plants and trees, contributing to food security, sustainability, and public engagement.

Methods

1. Promoting urban nature conservation through interdisciplinary collaboration and technical support, employing spatial planning methodologies, including GIS, wildlife and animal monitoring, biodiversity-inclusive design and AI.

2. Applying innovative knowledge, methods, and technologies to support the management of urban nature, respecting natural processes by reducing the load of management input (do less).

3. Strengthening public participation and education by fostering communities' co-creation and nature-based experiences and activities to raise conservation awareness of residents and nature understanding as a fundamental aspect of kids' learning in schools.

4. Developing clear and actionable indicators for urban nature conservation, integrating them into urban development strategies and spatial planning instruments at local, regional, and national levels, with the goal of increasing urban biodiversity.

5. Society engagement, both formal and informal, is crucial in more inclusive approaches to space management. The participatory planning methods, smart and digital technologies, such as remote sensing and data-driven platforms, can contribute to more resident-oriented planning and management.

6. Establishing urban living labs to experiment together with urban decision makers, practitioners, residents, and nature on how to overcome social-ecological-technological and structural challenges which constrain urban ecology in, of, and for cities.

Cooperation

1. Promoting in-depth exchanges between fast urban developing China and traditional and long-experienced urban development in Europe in the field of urban nature conservation and perception, particularly in policy development, practical implementation, and scientific research, through international cooperation bridges between countries and learning from different experiences.

2. Establishing a continuous international platform for dialogue and collaboration on urban nature conservation and perception, embracing plural values and perspectives.

3. Facilitating interdisciplinary collaboration among experts from different fields of experience, such as urban planning, ecology, landscape architecture, sociology, psychology, anthropology, and related fields, to develop integrated strategies or frameworks for urban nature conservation and perception.

4. Partnerships and exchange of experiences between cities are important, especially in terms of market preference trends that determine the actions of developers.

5. Strengthening transdisciplinary, multi-sectoral cooperation by encouraging collaboration among researchers, practitioners, decision-makers, and non-governmental organizations to bridge policymaking, scientific research, and practical application effectively.

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The Role of the Institutional Environment in Nature-Based Solutions in Developing Countries: A Conceptual Framework

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Abstract

Nature-Based Solutions (NBS) have emerged as transformative strategies to address interconnected environmental, social, and economic challenges in developing countries, including climate change, biodiversity loss, food insecurity, and poverty. These solutions, which involve protecting, managing, and restoring ecosystems, offer co-benefits for human well-being and ecological resilience but face significant barriers due to weak institutional environments. This paper investigates the critical role of formal and informal institutions in shaping the success of NBS initiatives in resource-constrained settings. Through a systematic literature review spanning 2015–2025 and a theoretical synthesis drawing from environmental governance and institutional economics, we analyze how institutional characteristics—such as regulatory frameworks, governance coherence, land tenure systems, community norms, and resource availability—influence NBS implementation. Key challenges include weak policy enforcement, institutional fragmentation, and unclear property rights, which often undermine project scalability, while opportunities arise from community-driven knowledge and local resilience. We propose a conceptual framework that integrates these institutional factors with NBS indicators, such as ecosystem health, social co-benefits, economic viability, stakeholder inclusion, and adaptive management. The framework highlights the need for adaptive governance models and inclusive stakeholder participation to align NBS with local contexts, thereby enhancing their sustainability and impact. Findings underscore that robust institutional environments are essential for leveraging NBS to achieve the United Nations Sustainable Development Goals in developing countries, where vulnerabilities to environmental and socio-economic stressors are pronounced. By addressing institutional barriers and harnessing local strengths, the framework provides a roadmap for policymakers and practitioners to design context-sensitive NBS interventions. Future research should focus on empirical validation of the framework through case studies across diverse developing country contexts to refine its applicability and ensure practical relevance for sustainable development.
Keywords: Nature-Based Solutions, Institutional Environment, Developing Countries, Conceptual Framework.

Introduction

Nature-Based Solutions (NBS) involve actions to protect, manage, and restore ecosystems to address societal challenges while promoting human well-being and biodiversity (Cohen-Shacham et al., 2016). In developing countries, NBS hold significant potential for mitigating climate change, improving food and water security, and fostering economic resilience (Seddon et al.,

2020). However, their implementation is often constrained by institutional environments, characterized by weak governance, limited resources, and complex stakeholder dynamics (Paavola & Adger, 2005).
The institutional environment, encompassing formal rules (e.g., laws, policies) and informal norms (e.g., cultural practices, community trust), shapes the planning and execution of NBS (Ostrom, 1990). In developing countries, challenges such as unclear land tenure or lack of community engagement can undermine NBS projects (WWF, 2021). Despite the growing adoption of NBS, there is a lack of systematic integration of institutional analysis into their planning, particularly in resource-constrained contexts.
This paper aims to develop a conceptual framework that elucidates the role of the institutional environment in NBS implementation in developing countries. The paper is structured as follows: a literature review explores NBS principles, institutional theory, and their interplay; the methodology outlines the theoretical approach; the results identify institutional characteristics and NBS indicators; and the conclusion proposes a conceptual framework linking these elements to guide policymakers and practitioners.

Literature Review

Nature-Based Solutions Approach NBS encompass interventions like reforestation, wetland restoration, and urban green spaces, designed to address challenges such as climate change, biodiversity loss, and human health (Cohen-Shacham et al., 2016). The International Union for Conservation of Nature (IUCN) emphasizes that NBS must deliver co-benefits for ecosystems and communities, aligning with the United Nations Sustainable Development Goals (SDGs) (IUCN, 2020). In developing countries, NBS are critical due to high vulnerability to environmental degradation and limited adaptive capacity (Seddon et al., 2020). However, their effectiveness depends on context-specific governance and stakeholder collaboration (WWF, 2021).
Relation Between Institutional Environment and Planning The institutional environment shapes planning by defining rules, norms, and power structures that influence resource allocation and stakeholder coordination (Ostrom, 1990). New Institutional Economics highlights how institutions reduce transaction costs and enable collective action (Paavola & Adger, 2005). In NBS planning, institutions affect land-use policies, conflict resolution, and project scalability. For instance, robust regulations can enforce conservation measures, while weak enforcement may lead to project failure (Jahanger & Balsalobre-Lorente, 2022). In developing countries, institutional fragmentation often necessitates adaptive governance models (Patterson, 2016).
Role of Formal and Informal Institutions in Nature-Based Solutions Formal institutions, such as laws and policies, provide the legal foundation for NBS. National climate pledges, like those in Nationally Determined Contributions (NDCs), signal government commitment to NBS (Seddon et al., 2020). However, in developing countries, formal institutions often face enforcement challenges due to corruption or resource limitations (Jahanger & Balsalobre-Lorente, 2022). Informal institutions, such as community norms and traditional ecological knowledge, foster local ownership but may resist external interventions if misaligned with project goals (WWF, 2021). Balancing formal and informal institutions is critical for inclusive and sustainable NBS.

Methodology

This study employs a qualitative, theory-building approach, synthesizing literature from environmental governance, institutional economics, and NBS research. A systematic literature review was conducted using databases like Scopus and Web of Science, covering peer-reviewed articles from 2015 to 2025. Search terms included "Nature-Based Solutions," "institutional environment," and "developing countries." Studies addressing governance, institutional dynamics, and NBS outcomes were prioritized. Thematic analysis identified institutional characteristics and NBS indicators, forming the basis for the conceptual framework. Future empirical research could validate the framework through case studies or mixed-methods approaches.

Results

Characteristics of Institutional Environment in Developing Countries The institutional environment in developing countries presents unique challenges and opportunities for NBS:

- Weak Regulatory Frameworks: Limited enforcement of environmental laws due to bureaucratic inefficiencies or corruption (Jahanger & Balsalobre-Lorente, 2022).
- Fragmented Governance: Overlapping jurisdictions and lack of coordination among agencies hinder effective planning (Paavola & Adger, 2005).
- Unclear Land Tenure: Ambiguous property rights complicate ecosystem restoration efforts (WWF, 2021).
- Strong Informal Norms: Community trust and traditional knowledge drive engagement but may resist external interventions (Ostrom, 1990).
- Resource Constraints: Financial and technical limitations restrict institutional capacity (Seddon et al., 2020).

Indicators of Nature-Based Solutions Effective NBS are characterized by measurable indicators, including:

- Ecosystem Health: Improved biodiversity and ecosystem services (Cohen-Shacham et al., 2016).
- Social Co-Benefits: Enhanced livelihoods, health, and community resilience (IUCN, 2020).
- Economic Viability: Cost-effective interventions with long-term sustainability (Seddon et al., 2020).
- Stakeholder Inclusion: Participation of local communities and indigenous groups (WWF, 2021).
- Adaptive Management: Flexibility to address environmental uncertainties (Patterson, 2016).

Discussion and Conclusion

The institutional environment significantly influences NBS outcomes in developing countries. Weak regulatory frameworks and fragmented governance pose barriers, while strong informal norms and community engagement offer opportunities for success. The proposed conceptual framework links institutional characteristics (e.g., governance coherence, land tenure clarity) with

NBS indicators (e.g., ecosystem health, stakeholder inclusion) through adaptive governance and inclusive participation. The framework suggests that aligning NBS with local institutional contexts enhances their scalability and sustainability. Policymakers should prioritize institutional capacity-building and stakeholder collaboration to maximize NBS impacts. Future research should empirically test the framework in diverse developing country settings.
Conceptual Framework Description: The framework is a flowchart that connects institutional characteristics (formal rules, informal norms, governance structures) to NBS indicators (ecosystem health, social co-benefits, economic viability) via two mediating factors: adaptive governance (flexible policy frameworks) and stakeholder inclusion (community and indigenous participation). Arrows indicate bidirectional relationships, emphasizing feedback loops between institutions and NBS outcomes.

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Spatial Isolation and Unequal Access to Urban Environment: Roma Ghettoized Structures in Bulgaria as a Challenge to Green Cities

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Abstract

Sustainable urban development and social inclusion are key aspects of contemporary urban planning, yet marginalized communities, such as Roma, are often excluded from these processes. This paper explores the spatial isolation of Roma ghettoized structures in Bulgaria and their limited integration into the concept of green cities. One of the core principles of green cities is the development of an accessible green infrastructure for all residents, regardless of their social status. Using tools from Geographic Information Systems (GIS), the study develops a typology of cities based on the degree of Roma residents' access to two main components of the green system: (1) public green spaces, including parks and gardens, and (2) semi-public green areas such as inter-block spaces. The threshold values of the indicators are determined in accordance with national regulations regarding urban green space access. The analysis is based on data from a nationally representative survey conducted under the project "Spatial Models of the Roma Ghettoized Urban Structures in Bulgaria," funded by the Bulgarian National Science Fund, Ministry of Education and Science. The findings reveal significant inequalities in Roma communities' access to urban infrastructure, public services, and green spaces. The lack of environmental infrastructure, such as inadequate waste collection, limited access to sewage systems, and restricted availability of parks and public green spaces, further exacerbates social and spatial segregation. This hinders the integration of Roma neighborhoods into sustainable urban development strategies. The paper argues that green cities cannot be truly sustainable if marginalized communities are excluded. A comprehensive approach is needed—one that improves access to urban infrastructure, fosters the active participation of local communities in urban planning, and integrates Roma neighborhoods into sustainability policies. Overcoming these challenges is essential for building environmentally sustainable and socially just cities.

Keywords: Roma ghettoized structures, spatial segregation, green cities, sustainable urban development, urban inequalities, Bulgaria

Introduction

In contemporary urban geography, there is a growing interest in the transformations of urban space and their social, cultural, and economic implications. These processes depend both on local government policies and on the behavior of urban residents. In this context, sustainable urban development and the concept of "green cities" have become key priorities in European and national policies, with an emphasis on ecological infrastructure, quality of life, and social inclusion (Rodrigues et al., 2024; Todorova, 2023; European Commission, 2022). However, the realization of this vision often faces barriers arising from spatial isolation and the social marginalization of vulnerable groups - such as the Roma community in Bulgaria (Ilieva, Tsvetkov & Boteva, 2023; Poleganova, Varadzhakova & Raykova, 2023). Roma ghettoized structures, predominantly located on the urban periphery, are characterized by limited access to green spaces, basic urban infrastructure, and public services (Petkova & Ilieva, 2025; Minority Rights Group, 2024). Urbanization pressure, the lack of available land, and unregulated construction further exacerbate these deficits, often pushing these areas outside the scope of urban regulation and the attention of local authorities (Rodrigues et al., 2024; Petkova, 2023).

Green spaces—a key component of sustainable urban environments - serve not only ecological functions but also social ones, including their role as potential settings for interethnic contact and inclusion (Caprari, Gulic & Trusiani, 2024; Battiston & Schifanella, 2023). Their absence or inaccessibility in ghettoized zones undermines efforts to build socially just and environmentally sustainable cities (Moi et al., 2024; Leboeuf et al., 2023). The issue of spatial segregation and the unequal distribution of resources is widely addressed in strategic EU documents. The Green Paper on Territorial Cohesion (2008), the Cities of Tomorrow report (2011), and the New European Bauhaus initiative (2021–2024) all emphasize the need to create accessible, aesthetic, and inclusive spaces that reflect Europe's social and ethnic diversity (New European Bauhaus, 2023; Concrete to Culture, 2024). Special attention is given to the application of an intersectional approach and the collection of disaggregated data to better understand exclusionary processes (Chronic Peripheralization…, 2025; European Commission, 2024).

This study analyzes the spatial dimensions of isolation in Roma ghettoized urban structures in Bulgaria and the extent of their access to green urban infrastructure. It draws on data from a nationally representative survey, geographic information systems (GIS), and satellite imagery (Todorova, 2023). The aim is to develop a typology of Bulgarian cities based on the level of Roma residents' access to key elements of green infrastructure. The article argues that without the active inclusion of marginalized communities in urban planning processes and without targeted policies to improve the environment in ghettoized neighborhoods, the vision of sustainable and green cities remains incomplete and inequitable (Rodrigues et al., 2024; Caprari et al., 2024; Petkova & Ilieva, 2025).

Methodology

This study employs a mixed-methodological approach that combines quantitative analysis, spatial research, and morphological classification of urban territories with Roma ghettoized structures (RGS) in Bulgaria (Pictures 1 and 2).

Picture 1. *Roma neighbourhood in the town of Straldzha (Yambol district, Bulgaria),*
Source: Pictures Velimira Stoyanova

Picture 2. *Roma neighbourhood in the town of Asenovgrad (Plovdiv district, Bulgaria),*
Source: Pictures Velimira Stoyanova

The research aims to assess the level of access to the green urban system in these structures, viewed as an indicator of spatial isolation and social exclusion (Figure 1).

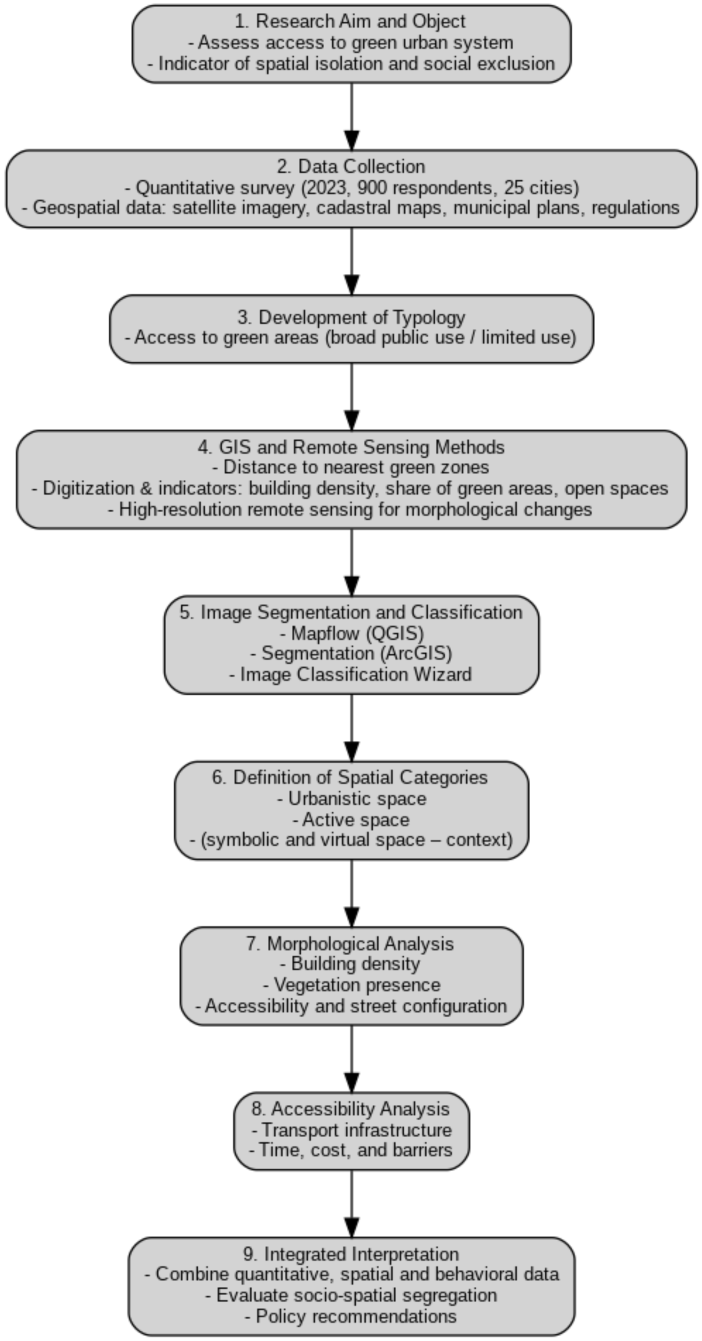

Figure 1. *Figure X. Research Workflow for Assessing Access to Green Urban Systems in Roma Ghettoized Structures",*
Source: Author's

The analysis is based on data from a nationally representative quantitative survey conducted in 2023 among 900 respondents from 25 cities, as part of the project "Spatial Models of Roma Ghettoized Urban Structures in Bulgaria", funded by the Research Fund of the Ministry of Education and Science (Picture 3).

Picture 3. *Surveys in Roma neighborhoods in Bulgaria,*
Source: Pictures Velimira Stoyanova

In addition, geospatial data were used from satellite imagery, cadastral maps, integrated municipal development plans, and regulatory documents (Ministry of Regional Development and Public Works, 2003). For this study, a typology of cities was developed based on two main indicators: access to green areas with broad public use (parks, gardens, forested areas) and access to green areas with limited public use (inter-block spaces, green strips surrounding institutions and residential buildings). Access to green urban infrastructure was measured using Geographic Information Systems (GIS) by calculating the distance from the center of the ghettoized neighborhoods to the nearest green zone. GIS tools were applied for the digitization of orthophotography and cadastral imagery, as well as for the calculation of key urban planning indicators: building density, share of green spaces within the neighborhood, availability of open space, and access to public-use parks (Wong, 1997; Lee & Culhane, 1998). Additionally, the study incorporates high-resolution remote sensing techniques, which enable the extraction of morphological characteristics of the neighborhoods, the tracking of temporal changes, and the identification of newly formed or expanded structures. (Camps-Valls, Tuia, Xiang-Zhu, & Reichstein, 2021; Jochem & Tatem, 2021). Automated tools for image segmentation and classification were applied in the study, including Mapflow in QGIS, the "Segmentation" tool in ArcGIS, and the "Image Classification Wizard," which utilizes supervised classification of satellite imagery (Blaschke et al., 2014). The spatial boundaries of the ghettoized structures were delineated through an integrated approach based on four types of space: urbanistic, active, symbolic, and virtual. The urbanistic space is defined by the architectural and morphological characteristics of the Roma ghettoized structures (RGS); the active space refers to the daily routes and activities of the residents (Gaebe, 2004; Golledge & Stimson, 1997); the symbolic space captures how residents perceive their neighborhood in their mental representations (Lefebvre, 1991); and the virtual space encompasses social networks and telecommunication connections that link community members regardless of physical proximity (Graham, 2004). Special attention is given to the concept of "space of action" (active space), which analyzes the movement of individuals between key points in their everyday life—home, school, places of recreation, and sites of social interaction. This behavioral approach is particularly useful in analyzing spatial dynamics and assessing actual access to green areas (Werlen, 1995; Heineberg, 2001). In the present study, two types of space are taken into account: urbanistic space (used to determine the proportion of green areas within the ghettoized structure itself), and the active space of "Recreation and Leisure" (used to assess the level of access to publicly accessible parks)

(Mumford, 1961). Green spaces for broad public use and green areas with limited public access are directly linked to the nature of urban morphology, which is assessed through morphological indicators related to the built form and the configuration of open spaces. (Mumford, 1961). As part of the analysis, the "Segmentation" tool was also applied, serving as a key component for object-based classification. Based on ArcGIS Desktop, "the segmentation and classification tools provide an approach to extracting features from imagery based on objects." As noted by Blaschke et al. (2004), image segmentation is not an end in itself. Segmentation is the partitioning of an array of measurements on the basis of homogeneity. It divides an image – or any raster or point data – into spatially continuous, disjointed and homogeneous regions." Morphological analysis enables the differentiation between planned and unplanned structures through indicators such as building density, presence of vegetation, accessibility, and the spatial organization of streets (Baud et al., 2010; Lehner & Blaschke, 2020; Kuffer et al., 2016). GIS-based analysis allows for the tracking of green space dynamics over time and the creation of an updatable spatial database, which can also be used by local authorities for the purposes of urban planning. The combined approach—encompassing quantitative surveying, spatial analysis, remote sensing, and the conceptualization of space—provides a robust framework for assessing inequalities in access to urban resources and places the issue of equity in green urban policies at the center of attention, particularly in relation to vulnerable communities.

The analysis of spatial segregation of an ethnic group focuses on two interrelated aspects: the absolute location of the group within the urban space and its access to urban resources—such as employment, education, green areas, healthcare services, and public transportation (Poleganova, Varadzhakova & Raykova, 2023). Fonseca et al. (2006) emphasize that spatial dimensions of integration are determined not only by a group's position in the urban fabric but also by access to resources and the degree of mobility. These three dimensions are tightly interconnected—access depends on the location of the ethnic group, the availability of facilities, and the configuration of the transport network. Recent empirical studies across Europe and Asia confirm the need for a multidimensional approach to measuring access to green spaces (Battiston & Schifanella, 2023; "Determinants influencing accessibility...", 2024). An important element in this context is access to recreational and leisure areas, which significantly shape the quality of the urban environment. Accessibility is generally defined by the level of difficulty in reaching one location from another, taking into account distance, time, and financial costs (Apparicio et al., 2008; Johnston, 2000). According to Geurs & van Wee (2004), key factors influencing accessibility include transport infrastructure quality, topography, speed limits, traffic intensity, vehicle characteristics, service schedules, and fuel prices. Coordinated transport and resource distribution policies help reduce spatial inequalities caused by inaccessibility (Moseley, 1979). Spatial accessibility analysis serves as a tool to measure the exclusion of certain areas and populations from local resources. It also generates new data to quantitatively assess the degree of spatial segregation based on time, reach, service quality, and access conditions (Battiston & Schifanella, 2023; "Determinants…", 2024). While some scholars argue that modern communication technologies and mobility reduce territorial constraints, Simmel (1997) and Harvey (2006) maintain that space remains an excluding dimension—two subjects cannot occupy the same location simultaneously. Durkheim & Mauss (1963) and Castells (1977) describe space as a product of social structure. Lefebvre (1968, 1991) argues that social space is produced at three interrelated levels: material spatial practices, representations of space (knowledge, meaning, symbols), and lived space (individual perceptions and memories). The concept of active space (Gaebe, 2004) refers to the spatial range within which an individual carries out daily activities. It emerged from behavioral geography in the 1970s (Heineberg, 2001) and was later expanded by Werlen (1995, 1997), who proposed an action-based perspective—where action is an intentional act shaped by cultural, social, and environmental conditions. Golledge & Stimson (1997) define active space as the environment with which an individual is in direct contact during daily functions—home, workplace, shopping, and recreation. Building on Lefebvre and Werlen, the present study identifies four spatial categories used to delineate Roma ghettoized urban structures (RGS): urbanistic space, active space, symbolic space, and virtual space (Graham, 2004). This research emphasizes two of them in relation to access to green infrastructure: Urbanistic space, through the analysis of green areas located within the ghettoized neighborhood; Active space, through the measurement of access to public parks. A broader understanding of green infrastructure is applied, including general-use spaces (parks, gardens), specific-use spaces (cemeteries, botanical gardens), and limited-access green areas (courtyards, green strips between buildings). According to Musterd & Deurloo (2002), neighborhood interactions should be studied at the micro level—street, block, or neighborhood. Van Kempen (2003) underlines that the neighborhood, as a space of everyday life, is the most appropriate unit for studying daily routines and patterns of segregation. In the case of RGS, boundaries correspond to morphological traits and homogeneity in terms of ethnicity, social status, and culture, encompassing essential social networks and services (Todorova, 2023; Kazakov et al., 2023). Finally, spatial segregation is interpreted not only as physical location but as a dynamic interaction between resources, infrastructure, social networks, and spatial perceptions. The application of concepts such as socially produced space, active space, and accessibility allows for new interpretations of ghettoization—as a process shaped by institutional, spatial, and behavioral dimensions.

Results

The data from the nationally representative quantitative survey, which covered 900 respondents from Roma ghettoized neighborhoods in 147 cities across Bulgaria, reveal alarming deficits in access to basic ecological and urban infrastructure—essential foundations for sustainable and inclusive urban development. The analysis focuses on key indicators related to the availability of green areas for broad public use, including parks and gardens; green spaces with specific functions—such as cemeteries, botanical gardens, and plant nurseries; and green spaces with limited public access.

The green subsystem is examined in two dimensions:

1. As an indispensable component of the residential environment, its presence largely determines the level of its integrated development. This applies primarily to facilities that meet the residents' everyday needs;
2. As the territorial distribution of service facilities of a higher hierarchical level, including those that meet the non-daily needs of neighborhood residents.

Green areas with limited public access are categorized as facilities that satisfy daily needs, while the green infrastructure intended for broad public use belongs to the higher-level category of urban services.

