

## Integrating nature-based solutions in cities: Strategic approaches with a focus on green gullies and linear parks

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### ABSTRACT

Effective implementation of nature-based solutions (NBS) in urban environments requires precise tools to support site selection, considering complex spatial, environmental and institutional conditions. The presented study refers to this issue in relation to two NBS types, which are pro-ecological gullies development and linear parks implementation. It focused on three main objectives: (1) to assess the feasibility of implementing these NBS types in urban areas, (2) to translate the IUCN Global Standard into operational local site-selection criteria, and (3) to identify both best-suited and optional locations through a multi-stage GIS-based analysis in relation to Lublin (Poland) case study. The methodology was based on the six local assessment dimensions: legal, environmental, economic, ecological, social and technical. A multi-stage exclusion procedure was applied, resulting in the identification of 32 optional and 6 best-suited locations for pro-ecological gullies development, as well as 84 optional and 3 best-suited locations for linear parks. The most significant localization factors were related to legal issues link to spatial planning policy and plans. The outcome of this study is a geospatial database of NBS possible locations that serves as a transparent and repeatable decision-support tool for planners and local authorities.

**Keywords:** global standards for nature-based solutions, pro-ecological gully development, linear park, urban planning, Poland.

### INTRODUCTION

Due to the increasing impacts of climate change and urbanization, urban ecosystems are at risk of degradation due to rising temperatures, increased occurrence of extreme weather events, expansion of built-up areas, overexploitation of natural resources, and habitat loss (Castelo et al., 2023, Kabisch et al., 2016). This poses a threat to the spatial sustainability of urban areas. Past strategies that relied on grey infrastructure are outdated, and cities need new, greener solutions that integrate nature into the urban environment from a more holistic perspective. Therefore,

sustainable and resilient measures need to be implemented in planning and development to enable cities to adapt to these changes (Chrysoulakis et al., 2021). Furthermore, ecosystems that support natural processes, or elements that replicate these processes through appropriate spatial planning, provide the greatest environmental benefits (Dremel et al., 2023, Wójcik-Madej et al., 2025). As a result, nature-based solutions (NBS) have been recommended by the European Commission and the International Union for Conservation of Nature (IUCN) as an approach to restore urban areas (e.g., Dumitru and Wendling Eds., 2021, EC, 2015, IUCN, 2020). NBS are now widely used in

many European cities, and beyond, as alternatives to grey or even hybrid solutions. This shift reflects a long tradition of urban planners seeking to connect cities with nature to increase synergies and address the challenges of anthropogenic pressures.

NBS encompasses many types of interventions and actions used in urban design. They are significant differences in various aspects, including the scale of implementation, the level of anthropogenic impact, and functionality. Each type of NBS therefore requires a different planning and engineering approach. At the plot level, issues such as access to water infrastructure, soil conditions, or sunlight may be important, while at the urban landscape scale, ecosystem linkages, integration with existing green networks, and adaptability to climate change become crucial (Albert et al., 2021, Castellar et al., 2021, Van Rooij et al., 2021). Furthermore, the effectiveness of the implemented NBS is highly dependent on site conditions, including responses to social challenges, ecosystem types, specific landscape characteristics, and the socio-economic systems (IUCN, 2020, Sowińska-Świerkosz et al., 2024). Strategically deployed NBS can perform macro-ecosystem functions, such as improving air quality or protecting against flooding, while locally adopted solutions focus on improving the quality of life of residents, such as enriching public spaces with green elements (Van der Jagt et al., 2023, Van Rooij et al., 2021). Therefore, the lack of precise site selection criteria for different types of NBS can be considered as one of the main obstacles to their effective implementation.

The site selection of NBS is usually based on an analysis of local environmental challenges, site-specific characteristics, and expected environmental and social outcomes. Key methods include integrated multi-criteria assessments, which enable different factors to be considered (Croeser et al., 2021, Wójcik-Madej et al., 2026). This process usually involves several stages: recognising the problem; identifying possible solutions; and selecting the best option based on criteria such as the type of threat, the scale of the impact, and the size of the area affected (Albert et al., 2021). Taken into account the interdisciplinary character of NBS, however, these site selection criteria should take into account technical, environmental, and social aspects. Such an approach can provide a basis for developing optimal implementation strategies tailored to specific local conditions (Albert et al., 2021, Castellar et al., 2021). Besides,

comprehensive comparative analyses of different implementation models to identify best practice in the context of specific cities are required (Albert et al. 2021; Castellar et al. 2021). As part of further research, it is crucial to identify the best site selection criteria for different types of NBS, taking into account both specific local conditions and a broad ecosystem perspective (Van Rooij et al., 2021, Sowińska-Świerkosz et al., 2024, Van der Jagt et al., 2023).

The presented paper focuses on the possibilities of incorporating in city planning two types of solutions, namely: pro-ecological development of gullies and linear parks, whose role as effective NBS types is underestimated in the literature. A review conducted by the authors using Scopus research (date: 15 October 2025; Criterion: Title, Abstract, Keywords, English language) showed that the knowledge of these two types of NBS is rather limited globally. With regard to the pro-ecological development of gullies as a NBS type, only twelve papers were found (search criterion: nature-based solutions AND ravine OR gully OR dry valley). Out of the mentioned, only one was considered relevant to the topic under study (Mira et al., 2021). The concept of linear parks as NBS was discussed in 10 papers (search criterion: nature-based solutions and linear park), mainly focusing on their role in climate change adaptation, improving water retention, reducing flood risk, and mitigating the urban heat island effect (examples include Kim et al., 2024, Orta-Ortiz and Geneletti, 2023). Therefore, it is essential to expand knowledge on these solutions as potential NBS types that can be implemented and used effectively in urban areas.

Gullies and dry valleys are unique geological structures within the urban fabric that are vulnerable to degradation due to strong anthropogenic pressures resulting from urban sprawl (Luo et al., 2024, Oviedo et al., 2022). On the one hand, such structures have high ecological value due to their diverse topography, specific water conditions, and unique plant associations, which should be preserved and maintained in their natural state. On the other hand, leaving them as undeveloped enclaves of natural, unorganized greenery often leads to their transformation into dumping grounds, which are perceived by local communities as dangerous areas (Dagar and Singh, eds., 2018). It is therefore important to manage these areas by finding a balance between their natural and scenic values and the

social and management needs (Luo et al., 2024, Oviedo et al., 2022, Rodzik et al., 2025). A potential solution is the adaptation of NBS principles into their management, particularly through the pro-ecological development of gullies. To transform gullies into multifunctional and socially friendly green spaces while preserving their unique values, this approach should limit access to the most natural and valuable areas (Rodzik et al., 2025). This can be achieved through the design of elevated paths above ground level and viewpoints for the observation of vegetation and wildlife. Such development ensures controlled access to biodiversity-rich areas and introduces educational elements (Maciejko and Wojtyszyn, 2019, Sumanapala and Wolf, 2019). According to the NBS typology presented by Dumitru and Wendling, Eds. (2021), such a solution can be classified as Type 1: minimal or no intervention in ecosystems, with objectives related to maintaining or improving delivery of ecosystem services within and beyond the protected ecosystems.

A linear park is a specific form of urban park characterized by an elongated, linear shape, usually located along roads, waterfronts, transport routes, or rivers (Ibrahim et al., 2020, Kim et al., 2024). These parks integrate elements of green infrastructure, such as ecological corridors, and often develop previously unused land, such as former railway or industrial sites (Park and Kim, 2019). Due to their structure and location, linear parks can connect various elements of the urban landscape, including green spaces, monuments, or city skylines (Park and Kim, 2019). Linear parks play a significant role in a pro-environmental approach to urbanism, promoting sustainable development and balancing urban functions with environmental protection. The typology of linear parks depends on their location and function, including parks along rivers and coastlines, near railway lines, or elevated parks such as the famous High Line in New York (Li et al., 2020, Sim, 2024). Their design adapts to local conditions and needs, allowing for the introduction of various forms and functions, including walking and cycling paths, resting areas, and landscaping elements (Yang et al., 2023, Li et al., 2022a). According to the NBS typology presented by Dumitru and Wendling, Eds. (2021), such a solution can be classified as Type 2: sustainable management and natural enrichment of existing green and blue urban infrastructure elements.

As described above, the pro-ecological development of gullies and the implementation of linear parks have the potential to be effective NBS in specific urban contexts, yet their contribution to the NBS framework remains insufficiently explored. This study addresses this knowledge gap by pursuing three main objectives: (1) to assess the feasibility of implementing two types of NBS – pro-ecological gully development and linear parks – in the urban context; (2) to translate the IUCN Global Standard for NBS into a set of locally applicable, operational site-selection criteria; and (3) to identify both best-suited and optional locations through a multi-stage GIS-based analysis in relation to Lublin (Poland) case study.

