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ASSESSMENT OF THE RECREATIONAL USABILITY OF STORMWATER MANAGEMENT SYSTEMS IN URBAN AREAS – A CASE STUDY OF WROCŁAW

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ABSTRACT: The article presents the potential of building an effective system for sustainable stormwater management in urban areas that fulfils recreational functions, using the Nowe Żerniki estate in Wrocław (Poland) as a case study. The methodology includes desk research, cartographical analysis of the studied areas, case study, indicator analysis, and an individual in-depth interview. The study identifies a lack of a holistic approach to retention systems that integrate recreational use, leading to underutilized urban spaces. The limitations involve the complexity of assessing individual system components, which was addressed through simplified indices – RUI-E (Recreational usability index of the element) and RUI-S (Recreational usability index of the system). This simplification allows for intuitive use but opens possibilities for further development, including integrating more detailed parameters. Originality/Value lies in the ability to assess the attractiveness of an area using the proposed procedure for determining the recreational usability of stormwater management systems in urban areas. At the same time, it can serve as a tool to support urban design, making it applicable to designers and researchers in both new and existing urban developments. The Nowe Żerniki system's recreational usability was moderate, with improvement potential.

KEYWORDS: stormwater management, retention systems, recreational index, green space, rainfall

Introduction

In contemporary conditions, the primary orientation of the global economy is the pursuit of sustainable development which becomes a fundamental, targeted goal at various levels of development strategy formulation and spatial planning. However, the methods for achieving it are diverse. Similarly, the definition of sustainable development itself can be understood in static or dynamic, narrow or broad, contextual, or interdisciplinary ways. Nevertheless, there is a consensus that sustainable development should guide current actions, with outcomes visible in the near or distant future; this implies that both present and future generations will be able to develop at an adequate level, ensuring the preservation of natural resources, ecosystems, and life-support systems (van den Berg & Nijkamp, 1991; United Nations, 1987; Communication, 2001). Additionally, the aim is to achieve a desired level of socially desirable goals, such as increasing real per capita income, improving public health, ensuring fair access to natural resources, and enhancing education levels (Pearce et al., 1990).

The impetus for widespread engagement in sustainable development issues arose from recognized threats resulting from excessive consumption and unrestricted use of Earth's resources, leading to adverse environmental impacts that could culminate in disaster; this was noted in the 1969 Report "Man and His Environment" (Report U Thanta) and emphasized in the 1987 World Commission on Environment and Development's Report "Our Common Future" (United Nations, 1987). The concept was further refined in Agenda 21, adopted in 1992 at the Rio de Janeiro Earth Summit on Environment and Development (Drexhage & Murphy, 2010), at the 2000 UN Millennium Summit on the Millennium Development Goals, and in 2015 when the UN adopted the 2030 Agenda for Sustainable Development (United Nations, 2015).

Climate change presents a particular challenge to the global economy (Veerkamp et al., 2021), and the pursuit of mitigating climate change and preventing its adverse consequences has become a priority for most territorial entities.

The growing attractiveness of urban areas as places to live (Chang et al., 2018), operate, and conduct business has led to approximately 55% of the global population residing in cities today. By 2050, this figure is projected to rise to 68% (United Nations, 2024). Due to limited space in cities, the pursuit of compact urban development and high quality of life aligns with sustainable development, which includes combating climate change and serves as a fundamental direction for urban growth.

Climate change results in rising temperatures, reduced biodiversity, extreme weather events, sea-level rise due to glacier melting, and restricted access to fresh water. These climatic changes lead to rapid flooding, heatwaves, wildfires, droughts, and desertification of areas (Revi et al., 2014). In this context, one of the most critical problems is rain- and stormwater management. Most elements of retention systems can also fulfil recreational/relaxation functions. Given the increasing urban population density and limited space, especially in the face of climate change, the multifunctional use of available areas is essential. Thus, it is crucial to design a system that optimizes space utilization, considering both its retention capacity and recreational potential[1]. The study aims to present the possibilities of building an effective system for sustainable stormwater management in urban areas that fulfils recreational functions. To achieve this goal, it is necessary to create an index that allows for the assessment of the potential for using stormwater infrastructure for recreational purposes.

The following methods were used for this purpose: desk research (including critical analysis of the literature, as well as an examination of documents, sources, and legal acts), case study, analysis of the studied areas using up-to-date cartographic materials, indicator analysis, individual in-depth interview conducted on May 28th 2024 with Piotr Fokczyński the former Director of the Department of Architecture and Building at the Wrocław City Office and the City Architect.