Access to Roma Ghettoized Structures to Green Areas for Broad Public Use

Parks designed for broad public use have the potential to function as spaces of social integration. They can serve as "shared territories" where members of different ethnic and social groups meet, interact, and build interpersonal relationships. This is particularly significant for Roma populations, who are often subject to social stigma and spatial segregation. In this context, public green spaces can act as zones of integration, where joint activities—such as sports, cultural events, festivals, or informal encounters—create opportunities for social cohesion and interethnic contact. Such interactions foster mutual understanding, tolerance, and cooperation between different segments of society. For Roma communities, who frequently face prejudice and isolation, these spaces can become sites for overcoming barriers, forming support networks, and participating in collective activities that contribute to inclusion and integration processes. The analysis shows that the characteristics of ghettoized Roma structures vary significantly depending on their location within the spatial structure of the city. The neighborhood's position largely determines the degree of physical and social segregation. In Bulgaria, almost all Roma ghettoized neighborhoods are located on the periphery of the urbanized territory, with few exceptions, such as Hadzhikhasan Mahala—one of the four Roma neighborhoods in the city of Plovdiv. More than 30% of Roma ghettoized structures are located outside the main urban fabric and are physically separated from it by linear transport infrastructure (railways, highways) or natural barriers (rivers, ravines, hills). This further restricts access to urban resources, including public green areas. Spatial analysis of accessibility to parks reveals clear patterns of inequality across neighborhoods. In most Roma ghettoized structures, the normative requirements for convenient access to green areas are not met. Only 32% of the studied neighborhoods fall within the officially designated 15-minute isochrone. In approximately 50% of cases, the time required to access green areas is up to twice the recommended threshold, while in 19% it exceeds 30 minutes. These figures indicate a high degree of spatial and social isolation from the rest of the urban environment. As a result of significant distance and poor connectivity, residents of ghettoized Roma neighborhoods rarely make use of park spaces. This further reinforces the territorial community's enclosure and limits opportunities for social integration (see Figure 2).

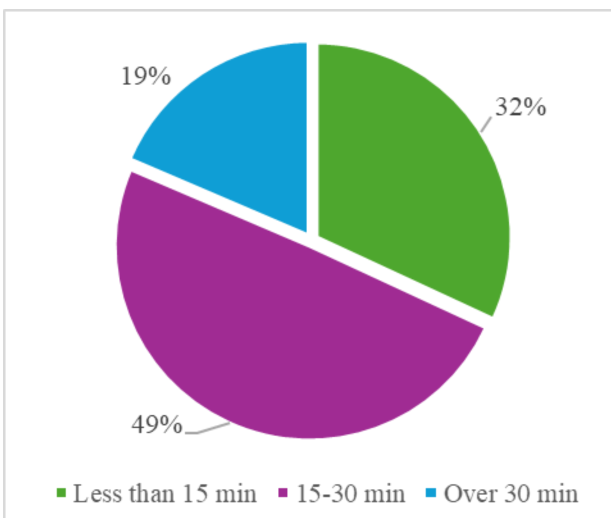

Figure 2. *Access to green areas for broad public use in Roma ghettoized structures (in minutes),* **Source:** Author's own calculations

Figure 3 graphically presents the access of Roma ghettoized structures to green areas for broad public use.

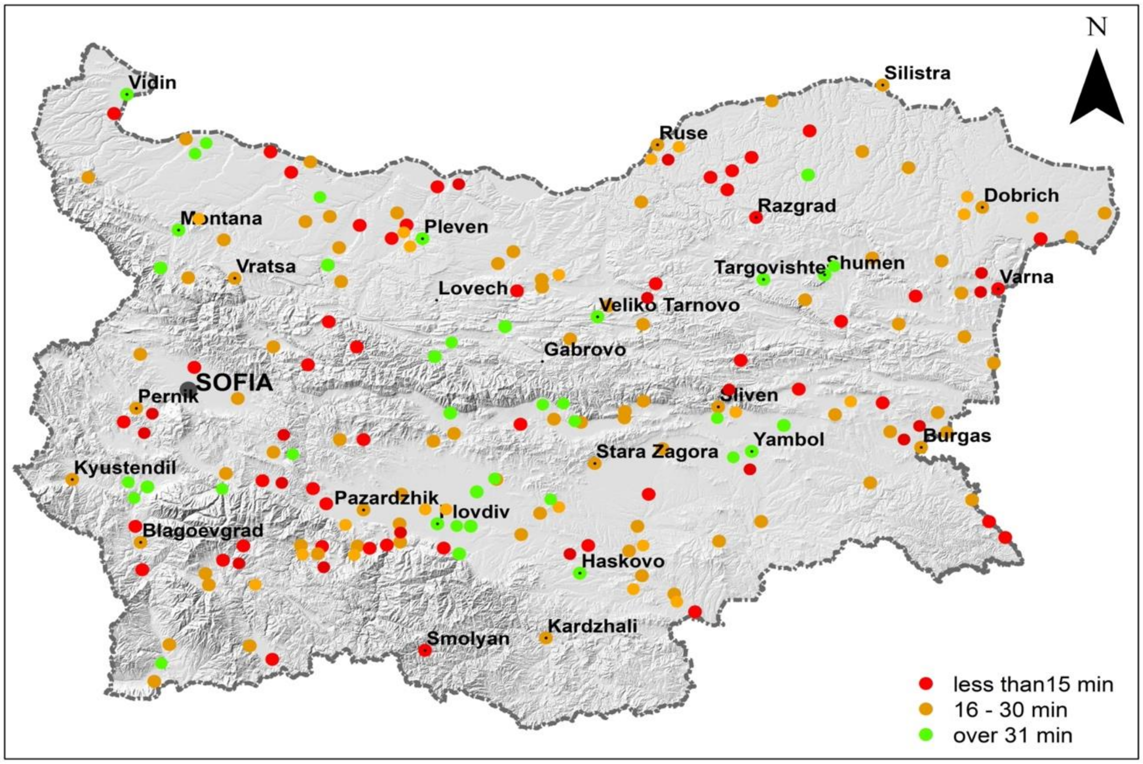

Figure 3. *Access of Roma Ghettoized Structures to Green Areas for Broad Public Use (in minutes): A Spatial Analysis,* **Source:** Author's own calculations

The spatial analysis of accessibility to green areas for public use reveals significant differences based on the population size of the cities. The most pronounced spatial exclusion is observed in medium-sized cities (with a population between 30,000 and 100,000 inhabitants), where only 6.3% of Roma neighborhoods fall within the officially approved 15-minute isochrone. In nearly half of the neighborhoods in this type of city, the time required to reach the nearest park exceeds 30 minutes, which serves as a serious indicator of ecological and social marginalization. The opposite trend is observed in very small towns (with a population of up to 10,000 residents), where the more compact urban structure enables faster and easier access to green spaces. In these towns, 43.7% of Roma neighborhoods are located within the normative 15-minute isochrone (see Table 1). These results suggest that urban scale and morphology play a key role in determining Roma residents' ability to access a city's green infrastructure. The more fragmented and peripheral the urban structure, the more likely it is that ghettoized neighborhoods will remain excluded from ecological infrastructure.

Table 1. *Access of Roma Ghettoized Structures to Green Areas According to Settlement Size (Travel Time in Minutes)*

Distribution of Roma ghettoized structures by city population size	Less than 15 min		15-30 min		Over 30 min	
	Number of cases	%	Number of cases	%	Number of cases	%
Very large cities– **over 200,000 inhabitants**	4	57.1	1	14.3	2	28.6
Large cities– **from 100,000 to 200,000 inhabitants**	3	37.5	5	62.5	0	0.0
Medium-sized cities– **from 30,000 to 100,000 inhabitants**	2	6.3	14	43.8	16	50.0
Small cities– **from 10,000 to 30,000 inhabitants**	12	20.3	29	49.2	18	30.5
Very small cities– **up to 10,000 inhabitants**	45	43.7	53	51.5	5	4.9

Source: Author's own calculations

Access to Roma Ghettoized Structures to Green Areas with Limited Public Use

For Roma neighborhoods—often characterized by high building density, underdeveloped infrastructure, and a lack of adequate public services—access to green areas is of critical importance. Internal green spaces can compensate, at least partially, for the unfavorable housing environment. Green areas with limited public use include inter-block spaces in residential complexes and green zones located on properties owned by private individuals or legal entities. These green areas are not subject to regulatory standards but play a vital role in the city's green system and overall urban ecology. While they complement the city's green infrastructure, these areas cannot replace core green spaces intended for broad public use, which serve not only ecological functions but are also required to meet the population's needs for recreation, sports, and leisure. Neighborhood green spaces are an essential component of urban infrastructure and are crucial for improving the urban environment and residents' quality of life. For Roma families—who, as confirmed by the previous analysis, often experience limited access to green spaces—such areas provide opportunities for daily physical activity, children's play, and social interaction with neighbors. Well-maintained local green spaces enhance the sense of safety, reinforce the feeling of belonging to the neighborhood, and contribute to the development of a shared community identity.

The spatial analysis of the proportion of green areas within the boundaries of Roma ghettoized structures shows that the highest share is among neighborhoods with only up to 5% green coverage, representing 31.9%. When neighborhoods with up to 10% green areas are included, this share increases to 41.4%. A low proportion of green spaces is particularly characteristic of medium, large, and very large cities in terms of population, which can be explained by the typically high building density and lack of available land within urbanized territories (see Fig. 4).

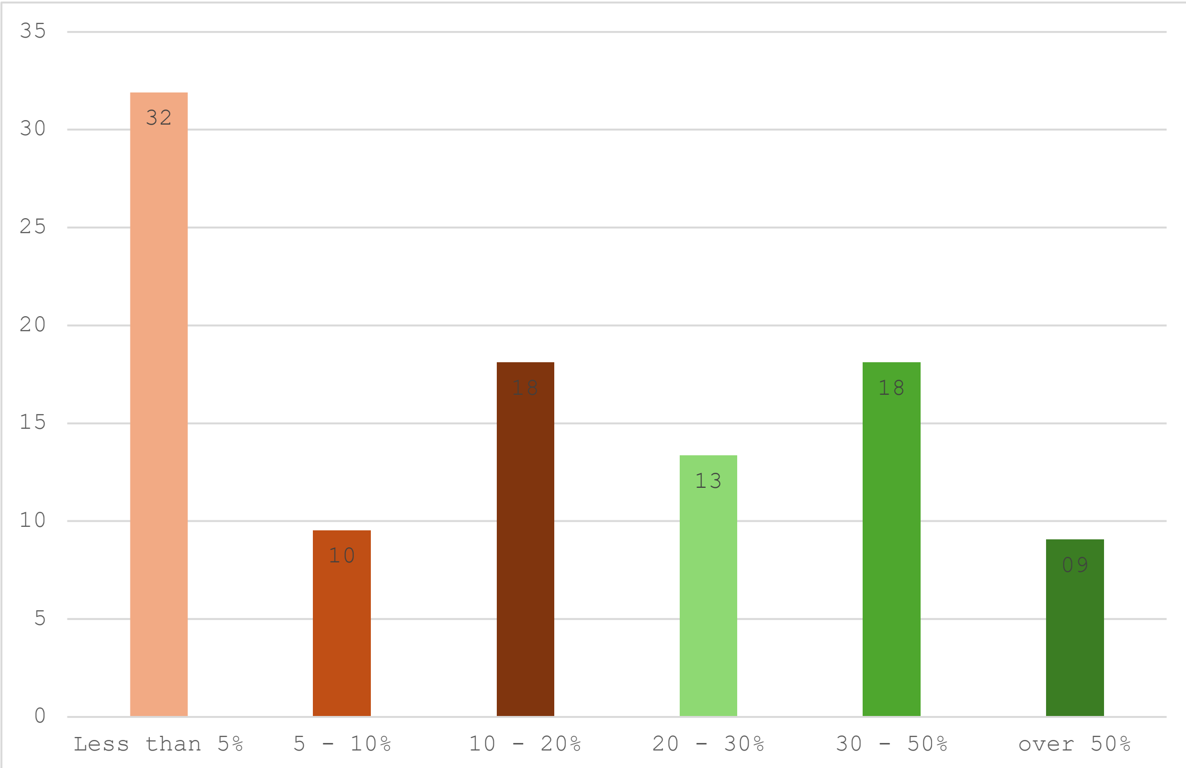

Figure 4. *Relative Share of Green Areas within Roma Ghettoized Urban Structures,*
Source: Author's own calculations

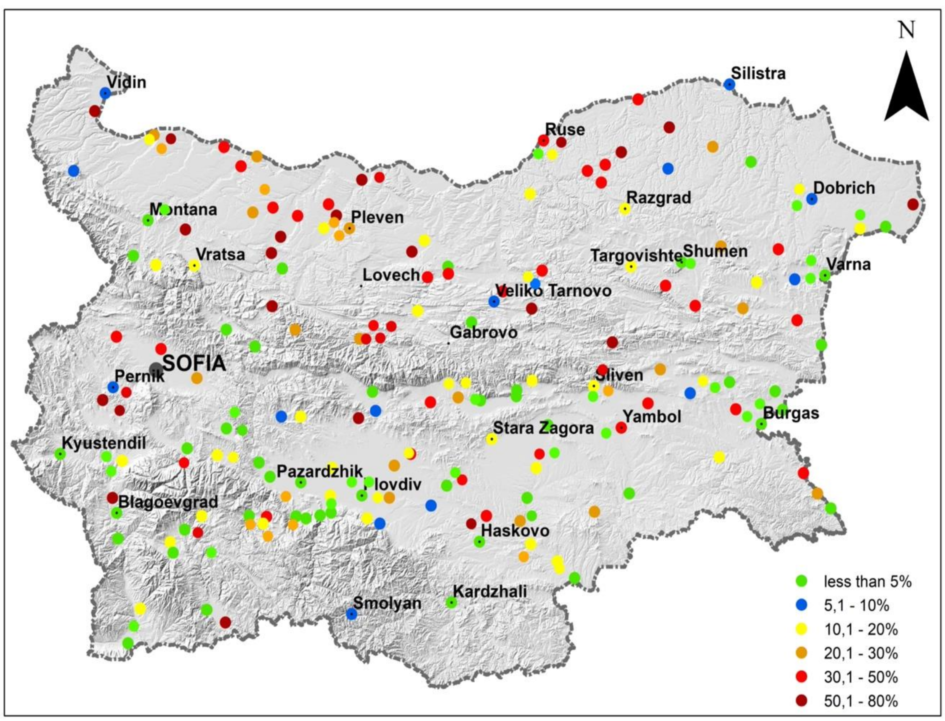

Figure 5. *Share of Green Areas within Roma Ghettoized Urban Structures: A Spatial Analysis,*
Source: Author's own calculations

Table 2. *Structure of Roma Ghettoized Neighborhoods by Relative Share of Green Areas and Settlement Type (According to City Population Size)*

Distribution of Roma ghettoized structures by city population size	Less than 5%		5 - 10%		10 - 20%		20 - 30%		30 - 50%		over 50%	
	Number of cases	%	Number of cases	%	Number of cases	%	Number of cases	%	Number of cases	%	Number of cases	%
Very large cities– **over 200,000 inhabitants**	6	85.7	1	14.3	0	0	0	0	0	0	0	0
Large cities– **from 100,000 to 200,000 inhabitants**	4	50	0	0	2	25	0	0	2	25	0	0
Medium-sized cities– **from 30,000 to 100,000 inhabitants**	8	25	11	34.4	6	18.8	2	6.3	5	15.6	0	0
Small cities– **from 10,000 to 30,000 inhabitants**	23	39.7	6	10.3	12	20.7	8	13.8	6	10.3	3	5.2
Very small cities– **up to 10,000 inhabitants**	22	21.2	7	6.7	17	16.3	15	14.4	27	25.9	16	15.4

Source: Author's own calculations

The data from Table 2 reveal a clear correlation between the size of the settlement and the share of green areas within Roma ghettoized neighborhoods. In the largest cities (over 200,000 inhabitants), neighborhoods with extremely low proportions of green space dominate—85.7% of them have less than 5% green coverage. As the share of green infrastructure increases, such neighborhoods virtually disappear from the structure of very large cities, indicating a severe ecological deficiency in the urban periphery, where ghettoized zones are typically located.

In large cities (100,000–200,000 residents), neighborhoods with low green space coverage (up to 10%) also predominate. However, there is an emerging presence of structures with higher levels of greening (up to 30–50%), suggesting more diverse spatial configurations and potential for targeted intervention. Medium-sized and small cities (between 10,000 and 100,000 inhabitants) display greater internal variation. The share of neighborhoods with 10% to 50% green space is substantial. Within this group, the highest concentration is observed in neighborhoods with moderate greening, positioning them in a transitional zone between ecological deficit and potential resilience. The most favorable situation is found in very small towns (under 10,000 inhabitants), where the highest relative share of neighborhoods with over 30% green space is recorded—amounting to 41.3% of all neighborhoods in this category. This can be attributed to lower building density and the presence of semi-rural residential structures, which include yards, gardens, and undeveloped inter-household spaces. In summary, the proportion of green areas in

Roma ghettoized neighborhoods is strongly correlated with the size of the settlement: the smaller the city, the higher the likelihood of ecologically significant internal zones. This indicates a structural inequality in ecological infrastructure that must be addressed through territorially differentiated policies.

Clustering of Roma Ghettoized Structures Based on Access to the City's Green Infrastructure

The clustering of Roma ghettoized urban structures based on the two analyzed indicators—the share of green areas and their spatial relationship with the city's broader green infrastructure—reveals several distinct groups (Figures 6).

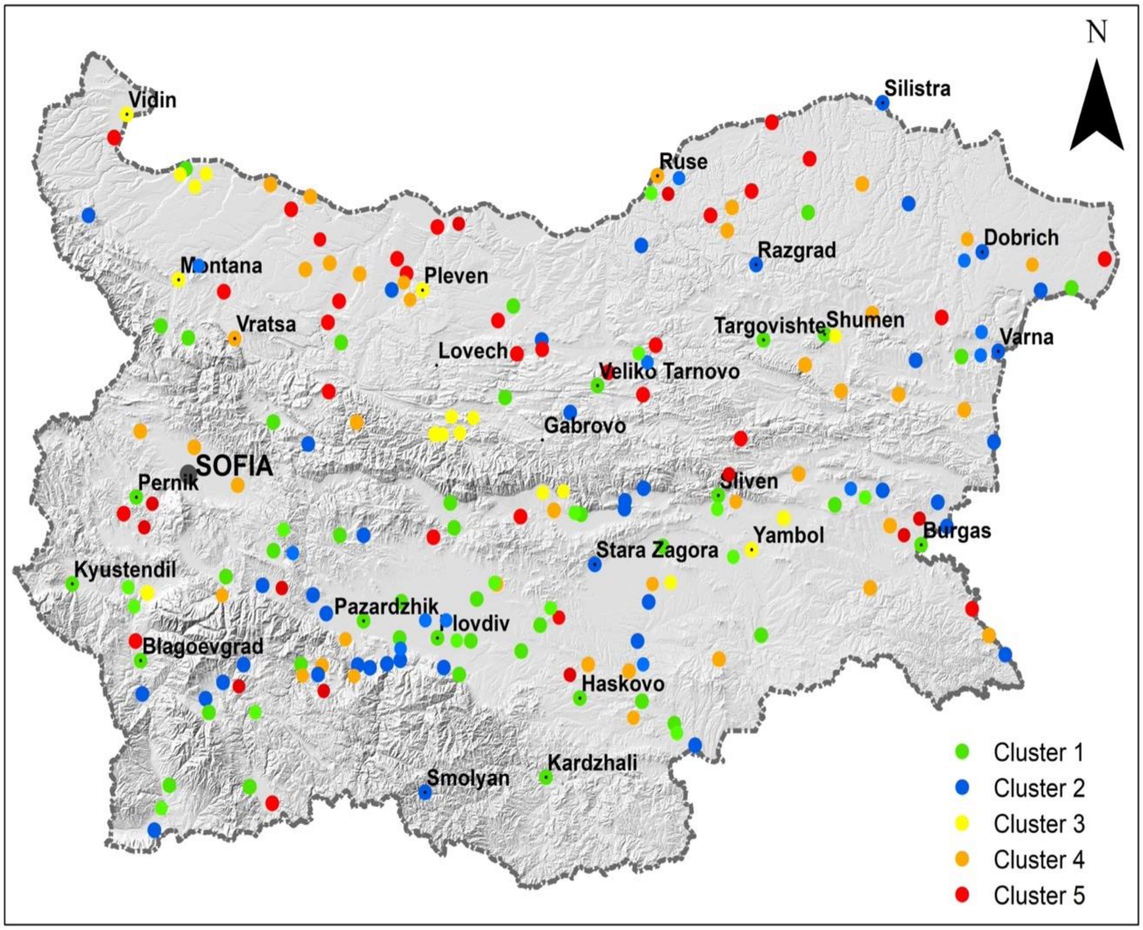

Figure 6. *Spatial Distribution of Clusters in Roma Ghettoized Structures Based on Access to the City's Green Infrastructure,*

Source: Author's own calculations

Table 3. *Summary of Clusters with Varying Degrees of Spatial Integration in Relation to Green Spaces*

Cluster	Variable			
	Mean	**Std. Deviation**	**Min**	**Max**
Share of green spaces within the urban Roma ghettoized structure				
Cluster 1: Segregated and Isolated Structures	7,9	6,6	0	25
Cluster 2: Doubly Excluded	6,9	5,6	0	21
Cluster 3: Internally Connected, Externally Isolated	22,9	13,9	2	50
Cluster 4: Internally Saturated, Externally Constrained	31,5	7,3	19	45
Cluster 5: Autonomous Green Enclaves	60,9	10,9	50	80
Total	**21,7**	**21,1**	**0**	**80**
Access to public green spaces for Roma in ghettoized structures				
Cluster 1: Segregated and Isolated Structures	28,5	4,8	22	40
Cluster 2: Doubly Excluded	14,3	4,8	5	21
Cluster 3: Internally Connected, Externally Isolated	47,9	12,9	37	80
Cluster 4: Internally Saturated, Externally Constrained	17,9	6,1	5	30
Cluster 5: Autonomous Green Enclaves	16,6	7,3	5	34
Total	22,3	11,8	5	80

Source: Author's own calculations

Cluster 1: Segregated and Isolated Structures

This cluster comprises Roma ghettoized urban structures with an extremely low degree of spatial integration in relation to the city's green infrastructure. It is characterized by a very low proportion of green areas within the neighborhood itself (an average of 7.9%) and significantly delayed access to external public green zones—most often exceeding twice the officially prescribed travel time to parks. This is the cluster with the most unfavorable indicators in terms of access to green infrastructure and represents the largest group, including 57 Roma neighborhoods distributed across various cities, regardless of their size. The neighborhoods in this cluster are typically spatially detached from the main urban core and exhibit limited connectivity with the rest of the city. This results in a low degree of daily interaction with the majority population. Spatial isolation significantly restricts both the temporal and territorial range of the residents *„active space"*—the area in which their everyday activities take place. In most cases, these are neighborhoods that were planned and established by the state during the 1960s and 1970s, with a designated residential function and without adequate provision of green areas. Furthermore, ongoing informal construction has led to additional reductions in the internal green infrastructure. Green spaces are virtually absent within the boundaries of these neighborhoods, making the comprehensive development of internal green zones—including areas with limited public use—necessary for improving both the ecological and social environment.

Cluster 2: Doubly Excluded

This cluster encompasses Roma ghettoized structures with a low degree of spatial integration in relation to green areas. Similar to Cluster 1, the neighborhoods in this group are characterized by high building density and an almost complete absence of internal green spaces, resulting in a severely degraded living environment. The average share of greenery within these neighborhoods is just 6.9%, and access to external green spaces is the lowest among all clusters (averaging only 14.3%). The structures in this cluster have emerged as a result of uncontrolled and informal development, under conditions of absent or weak institutional oversight by local authorities. Their urban configuration is chaotic—buildings are arranged without planning logic, street networks are narrow and irregular, and technical infrastructure is either missing or only partially developed. This cluster includes 58 Roma neighborhoods—the largest group in the classification. While some of them may be located relatively close to local green spaces, these areas typically do not function as urban parks and fail to compensate for the lack of greenery within the neighborhoods themselves.

Spatial isolation is further deepened by the configurational features of these areas—limited and weak connectivity to the surrounding urban fabric, which hinders residents' participation in public life and access to urban resources. As a result, Cluster 2 can be defined as *doubly excluded*—both in terms of spatial and ecological characteristics, and in terms of social participation.

Cluster 3: Internally Connected, Externally Isolated

Cluster 3 includes ghettoized Roma structures with a medium degree of spatial integration about the green system, exhibiting transitional characteristics. Neighborhoods in this group display significant advantages in terms of the proportion of green areas within their boundaries (averaging 22.9%), yet simultaneously have the most unfavorable values in terms of access to external park spaces (averaging 47.9%). This paradox underscores the complex nature of their isolation. The cluster comprises 18 Roma neighborhoods, primarily located in small (10,000–30,000 inhabitants) and medium-sized (30,000–100,000 inhabitants) towns. A common feature is that none of these neighborhoods shares a boundary with the rest of the urbanized area. This makes them some of the most spatially isolated structures in the analysis. Although they possess relatively more internal green spaces, their remoteness from city parks and the lack of functional connectivity with adjacent neighborhoods severely limit actual access to public green spaces. The morphology of these ghettoized areas—defined by the absence of contact zones and connecting infrastructure—significantly hinders spatial integration. As a result, despite the more favorable internal green profile, the neighborhoods remain socially and physically isolated, and opportunities for utilizing the external green system are minimal.