## MATERIALS AND METHODS

### Study area description

The study area encompasses the city of Lublin, located in the southeastern part of Poland (Figure 1A). Lublin is located in eastern Poland, between 51°15'N latitude and 22°34'E longitude, at an altitude of approximately 183 meters above sea level. The city is situated in the Lublin Upland, along the valley of the Byszczyca River. Lublin covers an area of 147 km<sup>2</sup> and is divided into 27 districts, with a population of approximately 331,000 inhabitants (2023), resulting in a population density of 2,251 inhabitants per square kilometer. Lublin serves as the centre of Lubelskie Voivodeship, with significant administrative, economic, educational, cultural, and tourist functions. Lublin ranks 11th out of 18 provincial cities in terms of the percentage of urban green areas in the total area of the city, which is 9.55%. In contrast, it ranks 6th out of 18 provincial cities for the percentage of protected areas in the urban area, which is 17.20% (State of the City of Lublin Report, 2023). Urban green spaces in Lublin include parks, gardens, green squares, urban forests and urban waters; however, there is still potential for further integration of green spaces into the existing urban infrastructure. A number of green interventions are currently taking place in the city, including planting trees and shrubs along streets, creating rain gardens and flower meadows, and establishing a river park.

## Relevance of the selected NBS types to the Lublin context

### *Ecological and spatial potential of the city*

Lublin is the only large city in Poland characterized by a typical loess relief, where the flat top of the plateau is intersected by various valley forms, creating a system of dry valleys and gullies (Inventory of Ravines in the Lublin City Area, 2012) (Figure 1B). Of the 87 such structures within the Lublin city limits, only 12 are fully or partially developed with paved footpaths, recreational areas and playgrounds, and are included in the city's green infrastructure system. Most of the smaller gullies, especially on the outskirts of the city, remain in their natural state with little or no human intervention. As a result, only a small number of Lublin's dry valleys are used by residents, mainly for jogging, cycling, and dog walking. Those that are undeveloped and lack proper management are often transformed into wild dumps, with negative social and ecological impacts (Rodzik et al., 2025). However, these areas have the potential to complement and enhance the existing NBS structure by creating multifunctional spaces that preserve their natural qualities and increase their utility value.

There are 23 urban parks in the city, covering 1.36% of its territory and located in 16 out of 27 districts. The concept of linear parks is still at an early stage of development in Lublin. As a result, no linear parks have been introduced yet that could be harmoniously integrated into existing ecological or transportation networks, or other urban infrastructure elements. Some sites, such as Rury Park and John Paul II Park, have elements characteristic of this type of space, but do not fully meet the criteria for linear parks. However, the city has the spatial potential to implement this type of NBS. Lublin is divided in two parts by the Bystrzyca River, creating a large green area along the river valley that could be developed into linear parks, connecting various elements of the urban green landscape. Additionally, the system of street trees along the main roads is fairly well developed, covering 0.28% of the city (Wójcik-Madej and Sowińska-Świerkosz, 2022). Some of these structures have recently been incorporated into the NBS, such as by implementing flowering meadows and green gardens (Wójcik-Madej et al., 2025). This system can be further enriched by transforming some of the areas along roads into linear parks. Therefore, integrating areas located

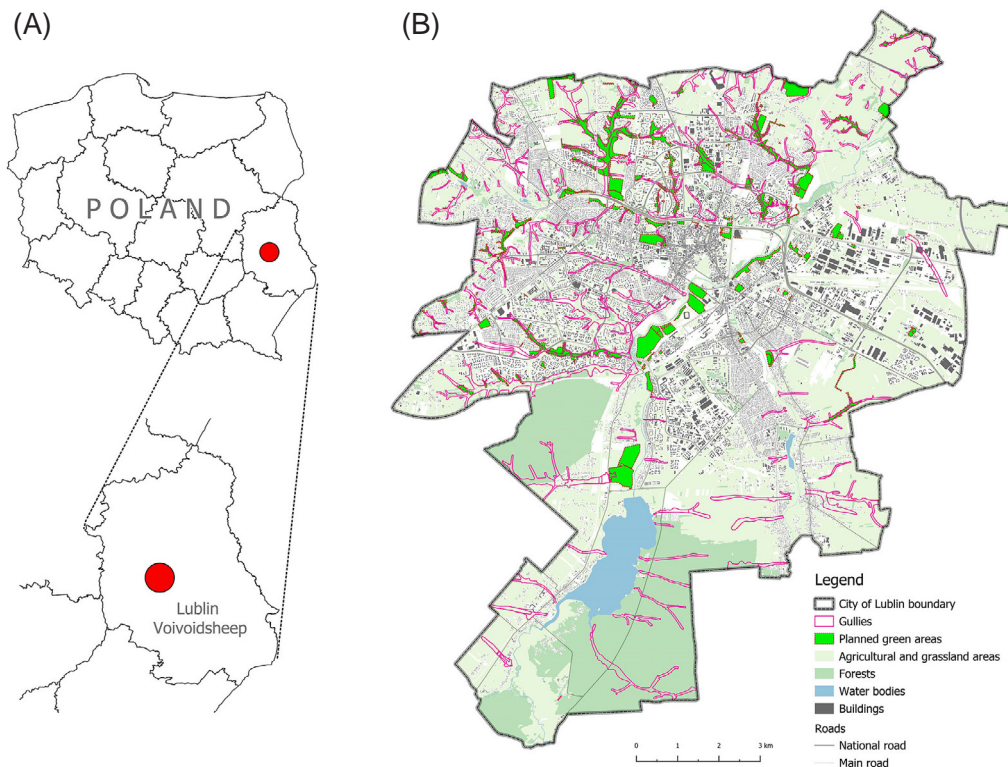
next to rivers and roads into the broader NBS structure could enhance their functionality, promote biodiversity, improve the aesthetics of the urban landscape, and provide city residents with spaces for outdoor recreation.

### *Urban planning policy*

The city of Lublin is constantly trying to become a 'green city' by implementing numerous pro-environmental initiatives and involving residents in the decision-making process. One of the key tools for public participation is the Green Budget, which allows residents to submit and select projects to improve the quality of the city's environment. As a result, a total of 80 projects has already been implemented as part of the Green Budget. Another initiative of the city, in cooperation with companies, is the implementation of a system of rain gardens, which aims to reduce the amount of rainwater entering the sewerage system, improve air quality and increase biodiversity in the city. The city is also investing in other NBS solutions, such as the development of green roofs - including the award-winning green roof on Lublin's main railway station - green bus stops, and riverside parks. Thanks to these measures, the number of parks and green spaces in the city is steadily increasing, improving the quality of life for residents. To reach the 'green city' status, the city's strategic and planning documents specify the percentage of the area of Lublin devoted to green spaces; sports and recreational areas: 1.7%; river banks and meadows: 5.1%; wooded areas: 11.9%; public green areas: 7.5%, and organised green areas related to the public's leisure and recreation needs: 3.7% (Figure 1B). Thanks to the commitment of the city authorities and the activity of its inhabitants, Lublin is gradually implementing a sustainable development strategy and becoming an increasingly friendly and green place to live.

### *Stakeholder preferences*

The assessment of stakeholder preferences, which was part of the previous authors' paper (Wójcik-Madej et al., 2025) showed high support for the two types of solutions analysed. Public preferences for innovative types of NBS for Lublin were measured through two online surveys conducted on the Microsoft Forms platform. The survey included employees of the Lublin City Office (LCO), representatives of various institutions



**Figure 1.** (A) Location of the city of Lublin within the borders of Poland; (B) location of gullies in the city of Lublin and areas designated for urban greenery according to the local spatial development plans of the city of Lublin, Poland (<https://geoportal.lublin.eu/2d/>), available 10.05.2025)

in the city, and residents, with a total of 120 respondents. The surveys were conducted between December 2021 and September 2024. In the case of the pro-environmental development of gullies, representatives of the Lublin City Office awarded 4.8 out of 5 points, while residents rated this type of development 4.6 out of 5 points. Urban parks, on the other hand, received 4.3 out of 5 points from city office representatives and 4.73 out of 5 points from residents. These results indicate a convergence of opinion between the two groups, which is crucial for the acceptance of NBS and their effective management.

### Preliminary study

The previous study conducted by the authors (Wójcik-Madej et al., 2025) revealed that the pro-ecological development of gullies and the introduction of urban parks in the form of linear structures are examples of the best-suited innovative NBS types for the city of Lublin. The multi-criteria evaluation performed focused on major urban challenges, social trade-offs and compliance with planning documents and urban planning policies. The study concluded that the implementation of

the selected solutions would provide multi-dimensional benefits, including landscape protection, climate change adaptation to and mitigation, and an overall improvement in the quality of life.

### Methodological assumptions

The research was based on the following methodological assumptions, which are further detailed in Table 1: MA1 – the effective implementation of the NBS in the city of Lublin requires the active involvement of the Lublin City Office, and MA2 – the use of IUCN global standards/principles facilitates the assessment of solutions from the perspective of the NBS concept.