[1] Recreation – various forms of activities undertaken outside the duties of daily life for rest, entertainment, and personal interest development; realized, among others, through rest and relaxation.

DOI: 10.34659/eis.2025.93.2.956

An overview of the literature

Background

Since the 1990s, cities have been increasingly sealed off, notably through extensive concreting (Zhou et al., 2021). This concreting of urban areas resulted from contemporary views on aesthetics, economic choices, and the ease of keeping these spaces clean, thus contributing to the hygienization of urban areas. However, this has led to increased risks and functional problems due to the lack of natural water drainage and the effects of climate change (Mees & Driessen, 2011).

Today, the approach to urban spatial planning is evolving, emphasising the necessity to combat climate change (Esraz et al., 2024; Boyd & Juhola, 2015; Goh, 2020). Considerable attention is given to rainfall and associated threats, such as flooding or contamination of rivers by rainwater that quickly flows and collects surface pollutants. Simultaneously, the opportunities presented by rainfall are highlighted, including providing water and nutrients to vegetation and animals and maintaining water levels in reservoirs.

In earlier periods, urban policies regarding rainfall focused on the rapid removal of rainwater from cities due to the associated risks. The approach has shifted towards retaining rainwater due to the opportunities it presents for subsequent use. Rainwater that is rapidly channelled away through surface runoff can lead to flooding. Conversely, rainwater that can freely infiltrate the ground serves as a flood protection measure, helps prevent drought, and regulates the city's microclimate by lowering temperatures.

Rainwater brings various benefits, including environmental, economic, and social advantages. These benefits include reducing water stress, adapting to climate change, decreasing the consumption of chemicals for rainwater treatment, reducing soil erosion, mitigating floods in urban areas, decreasing peak runoff flow, extending the lifespan of centralized water distribution infrastructure, postponing the need for new water supply infrastructure, enhancing flexibility and robustness of water supply systems, reducing electricity usage for water supply and sewage systems, and preventing illegal connections of rainwater with sewage networks (Rodrigues et al., 2022). Rainwater performs regulatory functions, making it essential to implement sustainable and integrated water management, which adopts a holistic approach to water (considering the entire catchment area and both anthropogenic and natural processes).

Rainwater management aims to minimise negative phenomena (such as floods, droughts, and the pollution of surface and groundwater) and to create opportunities for these waters' economic and natural utilisation without adverse effects on aquatic ecosystems and water-dependent systems. Additionally, effective rainwater management impacts environmental ecology, the functionality of spaces, and their landscape. It can create conditions for recreation/relaxation and cultural events, improve the quality of life for residents, enhance safety, and provide economic benefits.

To achieve these goals, the relationship between rainwater and green-blue infrastructure is utilised, engaging residents in activities, organising educational campaigns, and effectively leveraging the achievements and scope of green policies conducted within spatial planning to use available resources (European Union, 2007). In sustainable rainwater management, using natural methods supported by technological, technical, and communication advancements and the latest research results becomes particularly important. Therefore, sustainable rainwater management requires an interdisciplinary approach (Chathurika et al., 2024).

Due to the sealing of cities, most rainwater has been irretrievably lost, with this rate still reaching 70% because of the use of highly efficient sewer systems. It is essential to use solutions that ensure proper drainage, improve local retention, manage, self-clean, and discharge rainwater from a given area, and slow down its runoff. For this purpose, the following are used: reservoirs, catchments, ponds (including vegetated sedimentation ponds), drainage ditches, absorption swales, evaporation reservoirs, constructed wetlands for rainwater purification, the construction, expansion, and renovation of rainwater reservoirs with accompanying infrastructure (e.g., pre-treatment devices and water distribution installations), the elimination of soil sealing and impermeabilisation (using water-permeable reinforcements, such as lattice or gravel), lowering lawns relative to streets and sidewalks, buffer vegetation strips (e.g., strips, ditches, green roofs), infiltration systems (e.g., basins, absorption basins, reservoirs, catchments, and infiltration ditches), absorption wells (retaining rainwater on the surface, enhancing the landscape), permeable surfaces, e.g., green areas, permeable concrete, porous asphalt, and concrete lawn grids.

Utilising rainwater at its source becomes indispensable, taking advantage of its opportunities while minimising the consumption of high-quality water drawn from the water supply. Sustainable rainwater management methods should become crucial in revitalising older urban districts, post-industrial areas, and poorly or undeveloped areas within the city, as well as the planning and construction of new housing estates.