Cluster 4: Internally Greened, Externally Limited

Cluster 4 includes 37 Roma neighborhoods characterized by low to moderate levels of spatial integration with respect to green spaces. These neighborhoods demonstrate relatively favorable values for the internal share of green areas (averaging 31.5%), although considerably lower than those in Cluster 5. This suggests a moderately developed internal green structure, which nonetheless falls short of the standards of well-landscaped, autonomous enclaves. Access to external public green spaces (averaging 17.9%) is either close to or slightly exceeds the normatively acceptable time, indicating a moderate degree of spatial connectivity. Although the accessibility values are lower than those of Cluster 5, the green spaces are still realistically reachable and do not require significant effort to access. The ghettoized structures in this cluster often possess substantial contact zones with the main urban territory, making them better integrated into the urban morphology compared to the more isolated neighborhoods in other clusters. This spatial openness creates preconditions for improved social interactions and access to urban resources, despite some existing limitations.

Cluster 5: Autonomous Green Enclaves

This cluster includes 32 ghettoized Roma structures characterized by a high degree of spatial integration with green spaces. These neighborhoods exhibit the most favorable values for both indicators: a high share of green areas within the neighborhood (averaging 60.9%) and very short access time to external park spaces—typically under 15 minutes. The urban morphology of these areas features low building density, a wide contact zone with the main urban territory, and a well-developed street and communication network. Roma residents in these neighborhoods predominantly live in houses with spacious yards, offering private greenery and a high level of eco-comfort. Although located within the construction boundaries of the city, these neighborhoods often exhibit characteristics similar to rural areas, especially in the context of small settlements. The proximity to public green spaces and the high degree of internal greenery create conditions for meaningful participation in urban life, including daily recreational and leisure activities. Cluster 5 represents a model of successful spatial integration, which may serve as a reference point for the sustainable development of ghettoized neighborhoods in other urban contexts.

Discussion and Conclusion

Access to green spaces, as a key component of social integration processes, is an established priority in the policies for sustainable urban development and spatial planning of the European Union. Strategic frameworks such as the EU Urban Agenda, the Green Infrastructure Strategy, and the principles of the Green Deal emphasize the necessity of equal access to environmental resources—not only as a means to improve the urban environment but also as a tool to overcome social marginalization. In this context, green spaces are not merely an element of urban design but serve as territorial indicators of social justice. Despite the existence of strategic policy documents in Bulgaria—including the National Strategy of the Republic of Bulgaria for the Integration of Roma (2021–2030)—green infrastructure in Roma neighborhoods remains a peripheral issue in public policies. There is a lack of targeted and sustainable investment in green infrastructure in ghettoized Roma territories, which deepens existing territorial, environmental, and social inequalities. Equal access to urban green environments is not merely a matter of aesthetics or healthy living—it is a social necessity and a fundamental right. For marginalized communities such as the Roma, it represents an opportunity to enhance quality of life, increase visibility in public space, and foster inclusion in the everyday rhythm of urban life. Green spaces can serve as zones of transition—from isolation to participation, from alienation to encounter with the Other. Integrated, accessible, and well-maintained green areas have the potential to become "buffer zones" for interethnic coexistence, where shared activities—from sports and cultural events to educational initiatives—create new forms of social interaction. Investments in green infrastructure should be considered not only as part of urban development policy but also as an instrument of the welfare state aimed at reducing exclusion. This study highlights several structural challenges that hinder the development of a green system in Roma neighborhoods:

- Lack of planned and maintained green areas, resulting from institutional neglect and urban planning incompatibilities.
- Minimal public investment, leading to unequal territorial distribution of environmental resources.
- Limited participation of Roma communities in planning and maintenance, which undermines the sustainability and social legitimacy of any improvements.

Addressing these challenges requires integrated and just interventions, including:

- Priority zoning for green infrastructure in urban plans of neighborhoods with high concentrations of Roma populations.
- Investment in local green spaces—courtyards, mini-parks, playgrounds—even where available land is scarce.
- Establishing sustainable partnerships between municipalities, NGOs, and Roma organizations for joint planning and maintenance.
- Integration of greening initiatives into housing and social programs through European funding.
- Development of local indicators for equity in access to green spaces, with territorial and social disaggregation.
- Organization of cultural, educational, and sports events in park areas to promote interethnic cohesion.

Inter-institutional cooperation is essential. Municipalities, civil society organizations, and grassroots groups must establish long-term mechanisms for participatory planning. The active involvement of Roma communities—through public consultations, workshops, and volunteer initiatives—builds a sense of ownership and responsibility, without which any infrastructural change remains formal and unsustainable.
In conclusion, access to green spaces reflects the broader reality of spatial inclusion and social justice. Its realization requires not only physical restructuring but also a rethinking of the city as a place for all—including those who are often left outside the scope of policy.

Acknowledgements

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Development of a Toolbox for the Design and Sustainability Impact Assessment of Bioswales Using Digital Tools: A Case Study of Breitscheidstraße, Stuttgart

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Abstract

Bioswales are a sustainable solution for climate change adaptation and stormwater management, enhancing urban resilience. Urban areas face increasing risks of flooding and environmental challenges due to extensive impermeable surfaces and inefficient drainage systems.

Recent advancements in Building Information Modeling (BIM) provide powerful tools for designing nature-based solutions tailored to local conditions. However, their potential in the context of bioswale design remains underexplored.

Integrating bioswales into urban infrastructure presents several challenges, including soil permeability, existing drainage systems, topography and land slopes, land-use constraints, and the need to develop workflows that address technical, ecological, and social dimensions.

This study employs an inductive approach, combining qualitative and quantitative methods to evaluate the design and implementation of bioswales. The research includes a case study of Breitscheidstraße in Stuttgart, where Civil 3D and InfoDrainage were used to model and analyze the effectiveness of bioswales in stormwater management.

The case model analysis of Breitscheidstraße demonstrates how bioswales, as part of Sustainable Urban Drainage Systems (SuDS), can effectively retain stormwater volumes, unlike the existing drainage system, which failed under similar scenarios with a rainfall intensity of 35 mm/h. Bioswales also introduce cultural and recreational functions to the area.

This research expands the understanding of bioswale performance and their contribution to urban resilience. The developed bioswale design toolbox provides practical recommendations for urban planners and landscape architects, enabling solutions tailored to diverse environmental scenarios. Leveraging modern modeling tools like BIM ensures precise adaptation of bioswales to site-specific characteristics and project requirements. The integration of advanced design and analysis approaches improves the efficiency of bioswale implementation, contributing to the sustainable development of urban environments.

Keywords: Bioswales; Blue-Green Infrastructure; Sustainable Urban Drainage Systems; Stormwater Management; Building Information Modeling; InfoDrainage

Introduction

Urban areas are increasingly vulnerable to climate-related hazards such as extreme rainfall, surface flooding, and overheating. Conventional grey drainage infrastructure, primarily composed of underground pipes and collectors, is often unable to cope with the volume and intensity of contemporary storm events. The catastrophic floods of July 2021 in Germany, which caused more than 220 fatalities and an estimated €30 billion in damage, clearly demonstrated the limitations of existing stormwater networks and the urgent need for adaptive, sustainable solutions (Stache and Fassbender, 2022).

Blue-Green Infrastructure (BGI) has emerged as a key strategy for climate-resilient urban development by integrating hydrological and ecological functions into the built environment. Among BGI elements, bioswales play a crucial role in urban stormwater management. A bioswale is a shallow, vegetated channel designed to intercept, temporarily store, and infiltrate runoff from adjacent impermeable surfaces while improving water quality, mitigating the urban heat island effect, and supporting biodiversity (Boogaard et al., 2003).

Implementing such nature-based solutions requires accurate performance prediction and site-specific adaptation. This demand has increased interest in digital design environments, particularly Building Information Modeling (BIM), which integrates spatial, technical, and environmental data into a unified workflow. BIM enables visualization, coordination, and simulation of infrastructure performance but remains limited in assessing ecological functions and hydrological dynamics essential for sustainable drainage. Standard workflows rarely include infiltration modeling, runoff control metrics, or sustainability impact assessment for nature-based systems such as bioswales.

This study addresses these gaps by developing and testing a digital, BIM-supported toolbox for the design and sustainability impact assessment of bioswales. The methodology combines Autodesk Civil 3D with its InfoDrainage plugin to evaluate infiltration capacity, runoff reduction, and peak flow delay under realistic storm scenarios. Using a case study of Breitscheidstraße, Stuttgart, the research demonstrates how digital tools can support evidence-based decision-making for resilient and multifunctional stormwater management in urban environments.

Methodology

This study employs an inductive approach to develop practical recommendations for integrating bioswales into urban infrastructure using BIM for landscape architects and InfoDrainage. Inductive reasoning focuses on identifying patterns, trends, and hypotheses based on the collection of evidence to form justified conclusions.

The primary aim of the study is to evaluate the viability of bioswales as a solution for sustainable urban development, particularly in stormwater management, water purification, and improving urban environmental quality. Additionally, the possibility of using the InfoDrainage plugin for bioswale design is explored.

The research methodology includes the following components:

1. Literature review to analyze existing studies and project reports.
2. Case study to apply findings to a specific site.
3. BIM modeling using Civil 3D and InfoDrainage for bioswale performance simulations.
4. Analysis of quantitative and qualitative data to evaluate effectiveness.
5. Development of practical recommendations for landscape architects.

This workflow, illustrated in Figure 1: Research methodology diagram, provides a foundation for the systematic analysis of the effectiveness and applicability of bioswales in urban conditions.

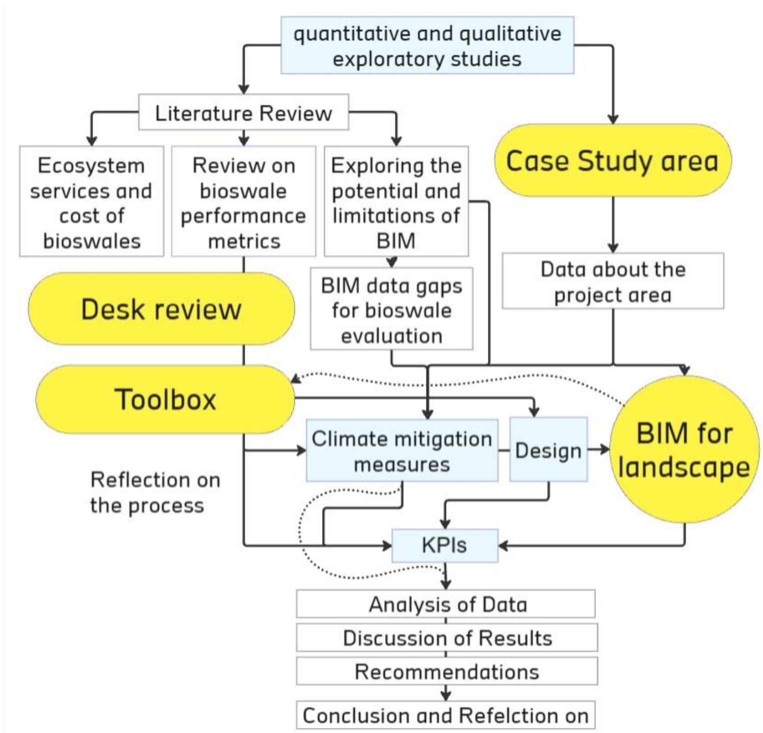

Figure 1. Research methodology diagram (Created by Author, Mariya Bodylevskaya, 2025).

The review focused on design principles and structural configurations of bioswales, including soil composition, vegetation types, hydraulic conductivity, and pollutant removal mechanisms. Performance indicators such as infiltration rate (cm/h), runoff volume reduction (%), and peak flow attenuation (%) were extracted and systematized for subsequent modeling. Special attention was given to ecosystem services, such as stormwater management, water quality improvement, biodiversity support, and climate adaptation. The review also explored the use of Building Information Modeling (BIM) tools in sustainable urban drainage design. Analysis of software capabilities led to the selection of Autodesk Civil 3D and its InfoDrainage plugin, which allows modeling infiltration, runoff reduction, and pollutant removal.

Building on the theoretical foundation, the bioswale design toolbox was developed as a structured workflow that links project objectives to technical and ecological requirements and is presented in Figure 2 (Bodylevskaya, 2025). The approach described by Forrester (1970) in "Systems Analysis as a Tool for Urban Planning" aligns with this toolbox as it emphasizes the need to consider multi-objective systems and understand feedback interactions. This is particularly relevant to bioswale design, where balancing ecological, hydrological, and urban development goals is essential for creating sustainable solutions.

The toolbox organizes the process of translating high-level sustainability goals — such as flood mitigation, biodiversity enhancement, and recreational value — into specific design parameters that can be tested digitally. It connects landscape design with the technical performance of stormwater systems, ensuring that proposed solutions respond both to environmental data and to urban context.

The toolbox was tested through a case study on Breitscheidstraße in Stuttgart. This location was chosen due to its central position, its proximity to Stadtgarten, and the opportunity to integrate new stormwater management measures into planned redevelopment. Field observations during the study year confirmed frequent surface water accumulation, highlighting the site's vulnerability and the relevance of bioswale implementation. A wide range of quantitative and qualitative data was gathered. Climate information from the Deutscher Wetterdienst (DWD, 2024) provided rainfall patterns and intensity-frequency statistics, while soil data from the Landesamt für Geologie, Rohstoffe und Bergbau Baden-Württemberg (LGRB, 2024) described permeability, texture, and water retention capacity. The municipal drainage authority, Stadtentwässerung Stuttgart (SeS, 2025), supplied sewer network data, including pipe dimensions, slopes, and inlet positions. Topographic and flood risk maps from public city resources (Starkregen Stuttgart, 2024) were used to understand runoff pathways and critical accumulation zones.

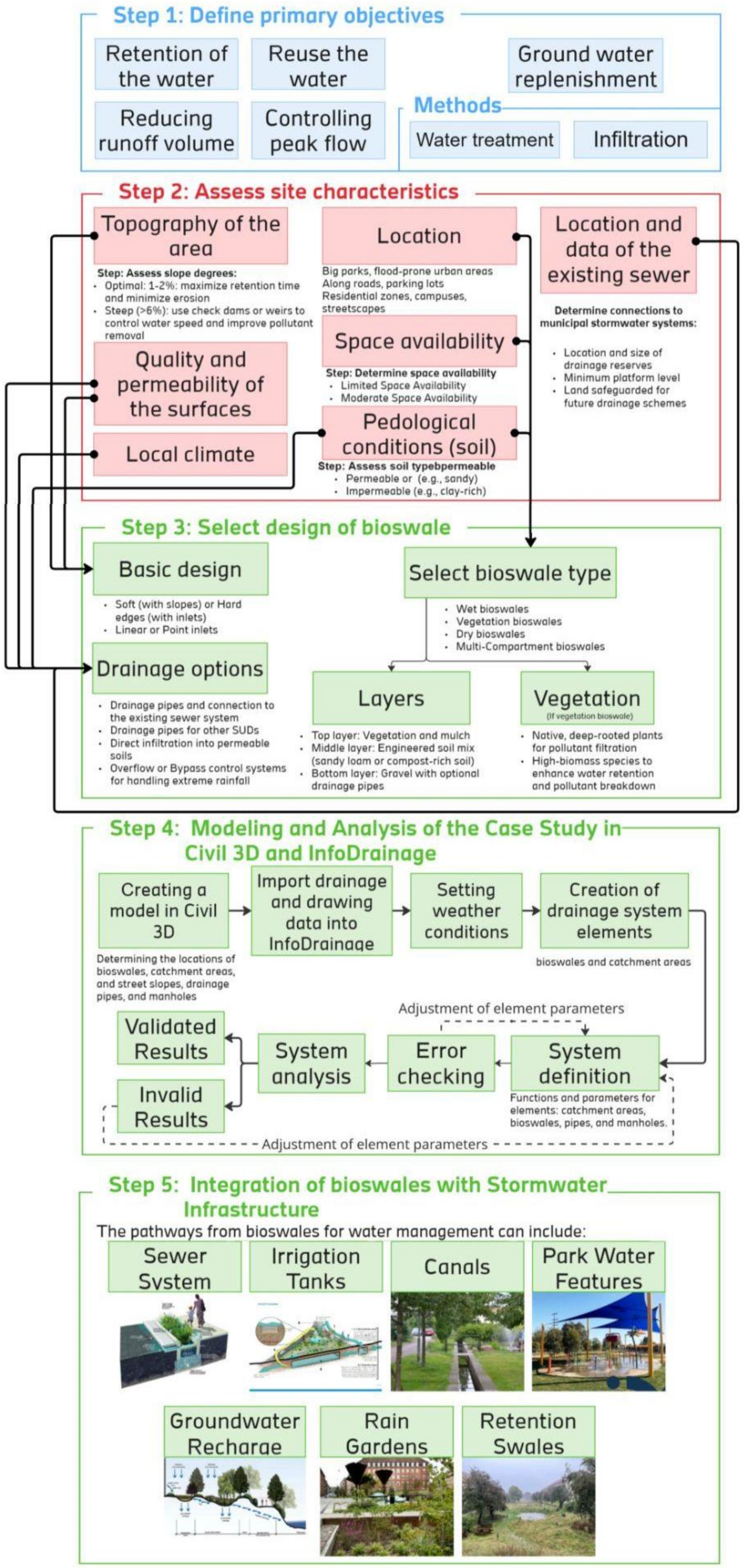

Figure 2. Toolbox for designing bioswales (Created by Author Bodylevskaya M., 2025).

The analysis of existing surfaces (Figure 3, adapted from Bodylevskaya, 2025) shows that most of the area is covered with asphalt, resulting in a high proportion of impermeable surfaces. This lack of greenery and permeable zones increases flood risk, intensifies the urban heat island effect, and reduces user comfort.

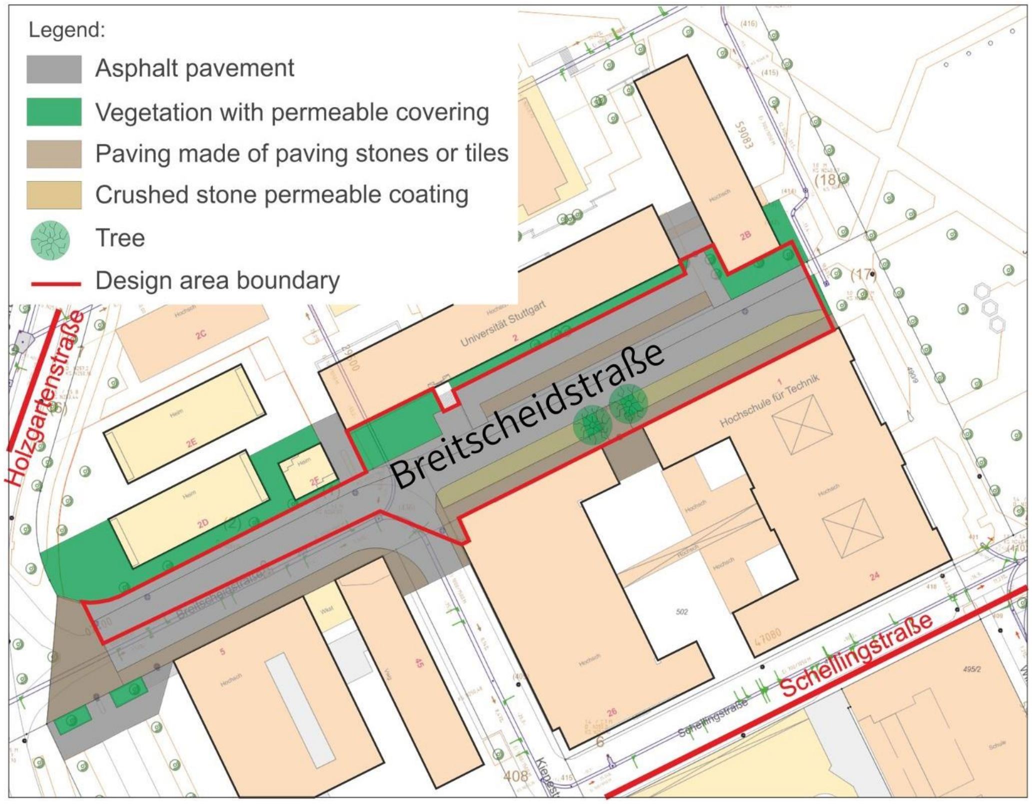

Figure 3. Analysis of existing green areas and surfaces, (Author Mariya Bodylevskaya, 2025).

Some data were incomplete, such as specific infiltration measurements for the selected bioswale areas. In these cases, values were estimated based on literature and comparable projects. Likewise, the absence of a ready BIM model of the drainage system required reconstructing it from 2D plans and available dimensions, which were then translated into Civil 3D for integration with the surface model (Figure 4, adapted from Bodylevskaya, 2025)

The digital modeling process used Autodesk Civil 3D to create a three-dimensional representation of the study area, including topography, road network, and existing drainage infrastructure.

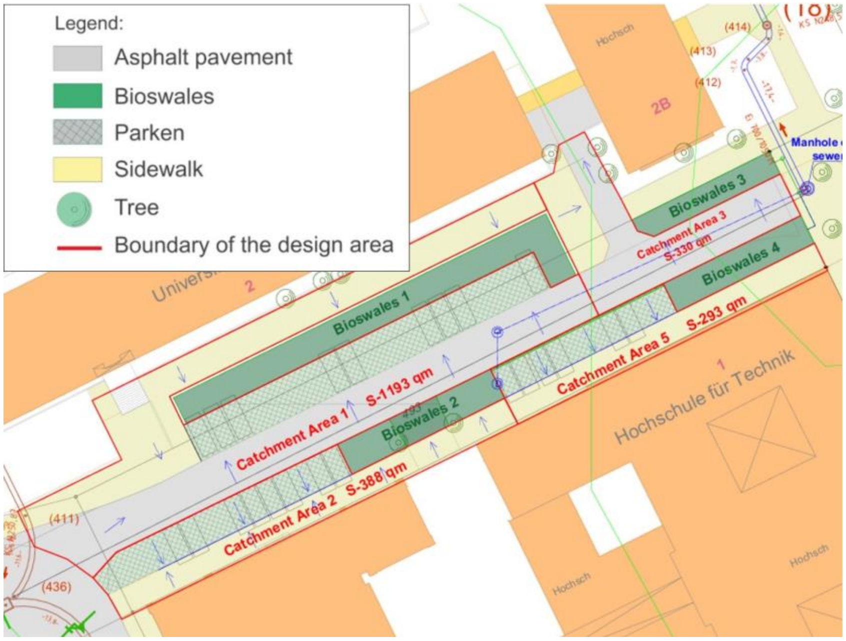

Figure 4. Drawing of the Breitscheidstraße street with bioswales (Created by Mariya Bodylevskaya, 2024).

In the new concept, the master plan is presented in Figure 5, showing the parking area relocated next to the road, a reduction in driveway space leading to the park, and an expansion of green and pedestrian-recreational zones (Created by Author Mariya Bodylevskaya, 2025).


Figure 5. The view from the exit of Building 5 towards Bioswale 1 (Created by Mariya Bodylevskaya, 2025).

The InfoDrainage plugin was then employed to simulate stormwater behavior under various rainfall scenarios, incorporating the proposed bioswale geometry, soil layers, and vegetation types. This simulation tested the performance of the system during a representative heavy rainfall event of 35 mm/h - a critical scenario according to local classification. Model outputs provided key indicators such as inflow, outflow, runoff volume reduction, and peak flow delay. These metrics allowed the evaluation and refinement of the toolbox to ensure it accurately supports decision-making and the design of resilient, multifunctional bioswales.

Results

The storm simulations conducted with InfoDrainage demonstrated a substantial improvement in stormwater management after the integration of bioswales into the study area on Breitscheidstraße, Stuttgart.

Table 1. Screenshot of InfoDrainage - analysis results of each bioswale's performance during a storm.

Stormwater Control	Max. US Elevation (m)	Max. DS Elevation (m)	Max. US Depth (m)	Max. DS Depth (m)	Max. Inflow (L/s)	Max. Resident Volume (m³)	Max. Flooded Volume (m³)	Total Lost Volume (m³)	Max. Outflow (L/s)	Total Discharge Volume (m³)	Percentage Available (%)	Status
Swale	0,531	-0,462	0,605	0,738	5,3	25,740	0,000	21,046	1,3	24,374	86	OK
Swale (1)	-0,221	-0,533	0,603	0,667	1,6	3,739	0,000	5,282	0,9	8,769	94	OK
Swale (2)	-0,203	-0,516	0,603	0,684	1,3	3,032	0,000	3,989	0,6	7,157	94	OK
Swale (3)	-0,202	-0,371	0,604	0,829	1,4	4,747	0,000	3,580	0,4	8,620	88	OK

After running the analysis, InfoDrainage provided the results shown in Table 1. The rainfall intensity of 35 mm/h, classified as severe weather conditions, was used as the input value, with a duration of 360 minutes. From this table, we can observe the maximum inflow into the bioswale and the maximum outflow. Table 2 presents the analysis results of the overall bioswale system's performance during a storm.

Table 2. Screenshot of InfoDrainage - analysis results of the overall bioswale system's performance during a storm.

Name	Max. Inflow (L/s)	Total Inflow Volume (m³)	Max. Outflow (L/s)	Total Outflow Volume (m³)
Structure - (205)			3,1	47,939
TOTAL	9,7	82,710	3,1	47,939

The key diagram of the bioswales' effectiveness in the context of sustainable stormwater management, as identified in the InfoDrainage model, is presented in Figure 6.

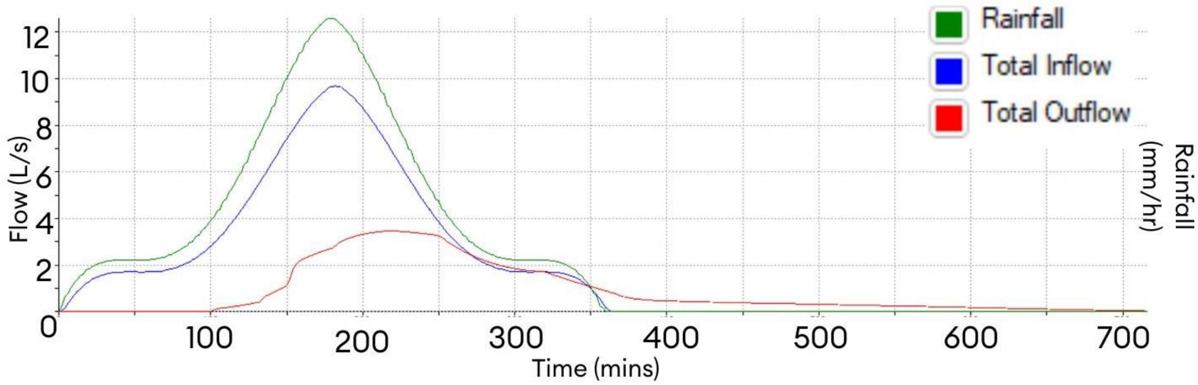

Figure 6. Screenshot of InfoDrainage - diagram of key performance indicators for the model in the case study, including 4 bioswales.