### Methods

To assess the implementation possibilities of the two selected solution types in relation to the city of Lublin, the IUCN global standards principles were applied. A locational criterion was matched to each of the IUCN criteria (2020) in order to capture the multifaceted nature of NBS. As a result, site criteria include various dimensions, such as legal, economic, environmental,

**Table 1.** Methodological assumptions and their implications in the adopted approach

Justification	Impact on research design
<b>(MA1)</b> The effective implementation of the NBS in the city of Lublin city requires the active involvement of the Lublin City Office (LCO).	
<ul style="list-style-type: none"> <li>• The Lublin City Office is the owner of most of the land designated for urban greenery.</li> <li>• The LCO is responsible for approving spatial plans that regulate land use, location, and restrictions.</li> <li>• The implementation of multifunctional green interventions, including the revitalization of gullies and riverbanks, is an integral part of the city's urban strategy.</li> <li>• The LCO has the necessary resources and experience to manage green and blue infrastructure interventions.</li> </ul>	<ul style="list-style-type: none"> <li>• The research was conducted in close collaboration with the Lublin City Office in terms of obtaining data, share opinions and consultations on the implementation of the NBS in the city.</li> <li>• The starting point for the assessment was a database of the dry valleys and gullies prepared by the LCO, as well as planned green areas outlined in city plans.</li> <li>• Land ownership by local government units and the State Treasury was taken as the economic criterion.</li> <li>• The accessibility of the sites to citizen was adopted as a social criterion.</li> <li>• The final locations were consulted with representatives of the LCO.</li> </ul>
<b>(MA2)</b> The use of IUCN global standards principles facilitates the assessment of solutions from the perspective of the NBS concept.	
<ul style="list-style-type: none"> <li>• To be classified as an NBS, a given solution must meet the criteria outlined by the IUCN (2020).</li> <li>• NBS are highly context-specific.</li> <li>• NBS should maximize benefits while minimizing trade-offs.</li> <li>• The design of NBS should acknowledge and respond to the interactions between the economy, society, and ecosystems.</li> </ul>	<ul style="list-style-type: none"> <li>• Assessment of legal, environmental, economic, social, ecological and technical criteria.</li> <li>• Application of an exclusion approach by eliminating sites that do not meet the specified criteria at each stage.</li> </ul>

social, ecological and technical ones (Table 2). Although the IUCN framework comprises eight general criteria, the study identified six practical groups of criteria that are better suited to local spatial and technical conditions. This method was developed and tested in a published study on modular green roofs (Wójcik-Madej et al., 2026), in which it was found to be highly effective in identifying the most suitable locations, as well as those that were optional. In that study, adapting the IUCN global standard criteria to local conditions was found to be a transparent, consistent and repeatable assessment approach. The results confirmed that this method is sufficiently flexible and sound in its methodology to be applied to pro-ecological gullies development and linear parks, while taking into account their specific functional and spatial conditions.

The criteria were divided into two basic categories. Mandatory, hard criteria, were used to identify ‘optional’ locations, i.e. areas of possible implementation that took legal and environmental conditions into account, but were not fully effective due to other factors. Additional soft criteria, the fulfilment of which significantly increased the functionality and effectiveness of implementing a given type of solution, determined the optimal locations. The hard criteria were analysed first, while the order of the soft criteria depended on the specifics of the solution in question. Of the

analysed criteria, legal and environmental criteria were adopted as hard criteria. As part of the legal criterion, the compliance of the preferred locations with the city of Lublin’s current planning documents was analysed. As part of the environmental criterion, the current state of land development and use was analysed to identify locations that could be developed to avoid functional and spatial conflicts. In the case of linear parks, an additional hard criterion was the technical criterion relating to the location and shape of this type of solution. Based on an assessment of spatial, morphological and infrastructural conditions, the implementation of individual types of NBS was analysed in terms of the technical criteria determining their effective implementation and functioning. As part of the economic criterion, land ownership was assessed to identify locations on land owned by the State Treasury or the Municipality of Lublin. This criterion was crucial in ensuring the feasibility of implementing NBS while maintaining sustainable costs (i.e. avoiding the need to purchase land and buildings or undergo lengthy administrative procedures). As part of the social criterion, accessibility was analysed to ensure that various groups of residents could access the selected locations. As part of the ecological criterion, the natural value of the selected locations was assessed to exclude those with high natural value that could be lost or disturbed by

**Table 2.** Selection of location criteria based on the principles of the Global IUCN Standards (Adapted and modified from Wójcik-Madej et al., 2026)

IUCN criterion	Local criterion and its justification
<b>Criterion 1:</b> NBS effectively address societal challenges: NBS address specified and well-documented challenges that have significant impacts on society as well as provide human well-being outcomes	<b>Legal</b> – taking into account the provisions of local spatial plans, which result from analyses concerning, among other things, the challenges related to the development of a given area <b>Social</b> – assessment of the accessibility to the areas that facilitates outdoor activities and promote mental and physical well-being
<b>Criterion 2:</b> Design of NBS is informed by scale: NBS recognizes economy, society and ecosystems interactions and is integrated with other interventions	<b>Environmental</b> – assessment of compatibility with other NBS interventions which allow for integration with other complementary existing activities and the pursuit of synergy.
<b>Criterion 3:</b> NBS result in a net gain to biodiversity and ecosystem integrity: NBS must be based on well-founded understanding of the ecosystems and key biodiversity values should be established	<b>Ecological</b> – appreciation of ecological values of no developed areas that are natural green enclaves and biodiversity hotspots
<b>Criterion 4:</b> NBS are economically viable: identify who pays and who benefits and test the cost-effectiveness and affordability of the solution	<b>Economical</b> – assessment of land ownership resulted in selecting sites that reducing investment costs <b>Technical</b> – assessment of specific technical requirements minimizing technical barriers and shortening implementation time thus making investment economically viable
<b>Criterion 5:</b> NBS are based on inclusive, transparent and empowering governance processes: obtain acceptance and involvement of key stakeholders and taken into account cooperation agreements between relevant authorities	<b>Expert consultations</b> with representatives of different departments of the Lublin City office as well as specialists and researchers to verify the validity of the proposed sites; consideration of responsibilities in land use management and spatial development of different authorities, including those of the State Forests and Polish Waters
<b>Criterion 6:</b> NBS equitably balance trade-offs between achievement of their primary goal(s) and the continued provision of multiple benefits: consideration of rights, usage of and access to land and resources and understanding cost and benefits of trade-offs	<b>Economical</b> – assessment of land ownership to understand rights, usage of and access to land and thus ensure the practical feasibility of solution implementation Detection of optional sites at each level of assessment that helps to understanding cost and benefits of trade-offs among different factors used in the analysis
<b>Criterion 7:</b> NBS are managed adaptively, based on evidence (applied to post-implementation period)	To ensure this criterion in the post-implementation period, the priority was given to the feasibility of NBS implementation by the LCO meaning that this authority will be also responsible for the solution management. Taken into account LCO resources, experience and functional model, the adaptive management can be achieved.
<b>Criterion 8:</b> NBS are sustainable and mainstreamed within an appropriate jurisdictional context: NBS are designed and managed with a view to long-term sustainability, and they are aligning with existed policy frameworks	<b>Legal</b> – consistency with local strategies, development plans and sectoral regulations to support institutional implementation.

the implementation of the NBS. The final stage consisted of expert consultations with representatives from Lublin City Council and specialists in spatial management, physical geography, and environmental engineering. These consultations enabled to verify the best locations to be identified. Figure 2 shows in details data sources used, pre-processing stages and description in relation to each criterion and analysed NBS type.

The location analysis was based on an elimination approach, whereby locations that did not meet the defined criteria were systematically excluded from further analysis (see Columns A–C of Figure 2). This process narrowed down the selection to the most suitable implementation areas. Such an approach has been used in some previous

studies. For example, Azadgar et al. (2025) used this method to identify areas requiring high-risk flood interventions in Gdansk, Poland, by adapting the appropriate NBS types such as rain gardens, drainage ditches and retention ponds. The multi criteria method proposed by Alves et al. (2024) also excludes areas that do not meet the technical criteria for rainwater management in terms of NBS implementation, such as bioswales, permeable pavements, rain barrels and infiltration trenches. All spatial analyses were conducted using QGIS software. As a result, a geospatial database of potential NBS locations was created, highlighting the advantages and limitations of NBS implementation at a given site, taking into account a variety of factors.