Sustainable rainwater management in urban areas is critical due to its protective function for the environment and residents' health and property (Smit & Wandel, 2006). However, planning and implementing these measures are often challenging due to the high density of buildings and the intensive use of space. Sustainable rainwater management prepares for, anticipates, and combats threats and creates opportunities for development and recreational functions (Bolund & Hunhammar, 1999; Gomez-Baggethun & Barton, 2013; Pamukcu-Albers et al., 2021). Creating additional recreational spaces based on sustainable rainwater management scenarios (Sañudo-Fontaneda & Robina-Ramirez, 2019) demonstrates the success of this dual-purpose approach. On the one hand, permeable spaces with a "sponge" structure are created (Jiang et al., 2017), which absorb, store, and release rainwater in various forms. On the other hand, these areas become places where people can spend leisure time, relax, be in nature, and engage in hobbies or sports.

In this regard, the usefulness of green roofs, rain gardens, riverbanks, lakesides, and water reservoirs is mainly considered, as well as lowered areas such as meadows, sports fields, parks, lawns, and playgrounds. Due to their specific (absorbent) structure, these areas absorb rainwater and can retain and store water, releasing it later when temperatures are high and during extended dry periods (water evaporation).

Recreational and relaxation benefits

Relaxation benefits of stormwater management include the potential to improve urban aquatic habitat, water quality in lakes, rivers, and streams, and the overall environment for recreational activities. Specifically, stormwater management practices like green infrastructure can help reduce flood rates, enhance urban aquatic habitat, and improve water quality. By implementing decentralized approaches for stormwater control, cities can create greener spaces that not only mitigate flooding and pollution but also provide residents with opportunities to enjoy nature and engage in recreational activities. Additionally, green infrastructure projects can generate ancillary environmental benefits that contribute to the overall well-being of urban areas (Ando et al., 2019). Such benefits highlight the importance of considering recreational aspects when evaluating the effectiveness and value of stormwater management initiatives in urban settings.

Stormwater management projects that prioritize recreational/relaxation benefits can contribute significantly to the overall well-being of urban areas in several ways beyond flood reduction and pollution mitigation. Firstly, these projects can enhance the quality of public spaces by creating green infrastructure such as parks, greenways, and recreational areas that offer opportunities for outdoor activities and social interactions. Such spaces provide residents with access to nature, which has been proven to have numerous physical and mental health benefits, including reducing stress, improving overall well-being, and promoting physical exercise (Londoño Cadavid, 2013).

Green roofs serve multiple functions: aesthetic, health-related, practical, ecological, and economic. As biologically active surfaces, they contribute to air purification and climate regulation, facilitate better rainwater management (Campisano et al., 2017; Lee et al., 2016; Mentens et al., 2006; Tassi et al., 2014; Wong et al., 2015), enhance the architectural value of buildings, and provide safe, usable spaces for people. The recreational function of green roofs can be extensive, including areas for relaxation, flower meadows, cultivation and gardening spaces, meeting and integration spots, gyms, running tracks, and spaces for gymnastics.

A rain garden is typically installed at the outlet of a gutter (or possibly a vegetative terrace) or a rainwater harvesting system. Its design allows it to absorb irregular water inflows, thereby mitigating the effects of storms and heavy rainfall. It is generally intended for water purification before proper infiltration; this is one of the recommended features in ecological gardens and cities, and it may include a small, more watertight area that gradually releases the accumulated water.

The recreational function of rain gardens centres on providing areas for relaxation and recreation around these structures.

Riverside areas, as well as the rivers, lakes, and water reservoirs themselves, become natural zones for absorbing excess rainwater. When properly managed, they store water and release it during high temperatures. The key to their function is maintaining the permeability of the riverside areas (to ensure the natural water cycle) and the appropriate level of water quality in the reservoirs. The recreational functions of these areas include opportunities for nature observation – such as nesting sites and diverse plant life, including wild species – relaxation, and water sports, gathering and integration spots, and the chance to engage with culture through events like water performances.

Lowered areas such as meadows, sports fields, parks, lawns, and playgrounds are typically kept dry most of the time. However, they can be designed as permeable areas to support sustainable rainwater management in urban environments. Their primary function is recreation and relaxation, while water retention is a complementary function.