The peak inflow into the bioswale network was reduced to 9.7 L/s, and the peak outflow fell to 3.1 L/s, indicating a delay and flattening of the discharge curve compared to the existing drainage system. The total runoff volume was reduced by approximately 42 %, significantly decreasing the load on the municipal pipes.

Subsequently, a similar simulation was conducted for the existing stormwater system with two water inlet grates, and the results are presented in Table 3.

Table 3. Screenshot of InfoDrainage - analysis results of the existing stormwater system.

Connection	Connection Type	From	To	Upstream Cover Elevation (m)	Max. US Water Elevation (m)	Max. Flow Depth (m)	Discharge Volume (m³)	Max. Velocity (m/s)	Flow / Capacity	Max. Flow (L/s)	Status
Pipe - (147)	Pipe	Structure - (202)	Structure - (203)	1,807	0,868	0,110	44,699	1,0	0,98	9,9	Surcharged
Pipe - (148)	Pipe	Structure - (2	Structure - (2	0,000	-0,225	0,110	86,388	2,0	1,82	19,2	Flood Risk
Pipe - (149)	Pipe	Structure - (2	Structure - (2	0,000	-1,083	0,110	86,385	2,0	1,99	19,2	Surcharged

From the Table 3, we can see that the system cannot handle the runoff, posing a risk of flooding. Reviewing the flow rate graph in Table 4, we see that the Max. Outflow is 19.2 L/s, and the Total Outflow is 86 m³.

In comparison to the existing stormwater system, the bioswale design achieved a sixfold decrease in maximum outflow and a 45% reduction in total outflow, significantly decreasing the load on the municipal drainage network.

Name	Max. Inflow (L/s)	Total Inflow Volume (m³)	Max. Outflow (L/s)	Total Outflow Volume (m³)
Structure - (205)			19,2	86,385
TOTAL	19,9	86,359	19,2	86,385

Table 4. Screenshot of InfoDrainage - overall performance metrics of the existing stormwater drainage system during a storm.

These findings align closely with performance metrics reported in the literature: typical infiltration rates of around 6.8 cm/h and average runoff reduction values of approximately 50 % for bioswales with sub-drainage pipes (Muerdter et al., 2018; Liao et al., 2017). The observed 42 % reduction in this study confirms the reliability of the modeling approach and supports bioswales as an effective Sustainable Urban Drainage System (SuDS) element.

Beyond hydrological improvements, the system contributed to greater climate resilience by increasing permeable surfaces and supporting vegetation, consistent with the multifunctional goals of Blue-Green Infrastructure (BGI) (Cruijsen, 2015; Foster et al., 2011).

Discussion and Conclusion

The InfoDrainage plugin is a new software tool that highlights the relevance of its study while demonstrating how effectively the performance of bioswales can be modeled during storm events.

The model demonstrated the ability of bioswales to delay and reduce peak runoff, aligning with the primary goal established at the beginning of the project. These effects showcased the superior performance of bioswales in managing stormwater on the site compared to the existing sewer system. However, it is worth noting that the program does not account for the condition and suitability of the existing sewer infrastructure.

Following the step-by-step bioswale design toolbox, the study classified the parameters of bioswales based on their initial objectives. This served as the foundation for understanding what adjustments needed to be made in InfoDrainage to address flooding scenarios effectively. This streamlined the design process for the bioswales on Breitcheidstrasse, which was crucial given the limited timeframe and the fact that I chose my own case study as an example of bioswale performance.

The effectiveness of bioswales in stormwater management was assessed by measuring the total volume of stormwater captured by the bioswales, as well as their inflow and outflow. This evaluation quantitatively demonstrated the reduction in peak flow and runoff volumes, highlighting the role of bioswales in mitigating urban flood risks and improving water resource management.

The study underscores the importance of using BIM for landscape architects to design and manage bioswales effectively. Drainage system pipe models built in Civil 3D were integrated into InfoDrainage to assess their performance parameters in handling runoff. InfoDrainage allows designers to revisit and flexibly adjust the parameters of system components to achieve both ecological and social benefits from implementing bioswales.

The bioswale model in InfoDrainage can coordinate the efforts of landscape architects, hydrologists, urban planners, utility services, developers, and ecologists to facilitate collaborative design, ensure regulatory compliance, and analyze environmental impacts.

The maintenance of bioswales is minimal, involving basic vegetation care, sediment removal, and occasional drainage system inspections. Using drought-tolerant plants further reduces costs. In contrast, traditional drainage systems require more expensive upkeep, including frequent cleaning and repairs, making bioswales a more economical and cost-effective solution.

The reduction of parking spaces in the project amounts to only 150 m², which is minimal, especially considering that the existing parking lot is underutilized, with vehicles often parked on sidewalks. However, repurposing this area to accommodate bioswales brings significant benefits: it enhances stormwater management, reduces the risk of flooding, increases the ecological value of the site, and improves its aesthetics, making the space more appealing and functional for residents.

This study aimed to evaluate the effectiveness of bioswales in managing stormwater runoff using Civil 3D and InfoDrainage for sustainable drainage systems (SuDS). Its goal was to understand the design sequence of bioswales and provide a design framework, which was tested through a case study.

Analyzing the example of Breitcheidstrasse in Stuttgart, the findings offered valuable insights into how bioswales reduce stormwater runoff compared to grey infrastructure. The modeling showed that an area with bioswales could manage a heavy storm with a rainfall intensity of 35 mm/h within 11 hours, while the traditional sewer system would overflow in just 1 hour. The data obtained from the BIM model emphasized the importance of design parameters such as soil type, infiltration rate, slope, and bioswale configuration for optimizing performance.

Additionally, the study demonstrated how integrating bioswales into the Stuttgart campus not only addressed stormwater management challenges but also created cultural ecosystem services. Transforming a paved area previously used solely as a pedestrian pathway into a multifunctional space with recreational zones significantly improved the urban environment. This enhanced space also served as an educational tool to showcase sustainable stormwater management processes, helping urban residents better understand these mechanisms in the context of sustainable development.

According to the literature, bioswales with drainage pipes reduce runoff volume by an average of 42%. While these metrics are averaged, their accuracy can be verified empirically after implementation. Meanwhile, BIM modeling with InfoDrainage enables storm simulations and the preemptive evaluation of bioswale performance, which is critical for addressing climate change and developing sustainable design solutions. The use of the InfoDrainage plugin has also proved valuable for adjusting and optimizing designs, helping to determine the optimal location, configuration, and orientation of bioswales based on site-specific characteristics.

The study also identified several challenges and limitations. The lack of localized weather and soil data in InfoDrainage reduced the accuracy of simulations. While soil data can be manually entered or matched to available options, the software currently lacks regional weather datasets for Germany, making it difficult to model realistic scenarios. Future research could address this limitation by integrating regional datasets into simulation software. Additionally, the absence of specific plant data in the software hindered the assessment of bioswale ecological benefits.

In my research using BIM and InfoDrainage, I focused on stormwater management and peak flow reduction. Initially, the scope also included studying bioswales for rainwater purification. However, site analysis revealed clay soils with low infiltration capacity, shifting the focus to runoff management. The results have demonstrated that bioswales are an effective solution for managing stormwater in such conditions.

For future studies, it is recommended to explore the use of bioswales for rainwater purification. This approach would allow for the development of more versatile solutions targeting multiple objectives, particularly in areas with highly permeable soils. Additionally, it is important to investigate the capabilities of InfoDrainage in reducing water pollution. The literature review highlighted that bioswale effectiveness depends directly on initial parameters and design decisions. Developing an interactive decision-support system based on the toolbox created in this study could provide real-time design recommendations, guided by the specific goals, site analysis, and configuration of bioswales.

This study has demonstrated the importance of designing landscape features such as bioswales, as components of SuDS, with full integration into all project phases using BIM. Bioswales are not merely aesthetic landscape elements but also engineered solutions for stormwater management. Their efficiency requires precise calculations, as they are implemented in urban areas to combat flooding. The use of digital tools in bioswale design is critical for bridging the gap between design and implementation. A logical next step would be analyzing the economic feasibility of bioswales in urban environments, considering maintenance costs and the long-term benefits of ecosystem services.

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Blue-Green Infrastructure Design Based on Flood Modeling

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Abstract

With the continual rise in global temperatures, increasing urbanization, deforestation, and greenhouse gas emissions, the frequency and intensity of urban flood events are projected to increase significantly. This creates a pressing need to develop sustainable stormwater management solutions, particularly in urban areas with high proportions of impervious surfaces. One such solution is the implementation of blue-green infrastructure (BGI), which enhances the natural water cycle and contributes to flood mitigation.

This study presents a practical methodology for selecting and dimensioning BGI elements based on the identification of flood-susceptible areas through hydrodynamic modeling. The research was conducted in the city of Vologda (Russia), where areas susceptible to flood were identified, and their inundation volumes were calculated pixel by pixel using GIS tools.
Based on the computed flood volumes and available urban space, typical BGI elements such as rain gardens, bioswales, and dry detention basins were selected and dimensioned. The methodology allows for quantitative spatial planning of BGI, bridging hydrological analysis with landscape design and enabling precise selection of BGI types and volumes required for flood control.

The modeling and design methodology demonstrated in this work shows that flood-susceptible areas identified through 2D hydrodynamic simulations provide an excellent basis for the spatial planning and technical specification of blue-green infrastructure. The proposed approach can be used as a framework for integrating hydrological modeling with sustainable landscape planning. It provides a replicable solution for data-informed flood management and climate adaptation in cities, especially relevant in contexts with increasing rainfall and underdeveloped stormwater infrastructure. This approach can potentially be used to analyze large areas of the city also with the use of AI. The proposed methodology can be applied in other urban areas, forming the basis for sustainable water-sensitive urban development.

Keywords**:** Flood modeling, Blue-green infrastructure, Landscape planning, Stormwater runoff.

Introduction

Flood events have become more frequent and widespread globally due to rise of global air temperatures, urbanization and soil sealing, deforestation, and emissions of greenhouse gases (Pörtner et al, 2022). In Russia, the average annual rainfall increased by 2.2 percent, and the rains became shorter and heavier (Kiselev, 2021). Such events may lead to premature deaths, infrastructure damage, and outbreaks of epidemics. In urban areas, where large proportion of land surface is paved or covered with impermeable artificial materials, there is a notable reduction in infiltration capacity and an acceleration of surface runoff. This contributes to pluvial flood that occurs when intense and heavy rainfall exceeds the capacity of sewage systems and natural water absorption in cities (Chen, 2009). Existing stormwater sewage system originally designed for lower flow rates may not be sufficient to effectively evacuate water, increasing the susceptibility of cities to floods (Singh, 2018).

To avoid the nuisance of frequent flooding during rainy season, designing an efficient stormwater drainage system and blue-green infrastructure (BGI) has become the need for engineers and urban planners. The methodology of identification of flood-susceptible areas (FSA) is an important step in stormwater runoff management and risk mitigation. Based on the analysis of territory and simulation results, the article develops a concept for implementing BGI elements for a specific urban area in a Russian city.

BGI refers to semi-natural objects that help in restoring landscapes and the natural water cycle, unload stormwater sewers and reduce the susceptibility to floods. BGI can reduce the volume of runoff, filter nutrients, pathogens and metals, restore groundwater and river runoff, and promote dilution of wastewater (Staddon, 2018).

The purpose of the research: A modeling of FSA in urban areas at the city level to support BGI. To study the selected problem, the following tasks were set and formed: 1) territory analysis; 2)choosing available materials for modeling; 3) flood modeling using 2D hydrodynamic models; 4) validation of the obtained modeling results; 5) identification of types of flood areas; 6) calculation of parameters and selection of characteristics of BGI elements based on existing methodological manuals.

Methodology

1. Research area

The city of Vologda is the administrative center of Vologda Oblast. Its area is 116 km². The relief is mostly flat with minor elevation differences. Geomorphologically, the territory includes the floodplains of the Sukhona, Vologda, and Lezha rivers with elevations of 107–112 meters, predominantly composed of sands and sandy loams, as well as overfloodplain terraces with elevations of 113–118 meters, represented by lacustrine-glacial deposits and loams (Sudakov, 2006; *Atlas of Vologda Oblast*, 1965). The prevailing soil type is sod-podzolic. A significant part of the city’s territory is built up, which leads to the formation of sod-anthropogenic, highly transformed embankment soils. The hydrographic network within the city and its surroundings is represented by the Vologda River and its tributaries. Groundwater occurs at depths of up to 110 meters. The climate in this area is moderately continental, with average July temperatures ranging from 16.6 to 17.5 °C, and January temperatures from -10.8 to -13.8 °C. The region is located in a zone of excessive moisture; annual precipitation amounts to 500–650 mm. The greatest share of precipitation falls in summer and autumn (Department of Natural of Vologda Oblast, 2021). The total area of urban green spaces is 515 hectares, of which 320 hectares are parks and public gardens. Stormwater runoff is managed by a storm sewer system, which is generally in unsatisfactory condition: in some sections it is absent, in certain places catch basins are clogged, and discharges into the river occur in an unregulated manner.

Methods and materials

This study presents a practical methodology for selecting and dimensioning BGI elements based on the identification of flood-susceptible areas through hydrodynamic modeling. To select suitable blue-green infrastructure (BGI) elements and define their parameters, a sequence of structured research steps must be undertaken. Our proposed methodology is based on consistent data collection, territorial analysis, hydrodynamic modeling, and validation of the obtained results. Only after these stages is it possible to proceed with the typology of flood-susceptible areas and the selection of appropriate BGI elements.

Step 1. Watershed and watercourses identification.

At first, on the basis of the DEM, watercourses and catchment basin boundaries were identified. This allows to correctly set the boundary conditions, flooding areas, and water distribution paths in the model.

Step 2. Data preparation

Required data for territory analysis and surface runoff modeling: Digital Elevation Model (DEM), satellite images, land cover, Manning's n value, runoff coefficient, soils hydrological group raster, soils type, soil parameters, precipitation.

For mapping, open medium-resolution spatial data were used: a digital elevation model (DEM) with a resolution of 12.5 m, derived from ALOS PALSAR data (JAXA), as well as Landsat-8 satellite imagery with a resolution of 30 m (USGS). Based on the satellite images, land cover rasters and a Manning's coefficient map were generated. According to the *Atlas of Vologda Oblast* (1965), as well as data from a field expedition by the Smart Urban Nature (SUN) Laboratory and the Landscape Engineers Guild Association (unpublished data, 2023), the optimal input parameters for the model were selected: capillary porosity — 150 mm, effective porosity — 0.437 mm/mm, permeability — 15 mm/h. These granulometric characteristics correspond to the average values for the prevailing soil type and represent generalized indicators.

As extreme precipitation, a rainfall event with a return period of once in 50 years was chosen. The rainfall duration was set at 20 minutes, in accordance with the standard SP 32.13330.2018 "Sewerage. External networks and facilities". Under these parameters, the amount of precipitation is 32 mm, based on the calculated data from A. M. Kurganov's tables.

Step 3. Model several scenarios.

The modeling stage involved considering precipitation events with return periods of once every 1, 10, 20, 50, and 100 years. The simulation is performed for several scenarios or for one of the most representative ones. Simulation scenarios can be carried out with and without storm sewers, as well as before and after the introduction of a BGI. For further design, we selected a 20-minute rainfall scenario with a return period of once every 50 years and a total precipitation of 30 mm. The simulations were carried out without accounting for stormwater sewer.

Step 4. Two-dimensional modeling

Further, surface runoff modeling was carried out using the two-dimensional hydrodynamic model Itzï. This made it possible to identify flood-susceptible areas and determine the areas where BGI elements should be implemented. Itzï is a simple two-dimensional flood propagation model based on volume conservation, which distributes the flood hydrograph over a system of square cells (tiles) (Itzï., 2024). The modeling outputs include maximum and final runoff depth values in meters, maximum surface runoff velocity values, and flow directions.

Step 5. Validation results of modeling

To verify the results obtained during the modeling, a field survey was carried out in the city of Vologda on October 30, 2024. During the two weeks preceding this date, 9.1 mm of precipitation fell in Vologda, and on the day of the survey, 4 mm of precipitation was recorded (RP5, 2024). The field route was laid through the modeled areas with the greatest flood depths in the city center. Validation points were selected both randomly and on an expert basis. Along the route, all observed flooding cases were also recorded, including those not predicted by the model. Based on the validation results, the following modeling accuracy indicators were calculated: omission error (false negative result), commission error (false positive result), producer's accuracy — the proportion of actual features correctly predicted by the model, and user's accuracy — the proportion of model-predicted features that actually exist.

Step 6. Identification of types of flood areas

All flooding sites can be divided into several types according to the different shapes, zones and volume of flooding.

Step 7. Concept of blue-green infrastructure

The modeled zones indicate where BGI elements can be optimally located, while the flood depths allow for determining the volumes of inundation required for calculating the parameters of the designed solutions.

First, the volume of surface runoff that the BGI element must retain during an extreme 50-year rainfall event was determined. In QGIS, based on the modeled flood depth raster layer, the forecasted volume of accumulated runoff in the flood zone was calculated pixel by pixel.

Next, based on the available areas for BGI elements, the recommended surface areas and dimensions for different BGI types, and the required volume of surface runoff to be managed, the necessary areas and depths of the BGI elements were selected.

The necessary characteristics of the elements — filter and drainage layer depths, composition of the filter and drainage layers, design, shapes and parameters — were taken from the recommendations provided in The SUDS Manual by CIRIA and the Methodological Guide for Designing Rain Gardens by LAEN.

Results

1. Modeled areas susceptible to floods and validation

Analyzing the modeled in 2D hudraulic areas, we see that they are located in depressions on DEM, in green areas and on impermeable surfaces (Fig.1). The largest number of areas susceptible to flooding is located in the central part of the city next to the river. There is almost no flooding in the southwest, because there is an elevated part of the city, in the east, on the contrary, there is a low-lying area where flooding is located, but the lower the territory goes, the less the runoff is delayed. The deepest flood areas are observed on the right bank of the river in the central part of the city.

Figure 1 - Map of final depth of flood during rain in Itzï (Ramikh M.A.)

In total, 26 places with flooding were noted along the chosen route of field trip, some of them were identified in green areas in depressions, some in depressions on roads (Fig.2).

According to Itzi, 24 flooding areas were modeled along the route, while 19 of them were validated. Accordingly, the user accuracy of Itzï modeling is 79,2 %, producer accuracy 73,1 % (Table 1). In the day with a rain of 4 mm, Itzï did not model all the zones with the parameters for the 50-year rain q20 that was recognized during field trip. Additional areas that were not detected were also modeled. Model showed high values of modeling accuracy, which means that it can be used to develop a concept for working with runoff during heavy precipitation and the implementation of BGI elements.

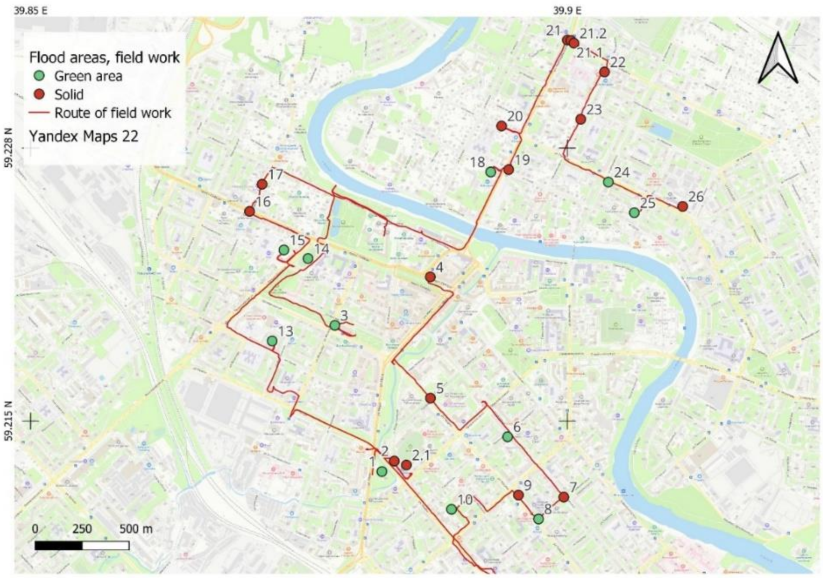

Figure 2 - The route of field work and the points of detected flood areas (Ramikh M.A.)

Table 1 - Validation of model

Programm	Modeled	Field result	TP	FP	FN	Comission error	Omission error	User accuracy, %	Producer accuracy, %
Itzï	24	26	19	5	7	5	7	79,2	73

2. Implementation blue-green infrastructure

We have analyzed all the flooding sites. All flooding sites can be divided into several types: flooding in depressions on the road (intersections, local depressions), flooding along the road over an extended area, and flooded, waterlogged green areas. In all three cases, we decided to implement elements of a blue-green infrastructure to deal with flooding. In the course of our study, we selected the most representative locations for each type of flooding and designed BGI elements for them. This design serves as an example for the development of various types of BGI elements, based on which appropriate solutions can be selected by analogy for all identified FSA in the city.

For local depressions on the road and intersections (spot flooding) we selected rain gardens (Fig.3,4). Rain gardens are localized solutions that are ideal for small areas where water accumulates, particularly near curbs, at road forks, and intersections. The volume of precipitation accumulated during an extreme 50-year rain event in point 21 is 196.28 m³. Based on the volume of stormwater that needs to be accommodated in the biodrainage swale, we selected the following parameters: depth of the bowl – 0,2 m, filter loading depth – 0, 8 m, drainage depth – 0,3 m, area – 450 m2.

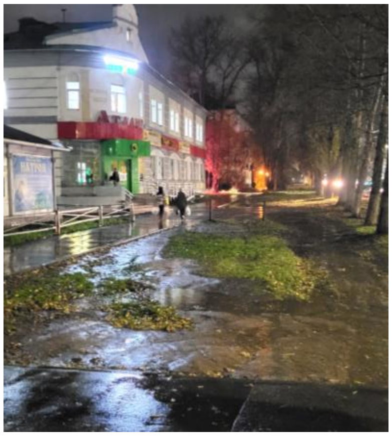

Figure 3. Point 21, flooded area (Ramikh M.A.)

Figure 4 - Visualization of rain garden on the site (Ramikh M.A. sketch+AI prosessing)

For flooding along roads and sidewalks we have selected the following solution: bioswale (Fig.5, 6). The linear form is ideally suited for placement along roads — it can be integrated into the landscaping between the sidewalk and the roadway. With proper calculation of the area and depth, a bioswale can retain a large volume of runoff from sidewalks and building roofs, thereby preventing flooding on the road. The volume of precipitation accumulated during an extreme 50-year rain event in point 23 is 541 m³. Based on the volume of stormwater that needs to be accommodated in the biodrainage swale, we selected the following parameters: depth of the bowl – 0,2 m, filter loading depth – 0, 45 m, drainage depth – 0,3 m, area – 2750 m2, width - 2.5 m.

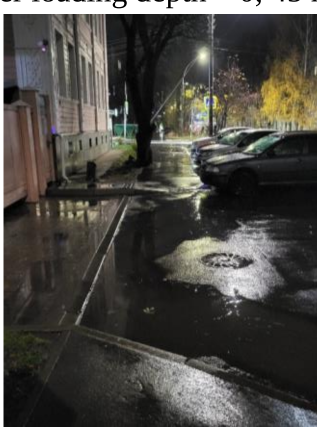

Figure 5. Flood in the point 23 (Ramikh M.A.)

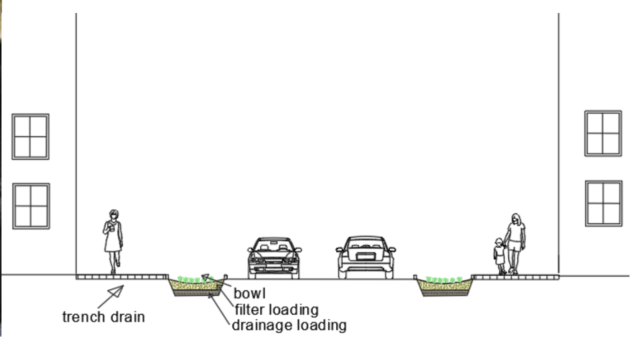

Figure 6 - The layout of the biodrainage swales in the street profile (Ramikh M.A.)

For flooding in green areas (Parks, Vacant Lots, Public Gardens, etc.) we propose the installation of a system of dry streams and detention basins (Fig. 7, 8), and the planting of moisture-loving vegetation. Detention basins are landscaped depressions that are typically dry and fill with stormwater runoff during periods of intense rainfall, providing storage and reducing peak stormwater flows. Dry streams, lined with stones, will serve as channels for water flow. The volume of surface runoff accumulating at this point during an extreme 50-year rainfall event in point 6 is 353.2 m³. Based on the required volume of surface runoff to be retained, we selected the following parameters for the detention basin: 1 meter in depth and 353.2 m² in area.

Figure 7. Flooded green area in point 6 (Ramikh M.A.)

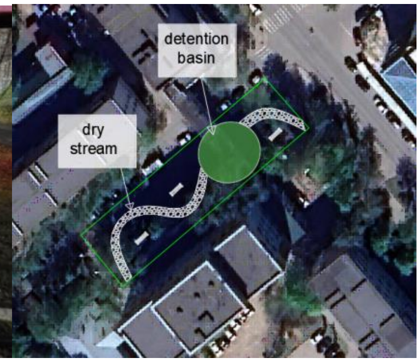

Figure 8 - The location of dry stream and detention basin (Ramikh M.A.)