SITE SELECTION PROCESS					
A. Stage number	B. Number of locations	C. % of locations retained	D. Criterion	E. Description: Data source and pre-processing	F. Description: Operational rules
<b>TYPE 1: PRO-ECOLOGICAL MANAGEMENT OF GULLIES</b>					
1	87	100	Input spatial database	<ul style="list-style-type: none"> <li>Data analysis and processing were performed in QGIS (version 3.34.15) using the ETRF2000-PL/CS92 coordinate system.</li> <li>Data on the location of the gullies was obtained from the City of Lublin's Planning Department.</li> <li>The data was in DWG format.</li> <li>The preliminary processing involved importing the data into QGIS, converting it from DWG to SHP format and verifying the attributes and geometry.</li> </ul>	<ul style="list-style-type: none"> <li>Elements with incomplete or incorrect attribute data (e.g. missing identifiers, names, or geometry discontinuities) were rejected from further processing.</li> <li>Objects representing gullies which were correctly located and had the correct geometry after conversion to SHP format were included in the analysis.</li> <li>During data verification, particular attention was paid to ensuring the topology was correct and that the coordinate system complied with the adopted spatial reference, ETRF2000-PL/CS92.</li> <li>There were difficulties in the form of inconsistencies between the reference layer and the source data layer, which required the manual correction of object positions in the QGIS environment.</li> </ul>
<b>Hard criteria</b>					
2	40	45,98	Legal criterion	<ul style="list-style-type: none"> <li>A database of gullies in SHP format was developed based on data obtained from the Planning Department of the Lublin City Council.</li> <li>The texts of the planning documents (Study of Conditions and Directions for the Spatial Development of the City of Lublin and Local Spatial Development Plans for the City of Lublin for 2005–2024) are available on the Lublin City Council website (<a href="https://bip.lublin.eu/strategia-i-planowanie/planowanie-przestrzenne/">https://bip.lublin.eu/strategia-i-planowanie/planowanie-przestrzenne/</a>).</li> <li>Drawings of the planning documents in WMS format can be found on the Open Data Lublin website (<a href="https://otwartedane.lublin.eu/">https://otwartedane.lublin.eu/</a>).</li> <li>Date of data acquisition: 30 March 2024.</li> <li>Preliminary processing includes adding WMS layers to the QGIS project, verifying the mapping is correct and referencing the dry valley location layer.</li> </ul>	<ul style="list-style-type: none"> <li>The gullies areas were analysed in the context of existing and proposed planning documents.</li> <li>Gullies located within areas planned for development other than landscaped green areas (e.g. residential, commercial or industrial development) were excluded from further analysis.</li> <li>Gullies designated for landscaped green areas in planning documents were selected for further analysis.</li> <li>In the absence of a valid local plan, the provisions of the Study of Conditions and Directions of Spatial Development were applied.</li> <li>For areas covered by multiple plans, the consistency of the provisions and the validity of the documents as of the date of the analysis were verified.</li> <li>The verification of the location and consistency of the data was carried out using reference layers in the QGIS environment.</li> </ul>
3	32	36,78	Environmental criterion	<ul style="list-style-type: none"> <li>The gullies database was updated in Stage I, and data on the location of buildings in Lublin was downloaded in QGIS as a data package in SHP format using the GUGiK Data Downloader plug-in as of 1 April 2024.</li> <li>The orthophotomap from 2023 was downloaded from the Otwarte Dane Lublin website (<a href="https://otwartedane.lublin.eu/">https://otwartedane.lublin.eu/</a>) as a GeoTIFF COG, which is connected to the programme.</li> <li>Preliminary processing:                             <ol style="list-style-type: none"> <li>This involved importing data on building locations and adding a raster with an orthophoto map to the programme. The consistency of building locations was then verified using satellite imagery, and layers were prepared for spatial analysis.</li> </ol> </li> </ul>	<ul style="list-style-type: none"> <li>Gullies containing buildings and landscaped greenery were excluded from further analysis.</li> <li>Gullies without buildings or greenery were selected for further analysis.</li> <li>The following difficulties were encountered: the need to manually check the location of buildings on the orthophotomap, and possible inconsistencies in the scale and resolution of the data.</li> </ul>
<b>Soft criteria</b>					
4	8	9,20	Economic criterion	<ul style="list-style-type: none"> <li>Database of gullies updated in Stage II.</li> <li>Database of plots in WFS format, obtained from the website of the Main Office of Geodesy and Cartography, GUGiK (<a href="https://integracja.gugik.gov.pl">https://integracja.gugik.gov.pl</a>) as of 1 April 2024.</li> <li>Regulation of the Minister of Development, Labour and Technology of 27 July 2021 on the register of land and buildings (Journal of Laws 2024.0.219)</li> <li>Preliminary processing:                             <ol style="list-style-type: none"> <li>Import of the database with the location of plots, conversion of the WFS data format to the SHP format.</li> <li>Classification of plots by type of ownership in accordance with the Regulation of the Minister of Development, Labour and Technology.</li> </ol> </li> </ul>	<ul style="list-style-type: none"> <li>Gullies located on privately owned land were excluded from further analysis.</li> <li>Gullies located on land owned by the State Treasury, the Municipality of Lublin or jointly owned by these entities were selected for further analysis.</li> <li>Difficulties: the need to manually check the location of gullies that partially overlapped with several plots of land, which required verification of which parts of the area were actually eligible for further analysis.</li> </ul>
5	8	9,20	Social criterion	<ul style="list-style-type: none"> <li>The gullies database was updated in Stage III.</li> <li>Vector data showing paved roads, cycle paths and footpaths for analysis were downloaded into the programme using the QuickOSM plugin, using the following key-value pairs: <i>highway=primary</i>, <i>highway=secondary</i>, <i>highway=tertiary</i>, <i>highway=residential</i>, <i>highway=cycleway</i>, <i>highway=footway</i>.</li> <li>Data on the location of car parks and bus stops was mapped in the programme using the OpenStreetMap connected to the project as a WMS service.</li> <li>Preliminary processing:                             <ol style="list-style-type: none"> <li>Integration of all spatial layers in the ETRF2000-PL/CS92 system,</li> <li>Updating the ravine database by adding the accessibility attribute,</li> <li>Classification of gullies according to transport accessibility: 'accessible', 'limited access' and 'no access'.</li> </ol> </li> </ul>	<ul style="list-style-type: none"> <li>Gullies that were difficult to access, i.e. classified as 'restricted access' or 'no access', were excluded from further analysis.</li> <li>Gullies that were easily accessible on foot, by bicycle, by car or by public transport and were classified as 'accessible' were selected for further analysis.</li> <li>Difficulties: heterogeneity of spatial data sources (different years and formats) and the need for manual verification of the course of roads, cycle paths and pavements.</li> </ul>
6	8	9,20	Ecological criterion	<ul style="list-style-type: none"> <li>The gullies database was updated in Stage V.</li> <li>Data for the analysis of natural values was obtained from various sources, including:                             <ol style="list-style-type: none"> <li>Study of conditions and directions of spatial development of the city of Lublin and local spatial development plans for the city of Lublin for 2005–2024 (<a href="https://bip.lublin.eu/strategia-i-planowanie/planowanie-przestrzenne/">https://bip.lublin.eu/strategia-i-planowanie/planowanie-przestrzenne/</a>),</li> <li>Climate Change Adaptation Plan for the City of Lublin until 2030 (<a href="https://bip.lublin.eu/strategia-i-planowanie/ochrona-srodowiska/plan-adaptacji-do-zmian-klimatu-miasta-lublin-do-roku-2030,3,28275,2.html">https://bip.lublin.eu/strategia-i-planowanie/ochrona-srodowiska/plan-adaptacji-do-zmian-klimatu-miasta-lublin-do-roku-2030,3,28275,2.html</a>)</li> <li>Geoportal of the City of Lublin (<a href="https://geoportal.lublin.eu/2d/">https://geoportal.lublin.eu/2d/</a>),</li> <li>Open Data Lublin (<a href="https://otwartedane.lublin.eu/group/przestrzen-srodowisko">https://otwartedane.lublin.eu/group/przestrzen-srodowisko</a>),</li> <li>Forest Data Bank (<a href="https://www.bd.lasy.gov.pl/portal/">https://www.bd.lasy.gov.pl/portal/</a>),</li> <li>Report of 7 December 2021 on the floristic and zoological inventory of two sections of the 'Stary Gaj' forest complex in Lublin, numbered 177 and 178 (<a href="https://lublin.eu/gfx/lublin/userfiles/_public/mieszkanicy/srodowisko/aktualnosci/2022/stary_gaj_-_ekspertyza_umcs-up_2_wykonania_inwentaryzacji_florystyczno-przyrodniczej.pdf">https://lublin.eu/gfx/lublin/userfiles/_public/mieszkanicy/srodowisko/aktualnosci/2022/stary_gaj_-_ekspertyza_umcs-up_2_wykonania_inwentaryzacji_florystyczno-przyrodniczej.pdf</a>),</li> <li>Official websites of the city and environmental institutions,</li> <li>Publicly available spatial databases and thematic maps,</li> <li>Reports for individual plots downloaded from the OnGeo.pl website,</li> <li>Inventory and natural valuation of the 'Dolina Trześniowska' area (<a href="https://lublin.eu/mieszkanicy/partycypacja/budzet-obywatelski/aktualnosci/opracowania-przyrodnicze,130,3627,1.html">https://lublin.eu/mieszkanicy/partycypacja/budzet-obywatelski/aktualnosci/opracowania-przyrodnicze,130,3627,1.html</a>),</li> <li>The available data was analysed in terms of records concerning various forms of protection of dry valleys in the city of Lublin.</li> </ol> </li> <li>Supplementary data: Orthophotomap from 2023.</li> <li>Preliminary processing:                             <ol style="list-style-type: none"> <li>Updating the ravine database by adding the attribute 'value',</li> <li>Classification of gullies according to their natural value: 'high', 'medium' and 'low'.</li> </ol> </li> </ul>	<ul style="list-style-type: none"> <li>Gullies that were protected and classified as having high natural value were excluded from further analysis.</li> <li>Gullies that did not have significant natural value, were not protected, and were classified as having medium or low natural value were selected for further analysis.</li> <li>Difficulties: diversity of data sources and the need to standardise them, varying levels of detail and timeliness of information, data gaps and information gaps, problems with spatial integration, subjective assessment of natural values, and the need for manual data updating and verification.</li> </ul>