Additionally, stormwater management projects focused on recreational benefits can help improve water quality in urban lakes, rivers, and streams, enhancing the aesthetics of these water bodies and creating more attractive environments for residents to enjoy; this can contribute to a sense of community pride and belonging, as well as increase property values (Ando et al., 2019).

Research methods

Recreational usability index of the element (RUI-E) of the stormwater infrastructure

Ten metrics were used to construct the Recreational usability index of the element (RUI-E) of the stormwater infrastructure; each assigned a numerical value from 1 to 3. A value of 1 represents the weakest performance in the assessment, 3 represents the highest performance, and 2 represents an average/moderate performance. The metrics examined and included in the index are as follows:

1. **Retention capacity:** 1-low, 2-moderate, 3-high (based on the average retention capacity).
2. **Operational ease:** 1-low, 2-moderate, 3-high.
3. **Water purification rate:** 1-soil only, filtration layers without plants, 2-grass cover, low vegetation, 3-low or high vegetation.
4. **Type of use:** 1-neutral, 2-supportive, 3-recreational function significant for the element.
5. **Continuity of use:** 1-temporarily excluded from the system, 2-temporarily challenging to use, 3-continuous.
6. **Person capacity:** 1-no capacity, 2-individual, 3-group.
7. **Multifunctionality potential:** 1-monofunctional, 2-temporarily multifunctional, 3-multifunctional.
8. **Inclusiveness:** 1-excluding, 2-excluding some social groups, 3-inclusive.
9. **Cost[2]:** 1-high, 2-moderate, 3-low.
10. **Landscape value:** 1-low, 2-moderate, 3-high.

The obtained values of the components of the RUI-E were summed, and the result indicates how useful a given system element is for recreational purposes while simultaneously performing the functions of receiving, storing, and releasing rainwater. The RUI-E values can range from 10 to 30. The recreational suitability index, considering retention capacity, was grouped into three ranges to determine the suitability of the analysed system elements. A value in the range of 10-16 indicates low suitability of the analysed tool, a range of 17-23 indicates moderate suitability and a range of 24-30 indicates high suitability.

Presented in Table 1 fourteen elements that could be applied within the system were examined, selected based on a literature review and using the expert method.

As a result of the conducted research, significant differences were found among the examined system elements regarding their recreational usability (RUI-E). In the lowest category, the least useful tools for building recreational usability included four elements: street inlet, permeable surface, permeable openwork surface, and infiltration trench. The group of tools with moderate usability,

[2] Refers to the minimum unit of surface area or capacity required for the system element to function.

based on RUI-E values, had six elements: extensive green roof, intensive green roof, absorbent mound, infiltration ditch, evaporation basin, and dry retention basin[3].

In the highest category, four elements with high usability were included: rain garden, surface infiltration basin, constructed wetland, and surface retention basin. Typically, technical system elements received the lowest ratings; therefore, they often become components of larger forms, achieving a composite value and raising the overall index value. This way, they can become significant elements of larger spatial forms dedicated to recreational functions.

Most elements fell into the moderate usability group; these are larger forms that often require substantial financial investments but are generally designed for use by a higher number of people simultaneously. High usability characterizes system elements that can be introduced relatively easily, often without significant financial outlays. They can be moderately effortlessly combined with other tools, which creates an additional advantage in terms of flexibility.

Table 1. Recreational usability index of the studied elements (RUI-E)

	Retention capacity	Operational ease	Water purification rate	Type of use	Continuity of use	Person capacity	Multi-functionality potential	Inclusiveness	Cost	Landscape value	Recreational usability index of the element (RUI-E)
Extensive green roof	1	2	2	2	2	1	2	3	2	1	18
Intensive green roof	1	2	2	3	2	3	3	3	1	3	23
Street inlet	1	2	2	1	3	1	1	1	3	1	16
Permeable surface	1	1	2	1	3	1	1	2	3	1	16
Permeable openwork surface	1	1	1	1	3	1	1	2	3	1	15
Infiltration trench	1	1	2	1	3	1	1	1	3	1	15
Rain garden	2	2	2	3	2	3	3	2	3	3	25
Absorbent mound	2	2	2	2	2	2	2	2	3	2	21
Infiltration ditch	2	1	1	2	3	2	2	2	3	2	20
Surface infiltration basin	2	1	2	3	2	3	3	3	2	3	24
Evaporation basin	2	3	1	3	1	3	2	2	2	3	22
Constructed wetland	2	2	3	3	2	3	3	3	2	3	26
Dry retention basin	3	3	1	3	1	3	2	2	2	2	22
Surface retention basin	3	3	1	3	2	3	3	3	2	3	26

Source: authors' work based on Lejcuś et al. (2021).