As a result of the flood modeling and subsequent design of blue-green infrastructure elements for three key locations, the main objective was achieved – to accommodate the calculated surface runoff volume from an extreme 50-year rainfall event within the available areas. The selected BGI elements will be able to fully withstand precipitation loads and prevent local flooding.

Discussion and Conclusion

The modeling and design methodology demonstrated in this work shows that flood-susceptible areas identified through 2D hydrodynamic simulations provide an excellent basis for the spatial planning and technical specification of blue-green infrastructure. Open-source numerical 2D hydrodynamic model have accurate results and can be used to implement BGI elements. 2D hydrodynamic models makes it also possible to determine the spatial distribution of the depths and volumes of water accumulation in these zones. Based on the modeled and validated FSA, BGI solutions and parameters can be proposed.

The proposed approach can be used as a framework for integrating hydrological modeling with sustainable landscape planning. It provides a replicable solution for data-informed flood management and climate adaptation in cities, especially relevant in contexts with increasing rainfall and underdeveloped stormwater infrastructure. This approach can potentially be used to analyze large areas of the city, also with the use of AI. The proposed methodology can be applied in other urban areas, forming the basis for sustainable water-sensitive urban development.

However, it should be borne in mind that model performance also depends on the quality of data used to construct a numerical representation of the catchment. This information includes soil characteristics, land use, topography and forcing conditions, all of which play an important role in the generation of an urban flood. In reality, these data vary in space and time, and their representation at an adequate spatio-temporal resolution is necessary for an accurate performance of the numerical tool. Also future research should include data calibration and modelling in different terrain and at different scales. In parallel, combining physical flood maps with socioeconomic layers of vulnerability will enable more holistic, risk-sensitive adaptation strategies for sustainable urban planning.

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Monitoring Technologies in Green Roof Management: A Multi-City Methodological Framework for Assessing Ecosystem Services Across Russia's Climatic Zones

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Abstract

Urban green roofs are a critical nature-based solution for climate adaptation, yet their implementation in Russia lacks standardized, climate-adaptive methodologies. This work presents the methodological framework developed and validated through the GreenRoof.PRO laboratory in Moscow (established in 2022), now scaled into multi-city research network funded by the Russian Science Foundation (RSF №24-17-00134). Grounded in a systematic review of international standards (FLL, 2018; GOST R 58875–2020) and empirical data on substrate composition, we designed a replicable methodology for evaluating hydrological, thermal, and carbon fluxes in extensive green roofs. Building on the pilot's validated protocols, we now operate a three-city framework in Moscow, Ekaterinburg, and Rostov-on-Don, each hosting two distinct experimental systems: 1) Three 1×1 m modules per city — designed to quantify stormwater runoff, retention, and drainage dynamics under controlled conditions, directly replicating the original pilot design; and 2) Eighteen 2×2 m plots per city — comprising six unique combinations of substrate (universal vs. regional) and vegetation (Sedum vs. native species), each replicated three times, enabling long-term assessment of vegetation succession, biodiversity, and ecosystem service resilience at a landscape-relevant scale. The methodology integrates: 1) continuous IoT monitoring of soil moisture, temperature, and precipitation; 2) periodical CO_2 fluxes, 3) standardized laboratory analysis of substrate physicochemical properties (granulometry, water retention, contents of available nitrogen and phosphorus, microbial activity); and 4) region-specific substrate formulations using locally sourced, circular-economy materials (wastewater sludge, foam glass, coconut coir, peat, compost, wood chips). This framework is the first in Russia to simultaneously evaluate both hydrological performance at module scale and ecosystem development at plot scale across a climatic gradient. While final ecosystem service quantifications are pending, this study establishes the first rigorous, open-access, and replicable protocol for green roof research in climate-diverse contexts. The GreenRoof.PRO platform serves as a foundational model for future climate-resilient urban infrastructure research.

Keywords: Urban sustainability, Climate adaptation, Carbon balance, Substrate quality, Monitoring, Green spaces, Russia

Introduction

Urbanization, climate change, and aging infrastructure have intensified challenges such as urban heat islands, stormwater flooding, and air pollution in Russian cities. Green roofs — multi-layered systems that integrate vegetation, substrate, drainage, and waterproofing — offer a proven, nature-based solution for mitigating these pressures through stormwater retention, microclimate cooling, and carbon sequestration (Berndtsson, 2010; Stovin et al., 2012). However, in Russia, the deployment of green roof technologies remains fragmented, driven by aesthetics rather than science, and lacks climate-zone-specific standards (GOST R 58875–2020). While international standards and decades of empirical research have shaped green roof science in the Global North, Russia's approach remains underdeveloped. A critical gap exists: there is no nationally coordinated, climate-adapted, multi-scale research infrastructure to guide green roof design across Russia's vast climatic gradient — from the subarctic taiga of Yekaterinburg to the semi-arid steppe of Rostov-on-Don. This paper addresses this gap by presenting the methodological foundation of the first integrated, scalable green roof research network in Russia, known as GreenRoof.PRO Open Laboratory.

The design of green roof substrates is not universal — it is deeply contextual, shaped by local materials, climate, regulations, and cultural priorities. In Germany, the FLL (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau) guidelines remain the gold standard, emphasizing inert, mineral-based substrates with an organic matter content limited to 5–10% for extensive roofs to prevent subsidence and nutrient leaching (FLL, 2018). Components, including expanded clay, pumice, and crushed brick, are standard for the mineral phase. The FLL focuses on long-term stability and low maintenance, which reflects a mature, regulatory-driven market where green roofs are mandatory on many public buildings. In North America, the approach is more pragmatic, namely, in Toronto, the world's first mandatory green roof bylaw (2009) requires 20–60% of new commercial and institutional roofs to be green, with substrates often based on lightweight aggregates (e.g., expanded shale) and compost blends (up to 15–20% organic matter) to support plant diversity (Toronto Green Roof Construction Standard, 2021). Similarly, in Chicago, the Eco-Roof Incentive Program has funded over 1,500 projects, with substrates frequently incorporating recycled materials like crushed concrete and fly ash, demonstrating a strong alignment with circular economy principles (Urban Green Council, 2019). In Asia, innovation is rapid and driven by extreme urban density and heat. In Singapore, the Green Mark certification scheme mandates green roofs on high-rise buildings, with substrates often comprising coconut coir (up to 40%), foam glass, and recycled concrete aggregates to maximize water retention and minimize weight on these structures (NParks, 2023). The use of wastewater sludge as a nutrient source is actively researched and piloted in controlled settings (Farah et al., 2024). In Japan, Tokyo's 2001 green roof ordinance requires 20% coverage on buildings exceeding 1,000 m², and substrates are often optimized for drought tolerance using zeolites and biochar to enhance water retention and nutrient buffering (TMG, 2022). In South Korea, Seoul's Green Roof Master Plan aims for 10 million m² of green roofs by 2030. Substrates often include peat alternatives (such as coir and composted bark) and local volcanic soil (e.g., scoria) to reduce import dependency and enhance drainage (Seoul Metropolitan Government, 2023). In China, the "Forest City" project in Luoyang uses substrates with high biochar content (up to 15%) to sequester carbon and improve water retention in arid regions (Boeri, 2018).

Russia's GOST R 58875–2020 represents a significant step forward, aligning with FLL on key parameters: organic matter content (6–12%), density (<1000 kg m^{-3}), and drainage requirements (>0.6 mm min^{-1}). However, it lacks critical elements: i) No guidance on long-term substrate degradation under freeze-thaw cycles, ii) No recognition of circular economy materials (water sludge, foam glass, coir) as viable, even preferred, components, iii) No regional differentiation — the same substrate recommendations apply from north to south, iv) No performance thresholds for novel components, leaving designers to rely on trial-and-error. Consequently, most Russian green roofs utilize imported, expensive materials (e.g., perlite, vermiculite, coconut fibers) or untested local mixes, often resulting in premature failure. The absence of long-term monitoring data and research infrastructure has stifled innovation.

Methodology

1 Pilot laboratory

The foundation of this study is built upon a two-phase research evolution: 1) the establishment of the GreenRoof.PRO Open Laboratory in Moscow (2022–2024), and 2) the expansion into a national, climate-gradient research network under the Russian Science Foundation grant RSF №24-17-00134 (2024–2026). The GreenRoof.PRO Open Laboratory, located on a flat industrial rooftop in Moscow (55.75° N, 37.62° E), was the first instrumented, long-term experimental platform for extensive green roofs in Russia. It consisted of four 1×1 m experimental modules (OL1–OL4), each with identical structural layers: root protection membrane (GRPro RP), geotextile filter fleece (GRPro F), drainage layer (GRPro Drain 25 or FDK 40), substrate layer (7 or 15 cm), plant community: Sedum acre or native herbaceous species. Each module differed in substrate composition and drainage membrane type (Fig.1), allowing for controlled comparison of: substrate type (S1: 45% coir + 20% foam glass + 25% sand + 10% sewage sludge; S2: 25% coir + 25% foam glass + 25% sand + 25% sewage sludge). The pilot laboratory featured two distinct plant community types: Sedum community (Sedum ewersii, Sedum rupestre "Angelina", Sedum acre, and *Sedum spurium* "Purpurteppich"). A native herbaceous community, consisting of *Matricaria chamomilla*, *Calamagrostis acutiflora*, *Achillea millefolium*, and *Erysimum cheiranthoides*.

Figure 1. The GreenRoof. PRO Open Laboratory. OL1: substrate type S1, plant community: Sedum spp., depth: 7cm; OL2: substrate type S2, plant community: native, depth: 15cm; OL3: substrate type S2, plant community: Sedum spp., depth: 15cm; OL4: substrate type S2, plant community: Sedum spp., depth: 7cm.

The monitoring system was equipped with a suite of sensors for continuous data collection: soil moisture and temperature were tracked using "Elitech RC-4HC" and "RS485 LORA LORAWAN" sensors; a "Misol" automatic weather station recorded air temperature and precipitation; an "RS485" precipitation gauge measured runoff volume; and CO2 emissions were measured bi-weekly using a portable "EGM-5" gas analyzer with an SRC-2 soil chamber (Korytina, 2025). This pilot phase (2022–2025) generated Russia's first long-term dataset on substrate hydrothermal behavior, validated sensor durability under extreme winter conditions (–25°C), and established standardized protocols for sampling, data logging, and quality control, directly informing the design of the national network.

2. National multi-city network design (RSF №24-17-00134)

Based on the pilot's success, we launched a nationwide, three-city network in 2024, targeting three distinct climatic zones: Moscow (humid continental, mean annual temp: 5.5°C), Yekaterinburg (cold continental, mean annual temp: 1.8°C), and Rostov-on-Don (humid subtropical, mean annual temp: 12.1°C). In each city, we installed two independent experimental systems (Table 1).

Table 1. Experimental systems of national multi-city network.

System	**Scale**	**Number per city**	**Purpose**	**Replication**
Hydrological Modules (HM)	1×1 m	3 per city	Quantify stormwater runoff, retention, and drainage dynamics under controlled conditions	1 replicate per treatment (T1, T3, T5)
Ecological Plots (EP)	2×2 m	18 per city	Assess long-term vegetation succession, biodiversity, thermal buffering, and ecosystem service resilience at landscape-relevant scale	6 treatments × 3 replicates

These are the core of the RSF project. Six unique combinations of substrate and vegetation were replicated three times (Table 2).

Table 2. Experimental scheme of national multi-city network.

Option №	Substrate	Vegetation	Drainage membrane type/layer height, cm	Comparison within the city, time dynamics
T1	Universal substrate	Sedum spp.	M25/15	1 vs. 2 vegetation 1 vs. 3 substrates
T2	Universal substrate	Native Vegetation	M25/15	2 vs. 5 green roof type (membrane)

T3	Regional substrate	Sedum spp.	M25/15	3 vs. 4 vegetation 4 vs. 2 substrates
T4	Regional substrate	Native Vegetation	M25/15	4 vs. 6 green roof type (membrane)
T5	Universal substrate	Native Vegetation	M40/25	5/6 substrate
T6	Regional substrate	Native Vegetation	M40/25	-

Universal substrate included: fermented larch bark (20%) + expanded clay (30%) + sand (30%) +compost (20%). Regional substrate development was based on literature (FLL, GOST), pilot data, and local material availability, and included: Moscow: fermented larch bark (33%) + expanded clay (33%) + sand (33%) + biochar (1%); Yekaterinburg: expanded clay (30%) + sand (20%) + lowland peat (20%) + larch bark (25%) + mycorrhiza (0.2 kg/m³) + vermiculite (5%); Rostov-on-Don: expanded clay (15%) + sand (30%) + lowland peat (10%) + shiitake compost (15%) + larch bark (20%) + silt (5%) + defecate (5%).

The experimental design employs a standardized vegetation scheme to ensure comparability across the climatic gradient. The Sedum community is uniform across all three cities, comprising *Sedum ewersii*, *S. rupestre* “Angelina”, *S. acre*, and *S. spurium* “Purpurteppich”. In contrast, the native plant communities were specifically tailored for each region to test their local adaptability and resilience. For Moscow, the native mix includes *Festuca glauca*, *Achillea millefolium*, and *Thymus serpyllum*. The Yekaterinburg assemblage features cold-hardy species such as *Veronica spicata*, *Aster alpinus*, *Origanum vulgare*, *Festuca glauca*, *Dianthus acicularis*, and *Festuca rubra*. The Rostov-on-Don community is composed of drought-tolerant species like *Artemisia stelleriana*, *Frankenia laevis*, *Carex panicea* “Pamira”, and *Bouteloua gracilis*. The planting density was standardized at 36 individual plants per 4 m^2 plot for all vegetation types.

Laboratory Analysis (bi-seasonal sampling): Physical: porosity, chemical: pH, available nitrogen and phosphorus forms (photometrically), biological: microbial biomass (substrate-induced respiration), enzyme activity (dehydrogenase, peroxidase, chitinase, β-glucosidase, phosphatase). Vegetation Monitoring: cover (%), species richness, phenology (start/end of growing season), biomass harvest (annual). Modeling (future phase): HYDRUS-1D (water flux), ENVI-met (microclimate), RomulHum (carbon dynamics) will be calibrated using field data to predict long-term performance under climate scenarios. All data are stored in a unified database (GreenRoof.PRO Platform). The substrate properties will be compared using an ANOVA model, and Principal Component Analysis (PCA) will be employed to identify the dominant drivers of ecosystem service variation. This integrated, multi-scale, multi-city protocol is the first of its kind in Russia, designed to generate data directly applicable to the revision of GOST R 58875–2020 and future national green infrastructure policy.

Results and Discussion

1. Implementation and data collection status (May 2025)

In Moscow and Ekaterinburg have been successfully installed and instrumented 3 hydrological modules (1×1 m) and 18 ecological plots (2×2 m) per city (fig.2). IoT sensor networks are operational with >95% uptime since spring 2025. Bi-monthly soil and vegetation sampling is ongoing.

Figure 2. Experimental plots in Moscow, RUDN and Yekaterinburg.

2. *Preliminary findings from Moscow site (GreenRoof.PRO Open Lab)*

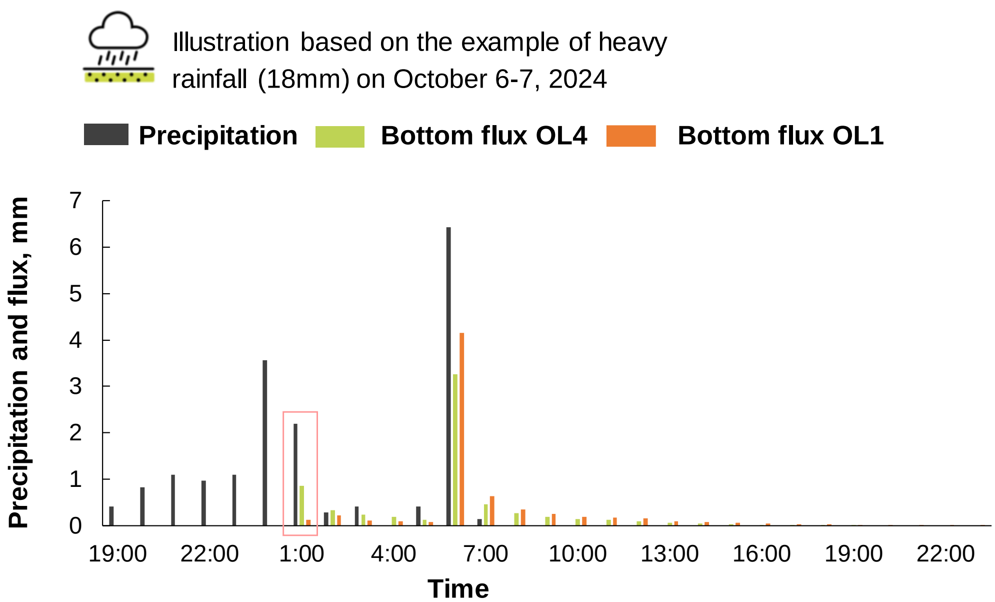

Figure 3. Precipitation and bottom flux for experimental boxes OL1 (substrate type S1, plant community: Sedum spp., depth: 7cm), OL4 (substrate type S2, plant community: Sedum spp., depth: 7cm).

Data from the original Moscow pilot (2022–2024) from 2 experimental boxes (OL1, OL4) inform the national network design and provide baseline trends: 1) During a heavy rainfall event (18 mm, October 2024), both substrates retained more than 60% of the precipitation, with S2 (25% water sludge) retaining 64% compared to S1 (10% water sludge), which retained 61% (Fig. 3). 2) Both substrates showed a 6 h delay in peak runoff, reducing stress on urban drainage systems. Maximum daily amplitude on bare roof: 76.6°C, Maximum amplitude in substrate (15 cm depth):

56.4°C. The semi-intensive roof (OL2) had the longest frost-free period: 202 days (compared to 156 days for Sedum-only and 155 days for the urban reference).

3. Preliminary findings from new sites (2024–2025)

Regional substrate (T3) in Moscow retained 22% more moisture than universal substrate during summer. Substrate moisture content gradually declined from early June to late September, with short-term peaks corresponding to rainfall events. By the end of summer, moisture levels had reached their lowest values, indicating limited water retention in the substrate under prolonged dry conditions. The substrate temperature closely followed air temperature dynamics, showing clear daily and seasonal fluctuations. Substrate temperature consistently exceeded air temperature by 2–3°C, indicating thermal buffering even under urban heat island conditions. From July onwards, the amplitude of substrate temperature variation increased, reaching maximum values in August. These patterns highlight a strong dependence of substrate microclimate on atmospheric conditions, with moisture availability progressively decreasing over the growing season.

In Yekaterinburg, substrate temperature dynamics closely followed the pattern of air temperature, with clear daily oscillations and a gradual decline toward October. Maximum values were observed in July and August, with peak substrate temperatures exceeding 30 °C during warm periods. Compared to air temperature, the substrate demonstrated a buffering effect, with slightly reduced amplitude of daily fluctuations. Substrate water content decreased steadily from June through early autumn. Two substrates showed similar trends, although the universal substrate responded more rapidly to precipitation and irrigation events, with sharp increases in volumetric water content followed by rapid drying. In contrast, the regional substrate showed more stable moisture conditions but also had a gradual long-term decline. By late September, both substrates had reached a minimal water content, indicating the progressive drying of the substrate due to plant uptake and the seasonal reduction in precipitation. Overall, the results highlight strong climatic control over substrate temperature and water availability in Yekaterinburg, with the system showing higher thermal variability but more persistent water limitation compared to early summer.

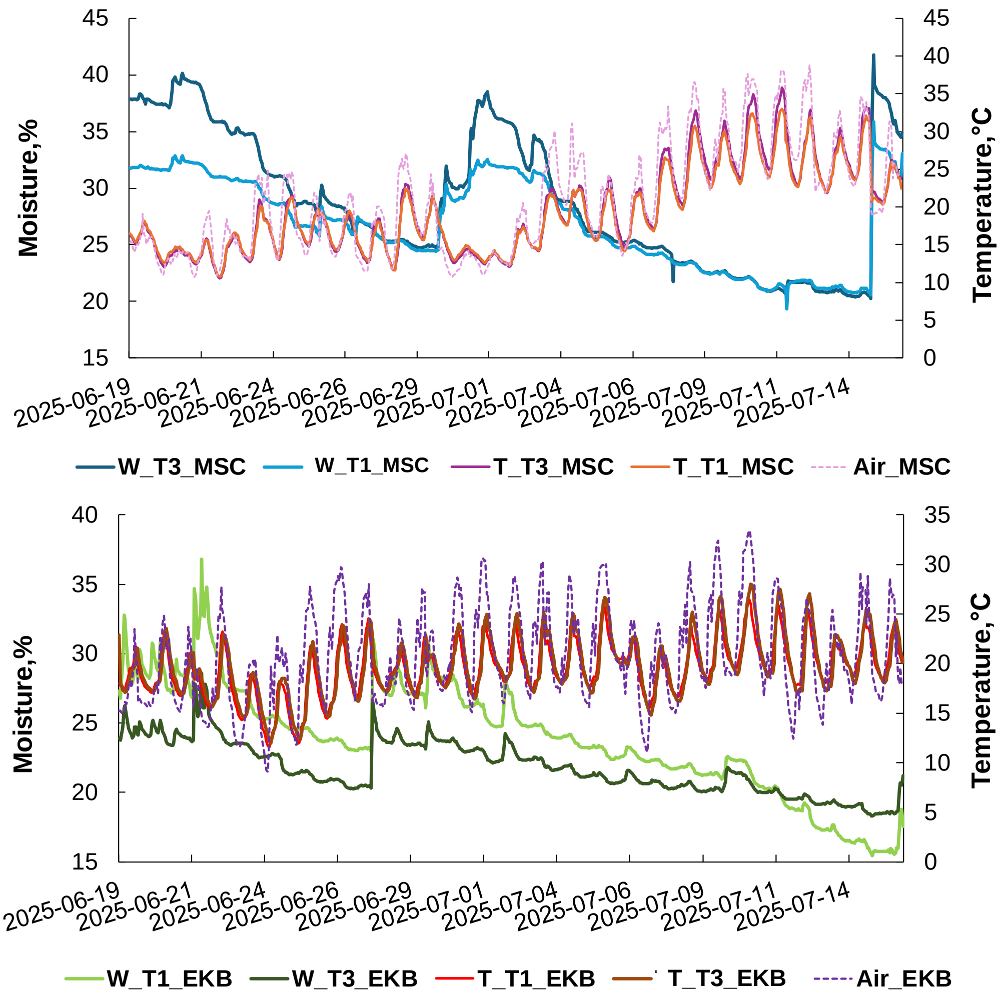

Figure 4. Moisture and temperature dynamics in Moscow (Top) and in Ekaterinburg sites (Bottom). T1 is the universal substrate and sedum plant community. T3 is the regional substrate and sedum plant community.

Conclusion

The successful implementation of a standardized yet regionally adapted vegetation scheme is a key outcome. The use of identical Sedum communities allows for a direct cross-city comparison of substrate and climate effects on a uniform plant system. Conversely, the tailored native communities for each city (e.g., drought-tolerant *Bouteloua gracilis* in Rostov, cold-hardy *Aster alpinus* in Yekaterinburg) are designed to test the hypothesis that locally-sourced flora will demonstrate great long-term resilience and ecosystem service provision, such as extended seasonal activity and higher biodiversity, as suggested by prior pilot studies [13]. The integrated sensor network provides a robust, high-resolution dataset on the biophysical processes driving these ecological outcomes

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Development of a Partıcıpatıve Approach to Co-Desıgn, Co-Create and Co-Implement Urban Green Infrastructure

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Abstract

Cities are currently confronted with numerous challenges arising from both internal and external development processes. Many of these challenges are being addressed through measures involving green infrastructure at various scales. Decision-making processes related to the introduction of greenery into urban spaces require the participation of stakeholders, including residents. The forms of such public involvement depend on the specific nature of green projects and evolve in response to changing social needs and growing awareness of the role and significance of nature in enhancing quality of life. Moreover, awareness-raising itself is developing in parallel with advances in methods for analysing and assessing nature-based solutions (NbS), while public perception and appreciation of the importance of green infrastructure in cities continue to increase.

Experience gained from several projects implementing green solutions in urban areas demonstrates the wide range of measures and tools employed to encourage different groups of residents to participate in processes of urban green regeneration. The participatory approach has evolved from project to project in response to emerging needs and challenges, such as climate change, health impacts, and the provision of attractive spaces for diverse social groups, including children and women. It has also been shaped by the specific roles and functions of greenery, particularly through approaches grounded in ecosystem services analysis and assessment. The aim of this study is to show the evolution of this participatory approach through illustrative and practical examples and case studies drawn from three projects carried out under the INTERREG Programme for Central Europe: LUMAT (2016–2019), SALUTE4CE (2019–2022) and CICADA4CE (2024–2026).

Keywords: green infrastructure, participation, NBS

Introduction

The rapid and unprecedented expansion of metropolitan areas presents significant challenges to maintaining liveable and biodiverse urban environments. Consequently, the role of urban green infrastructure and nature-based solutions in supporting urban sustainability and ecosystem services is becoming increasingly prominent and is frequently addressed in the academic literature (Lafortezza et al., 2019; Fang, 2023; van der Jagt et al., 2019). The current accelerated pace of urbanisation (UN World Cities Report, 2022) places mounting pressure on green spaces within cities. Nonetheless, residents continue to demand high-quality living conditions, including access to well-designed and accessible urban green spaces.

Urban spaces are characterised by competing demands on limited land, while multiple stakeholders simultaneously pursue greening initiatives (Mattijssen et al., 2024). In this context, governing authorities must navigate and reconcile diverse policy objectives with the often conflicting interests and needs of a heterogeneous set of urban actors (Proutsos & Solomou, 2025). To optimise the environmental outcomes of active citizenship, governments should adopt an enabling and facilitative governance approach that harnesses the transformative potential of civic engagement in environmental planning and management (Buijs et al., 2016).

Engaging a broad range of stakeholders in processes of collaborative action and learning is essential (van der Jagt et al., 2019). The involvement of diverse actors provides access to a wider set of competencies and perspectives in green space planning, thereby strengthening the potential of nature-based solutions (NbS) (Brokking et al., 2021, Fang et al, 2023). Moreover, co-creation and genuine participation constitute powerful means of ensuring the relevance, legitimacy, and public acceptance of NbS.