Figure 2. Characteristics and sequential stages of the site selection process, together with number of identified best-suited and optional locations for the analysed NBS types

SITE SELECTION PROCESS					
A. Stage number	B. Number of locations	C. % of locations retained	D. Criterion	E. Description: Data source and pre-processing	F. Description: Operational rules
<b>TYPE 1: PRO-ECOLOGICAL MANAGEMENT OF GULLIES</b>					
7	6	6,90	Technical criterion	<ul style="list-style-type: none"> <li>The gullies database was updated in Stage IV.</li> <li>The data was obtained on the basis of a field survey and expert consultation.</li> <li>The field survey was conducted in August 2024, together with photographic documentation.</li> <li>The expert consultation was conducted in September 2024 with an expert specialising in physical geography, geomorphology and palaeogeography from UMCS Lublin</li> <li>Preliminary processing:                             <ol style="list-style-type: none"> <li>Preparation of notes from the expert consultation and a summary in tabular form.</li> <li>Identification of conclusions regarding technical and organisational barriers to the implementation of pro-ecological management of gullies.</li> </ol> </li> </ul>	<ul style="list-style-type: none"> <li>Gullies where trees had been felled, leading to the destruction of their structure, and valleys identified by the expert were rejected from further analysis.</li> <li>Gullies which, based on field observations and expert consultation, could be developed in an environmentally friendly manner were selected for further analysis.</li> <li>Difficulties: varying levels of detail in the information on the geomorphology of individual gullies.</li> </ul>
8	6	6,90	Expert consultation	<ul style="list-style-type: none"> <li>The gullies database was updated in Stage VI.</li> <li>Qualitative data was obtained as a result of expert consultations conducted between February and April 2025.</li> <li>Representatives of the Lublin City Council participated in the consultations.</li> <li>The consultations took the form of online meetings, face-to-face discussions and e-mail correspondence.</li> <li>Preliminary processing:                             <ol style="list-style-type: none"> <li>Preparation of notes from discussions and summaries in tabular form.</li> <li>Identification of recurring conclusions regarding technical and organisational barriers to the implementation of pro-ecological management of gullies.</li> </ol> </li> </ul>	<ul style="list-style-type: none"> <li>Gullies which, according to representatives of the Lublin City Council, could not be developed in an environmentally friendly manner were rejected.</li> <li>Gullies whose environmentally friendly development was in line with the internal arrangements presented by representatives of the Lublin City Council were considered the best locations.</li> <li>The results of the consultation were used to verify the assumptions regarding the implementation of pro-ecological management of gullies.</li> <li>Difficulties: varying levels of detail in the information provided by participants.</li> </ul>
<b>TYPE 2: LINEAR PARKS</b>					
1	2813	100	Input spatial database	<ul style="list-style-type: none"> <li>Data analysis and processing was performed in QGIS (version 3.34.15) using the ETRF2000-PL/CS92 coordinate system.</li> <li>Data on the location of green areas in the city of Lublin was downloaded into the programme using the BDOT10k plug-in as an SHP data package.</li> <li>Data attributes: xcode, type, species, data status as of 24 June 2024.</li> <li>Preliminary processing:                             <ol style="list-style-type: none"> <li>Importing data into the programme,</li> <li>Verifying the geometry of objects,</li> <li>Checking the correctness and completeness of attributes.</li> <li>Verifying the compliance of the reference system.</li> </ol> </li> </ul>	<ul style="list-style-type: none"> <li>Objects with missing or incorrect data were rejected.</li> <li>Green areas that were correctly located and had a complete set of required information were included in the analysis.</li> <li>Difficulties: the need to check the compatibility of the reference system and the correctness of data imported into QGIS.</li> </ul>
<b>Hard criteria</b>					
2	184	6,5	Legal criterion	<ul style="list-style-type: none"> <li>A database of green areas in the city compiled on the basis of data downloaded from the programme using the BDOT10k plug-in.</li> <li>The texts of planning documents (Study of conditions and directions of spatial development of the city of Lublin, Local spatial development plans for the city of Lublin for 2005-2024) are available on the website of the Lublin City Council (<a href="https://bip.lublin.eu/strategia-i-planowanie/planowanie-przestrzenne/">https://bip.lublin.eu/strategia-i-planowanie/planowanie-przestrzenne/</a>).</li> <li>Drawings of planning documents in WMS format are available on the Open Data Lublin website (<a href="https://otwartedane.lublin.eu/">https://otwartedane.lublin.eu/</a>).</li> <li>Date of data acquisition: 30 March 2024.</li> <li>Preliminary processing includes adding WMS layers to the QGIS project, verifying the correctness of the mapping and referencing the layer with the location of green areas in Lublin.</li> </ul>	<ul style="list-style-type: none"> <li>The aim of the analysis was to develop a database of preferred areas for the location of landscaped greenery, park greenery, recreational greenery, low, medium and high greenery.</li> <li>Areas located within the boundaries of land for which development other than landscaped green areas is planned (e.g. residential, commercial, industrial) were rejected from further analysis.</li> <li>Areas covered by planning documents and meeting legal requirements were selected for further analysis.</li> <li>Difficulties: the need to check the compatibility of the reference system and the correctness of the import of WMS data and documents into the QGIS environment.</li> </ul>
3	165	5,87	Technical criterion (1)	<ul style="list-style-type: none"> <li>Database with preferred areas for green space location updated in Stage I.</li> <li>Orthophoto map from 2023 downloaded from the Open Data Lublin website (<a href="https://otwartedane.lublin.eu/">https://otwartedane.lublin.eu/</a>) as GeoTIFF COG connected to the programme.</li> <li>Preliminary processing:                             <ol style="list-style-type: none"> <li>Updating the database of preferred areas for green space implementation by adding the location attribute.</li> <li>Classification of areas by location: 'river', 'road', 'railway line' and 'other' based on location analysis using the orthophoto map.</li> </ol> </li> </ul>	<ul style="list-style-type: none"> <li>Areas whose location was defined as 'other' were rejected from further analysis.</li> <li>Areas with the location attribute 'river', 'road' or 'railway line' were selected for further analysis.</li> <li>Difficulties: the need to manually verify the location of areas in the QGIS environment and check their compliance with the orthophoto map and the database of preferred areas.</li> </ul>
4	84	2,99	Environmental criterion	<ul style="list-style-type: none"> <li>Database of preferred areas for green space location updated in Stage II.</li> <li>Data on the location of buildings in Lublin was downloaded in QGIS as a data package in SHP format using the GUGIK Data Downloader plug-in (as of 1 April 2024).</li> <li>Orthophotomap from 2023 downloaded from the Otwarte Dane Lublin website (<a href="https://otwartedane.lublin.eu/">https://otwartedane.lublin.eu/</a>) as GeoTIFF COG connected to the programme.</li> <li>Preliminary processing:                             <ol style="list-style-type: none"> <li>Importing data with building locations and adding a raster with an orthophoto map to the programme.</li> <li>Verifying the consistency of building locations with satellite imagery and preparing layers for spatial analysis.</li> </ol> </li> </ul>	<ul style="list-style-type: none"> <li>Areas with buildings and landscaped greenery were excluded from further analysis.</li> <li>Areas without buildings and without landscaped greenery were selected for further analysis.</li> <li>Difficulties: the need to manually check the location of buildings on orthophotomaps and possible inconsistencies in the scale and resolution of data.</li> </ul>
<b>Soft criteria</b>					
5	41	1,46	Economic criterion	<ul style="list-style-type: none"> <li>Database of preferred areas for green space location updated in Stage III.</li> <li>Database of plots in WFS format, obtained from the website of the Main Office of Geodesy and Cartography, GUGIK (<a href="https://integracja.gugik.gov.pl">https://integracja.gugik.gov.pl</a>) as of 1 April 2024.</li> <li>Regulation of the Minister of Development, Labour and Technology of 27 July 2021 on the register of land and buildings (Journal of Laws 2024.0.219).</li> <li>Preliminary processing:                             <ol style="list-style-type: none"> <li>Import of the database with the location of plots, conversion of the WFS data format to the SHP format.</li> <li>Classification of plots by type of ownership in accordance with the Regulation of the Minister of Development, Labour and Technology.</li> </ol> </li> </ul>	<ul style="list-style-type: none"> <li>Areas located on privately owned land were excluded from further analysis.</li> <li>Areas located on land owned by the State Treasury, the Municipality of Lublin or jointly owned by these entities were selected for further analysis.</li> <li>Difficulties: the need to manually verify the location of areas preferred for green space, as they partially overlapped with several plots, which required determining which parts of the area were eligible for further analysis.</li> </ul>
6	19	0,68	Technical criterion (2)	<ul style="list-style-type: none"> <li>Database of preferred areas for green space location updated in Stage IV.</li> <li>Preliminary processing:                             <ol style="list-style-type: none"> <li>Calculation of the area of each area in the programme using the Field Calculator tool.</li> <li>Analysis of the shape of the areas by assessing whether they are elongated.</li> <li>Determination of the minimum area for areas eligible for further analysis: 0.55 ha (Alexandra 2008; Korwel-Lejkowska and Topa 2017).</li> </ol> </li> </ul>	<ul style="list-style-type: none"> <li>Areas with an area of &lt; 0.55 ha and a shape other than elongated were excluded from further analysis.</li> <li>Areas with an area ≥ 0.55 ha and an elongated shape were selected for further analysis.</li> <li>Difficulties: the need to manually verify the shape and proportions of areas to confirm that they meet the technical criteria for elongation and minimum area.</li> </ul>

Cont. Figure 2.