Recreational usability index of the system (RUI-S)

The evaluation and determination of the RUI-E values for individual elements of the stormwater management system, based on the referenced metrics, constitute the first step in creating a tool that enables the planning of solutions for various system variants. The considered variants allow for a precise understanding of the effectiveness of the applied solutions and the identification and selec-

3 The condition for including the green roof solutions in the calculation of the RUI-E index is to ensure its accessibility for users.

DOI: 10.34659/eis.2025.93.2.956

tion of areas for optimization; this enables the creation of variants that can prioritize selected system characteristics according to chosen metrics. Utilizing the tool allows for comprehensive planning of strategies that can significantly contribute to sustainable and efficient resource management in subsequent project implementation stages while verifying the recreational usability of the proposed solutions.

Knowing the individual RUI-E values for each element of the system, the tool enables the controlled planning of the system structure in terms of selecting specific elements and determining the appropriate quantity of their application to achieve the highest possible recreational usability index. At the same time, it is essential to note that the presented tool is open-ended. At the initial stage of its use, the user can decide to add a previously unconsidered system element within the table. In such cases, the user must complete the values for the fields corresponding to the respective metrics. This design allows the tool to be universal and adaptable, enabling customization to the users' needs and accommodating the evolving state of knowledge and development of solutions in stormwater management.

To evaluate a selected variant and, consequently, the planned system as a whole, it is necessary to determine the recreational usability index of the system (RUI-S). RUI-S is calculated as the sum of the products of RUI-E and the number N, which is the weight of the applications of a given element within the system, corresponding to the area of the applied system elements.

Usability ranges of the considered system

Given the open-ended nature of the tool and the variable total area of the applied elements within the considered system (number N), the ranges for evaluating the usability of the constructed system are determined automatically each time the list of applied elements is finalized. These ranges are established as follows:

1. the minimum range boundary (gmin) is determined as the product of the number N and the lowest RUI-E value on the list of all system elements in the table (lower boundary of the low usability range);
2. the maximum range boundary (gmax) is determined as the product of the number N and the highest RUI-E value on the list of all system elements in the table (upper boundary of the high usability range).
3. the subsequent range boundaries are defined as thirds of the difference between the previously determined boundaries.

The above-described interval designation is presented in the Table 2.

Table 2. The method of calculating ranges for evaluating the usability of the constructed system

low usability	$g_{min} = N \times RUI\text{-}E_{min}$	$g = g_{min} + 0.3 \times (g_{max} - g_{min}) - 1$
moderate usability	$g = g_{min} + 0.3 \times (g_{max} - g_{min})$	$g = g_{min} + 0.6 \times (g_{max} - g_{min})$
high usability	$g = g_{min} + 0.6 \times (g_{max} - g_{min}) + 1$	$g_{max} = N \times RUI\text{-}E_{max}$

At the same time, it is important to note that, as previously indicated, the tool automatically determines the boundary values of the usability ranges within the presented table.

The value of the RUI-S index, as presented above, is a relative value specific to a given analysis case and serves to evaluate and compare different solution variants within one defined research area. This approach allows designers to assess the structure and recreational usability of the retention system in the context of a specific location. The primary assumption of the presented tool is to support comparative analyses within the selected research area, considering local spatial and functional conditions. However, in response to the need to extend the scope of analyses to various independent locations, the RUI-S index can be transformed into an contribution index, denoted as RUI-S%. This index enables the comparison of retention systems with different areas and spatial conditions. The RUI-S% value is expressed according to the formula:

$$RUI - S\% = (b/a) \times 100\%,$$

where:

a = $g_{max} - g_{min}$ (the range of possible index values in the given case),

b = g_{max} – RUI-S (the difference between the maximum achievable value and the value obtained in the analyzed case).

The obtained RUI-S% value, as an contribution value, serves as a basis for comparing the recreational usability of retention systems across different areas, regardless of their scale or characteristics, which significantly enhances the application potential of the developed tool (providing its additional functionality).

Evaluation of the usability of the proposed scenario through RUI-S

In creating the discussed tool as a table, the authors aimed to simplify its operation as much as possible. Therefore, values such as RUI-E, RUI-S, and the previously discussed usability range boundaries are automatically calculated based on established formulas; this aims to optimize the tool's usage process and shift the user's focus maximally towards the design process rather than the operation of the tool itself.