Against this backdrop, urban greening often constitutes a multifaceted governance challenge. The complexity of such initiatives arises from the interplay between diverse stakeholder activities and interests, policy objectives operating across multiple spatial and administrative scales, and the distinctive social, economic, and environmental conditions of each city. As a result, top-down policy approaches are increasingly regarded as insufficient for effective implementation, as they frequently fail to align with the actions and initiatives of local stakeholders and citizens (Buijs et al., 2016a).

Urban greening represents a multifaceted governance challenge that requires the coordination of diverse stakeholders, including governmental agencies, local communities, private actors, and NGOs. Effective governance must integrate cross-sectoral policies, aligning green infrastructure with urban planning, transport, housing, climate adaptation, public health, and biodiversity objectives. Ensuring equitable public participation and representation of marginalized groups is essential for inclusive decision-making, while sustainable resource allocation, long-term maintenance, and adaptive management are critical to the durability of green spaces. Additionally, governance must navigate complex regulatory frameworks, bridge knowledge and capacity gaps, and resolve conflicts and trade-offs between competing social, ecological, and economic interests. Addressing these interrelated dimensions is necessary to maximize the multifunctional benefits and long-term resilience of urban green infrastructure (Garmestani & Benson, 2013, Green and healthy Nordic cities, 2024).

A participatory approach is widely recognised as essential in the planning, implementation, and management of urban green infrastructure (UGI), which is increasingly perceived as a key provider of ecosystem services in urban environments. The engagement of local stakeholders - residents, community groups, and municipal actors - helps to ensure that UGI reflects the diverse needs, values, and lived experiences of urban populations (Buijs et al., 2016).

Public involvement is assuming increasing importance in the introduction of green infrastructure in cities for several reasons. Most notably, engaging citizens helps to ensure that green spaces and nature-based solutions are designed to address the actual needs and preferences of the local population, including marginalised groups (Buijs et al., 2016). Recent projects, for instance, have employed large-scale surveys with thousands of participants at each site to correlate the characteristics of green spaces with self-reported quality of life and well-being. Such approaches help to address gaps in knowledge regarding the impacts of green infrastructure on mental health and inclusivity.

Public participation also introduces diverse perspectives, contributing to the creation of more equitable and secure green spaces. Many local governments now require community consultation in the case of major changes to the built environment, recognising public involvement in planning processes as a standard component of most strategic developments (Cuthill, 2001, Naumann, S. et al, 2020). Through community engagement, cities are better able to identify which landscape types and settings are most beneficial for mental health, security, and inclusivity, thereby making green infrastructure more effective and broadly accepted (Ihle et al., 2024; Oosterbroek et al., 2024).

Finally, there is a growing trend towards integrating interdisciplinary research with community feedback to develop auditing tools and metrics for green spaces. These tools draw on public input to evaluate the effectiveness and accessibility of green infrastructure, thereby ensuring that projects are not only environmentally sustainable but also socially beneficial. Evidence demonstrates that participatory approaches foster co-learning, trust, and shared ownership, which in turn enhance the social acceptability and long-term sustainability of green infrastructure initiatives (Frantzeskaki et al., 2016; Langemeyer et al., 2020; Brokking et al., 2021). In other words, public involvement results in better designed, more inclusive, and more effective green infrastructure, while simultaneously promoting community well-being and acceptance.

In the context of climate change, rapid urbanisation, and widening social inequalities, participatory approaches to UGI governance are crucial for creating inclusive, resilient, and adaptive cities. These approaches may take a variety of forms, including co-design, co-creation, and co-implementation of urban green infrastructure (Boeri et al, 2022).

Co-design refers to the participatory process through which multiple stakeholders jointly conceptualise green infrastructure solutions. This phase emphasises knowledge co-production by aligning local experiential knowledge with expert-led planning. Scholars identify various forms of co-design, including participatory GIS (Radu et al., 2024), design charrettes (Frantzeskaki et al., 2021), and scenario-planning workshops (Gobin et al., 2020).

Co-creation, according to Seve et al. (2022), describes participatory processes that are more genuine and inclusive, stressing the active, bottom-up involvement of stakeholders in shaping urban environments. It moves beyond ideation towards the iterative development, testing, and refinement of UGI interventions, frequently undertaken within urban living labs or real-world experimental contexts. Examples include structured living labs in real-life settings (Frantzeskaki et al., 2021; Raymond et al., 2022), feedback loops (Arias et al., 2023), and digital co-creation platforms (Gobin et al., 2020). As Raymond et al. (2022) observe, “co-creation provides a space to prototype and test UGI interventions collaboratively, embedding social learning and adaptive governance.”

Co-implementation encompasses collective action to operationalise UGI plans, covering construction, maintenance, monitoring, and governance. Forms of participation at this stage include Community Stewardship Models (Raymond et al., 2022), Task Distribution Grids (Frantzeskaki et al., 2021), and Collaborative Governance Frameworks (Arnstein, 1969; van der Jagt et al., 2019).

The active involvement of societal stakeholders in processes of co-design, co-creation, and co-implementation yields significant benefits for research, innovation, and policy development. Such participatory approaches foster inclusivity by integrating diverse perspectives, local knowledge, and lived experiences into the design and delivery of solutions, thereby enhancing their relevance, cultural appropriateness, and overall effectiveness. Empirical evidence demonstrates that collaborative processes increase the legitimacy of outcomes, build public trust, and promote stakeholder ownership (Frantzeskaki et al., 2021, Capello et al, 2024), which in turn strengthens adoption rates and ensures long-term sustainability. Furthermore, these approaches stimulate innovation by enabling the exchange of ideas across disciplines and social groups, often generating creative, context-sensitive solutions that incorporate multiple knowledge systems (Radu et al., 2024). Co-implementation processes additionally reinforce democratic engagement, social cohesion, and accountability, while supporting more adaptive and responsive governance structures (Raymond et al., 2022). Taken together, the involvement of society as an active partner enhances both the quality and impact of interventions across sectors (Voorberg, Bekkers, & Tummers, 2015).

While social participation through co-design, co-creation, and co-implementation offers considerable benefits, it also entails critical challenges that must be carefully addressed. Facilitating meaningful engagement demands substantial time, financial investment, and human resources to ensure that processes are both inclusive and well structured (Arias et al., 2023). Without explicit efforts to involve marginalised or underrepresented groups, participatory initiatives risk reproducing existing power asymmetries, thereby undermining equity and the legitimacy of outcomes (Gobin et al., 2020). Moreover, the effectiveness of social participation is often contingent upon the willingness of institutions to share decision-making authority and genuinely integrate public input into final outcomes. In the absence of institutional commitment to power sharing and transparency, participatory practices risk becoming tokenistic, eroding trust and diminishing the impact of collaborative efforts.

The objective of this article is to review participatory approaches developed within several Interreg CE projects and to demonstrate that the integration of co-design, co-creation, and co-implementation processes in the planning and development of urban green infrastructure yields optimal results. Furthermore, the study highlights that inclusive stakeholder engagement enhances both ecological and social outcomes while ensuring sustainable, context-specific solutions for urban environments. Our study contributes new insights into collaborative governance and the processes of sustainable urban transformation.

A valuable finding presented in this article is the variability over time in the degree of engagement of city residents, from passive participation to active, fully engaged participation. This aligns with Arnstein's (1969) conceptualization of participation levels, illustrating how civic engagement can fluctuate across a spectrum from tokenism to citizen power (Fu et al., 2025).

Methodology

This study presents a selection of tools and methods employed across three Interreg Central Europe projects, each focusing on public involvement in the planning, implementation, and management of green infrastructure within urban contexts. A common characteristics of these projects is their engagement with urban management challenges, which are addressed through the application of nature-based solutions. In all three cases, public participation plays a central role, facilitated through a range of participatory tools and approaches. The analysis highlights how these methods demonstrate an evolving understanding and practice of public engagement in the governance of urban green infrastructure.

Participatory methods such as co-design workshops, citizen science, and community-based participatory research facilitate the integration of scientific and local knowledge, thereby enhancing both ecological outcomes and social equity in urban green space planning (Wilker et al., 2016; Raymond et al., 2017). A wide range of methods and tools has been developed to embed public involvement in green infrastructure projects, reflecting the increasing complexity and ambition of contemporary urban sustainability initiatives:

• Digital Tools and Platforms: Cities like Prato have advanced in using digital tools, including digital twins and online platforms, to engage citizens. These technologies facilitate participatory planning, allow for real-time feedback, and support cross-funding mechanisms where citizens can directly contribute to project financing. Such tools also enable broader and more inclusive participation, overcoming traditional barriers of time and location.

• Surveys and Questionnaires: Large-scale surveys are commonly used to gather input from diverse groups, including marginalized populations. For example, some projects deploy surveys with thousands of participants at each site to correlate green space characteristics with self-reported well-being and quality of life. This data-driven approach ensures that interventions reflect community needs and preferences.

• Workshops and Collaborative Meetings: Exchange meetings, workshops, and collaborative sessions between cities and stakeholders are organized to share experiences, co-design solutions, and build capacity. These events foster learning between cities at different stages of implementing nature-based solutions (NBS) and help transfer best practices.

• Citizen Science and Participatory Indicators: The mainstreaming of citizen science allows residents to contribute directly to data collection and monitoring, especially for biodiversity and ecosystem services. Participatory planning and governance indicators are being developed and implemented in urban nature projects, enhancing transparency and accountability.

• Standardized Templates and Frameworks: The development of indicator handbooks, data templates, and standardized evaluation frameworks supports consistent monitoring and reporting. These resources often include stakeholder engagement as a core component, ensuring that public input is systematically integrated into project evaluation and decision-making.

In summary, the implementation of public involvement in green infrastructure now leverages a mix of digital innovation, participatory research, collaborative events, and standardized frameworks, making engagement more effective, inclusive, and impactful.

Results

1 Public involvement in example projects

1.1 LUMAT project

The main objective of the LUMAT project was to strengthen integrated environmental management in functional urban areas (FUAs) through sustainable land use and the development of ecosystem services. The project was premised on the recognition that land use and management play a pivotal role in achieving the goals of sustainable environmental development. Land-use planning is intended to integrate environmental, social, and economic objectives. However, when reliant on a rigid institutional framework for fostering multi-interest cooperation, it often generates territorial conflicts and encourages the expansion of urbanised areas into agricultural or semi-natural landscapes. For this reason, environmental management should place greater emphasis on enhancing the tools available for land-use planning, in order to prevent undesirable spatial patterns such as urban sprawl and land degradation. An ecosystem-services-oriented approach also provides a promising pathway to reconcile conservation and production by developing market-based mechanisms that ascribe economic and social value to ecosystem services. In doing so, it improves human well-being by embedding economic valuation into environmental management decisions.

The action plans developed within the project for six functional urban areas in Central Europe demonstrated an integrated territorial and environmental approach to sustainable urban management, supported by a range of participatory tools. One such tool was the Interactive Visualisation Tool (InViTo), conceived as a toolbox for visually supporting the analysis, exploration, visualisation, and communication of both spatial and non-spatial data in order to facilitate policy- and decision-making processes. InViTo places particular emphasis on data sharing and the visual representation of information as vehicles for enhancing social inclusion in planning processes.

The tool generates maps in which the correlation between information and its spatial localisation becomes a crucial instrument for understanding urban dynamics and for assessing resilience in relation to specific policies. This improved knowledge base enhances decision-making by providing opportunities for better-informed choices. Accordingly, InViTo can be classified as a spatial Decision Support System (sDSS) operating as a Web-GIS platform. Importantly, it does not prescribe spatial solutions; rather, it seeks to facilitate the analysis, exploration, visualisation, and communication of data, thereby improving dialogue between stakeholders with diverse backgrounds and interests.

The system is designed to be accessible, enabling users with limited expertise in GIS technologies to set up and manage projects in a straightforward manner, while also allowing more advanced users to customise projects and associated visualisations. Moreover, InViTo is well suited for collaborative working sessions, such as meetings and workshops, due to its interactive and dynamic interface. Its quick responsiveness and visually intuitive environment support discussion, providing a shared basis for debate and enhancing collective decision-making (Microsoft Word - InViTo_OnLineTutorial_September2017_.docx).

InViTo was developed as a set of instruments designed to address a variety of spatial issues, disciplines, and case studies. The tool enables the weighting of different maps, similar to a simplified multi-criteria analysis, and allows the export of maps with applied filters and weights into multiple formats (*.csv, *.pdf, *.jpg), ensuring that outputs can be reused for a range of purposes. Access to InViTo is structured around the level of user involvement in projects. Three types of users are distinguished: project contributors, who hold personal accounts providing full access to the creation and editing of projects; project advisors, who also have personal accounts, enabling them to access non-public projects, download maps, and leave comments; and public users, who do not require an account but are limited to viewing and exploring data within publicly available projects.

In the LUMAT project, public involvement was realised through a series of stakeholder meetings dedicated to the consultation of proposed action plans (Photo 1). These action plans covered a range of topics, including the management of post-industrial sites, the resolution of land-use conflicts, and the introduction of innovative circular economy solutions in land use, such as industrial symbiosis. Consultations of this kind were primarily limited to periodic, indoor meetings where discussions were held with stakeholders, including city residents.

Photo 1 Stakeholders' meetings within LUMAT project

1.2 SALUTE4CE project

The main objective of the SALUTE4CE project was the protection and development of natural resources through the integrated environmental management of green and blue infrastructure, with a particular focus on planting native and climate-resilient vegetation in functional urban areas (FUAs) lacking large sites for this purpose. The project sought to strengthen the capacity of the public sector and related entities in managing green and blue infrastructure by making use of small urban spaces that were otherwise unattractive for alternative purposes.

The project partnership implemented the concept of Urban Environmental Acupuncture (UEA), which entails surgical and selective interventions in the urban environment, in contrast to large-scale projects requiring extensive land and substantial financial resources. Numerous small interventions distributed across FUAs were shown to generate positive effects at the wider territorial scale. To this end, the partnership developed a common methodology and criteria for selecting both sites and types of interventions, which were subsequently applied in the elaboration of action plans for four FUAs. These action plans demonstrated the effectiveness of UEA as an innovative and integrated approach to environmental management, contributing to the creation of more liveable urban spaces.

Pilot actions in the four FUAs illustrated step-by-step implementation of the UEA concept through small-scale investments. These pilots were carried out in Alessandria (Italy), Chorzów (Poland), Liptovský Mikuláš (Slovakia), and the German Impulse Region comprising Weimar, Erfurt, Apolda, and Jena. Stakeholder engagement was integral to implementation in all project cities and was structured across three levels:

- Public communication – policy-makers transmitted information to stakeholders in a one-way flow, with no expectation of input.
- Public consultation – policy-makers collected information from stakeholders, regarded as representative of broader societal views.
- Public participation – citizens, stakeholders, and policy-makers exchanged information through interactive processes.

These forms of engagement were supported by a variety of tools and measures, among which living labs were particularly important. In SALUTE4CE, living labs focused on advancing the UEA system, specifically through the identification of suitable sites within urban areas (Photo 2) and the discussion of pilot investments in small urban plots. These investments formed integral components of the future UEA system in each city.

Photo 2 Exploratory walks to identify green spaces for Urban Environmental Acupuncture in Chorzów within SALUTE4CE.

1.3 CICADA4CE project

Among recent territorial challenges the climate change is perceived as one of the most pressing problems of global character, but with very specific regional and local implications. Climate change impact in local scale of a city brings about a number of challenges which appear in different intensity depending on many various features of a city. Cities struggle with so-called urban flooding caused by torrential rains, turbulent wind, long lasting drought, overheating which causes urban heat islands. The effects of these phenomena appear in form of health problems, in deterioration of nature like e.g. dying trees, in damages of constructions and buildings and other secondary adverse outcomes. The cities` authorities develop their strategies and plans focused on mitigating these climate change impacts, in order to adapt the cities to climate change, and adjust them to present or predicted effects of climate change. But, as the analyses show (e.g. Lenzholzer S. at all, 2020: Awareness of urban climate adaptation strategies –an international overview), the efficiency of these strategies` and plans` implementation and sustainability of their effects are weakened by the lack of integration and synergies between technical/technological, environmental, economic and social innovations addressing the climate change problems, lack of engagement of social groups across city and synergies between their actions. High potential in using nature based solutions and collective actions of different stakeholders is not properly used to increase resilience of cities.

Therefore, the project CICADA4CE has highlighted the need for addressing social and natural capital by mobilizing urban ecosystems potential via functionally effective and economically efficient measures offering climate adaptive services, and by social involvement in actions integrated in sustainable process of collective decision making and implementing adaptation solutions, strengthening responsibility of the stakeholders for climate change adaptation (Photo 3).

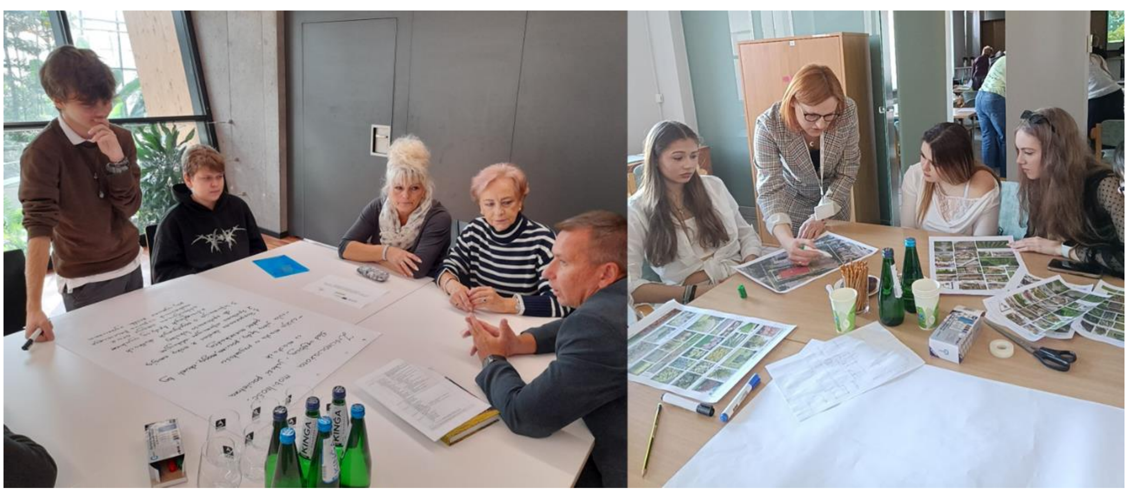

Photo 3 Intergenerational workshop in Sosnowiec on climate adaptation within CICADA4CE

The approach applied in the project is meeting the needs for strengthening urban climate resilience by mobilizing sustainable processes of common actions of the communities starting with raising awareness and involvement of local inhabitants in the development of adaptation strategies, identification of proper territory based actions, management of shared and divided responsibilities for implementation of particular interventions and their use in self-learning process in the community. To this purpose, CICADA4CE project intends to adopt specific strategies aimed at modifying the mindset and behaviours of citizens and administrations and to commit them to jointly reach the common goal. The project combines the potential of people who are aware of the necessity for climate change adaptation and believe in the powerful strength of ecosystem services which is to be mobilized by them. So first people are to be convinced that ES potential can and has to support climate change adaptation and then these people can and should mobilize this potential for acting towards climate change adaptation in urban areas.

The concept of ecosystem and community based adaptation (ECbA) is being applied in suitable action plans for the cities and further tested by means of pilot actions, which are going to give innovative solutions.
In the project the approach of Urban Living Labs has been proposed as a suitable measure for implementing the process of public involvement in co-design, co-creation, co-implementation and co-management of climate adaptation plans for 5 cities. Particular emphasis was placed on the use of ecosystem services in adaptation to climate change. Mobilizing and integration of these two potentials in the framework of Urban Living Labs will give a synergy multi-dimensional effect.
Urban Living Labs are implemented as a continuous process led according to a road map and supported by experts, whose role is to ensure an effective course of the process.

Discussion and Conclusion

The development of public involvement tools in urban management has evolved through several key stages, reflecting both technological advances and a growing recognition of the importance of stakeholder engagement (Figure 1).

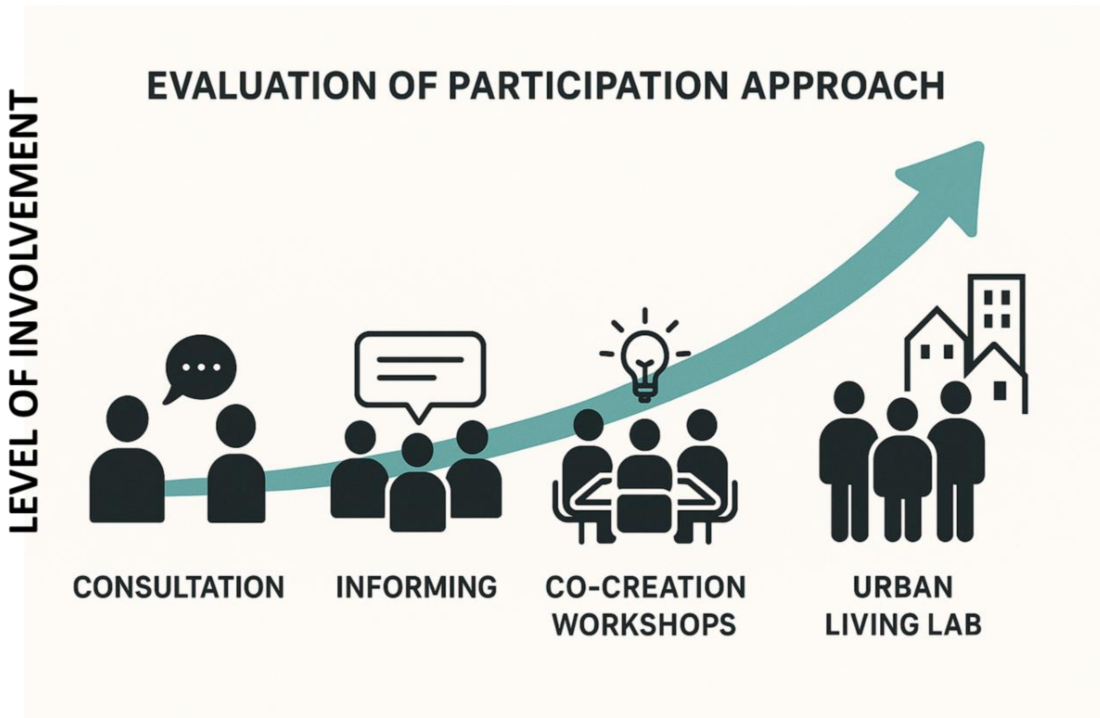

Figure 1 Evaluation of participation approach

In recent years, involvement of citizens in greenspace governance has developed from a focus on public participation in government policies towards increased active citizenship (Hoskins 2009). The projects mentioned in the previous chapters reflect the subsequent stages of development of tools and methods of social inclusion (Table 1). The examples concern urban management in case of brownfields redevelopment, green/environmental acupuncture and adaptation to climate change.

Table 1 Participatory Methods and Tools in exemplary Interreg CE projects

Project	Participatory Methods	Examples	Purpose	Tools
LUMAT	• consultations • stakeholder interviews • public events • training seminars	• co-developing land-use plans • conferences and workshops	integrate local knowledge into functional urban areas (FUA) strategies	Interactive Visualisation Tool (InViTo)
SALUTE4CE	• Urban Living Labs • digital platforms • co-creation workshops	• stakeholders co-designing green interventions • online feedback tools	foster co-creation, transparency, and local trust	concept of Urban Environmental Acupuncture implemented by living labs
CICADA4CE	• establishment of Urban Living Labs to organise inclusive cummunity participation & tranining	• public events • commented walks • public participation in creation of climate adaptation plans • intergenerational workshops	build climate resilience through inclusive ECbA planning	concept of ecosystem and community based adaptation (ECbA) implemented by Urban Living Lab

Early Approaches and Stakeholder Engagement

Initially, public involvement in urban management relied heavily on traditional methods such as public meetings, focus groups, and surveys. These approaches aimed to gather input from citizens and stakeholders but often faced limitations in reach and inclusivity. Wamsler et al. (2020) also confirms that despite the many opportunities to co-create NBS with citizens, the potential for participation and co-management is still underutilized and often limited to lower levels of citizen involvement such as information providing or consultation. Over time, the need for more systematic and standardized engagement became clear, especially as urban projects grew in complexity and scale. Stakeholder engagement became a dedicated workstream in many projects, with efforts to bring in city partners, demonstration cases, and end users who might not see themselves as "data people" but whose input is essential for effective urban management. It is proved that understanding of different groups of stakeholders is a fundamental part of any co-creation process (Morello and Mahmoud 2018a).

In case of LUMAT the redevelopment projects included investments in the city of Ruda Śląska (Poland) and Trnava (Slovakia), where the engagement of stakeholders was limited to public hearings because of a large scale investments with many technical details. Therefore the discussions were of general character concentrating on some hints concerning solutions for sports and leisure activities.

Digital Transformation and Innovative Tools

Recent years have seen a significant shift toward digital tools for public involvement. Cities and urban management projects have started using digital platforms, online surveys, and even real-time data collection via sensors and wearables to gather both quantitative and qualitative feedback from the public. For example, some projects have explored the use of digital twins, cross-funding with citizens, and innovative data visualization tools to make public input more accessible and actionable. These digital approaches not only broaden participation but also enable more dynamic and ongoing engagement, as seen in cities like Prato, which serves as a leading example in implementing diverse digital and participatory tools.

In LUMAT also the digital tools have been developed (InVito) for the city of Torino and for Dresden. The tools were meant to view and explore the data within the public projects. Case studies show that the best results in implementation green infrastructure can be achieved by combining several aspects, mainly spatial data with expectations of local stakeholders and experience of researchers to identify criteria for greening, site visits to validate the model results and translate this into concrete plans for greening several locations (Mattijssen et al., 2024).