SITE SELECTION PROCESS					
A. Stage number	B. Number of locations	C. % of locations retained	D. Criterion	E. Description: Data source and pre-processing	F. Description: Operational rules
<b>TYPE 2: LINEAR PARKS</b>					
7	19	0,68	Social criterion	<ul style="list-style-type: none"> <li>Database of preferred areas for green space location updated in Stage V.</li> <li>Vector data showing paved roads, cycle paths and pavements for analysis were downloaded into the programme using the QuickOSM plugin, using the following key-value pairs: highway=primary, highway=secondary, highway=tertiary, highway=residential, highway=cycleway, highway=footway.</li> <li>Data on the location of car parks and bus stops was mapped in the programme using the OpenStreetMap connected to the project as a WMS service.</li> <li>Preliminary processing:                             <ol style="list-style-type: none"> <li>Integration of all spatial layers in the ETRF2000-PL/CS92 system.</li> <li>Updating the database with preferred areas for green space by adding the accessibility attribute.</li> <li>Classification of areas according to transport accessibility: 'accessible', 'limited access' and 'no access'.</li> </ol> </li> </ul>	<ul style="list-style-type: none"> <li>Areas that were difficult to access, i.e. classified as 'restricted access' or 'no access', were excluded from further analysis.</li> <li>Areas that were easily accessible on foot, by bicycle, by car or by public transport were selected for further analysis and classified as 'accessible'.</li> <li>Difficulties: heterogeneity of spatial data sources (different years and formats) and the need for manual verification of the course of roads, cycle paths and pavements.</li> </ul>
8	4	0,14	Technical criterion (3)	<ul style="list-style-type: none"> <li>Database of preferred areas for green space location updated in stage VI.</li> <li>Documentation of site visits carried out in October and December 2024, including photographs of locations.</li> <li>Preliminary processing involved supplementing area attributes with information on the condition of the sites obtained during the visits.</li> </ul>	<ul style="list-style-type: none"> <li>Further analysis ruled out areas in poor technical and spatial condition, unsuitable for development as a park, as well as those with minor green elements introduced by residents, such as flower pots or flower beds.</li> <li>Areas in good technical and spatial condition, which allowed for the development of the site as a park and created the potential for new plantings and small architectural elements, were selected for further analysis.</li> <li>Difficulties: the need to manually verify the condition of the areas, match the results of the field surveys to spatial data in the QGIS environment, and evaluate the documentary photographs.</li> </ul>
9	3	0,11	Ecological criterion	<ul style="list-style-type: none"> <li>Database of preferred areas for green space (updated in the previous stage).</li> <li>Data for the analysis of natural values was obtained from various sources, including:                             <ol style="list-style-type: none"> <li>Study of conditions and directions of spatial development of the city of Lublin, and local spatial development plans for the city of Lublin for 2005–2024 (<a href="https://bip.lublin.eu/strategia-i-planowanie/planowanie-przestrzenne/">https://bip.lublin.eu/strategia-i-planowanie/planowanie-przestrzenne/</a>).</li> <li>Climate Change Adaptation Plan for the City of Lublin until 2030 (<a href="https://bip.lublin.eu/strategia-i-planowanie/ochrona-srodowiska/plan-adaptacji-do-zmian-klimatu-miasta-lublin-do-roku-2030.3.28275.2.html">https://bip.lublin.eu/strategia-i-planowanie/ochrona-srodowiska/plan-adaptacji-do-zmian-klimatu-miasta-lublin-do-roku-2030.3.28275.2.html</a>).</li> <li>Geoportal of the City of Lublin (<a href="https://geoportal.lublin.eu/Zd/">https://geoportal.lublin.eu/Zd/</a>).</li> <li>Open Data Lublin (<a href="https://otwartedane.lublin.eu/group/przestrzen-srodowisko/">https://otwartedane.lublin.eu/group/przestrzen-srodowisko/</a>).</li> <li>Official websites of the city and environmental institutions.</li> <li>Publicly available spatial databases and thematic maps.</li> <li>Reports for individual plots downloaded from the OnGeo.pl website.</li> <li>The available data was analysed in terms of records concerning various forms of protection of areas preferred for the location of green spaces in the city of Lublin.</li> </ol> </li> <li>Supplementary data: Orthophotomap from 2023.</li> <li>Preliminary processing:                             <ol style="list-style-type: none"> <li>Updating the database of preferred areas for green space location by adding the attribute 'value'.</li> <li>Classification of areas according to natural values: 'high', 'medium' and 'low'.</li> </ol> </li> </ul>	<ul style="list-style-type: none"> <li>Areas that were protected and classified as having high natural value were excluded from further analysis.</li> <li>Areas that did not have significant natural value, were not protected, and were classified as having medium or low natural value were selected for further analysis.</li> <li>Difficulties: diversity of data sources and the need to standardise them, varying levels of detail and timeliness of information, data gaps and information gaps, problems with spatial integration, subjective assessment of natural values, and the need for manual data updating and verification.</li> </ul>
10	3	0,11	Expert consultation	<ul style="list-style-type: none"> <li>Database of preferred areas for green space location (updated in the previous stage).</li> <li>Qualitative data was obtained as a result of expert consultations conducted between February and April 2025.</li> <li>The consultations involved scientists involved in the implementation and monitoring of urban parks and representatives of the Lublin City Council.</li> <li>The consultations took the form of online meetings, face-to-face discussions and e-mail correspondence.</li> <li>Preliminary processing:                             <ol style="list-style-type: none"> <li>Preparation of notes from discussions and summaries in tabular form.</li> <li>Identification of recurring conclusions regarding technical and organisational barriers to the implementation of linear parks.</li> </ol> </li> </ul>	<ul style="list-style-type: none"> <li>Areas which, according to experts and representatives of the Lublin City Council, could not be designated for linear parks were rejected.</li> <li>Areas that, according to experts and representatives of the Lublin City Council, could be designated for linear parks were considered the best locations.</li> <li>The results of the consultation were used to verify the assumptions regarding the implementation of environmentally friendly development of dry valleys.</li> <li>Difficulties: varying levels of detail in the information provided by participants.</li> </ul>

Cont. Figure 2.

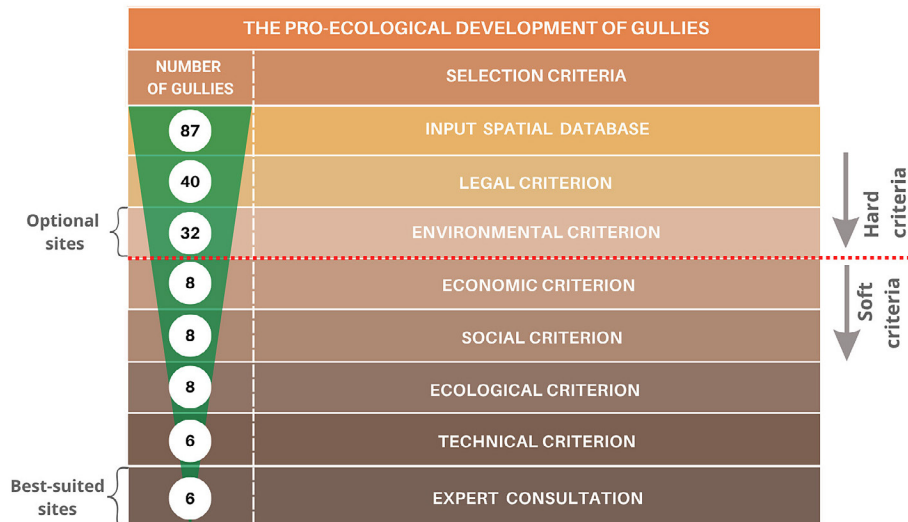
## RESULTS

### Pro-ecological development of gullies

The assessment showed that out of 87 gully sites within the borders of Lublin included in the input spatial database (Figure 1B), 32 meet the hard legal and environmental criteria (Figure 3). This is due to the fact that 47 gullies are not designated as green recreational areas according to local development plans. In addition, eight sites have already been developed as green areas, but not in a pro-ecological form (e.g., concrete pavements have been

introduced). The remaining 32 sites can be considered as potential sites for the implementing of pro-ecological management of gullies.