Standardization and Best Practices

A recurring challenge in the development of public involvement tools is the lack of standardization in data collection and reporting. Efforts are underway to create standardized templates and indicators, often through collaborative processes involving city partners and demonstration sites. These templates are designed to be flexible, allowing for adaptation to local contexts while ensuring that data is comparable and useful for evidence-based decision-making. Stakeholder engagement is central to this process, with feedback loops and iterative refinement of tools based on user experience and project needs.

In SALUTE4CE the involvement of inhabitants took the form of working contacts with the designer of the urban green acupuncture (UGA) system. There were commented walks organized during which the participants were indicating specific sites in the urban area for acupuncture interventions, also with suggestions on nature based solutions to be applied. The reason was that the idea of UGA is understandable and, moreover, the selection of small plots in the urban area was much easier due to their availability.

Collaborative Learning and Exchange

Urban management projects increasingly emphasize collaborative learning, where cities at different stages of implementing public involvement tools share experiences and best practices. Exchange meetings and networks facilitate this process, enabling less experienced cities to learn from those with advanced participatory systems. This peer-to-peer learning helps accelerate the adoption of effective public involvement tools and fosters innovation across urban management contexts. By engaging a broader range of actors, urban planning can expand the pool of competencies and integrate diverse perspectives in green space planning, thereby more effectively leveraging the full potential of nature-based solutions (Brokking et al. 2021).

Project CICADA4CE is most directly related to social participation in the process of creating plans for adapting cities to climate change. Its objective addresses activating social potential for supporting urban climate adaptation and resilience by using the approach of Urban Living Labs. This method involves launching a process during which participants acquire knowledge about the role and functions of ecosystem services offered by NBS and, in subsequent stages, take an active part in designing adaptation measures with particular emphasis on green infrastructure as one of the most important adaptation factors.

Public participation in the design, management, and maintenance of urban green spaces plays a critical role in enhancing their ecological, social, and democratic value. Involving communities not only ensures that green spaces are inclusive, accessible, and responsive to diverse needs, but also fosters a sense of ownership, responsibility, and long-term stewardship. Moreover, participatory processes strengthen public awareness of the benefits of green infrastructure, encourage sustainable practices, and contribute to more effective, democratic, and resilient urban policies.

Finally, the study confirms several benefits of public involvement in creating green spaces, including:

- increasing public acceptance and support for green areas
- allowing planners to better understand the specific needs and preferences of diverse community members
- informing the public about green space designs, ensuring accessibility, safety, and other key factors
- educating the public on the benefits of green spaces, fostering a greater appreciation for nature, and encouraging sustainable practices
- strengthening democracy and decision-making processes, making policies more effective and responsive to community needs
- encouraging communities to actively participate in the maintenance and protection of green spaces.

In summary, the development of public involvement tools in urban management has progressed from traditional, often ad hoc methods to more systematic, digital, and standardized approaches. The focus is now on inclusivity, adaptability, and continuous improvement, supported by collaborative networks and real-time data integration.

The study conducted by the authors provides a foundational framework for further research on the inclusive and active engagement of urban communities in the co-design, co-creation, and co-implementation of urban green infrastructure.

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A Study on the Park Capacity of Selected Cemeteries in Istanbul

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Abstract

This study investigates the park function potential of selected cemeteries in Istanbul, focusing on their roles beyond traditional burial sites. In a highly urbanized city like Istanbul, cemeteries provide not only burial spaces but also valuable green areas that contribute to ecological balance and offer recreational opportunities for the public. The research evaluates the physical characteristics, green space distribution, biodiversity, and usage patterns of these cemeteries. Field observations, mapping techniques, and surveys were employed to assess whether the infrastructure of these cemeteries is suitable for adaptation into park spaces.

One key aspect discussed is that in some areas of the city, access to cemeteries is easier than access to parks, yet these spaces are underutilized for recreational purposes. Despite the lack or minimal presence of park-like functions, cemeteries, particularly those adjacent to residential areas, have high landscape value due to their proximity to ecological spaces. The study reveals that cemeteries can provide significant ecological services such as air purification, biodiversity support, and temperature regulation, while also serving as places for rest, reflection, and leisure.

Cemeteries are often overlooked in urban planning, yet they have the potential to make meaningful contributions to the quality of life in cities by addressing the need for more green spaces. This analysis highlights the untapped potential of cemeteries to serve as urban parks, offering spaces for public relaxation, leisure activities, and environmental services. The findings provide valuable insights into how cemeteries can be better integrated into the broader urban green space network, offering new opportunities for sustainable urban planning. By recognizing cemeteries' park-like functions, these spaces can contribute to improving ecological sustainability, increasing urban biodiversity, and offering residents and visitors alternative spaces for rest and reflection.

Key Words: Keywords: Cemeteries, park capacity, urban green space, recreation, ecological function, Istanbul

Introduction

The formal and functional transformation processes of cities are reflected not only in the spaces of the living but also in those reserved for the dead. With modern urbanization, cemeteries have evolved from being solely places of burial and mourning into public, cultural, and symbolic spaces (Rugg, 2000). This transformation necessitates a renewed sociological, spatial, and cultural evaluation of cemeteries.

Cemeteries represent not only individual memories but also the spatial embodiment of collective memory. The graves of well-known figures allow for personal commemorative practices while simultaneously symbolizing the continuity of social remembrance (Verdery, 1999). Visits to the graves of figures such as Müslüm Gürses, Yahya Kemal, Necip Fazıl, and İlhan İrem in four cemeteries in Istanbul indicate that public visibility continues even after death, positioning cemeteries as spaces of remembrance (Maddrell & Sidaway, 2010).

Cemeteries are also regarded as spaces of sensory, aesthetic, and intellectual experience. Expressions frequently heard in Aşiyan Cemetery, such as "the view is beautiful, you can't hear the traffic," support Loukaitou-Sideris's (2010) conceptualization of the "use of cemeteries as urban parks." In this context, cemeteries can be defined as quiet and peaceful public areas intertwined with nature. Especially Aşiyan and Eyüp Sultan Cemeteries, which preserve their natural texture, offer an alternative public space potential to address the lack of green areas within the city (Kong, 1999).

The frequent references to the "cemetery of the rich" or "luxury burial ground" in Zincirlikuyu Cemetery reveal that social class divisions are also visible within burial spaces. According to spatial justice debates, areas in the city that should be equally accessible to everyone have become differentiated under class-based domination (Soja, 2010). The fact that cemeteries themselves are segregated by status demonstrates that spatial discrimination persists even after death (Park, 2016).

Cemeteries have traditionally been viewed as sacred and private spaces. Indeed, some participants found activities such as drinking tea, filming, or allowing children to play in cemeteries inappropriate. Such sensitivities, as emphasized by Kong (1999), reveal the tension arising from cemeteries being both public and private spaces. This dual nature brings forth the debate over whether cemeteries should be opened as part of public life or preserved within traditional regimes of respect (Rugg, 2011).

Expressions such as "school trips," "Ottoman tombstones," and "interest in literary figures" mentioned in Aşiyan and Karacaahmet Cemeteries further reveal their educational and cultural landscape characteristics. According to Tuan (1977), places gain meaning through experience. In this sense, cemeteries serve not only as spaces associated with death but also as sites for learning and establishing cultural connections during life.

In this study, cemeteries are examined through spatial observation and participants' experiences. The findings indicate that cemeteries are hybrid spaces carrying multiple layers of meaning related to collective memory, public space use, integration with nature, social inequality, spirituality, and cultural heritage. This multifunctionality distinguishes cemeteries from other public spaces within the city, highlighting the need for their careful, inclusive, and culturally sensitive management.

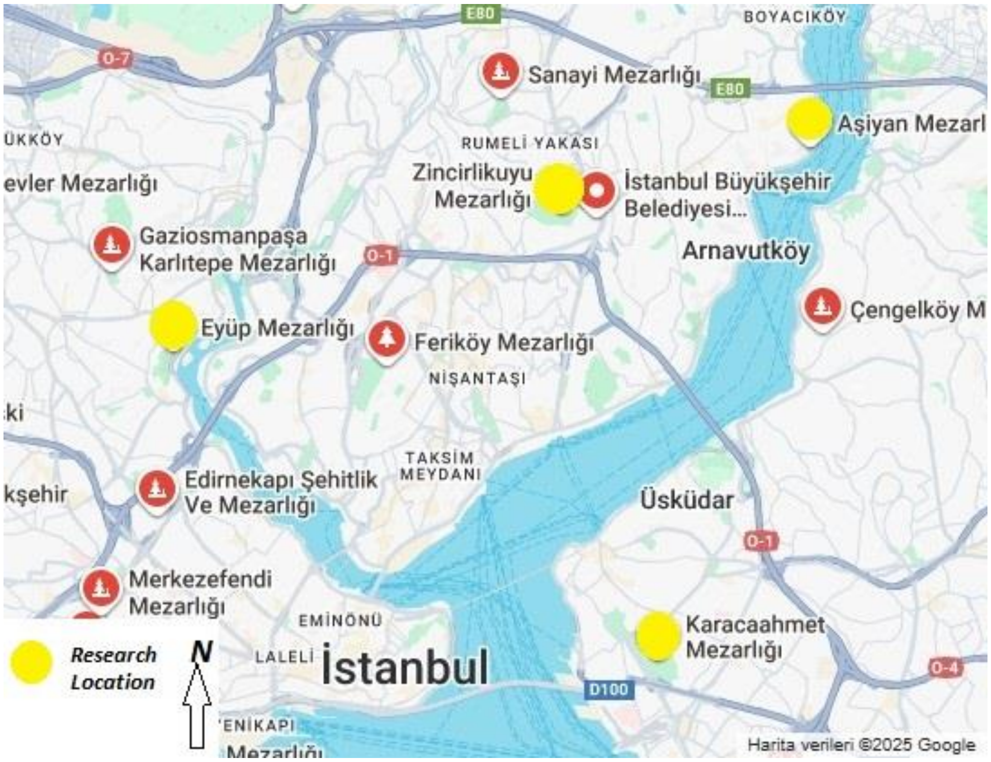


Figure 1: Location of the research cemetery area in Istanbul

In this context, four cemeteries located in central Istanbul were selected for analysis (Figure 1). The study aims to identify these areas' potential not only for providing urban ecological services but also for functioning as park spaces that people can use for recreation. Accordingly, the main research question of this study is: *"Do cemeteries in Istanbul have the potential to be used as parks?"*

Methodology

Research Design

This study is a qualitative field research conducted in four major urban cemeteries in Istanbul — Zincirlikuyu, Eyüp Sultan, Aşiyan, and Karacaahmet — based on a field study involving a total of 423 participants (see Table). The research focuses on whether cemeteries are used solely as burial spaces or whether they carry different meanings and functions. The study was structured using a **descriptive qualitative analysis** approach, aiming to identify emerging themes and patterns of meaning based on participants' experiences (Yıldırım & Şimşek, 2021).

Sample Group

Table 1 presents the distribution of participants according to age groups and cemetery locations. A total of **421 individuals** participated in the study, with relatively balanced representation across the four cemeteries. The largest number of interviews was conducted in **Eyüp Sultan Cemetery** (n=124, 29.6%) and **Aşiyan Cemetery** (n=121, 28.7%), followed by **Karacaahmet** (n=100, 23.7%) and **Zincirlikuyu Cemetery** (n=76, 18.0%).

Table 1: Distribution of Interview Locations and Age Groups

Interview Locations	Age Groups					Total	
	Under 18	18-30	31-45	46-60	60 yaş üstü	n	%
Zincirlikuyu	3	24	16	18	15	76	18,0
Aşiyan	7	55	23	24	12	121	28,7
Eyüp	9	38	43	26	8	124	29,6
Karacaahmet	2	18	27	28	25	100	23,7
Total	**21**	**135**	**109**	**96**	**60**	**421**	**100**

When analyzed by age groups, the **18–30 age group** constitutes the largest proportion of participants (n=135), followed by the **31–45 age group** (n=109). In contrast, the **under-18 group** (n=21) and the **60+ group** (n=60) are less represented. This distribution suggests that **younger and middle-aged adults** are more active users of cemetery spaces in Istanbul, either as visitors, tourists, or individuals with cultural or emotional motivations.

The relatively high number of participants in **Eyüp Sultan** and **Aşiyan Cemeteries** may be attributed to their **historical, cultural, and touristic significance**, as well as their **accessibility and scenic qualities**. These cemeteries are not only burial sites but also places that attract visitors for spiritual reflection, heritage appreciation, and aesthetic experience.

Conversely, **Zincirlikuyu Cemetery**, often perceived as a more formal and elite burial ground, has a lower number of visitors, which aligns with its **limited recreational and cultural interaction potential** compared to other cemeteries.

Overall, the data indicate that cemetery visitation in Istanbul is **not limited to older or bereaved individuals**, but also includes younger groups who engage with these spaces for cultural, historical, and experiential purposes. This finding supports the study's broader argument that cemeteries can function as **multifunctional urban spaces** with educational, ecological, and reflective dimensions beyond their primary funerary role.

Table 2: Distribution of Interview Locations by Gender

Interview Locations	**Female**		**Male**		**Total**	
	n	**%**	n	**%**	n	**%**
Zincirlikuyu	31	40.8	59.2	45	76	18.1
Aşiyan	72	60.0	40.0	48	120	28.6
Eyüp	48	39.0	61.0	75	123	29.4
Karacaahmet	36	36.0	64.0	64	100	23.9
Total	187	46.6	232	55.4	419	100

Table 2 presents the gender distribution of participants across the four cemeteries included in the study. Of the **419 respondents**, **187 (44.6%) were female** and **232 (55.4%) were male**, indicating a slightly higher participation of men in cemetery visitation and observation activities.

When the data are examined by location, **Aşiyan Cemetery** shows a notably higher number of female participants (n=72) compared to males (n=48). This finding may be associated with Aşiyan's **literary and aesthetic character**, as it hosts the graves of several renowned writers and artists, making it a place of **cultural and emotional engagement** particularly appealing to women visitors.

In contrast, **Eyüp Sultan** and **Karacaahmet Cemeteries** recorded higher male participation, with 75 and 64 men respectively. This pattern may reflect the **religious and traditional nature** of these sites, where men often take a more visible role in religious visits, maintenance, or caretaking activities.

Zincirlikuyu Cemetery, known for its modern layout and association with upper social classes, displays a relatively balanced gender distribution (31 women, 45 men), which may correspond to its **formal and institutionalized urban context**.

Overall, the gender distribution suggests that **cemetery visitation in Istanbul is not gender-exclusive**, but the purpose and motivation for visiting may vary. Women tend to engage more with cemeteries that offer **aesthetic, historical, or reflective experiences**, whereas men are more represented in **religious and traditional contexts**. This distinction reinforces the idea that cemeteries in Istanbul serve **diverse social functions** — spiritual, cultural, and symbolic — appealing to different demographic groups in varying ways.

Data Collection Process

Data were collected in April and May 2025 by the researchers directly in the cemeteries, at different times of day and on various days of the week. The main open-ended questions directed to visitors were as follows:

1. Have you noticed any particular situation, person, or activity that caught your attention in this cemetery?
2. How would you describe your behavior during your visit?
3. Did you observe other visitor profiles (tourists, researchers, staff, etc.)?
4. Were there any notable behaviors or observations?
5. Researcher’s notes/comments.

Approximately 421 qualitative responses were collected, evenly distributed across the four cemeteries. All interviews were conducted orally, with some observations recorded in note form. During the interviews, demographic data such as age, gender, and socioeconomic status were also collected.

The main focus of the study was to identify visitors’ motivations for visiting cemeteries, their activities and emotional responses during the visit, and to evaluate cemeteries not only as burial sites but also as urban ecological areas with multiple social and functional values.

Data Analysis

The qualitative data obtained were analyzed using the **descriptive analysis** approach (Creswell, 2013). The data were first transcribed, then coded, and thematic categories were developed. Codes were derived from recurring concepts, emotions, and observations found in participants’ statements.

The coding process followed four main steps:

1. All responses to each research question were compiled into separate Word documents and categorized by cemetery.
2. These documents were then uploaded to the ChatGPT artificial intelligence platform to generate preliminary theme and code tables based on the research questions.
3. The resulting tables were reviewed and verified by the researchers to ensure consistency with the data.
4. Once validated, the findings were synthesized and written up accordingly.

To enhance the reliability of the analysis, direct quotations from participants were included, and similarities and differences among the cemeteries were comparatively evaluated. For the quantitative part of the study, **SPSS** software was used to identify comparable and differing aspects between the cemeteries.

Ethical Considerations

During the interviews, participants provided informed consent, and no personal information or names were recorded. Their statements were used solely for scientific purposes and kept completely anonymous. Although the study did not require formal ethics committee approval, it was conducted in accordance with the principles of **voluntariness** and **confidentiality.** Additionally, the research received approval from the **Ethics Committee for Social and Human Sciences Research at Yıldız Technical University** on 02 May 2025.

Results

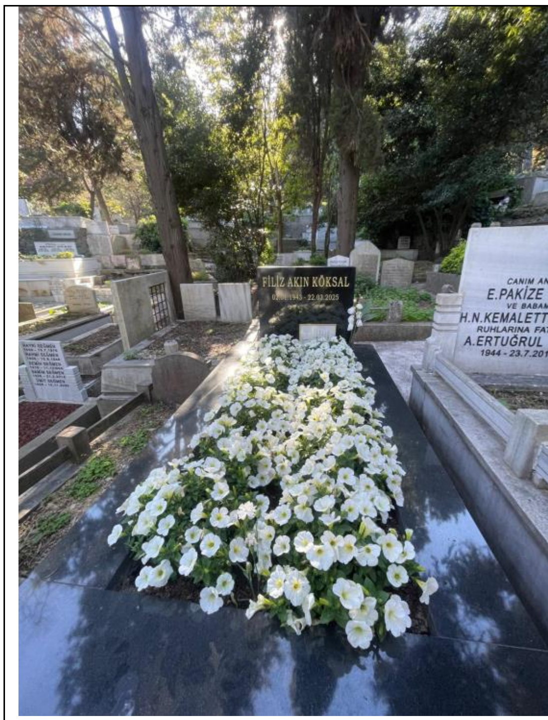
1. Prominent Elements in Cemeteries

The qualitative study conducted in four major cemeteries in Istanbul revealed that participants' responses to the question: "Have you noticed any particular situation, person, or activity in this cemetery?" can be categorized into five main themes (Table 3). These themes, derived from participants' expressions and observations, indicate that cemeteries function not only as burial and mourning spaces but also as social, cultural, and spatial public spaces.

Table 3. Distribution of Prominent Elements in Cemeteries by Theme

Theme	Codes
Celebrities and Visits	Graves of famous artists/writers (Müslüm Gürses, Yahya Kemal, Tanpınar…)
	Graves of historical figures (Fevzi Çakmak, Necip Fazıl, etc.)
	Crowded funerals, commemorative ceremonies
Maintenance and Physical Conditions	Neglect and poor maintenance of cemeteries
	Cleanliness and infrastructure (trash, fountains, pathways)
	Unattended or abandoned graves
Socio-Cultural Observations	Emotional/spiritual experiences within the cemetery
	Visits, prayers, drinking tea, daily activities in the cemetery
	Tourists, filming, students
Spatial and Structural Features	Views, natural environment, tranquility
	Lack of planning, disorder
	Concentration of tombs, historical structures
Discrimination and Criticism	Wealth/poverty-based cemetery divisions, status differences
	Damage to historic cemeteries, lack of preservation

Celebrities and Visits: The presence of famous artists, writers, and historical figures attracts visitors, highlighting cemeteries as cultural and commemorative sites. Crowded funerals and memorial ceremonies further reinforce this public function (Photo 1). Since the cemeteries in the research area are large burial grounds located in the central parts of Istanbul, each contains sections where the graves of well-known and beloved cinema and music artists, writers, and influential figures who have guided society are found. These areas draw visitors to the cemeteries. In Photo 1a, the grave of Filiz Akın, one of the prominent actresses of Turkish cinema, can be seen in the Aşiyan Cemetery, located along the Bosphorus. Many visitors come to Aşiyan to see her grave. In Photos 1b, the grav of prominent vocal artist of Turkish music is shown. These graves are frequently visited by their fans, who often leave various gifts as tokens of affection and remembrance.



1a. Aşiyan Cemetery (Filiz Akın)

1b. Zincirlikuyu Cemetery (Müslüm Gürses)

Photo 1. The graves of well-known cinema and music artists are the most frequently visited spots within cemetery areas.

Maintenance and Physical Conditions: Participants noted issues of neglect, inadequate cleanliness, and poorly maintained graves, emphasizing the role of cemetery management and infrastructure in shaping visitor experiences.

Socio-Cultural Observations: Cemeteries serve as spaces for emotional reflection, prayer, casual visits, or even social interactions such as drinking tea. They also attract tourists, students, and media crews, suggesting multifunctional usage.

2a.Zincirlikuyu cemetery: Mezarlık ana girişinde dinlenme noktası

2b. Karacahmet Cemetery: Dini cemaat mensuplarının cemaat önderinin mezarı başında etkileşim

Photo 2: Cemetery areas as places of social interaction

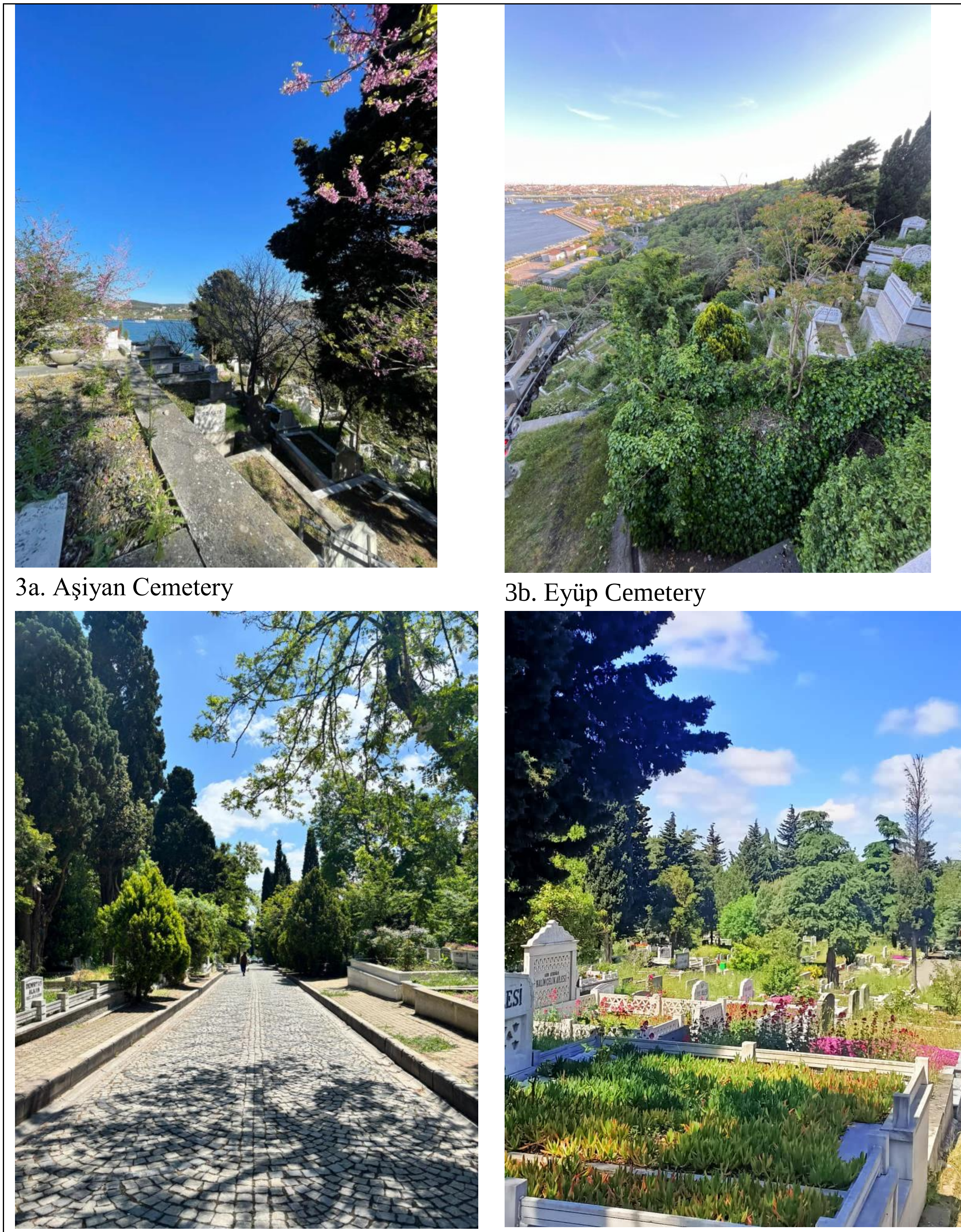
Spatial and Structural Features: Visitors valued natural views, tranquility, and historical architectural elements. Conversely, poor planning or disorderly layouts were criticized, indicating the importance of design and spatial organization.

The photograph clearly reveals the spatial and structural characteristics of **Aşiyan Cemetery**. Situated on a sloping terrain overlooking the Bosphorus, the cemetery features a terraced layout that harmonizes with the topography, offering a scenic view of the sea. The graves are arranged on different levels, connected by narrow pathways and stepped passages. The vegetation mainly consists of pine, cypress, and flowering trees such as Judas trees, which provide both shade and natural boundaries within the site. The lush greenery and blooming trees in the photograph lend the cemetery a serene and aesthetically pleasing landscape, while the Bosphorus view enhances its tranquil and contemplative atmosphere. With these qualities, Aşiyan Cemetery stands out as one of Istanbul's most distinctive burial grounds, both culturally and ecologically (Photo 3a).

The photograph clearly illustrates the spatial and structural characteristics of the **Eyüp Cemetery**. Situated on a hillside overlooking the Golden Horn, the cemetery features a terraced layout that adapts to the natural topography. The graves are arranged parallel to the slope, combining both historical and natural landscape elements. Dense vegetation—particularly ivy, cypress, and pine trees—defines the natural boundaries of the area and creates a lush green cover. The photograph highlights the cemetery's integration with the Golden Horn view, enhancing both its spiritual and visual significance. Narrow pathways and stepped routes connect different levels, ensuring pedestrian access throughout the site. With these features, Eyüp Cemetery stands out as a unique urban open space that reflects both Istanbul's historical identity and its natural landscape character (Photo 3b).