Regarding the best-suited sites, the application of the economic criterion showed that only 8 sites are located on land owned by the State Treasury or the Municipality of Lublin (the other sites are privately owned). All eight of these sites meet the social criterion as they are easily accessible to citizens: access to the gully is possible directly from the paved road, from the pavement near the parking lot or from the pavement near the bus stop. Besides, five sites are crossed by a



**Figure 3.** The process of selecting the optional and best-suited sites for pro-ecological development of gullies in Lublin, together with the number of sites selected at each stage

cycle path. In addition, all of them have moderate ecological values which do not prevent their pro-ecological development. Site no 1 contains valuable species of so-called ‘primeval relics’ as well and 24 insect species unique for the Lublin region. Other sites are located in a forested protected landscape area. Among them, six sites met the technical criterion (sites no 1-6, see Figure 4), as two sites were rejected due to the intensive forest management in their area, which prevents the introduction of tourist infrastructure. The remaining six sites were consulted with experts to determine the feasibility of their pro-ecological development. They were approved by the geomorphologist and 10 representatives of different Department of the Lublin City Office.

In summary, the research identified 32 sites (37% of the input database) were identified as optional sites, and six sites (7%) were identified as best-suited sites for the implementation of pro-ecological development of gullies (Figure 4). The characteristic of six best-suited sites together with the general guidelines for their pro-ecological development is provided in Appendix A.

### Implementation of linear parks

The assessment showed that out of 2813 green areas within the borders of Lublin included in the input spatial database, 84 meet the hard legal and environmental criteria (Figure 5). This is due to the fact that only 184 sites have been designated in local planning documents to provide open green spaces such as parks and gardens. In addition, 19

of these 184 sites are not located along a river, road or railway line and therefore do not meet the linear park characteristic (technical criterion 1), and 81 sites have already been developed as open green space (environmental criterion). The remaining 84 sites be considered as potential sites for the implementation of linear parks.

With regard to the best-suited sites, the application of the economic criterion showed that 41 sites are located on land owned by the State Treasury or the Lublin Municipality (the other sites are privately owned). The application of technical criterion 2 showed that 19 sites do not have an elongated shape and/or a minimum area of 0.55 ha and thus were rejected for further assessment. Remaining 19 sites met the social criterion, as they are easily accessible to citizens, both by car, public transport and by walking. The technical criterion no 3 was met by four sites, as rest of them have been already developed in various extent (e.g. benches, playgrounds, new planting of flowers, shrubs and trees), which were not visible on the orthophotomap from 2023 and therefore these sites were not excluded based on environmental criterion. Finally, only 3 sites met the ecological criterion. One site is of high natural value and should be remain it its natural character without human intervention in the ecosystem. The remaining 3 sites were consulted with experts to determine the feasibility of transforming them into linear parks. They were approved by a green infrastructure expert and 10 representatives of the Lublin City Office, representing different department.

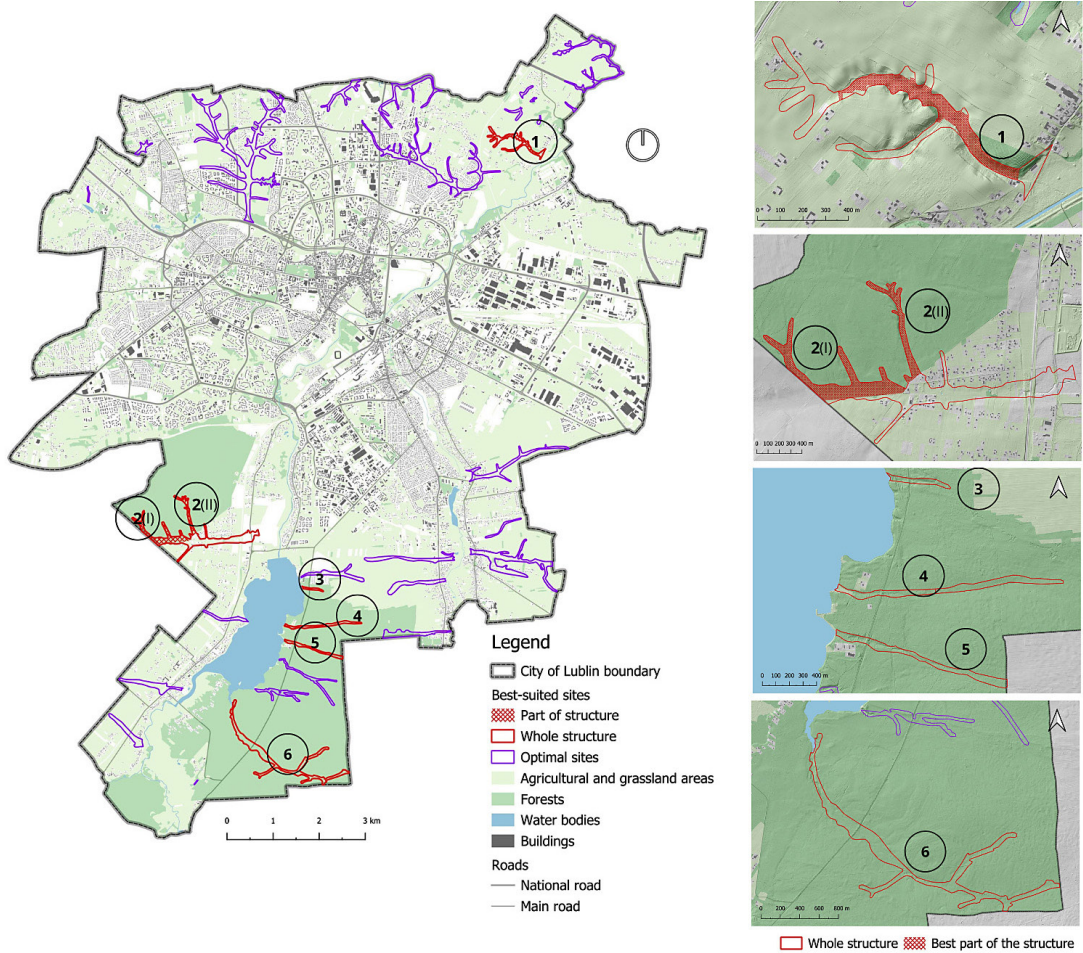


Figure 4. Optional 32 sites and 6 best-suited sites for the implementation of pro-ecological development of gullies in Lublin

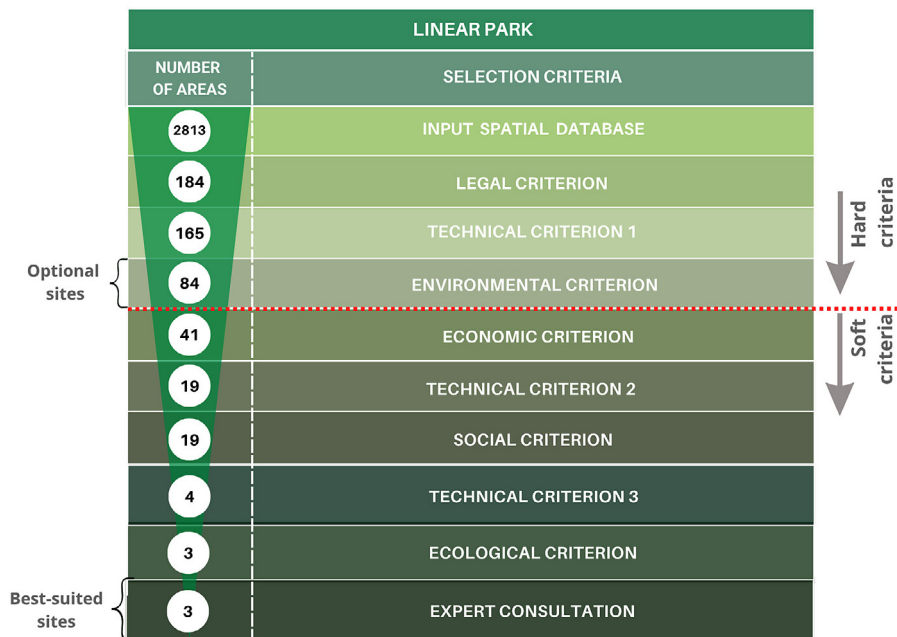


Figure 5. The process of selecting the optional and best-suited sites for linear parks implementation in Lublin together with the number of sites selected at each stage

In summary, the research identified 84 sites (3% of the input database) were identified as optional sites and only three sites (0.1%) were identified as best-suited sites for the implementation of a linear parks in Lublin (Figure 6). The characteristic of six best-suited sites together with the general guidelines for their pro-ecological development is provided in Appendix B.