Karacaahmet Cemetery, one of the oldest and largest burial grounds in Istanbul, represents a unique urban landscape where natural structure and historical continuity coexist. As seen in the photo, the wide cobblestone pathways, tall tree canopy, and orderly arrangement of graves reflect the site's harmonious balance between nature and culture. Spatially, Karacaahmet Cemetery follows a layout adapted to the natural topography. The central cobblestone path visible in the image forms a strong linear axis that guides visitors through the space. This axis connects different sections of the cemetery while establishing a monumental perspective. On both sides of the path, the graves are arranged in a symmetrical and organized manner, bordered by low vegetation and stone edges that define the burial plots. Structurally, the ground surface consists of small-scale natural stone paving, which contributes to the site's historical aesthetic while ensuring permeability for rainwater. The curbstones lining the edges of the path reinforce its linearity and order. The graves, mostly constructed of marble and natural stone, display a restrained yet harmonious architectural style consistent with the overall atmosphere of the site. Vegetation plays a defining role in the cemetery's character. Along the pathways, tall species such as cypress, pine, and oak trees create shaded areas and provide a sense of serenity and solemnity. Between them, shrubs and groundcovers soften the hardscape surfaces, enhance biodiversity, and contribute to the ecological value of the space. One of the remarkable features of Karacaahmet Cemetery is the balance between open and enclosed spaces. The tree trunks and branches form a natural canopy at the pedestrian level, offering shade and enclosure, while the visible sky above maintains a feeling of openness and lightness. This combination creates a tranquil and contemplative atmosphere, reinforcing the cemetery's role as both a place of remembrance and an urban ecological corridor. In conclusion, this section of Karacaahmet Cemetery illustrates the harmonious coexistence of natural landscape and human design. Through its spatial order, material integrity, and vegetative richness, the cemetery serves not only as a burial ground but also as a cultural landscape representing Istanbul's ecological and historical memory.

Zincirlikuyu Cemetery; located in a central part of Istanbul, Zincirlikuyu Cemetery represents a significant green space within the dense urban fabric, serving as both an ecological and cultural landscape. As seen in the photo, the cemetery is characterized by its rich vegetation, terraced layout, and orderly arrangement of graves. Spatially, the site occupies a slightly sloping topography, organized into terraced levels supported by low stone walls and marble borders. This terraced configuration allows for efficient use of space and effective drainage management during rainfall. The arrangement also provides a clear spatial hierarchy and rhythm across the cemetery landscape. Structurally, the cemetery exhibits diverse grave forms and materials, reflecting traditional burial architecture. The gravestones are predominantly made of marble, travertine, and natural stone, with varying geometric patterns and engraved inscriptions that contribute to the cemetery's historical and aesthetic identity.



3a. Aşiyan Cemetery

3b. Eyüp Cemetery

3c. Karacaahmet Cemetery

3d. Zincirliyuyu Cemetery

Photo 3: Sections from the general view of the ecological and environmental features of the cemeteries included in the research in Istanbul

The vegetation is an essential element of the site's structure. Succulents, flowering groundcovers, roses, and junipers are commonly used for their aesthetic appeal and low maintenance requirements. Tall and mature trees—such as cypresses, pines, and plane trees—dominate the upper canopy, providing shade and reinforcing the monumental atmosphere typical of traditional cemeteries. This vegetation also adds visual depth and seasonal color variation to the landscape. The internal pathways are generally narrow, winding, and adapted to the natural topography, dividing the cemetery into smaller sections while maintaining overall spatial coherence. Along these paths, planted strips and flowerbeds soften the hardscape surfaces, creating a calm and contemplative atmosphere suitable for visitors. Overall, Zincirlikuyu Cemetery functions not only as a place of remembrance but also as an important urban green corridor, preserving ecological continuity within the city. It embodies a harmonious coexistence of nature, culture, and memory in the heart of metropolitan Istanbul (Photo 3d).

Discrimination and Criticism: Socioeconomic differences were visible within cemeteries, with wealthier areas receiving better maintenance. Concerns were also raised regarding the deterioration of historical cemeteries, reflecting social and cultural tensions.

Overall, these findings demonstrate that cemeteries in Istanbul operate as multifaceted urban spaces, combining elements of commemoration, culture, recreation, and social interaction.

2. 2. Cemeteries as Urban Parks

Table 4. Assessment of Cemeteries' Potential for Urban Park Use educational and culturally significant spaces, contributing to collective memory.

Positive Aspects	Limiting Factors
Quiet, peaceful, and natural environment	Neglect and infrastructure problems
Cultural and historical richness, educational function	Perception of the cemetery as a sacred place (cultural sensitivity)
Presence of social activities such as tea-drinking, sitting	Security, behavior, and lack of public control
Scenic views, trees, architecture — especially Aşiyan and Eyüp Sultan Cemeteries	Rights and privacy expectations of grave owners

2.1 Supporting Factors

a. Silence and Natural Environment

Aşiyan and Eyüp Sultan Cemeteries were frequently described as "quiet, peaceful, and immersed in nature."

Aşiyan: "The view and tranquility are wonderful," "No traffic noise, very calming."

Eyüp Sultan: "There is a lot of greenery (trees)," "Some cemeteries smell very nice."

These observations indicate that cemeteries possess park-like qualities through their natural serenity and green landscape.

b. Non-Visitation Uses

Zincirlikuyu Cemetery:

> "I would like to bring children to play. It should be like cemeteries in France."
> "There are places to drink tea; the tea vendor is present."

Karacaahmet Cemetery:

> "Foreign tourists were walking around with cameras and maps," "A group prayed at a grave together."

These uses suggest that cemeteries could serve as social and recreational spaces similar to urban parks.

c. Cultural and Educational Visits

Aşiyan Cemetery:

> "I came across a school trip," "I wanted to see the graves of writers because I read a lot of books."

Karacaahmet Cemetery:

> "The Ottoman inscriptions on the tombstones caught my attention; I like reading them."

These findings highlight cemeteries as educational and culturally significant spaces, contributing to collective memory.

2.2 Limiting Factors for Park Use

a. Maintenance Deficiencies and Infrastructure Problems

Complaints were especially frequent in Zincirlikuyu and Karacaahmet Cemeteries:

> Neglected graves, trash, narrow paths, broken pavements.
>
> "Weeds have grown up to my height," "Walking paths are in poor condition."

Such physical conditions constitute a **significant barrier** to park-like usability.

b. Societal and Cultural Sensitivities

Some participants reacted negatively to the idea of using cemeteries as parks:

> "It is a spiritual place; nothing different should happen here," "If it's not acceptable in a mosque, it shouldn't be a park here either."

Cemeteries' perception as sacred or private spaces creates **cultural resistance** to unrestricted public use.

c. Safety and Inappropriate Behaviors

For Eyüp Sultan and Karacaahmet, certain concerns were noted:

> "At night, young people gather and litter the area," "Problems with dogs," "Aggressive security personnel."

These factors indicate **behavioral risks** that may limit safe and peaceful use as public spaces.

Overall, some cemeteries in Istanbul — particularly Aşiyan and Eyüp Sultan — exhibit features closely aligned with the concept of urban parks, such as tranquility, natural surroundings, and historical/cultural value. However, social sensitivities, maintenance deficiencies, and legal/cultural limitations suggest that their use as parks should be limited, controlled, and conducted respectfully, rather than fully open for unrestricted recreational purposes.

Discussion and Conclusion

The findings obtained from observations and interviews conducted in four major cemeteries in Istanbul — Zincirlikuyu, Eyüp Sultan, Aşiyan, and Karacaahmet — indicate that cemeteries are not merely sites for burial and mourning; they also carry social, cultural, and spatial significance**.** This aligns with recent discussions on the re-evaluation of cemeteries as urban spaces (Çelik & Tanyeli, 2021; Rugg, 2000).

Firstly, visits to the graves of prominent individuals in all four cemeteries demonstrate that these spaces function as sites of collective memory. For example, visits to figures such as Müslüm Gürses, Yahya Kemal, Necip Fazıl, or İlhan İrem show that graves operate not only as individual mourning spaces but also as stages of public memory**.** This observation corresponds with the literature on cemeteries' symbolic space function (Verdery, 1999) and the concept of posthumous public visibility (Maddrell & Sidaway, 2010).

Moreover, the observed **tranquility, natural integration, scenic views, and historical depth**, particularly in Aşiyan and Eyüp Sultan Cemeteries, indicate that these areas provide functions similar to **urban parks**, such as meditation, reflective retreat, and relief from daily stress. In this context, the notion that cemeteries could be considered **new types of public spaces** resonates with the discussions on urban deathscapes by Loukaitou-Sideris (2010) and Kong (1999).

On the other hand, **physical limitations** such as neglect, infrastructure issues (trash, overgrown vegetation, narrow paths), and spatial disorder were highlighted by many participants as barriers to cemeteries' potential park function. Rugg (2011) argues that in modern cities, cemeteries transform into spaces that are simultaneously forgotten and burdened with maintenance responsibilities, a perspective supported by the findings of this study.

At the **societal level**, some participants emphasized that cemeteries are spiritual, sacred, and private spaces, suggesting that activities such as tea-drinking, playing, or filming may exceed the boundaries of **respectful use**. These sensitivities align with Park's (2016) observation regarding the **role of cultural norms in the public use of cemeteries**. Therefore, integrating cemeteries into urban life is possible only within clearly defined limits that respect local cultural values and religious/spiritual contexts.

Finally, examples such as the observation of historic tombstones and visits to writers' and poets' graves for educational purposes indicate that cemeteries should also be considered as **cultural landscape elements**. This was particularly evident in Karacaahmet and Aşiyan Cemeteries. As Tuan (1977) emphasizes, "the meaning of place is shaped by human experience"; from this perspective, cemeteries are spaces where meaning is constructed not only through death but also through life.

In conclusion, the qualitative data from this study reveal that cemeteries in Istanbul are **multilayered urban spaces**, intertwined with memory, culture, religion, identity, and nature. Consistent with contemporary literature, particularly in the cases of Aşiyan and Eyüp Sultan Cemeteries, these spaces can be redefined as "quiet parks" or "memory gardens"**.** However, such transformations must be approached in conjunction with local sensitivities, cultural norms, and physical infrastructure improvements**.**

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Urban Flood Exposure and Disaster Risk in Alsancak, Izmir: Insights from a 500-Year Flood Scenario and Nature-based Adaptation Strategies

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Abstract

In recent years, the frequency and intensity of fluvial floods have increased significantly due to climate change, which has intensified extreme rainfall events. This trend poses growing risks to densely populated and highly urbanized areas, making urban flood risk a critical consideration in city planning and disaster risk management.

This study examines the impacts of flooding caused by the Meles Stream in the Alsancak District of Konak, one of the most densely built-up areas in İzmir. It aims to answer the question: "How many buildings and what percentage of the vulnerable population are exposed to a 500-year flood event occurring over a 24-hour period?" To assess potential exposure, a 500-year flood scenario was modeled using the HEC-RAS 2D flood simulation tool.

The results show that floodwaters extend across 35.24 hectares, advancing from the river channel into the urban core. Approximately 70% of Alsancak's population (14,621 people) is exposed to flooding, including 4,466 individuals identified as part of vulnerable population groups. Additionally, 72% of the district's 2,560 buildings are affected. These impacts pose serious risks to daily life, infrastructure, and public safety.

Given the scale of exposure, the findings highlight the urgent need for localized adaptation strategies. To improve flood resilience in Alsancak, the study recommends the implementation of site-specific Nature-based Solutions (NbS) at multiple scales. Potential NbS strategies include the restoration of riparian zones, integration of permeable surfaces, creation of urban wetlands, and expansion of green corridors. These measures can reduce surface runoff, slow floodwater progression, and increase infiltration, thereby mitigating flood risks while contributing to long-term climate adaptation.

Key Words: Fluvial flooding, vulnerability, sensitive populations, Nature-based Solutions

Introduction

The effects of climate change have led to an increase in extreme rainfall events on a global scale, significantly heightening flood risks (IPCC, 2021). Particularly in densely urbanized areas, the rise in impervious surfaces and the inadequacy of infrastructure systems cause rainfall to turn into flash floods in a short time (IPCC, 2012; Kundzewicz et al., 2014). Such events threaten not only physical infrastructure but also human life, creating serious challenges in terms of disaster management (UNDRR, 2020).

Floods have disproportionately severe impacts on vulnerable communities, especially in urban areas. Elderly individuals, children, persons with disabilities, and socioeconomically disadvantaged groups are at greater physical and social risk during disasters (Cutter et al., 2003; Wisner et al., 2004). Therefore, a comprehensive risk assessment that considers not only physical exposure but also demographic vulnerability is essential (Birkmann et al., 2013).

Various hydrodynamic models are effectively used to model flood risk in urban areas. When integrated with high-resolution topographic and hydrological data, these models can realistically simulate spatial extent, depth, and flow velocity of floods, providing detailed and reliable results (Snikitha et al., 2025). Their use offers significant advantages in determining and predicting flood risks, especially in small- to medium-sized basins with dense urban development. In this context, hydrodynamic models are widely preferred in urban flood analyses and provide decision-makers with reliable data (Teng et al., 2017).

In recent years, the increasing potential of short-duration, high-intensity rainfall to trigger urban flooding has further emphasized the importance of spatially modeling flood risk and identifying exposed buildings and communities. Identifying vulnerable groups and structural components in advance plays a critical role in developing disaster risk reduction strategies (Alfieri et al., 2017). In this regard, exposure analyses not only quantify existing risks but also support the prioritization of interventions.

Flood events in cities within the Mediterranean basin have increased in recent years due to the combined effects of climate change and urbanization (Nastos and Saaroni, 2024). Numerous scientific studies report that short and intense rainfall events, particularly in the coastal cities of Spain, Greece, and Italy, frequently lead to floods and that this situation has intensified due to the joint effects of climate change and urbanization (Wolf et al., 2020; Faccini et al., 2021). Based on this information, high-risk areas can be identified through flood exposure analyses, enabling the development of disaster risk reduction strategies within urban planning processes, and thus helping to prevent the devastating impacts of floods.

The aim of this study was to determine flood exposure in the Alsancak neighborhood of Konak district, one of the central districts of İzmir, which frequently experiences flood disasters. The research question was defined as follows: Under a 500-year return period flood scenario occurring within a 24-hour timeframe, how many buildings and what percentage of the vulnerable population would be exposed?

Study Area

The study area is the Alsancak neighborhood, located within the Konak-Meles Basin boundaries, through which the Meles stream passes in the Konak district of İzmir (Figure 1). Flowing from the south to the north of the basin, the Meles stream passes through densely built-up areas and discharges into the İzmir Bay. The length of the Meles stream is approximately 24.56 km. A large portion of the stream corridor has been converted into a concrete channel, and the channel width varies between 8 and 50 meters throughout the basin.

Alsancak is located to the south of the İzmir Bay and to the north of the Konak-Meles Basin, covering an area of 2.61 km². The Meles stream channel passes through the eastern boundary of the neighborhood and discharges into the bay. The section of the stream passing through this neighborhood has also been converted into a concrete channel, with an average width ranging from 18 to 30 meters.

To the north of Alsancak lies the Alsancak and İzmir ports. In the southern and southwestern parts of the neighborhood, commercial and industrial buildings are predominant. Residential areas and housing-type buildings are densely located in the western part of Alsancak. The total population of the Alsancak neighborhood is 14,621, of which 30% consists of vulnerable groups, including young and elderly residents.

İzmir has a Mediterranean climate, characterized by hot and dry summers and mild, rainy winters. The annual average temperature is 18°C. The average number of rainy days per year is 77 mostly between December and March and the total annual precipitation is 712.1 mm (TSMS, 2025).

In recent years, sudden heavy rainfall events have caused severe flood disasters in İzmir, resulting in both loss of life and property damage. Notably, during the flood disaster in 2021, approximately 130 mm of rainfall fell in one night. In the Alsancak neighborhood, several areas were inundated, causing damage to many homes and businesses. In 2023, excessive rainfall throughout İzmir led to further flooding events that adversely exposed urban functions (AFAD, 2023).

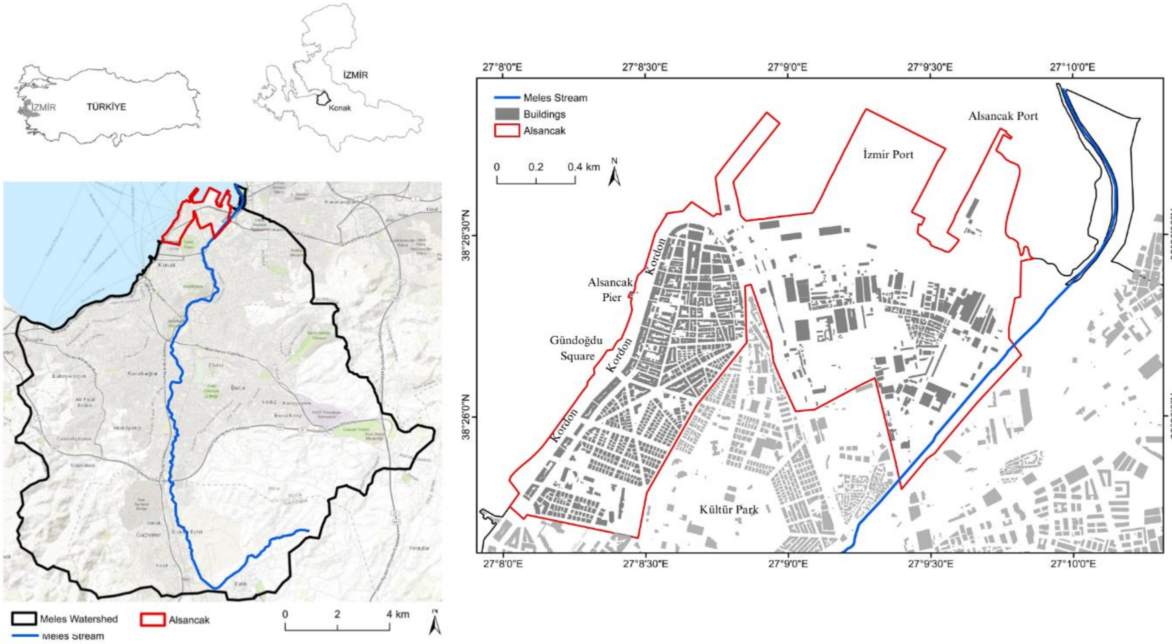

Figure 1. Study area

Methodology

In this study, the 2D hydraulic model HEC-RAS 6.5, which successfully estimates areas exposed to floodwaters, was used (Samarasinghe et al., 2022; Siakara et al., 2024). The model performs flood simulations by solving equations that calculate water depth and flow velocity, taking into account gravitational and frictional forces (HEC-RAS 2D User Manual). The geographic data required for the HEC-RAS 2D flood model were provided by a Digital Surface Model (DSM) with a spatial resolution of 0.5 x 0.5 meters, obtained from the General Directorate of Mapping. The DSM data were defined within the HEC-RAS 2D flood model to represent the topographic structure of the study area.

For the 2D river flow analysis, a grid structure with cells sized 30 x 30 meters was created using the RAS-Mapper tool in order to determine water flow velocity and depth at the cell level. The Manning's roughness coefficient required for unsteady flow calculations was defined between 0.25 and 0.35 based on the characteristics of the riverbed.

The 2D flood simulation for the Meles stream was run using a Q500 discharge value of 262.57 m^3/s, as specified in the Basin Flood Management Plan of the Ministry of Agriculture and Forestry, over a 24-hour period. The simulation results were converted into flood hazard maps using ArcGIS 10.8.2 software.

In this study, vulnerable groups were defined as young and elderly individuals. Census data for the elderly population (aged 65 and above) and the young population (ages 0–16) were used as indicators of vulnerability. Population data with a spatial resolution of 1 km^2 for İzmir were obtained from the address-based population database of the Turkish Statistical Institute. The population grid data were intersected with building data obtained from İzmir Metropolitan Municipality in order to determine the total population exposed to urban flooding.

Results and Discussion

The river flood simulation shows that the flood originated in the southern part of the Konak-Meles Basin and advanced northward, eventually reaching the coastal Alsancak area (Figure 2a). Approximately 13% of the total flood extent within the basin exposed Alsancak, covering an area of 0.35 km² (Figure 2b).

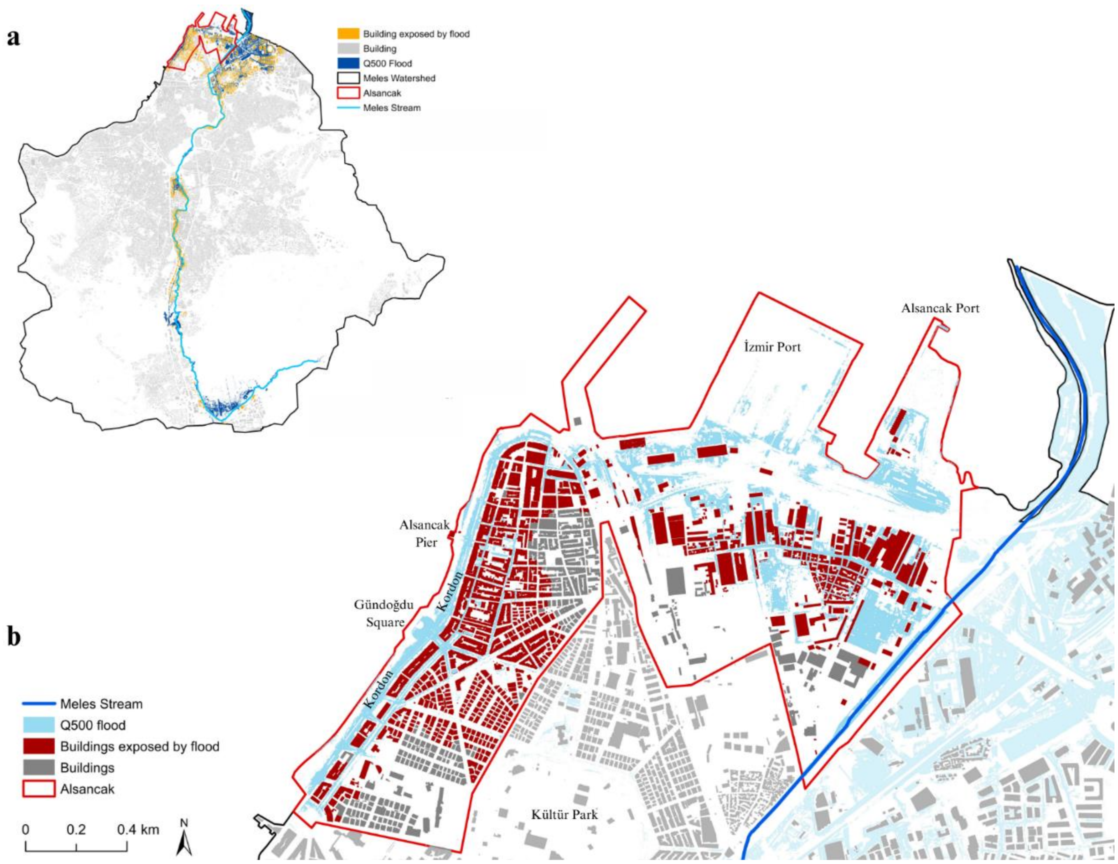

Figure 2. a Konak-Meles watershed flood, **b** Alsancak flood

A total of 1.851 out of 2.560 buildings in Alsancak were exposed by floodwaters, indicating that 72% of the neighborhood's buildings are exposed to flood risk. Although the flood covered only 13% of Alsancak's area, the large number of exposed buildings reveals the neighborhood's high building density and its vulnerability to flood impacts.

The floodwaters caused inundations on the school campus located near the river, resulting in the exposure of structures in the area. The flood then advanced in a northern and northwestern direction, reaching Alsancak Port approximately 500 meters away, where it spread extensively and led to the exposure of buildings surrounding the port. Moving westward through the neighborhood, the floodwaters extended toward the coastal areas, reaching Gündoğdu Square and the Kordon district, submerging wide areas along the coastal road. Particularly, the buildings lining the street in the Kordon area experienced significant exposure during this process.

A total of 830 apartments are located on the ground floors of 196 flood-exposed buildings in Alsancak, all of which are impacted by the flood. Additionally, 149 apartments located in the basement levels of 32 exposed buildings are exposed to flood risk.

Vulnerable individuals make up 30% of Alsancak's total population. Among the 4.466 people classified as vulnerable, 3.154 are elderly and 1.312 are children and youth. Of these, 2.177 elderly and 906 young individuals are exposed by flooding. This means that 69% of both vulnerable groups have been exposed to the flood. The high number of vulnerable people exposed highlights the potential structural and social challenges Alsancak may face during and after the disaster.

Conclusion

In this study, the spatial impacts of a 24-hour Q500 flood scenario occurring in the Konak-Meles Basin were analyzed using the HEC-RAS 2D hydrodynamic model. Although only 13% of Alsancak Neighborhood's area was submerged as floodwaters advanced from the southern part of the basin toward the neighborhood, the majority of the buildings in the area were exposed by the flood. This indicates that high building density and insufficient spatial planning significantly increase flood risk.

The flood extended particularly into coastal transportation, commercial, and public areas, severely impacting buildings located near the port, university campus, and shoreline. The flood disaster not only damaged physical infrastructure but also deepened social vulnerability due to the high proportion of exposed vulnerable population.

To mitigate the impacts of floods, promoting nature-based solutions in urban areas under development pressure is of critical importance. Reducing impervious surfaces and implementing green infrastructure can effectively limit surface runoff, and thereby reduce flood formation and spread. Additionally, identifying vulnerable groups in advance, supporting them with early warning systems, and prioritizing them in post-disaster response plans will help alleviate the social consequences of floods. The findings emphasize the need to address both structural and non-structural measures through an integrated approach and highlight the necessity of multi-scale strategic planning for flood risk reduction.

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