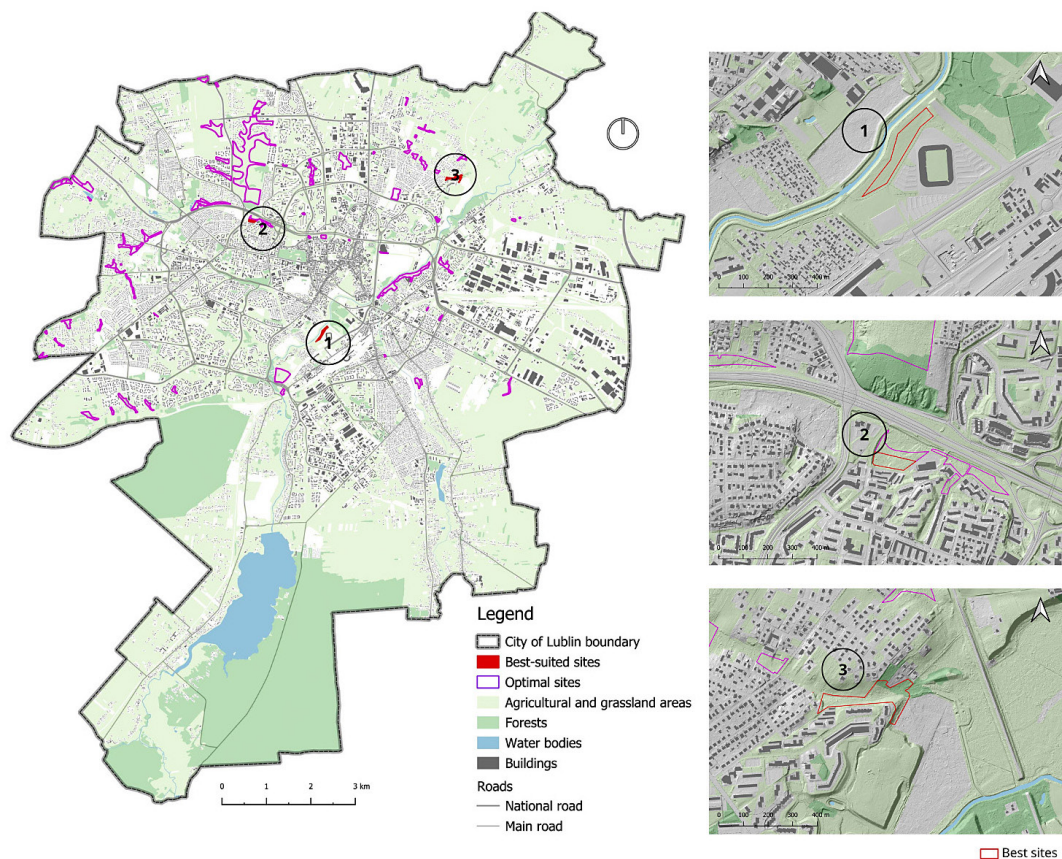
## DISCUSSION

### Site criteria for NBS and possibilities for NBS implementation in the city

The selection of location criteria for NBS is primarily based on environmental aspects, including terrain, hydrological conditions, land cover and biodiversity indicators, as well as technical criteria. Social and management aspects, however, are given less consideration. For instance, when selecting locations for urban parks, Li et al. (2022) considered criteria such as terrain elevation, slope, precipitation and vegetation indices, as well as one social factor: access to public transport. Asare et al. (2024) to select suitable sites for

a specific type of NBS to mitigate urban flooding in Accra, Ghana, was also strongly oriented towards environmental factors such as distance from rivers. Unlike these studies, the set of soft criteria adopted in the present study represents a sustainable approach to site selection, as none of the criterion types was given the predominant role. Ecological criteria were limited to the designation of valuable/protected areas due to environmental and/or landscape values based on the baseline analysis to avoid the destruction of valuable habitats by NBS implementation. Due to the current moderate negative impact of climate change on the analysed city, an additional criterion related to e.g. water retention or urban cooling was not taken into account. Such an additional aspect would be crucial in relation to other urban areas suffering from the occurrence of the extreme weather conditions such as heat waves, strong winds, floods or droughts.

Regardless of the adopted criteria and their importance, studies on the selection of NBS locations most often use a multi-criteria method. This involves eliminating locations that do not meet specific technical or environmental requirements



**Figure 6.** Optional 84 sites and 3 the best-suited for the implementation of linear parks in Lublin

and then assessing the remaining areas in terms of feasibility and social accessibility (Azadgar et al., 2025; Alves et al., 2024). This dissertation adopted a similar approach, except that the selection of location criteria was based on the global criteria of the IUCN (2020). This is an innovative approach. This approach was adopted to facilitate the assessment of the analysed solutions from the perspective of the NBS concept, capturing their multidimensional nature (Wójcik-Madej et al., 2026).

As a result of the adopted approach, in the case of the city of Lublin, despite of the large number of sites included in the input databases, only 6 sites (7% of the total analysed) were qualified as best-suited for the pro-ecological development of gullies and only 0.1% (3 out of 2813) were considered particularly suitable for the implementation of linear parks. In addition, optional sites represent 37% of the total input database of gullies and 1.6% of the planned parks. The results obtained in terms of best-suited sites for both analysed NBS types, however, have a strong implementation potential, as the study was conducted in the close cooperation with the LCO, e.g. in terms of data sharing and expert consultation. Taken into account LCO resources, experience and functional model, the adaptive management can be achieved, being one of the key aspects of NBS (Kauark-Fontes et al., 2023). Another advantage of the methodology is also the inclusion of legal criteria, which ensures compliance with the city's existing urban planning documents. This ensures that the analysis is based on viable spatial development plans, reducing the risk of incompatibility with the city's development policy. Consideration of existing policies, local laws, spatial plans and sectoral regulations as legal factors would facilitate NBS mainstreaming within an appropriate jurisdictional context (Brokking et al., 2021). In addition, priority was given to the land ownership by local government units and the State Treasury in order to facilitate the implementation of the solution from an economic point of view. Result obtained are also consistent with the needs of residents and city authorities for the implementation of solutions that have a low impact on the natural environment (Wójcik-Madej, 2025). One of the other advantages is the analysis of social accessibility, which ensures that the area is easily accessible both on foot and by public transport, thus increasing its usability and attractiveness for the residents (Mitropoulos et al., 2023, Rossetti et al., 2020). Therefore, as a key advantage of the

approach is considered the integration of various criteria such as environmental, legal, economic, social, ecological and technical, allowing the identification of sites with a high implementation potential that can be implemented within the formal and legal context of the city. In particular, the results of the study confirm the significant potential for the implementation of pro-ecological development of gullies in Lublin. According to e.g. Trzaskowska and Adamiec (2014) and Rodzik et al. (2025), gullies play an important role in the structure of urban greenery and can provide an alternative to intensively developed recreational areas. Moreover, their natural preservation is important for users, allowing them to commune with nature regardless of the amount of recreational and leisure infrastructure (Boguszewska and Boguszewski, 2014). The allocation of gullies for the implementation of green spaces is important from the point of view of protecting them from development, so that they are well preserved. When implementing infrastructure, it is important to ensure that it does not destroy the structure of the gully, for example by filling in branches or placing overused buildings such as slopes or sports and entertainment halls (Trzaskowska and Adamiec, 2014). Geotourism is also possible in the gully areas, which would allow the discovery of landscape gullies by establishing special routes so that the natural environment is not damaged by visitors (Kołodzyńska-Gawrysiak, 2014). An important element that should appear in the gully areas is the educational element, which could be implemented in the city schools not only through the insertion of information boards, but also through field classes with educators trained in physical geography, geomorphology and paleogeography (Pytko et al., 2014).

The introduction of linear parks in Lublin also would bring many benefits to both residents and the environment. Such parks can provide valuable recreational spaces, offering residents places to rest, walk or play sports. Increasing biodiversity and creating ecological corridors helps to protect local ecosystems, improve air quality and reduce noise. Linear parks created along transport infrastructure improves the aesthetics of urban spaces and mitigate the negative effects of the presence of roads or railways (Yang et al., 2019, Argüelles et al., 2022). In terms of sustainability, linear parks help cities adapt to climate change by increasing rainwater retention and improving the microclimate (Kimic, 2013). They also contribute to

urban sustainability by linking green spaces with residential and commercial areas and increasing the value of surrounding properties. Such investments can also act as tourist attractions, attracting visitors and promoting Lublin as a city that cares about the balance between urbanisation and environmental protection.

## CONCLUSIONS

This study fully achieved its objectives of assessing the potential for implementing two types of nature-based solutions (NBS) in Lublin, adapting the International Union for Conservation of Nature (IUCN) Global Standard criteria to local conditions, and identifying the most suitable and optional locations through a multi-stage geographic information system (GIS) analysis. Furthermore, the results confirm that the adopted methodological approach enables a consistent, transparent and repeatable assessment of the implementation potential of NBS in complex urban conditions.

The study highlights the potential of linear parks and pro-ecological gully developments as undervalued yet important types of NBS in contemporary urban planning. The multi-criteria spatial analysis demonstrated that these solutions can simultaneously fulfil legal, environmental, technical, economic, social and ecological functions while contributing to the revitalisation of neglected urban areas. Applying the method in the case of Lublin made it possible to identify both best-suited and optional locations, providing valuable support for municipal authorities and urban planners in spatial decision-making.

The proposed site-assessment methodology constitutes a versatile and replicable tool that can be adapted to other urban contexts facing similar environmental challenges. The framework is not limited to the two NBS types characteristic of Lublin's local conditions and can therefore be applied in other spatial contexts, regions and countries with different levels of NBS implementation. Because the multi-criteria suitability assessment is grounded in widely recognised IUCN global standards, the presented location-selection scheme has a universal character and can be used in both Polish and broader European settings. The method enables an evaluation of any selected NBS type within the adopted soft criteria, based on the knowledge and expertise of researchers or

specialists working with specific solutions. Moreover, the proposed methodology for identifying best-suited sites for NBS implementation in urban areas can be extended to other NBS based on the sustainable management of green and blue infrastructure, provided that appropriate technical criteria are defined to capture the specificity of each solution.

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