With this in mind, the user makes decisions regarding the proposed application of specific system elements by entering the quantity of each applied system element in the table. The calculated RUI-S is then compared to the usability ranges, directly providing the evaluation result of the system composed of the proposed elements.

Simultaneously, the other values are updated in real-time while planning and entering data into the table. This allows the user to immediately see the impact of their decisions on the recreational usability index while ensuring total control and intuitive operation when using the proposed tool.

Furthermore, to expand the comparative potential of the tool beyond a single location, the calculated RUI-S value can be transformed into an contribution index – RUI-S% – allowing for the evaluation and comparison of system usability across different sites. This additional functionality enhances the tool's versatility, enabling its use not only in project-specific assessments but also in broader comparative analyses of retention systems implemented in diverse urban contexts.

Results of the research

Study area: Nowe Żerniki – introduction

Using the previously described model to determine the efficiency of stormwater management in a given area, the authors employed a case study using the Nowe Żerniki housing estate in Wrocław, Poland, as the analyzed example.

Wrocław is a city with variable average annual precipitation (in 2020-2023, it ranged between 496 and 727 mm), and in 2023 it amounted to 644 mm. The length of the sewage distribution network in the city in km is 1324.8 (as of December 31, 2023). Publicly accessible urban and housing estate green areas of the total city area are 6.4% (1874.26 ha – as of December 31, 2023), including publicly accessible urban green areas: walking and recreation parks 814.77 ha and green areas 261.64 ha, and housing estate green areas 797.85 ha. According to the Study of Conditions and Directions of Spatial Development of Wrocław 2018 (GiS, 2025), the area of Nowe Żerniki is 197 ha, including 14% green areas. There is a development area with increased investment traffic in the model housing estate, Nowe Żerniki. The challenges for this unit are maintaining an adequate proportion between newly constructed buildings and green areas, building a local identity and spaces integrating residents, ensuring the possibility of implementing a recreational function and developing a compact functional and spatial structure, in particular in the area of development of the model housing estate Nowe Żerniki.

From the case study perspective, it is significant that the estate is being developed in stages. This allows for the analysis of already completed stages within the research work and their evaluation in terms of the recreational usability of the stormwater management system.

DOI: 10.34659/eis.2025.93.2.956

As a result, within the framework of the case study on stormwater management, the solutions implemented in the Nowe Żerniki housing estate during its development were described, along with an analysis of the recreational usability of the applied system considering its retention capacity through the presented model. This analysis covered the solutions in the already completed multi-family residential buildings and the planned Community Center.

The Nowe Żerniki estate, also known as WuWa 2, is an innovative urban project developed in Wrocław, referencing the historic WuWa (Wohnungs- und Werkraumausstellung) estate from 1929. This initiative emerged as part of the European Capital of Culture 2016, highlighting its cultural and social significance. The initial infrastructure construction began in 2012, and the implementation of further construction was divided into stages. The first stage of Nowe Żerniki covers an area of over 7 ha and is intended for more than 5,000 residents (within 1,500 apartments). Ultimately, the estate is planned to cover approximately 60 ha. A significant aim is the simultaneous development of public spaces alongside residential buildings, including a kindergarten, school, community centre, church, local market, senior care home, sports field, and family doctor's clinic. In the first stage, key projects include the community centre, senior care home, and portions of green and recreational areas.

WuWa 2 addresses contemporary housing and urban challenges by emphasizing sustainable development, modern technologies, and social integration. The project is unique due to the extensive collaboration between the public sector, designers, developers, and future residents, including housing cooperatives. This collaborative approach has allowed for the harmonious integration of various perspectives and needs from the very beginning of its creation. The initiative aims to create a model estate of the future, combining a high quality of life for residents with modern architectural and ecological solutions.

The main principles of the WuWa 2 project include:

- Sustainable Development: The project emphasizes ecology and energy efficiency. Buildings in the estate are equipped with modern heating and cooling systems and photovoltaic installations. A significant amount of green spaces and bicycle infrastructure support the idea of eco-friendly living.
- Innovative Technologies: Nowe Żerniki utilizes the latest construction and infrastructure management technologies. Some innovations applied include intelligent energy consumption monitoring systems, building automation, and modern urban transportation solutions.
- Social Integration: The project addresses the needs of various social groups by offering diverse housing types, from studios to larger family apartments in various building types – from single-family homes and urban villas to multi-family buildings of different scales. Common areas like playgrounds and recreational and cultural centres promote integration and community building.
- Aesthetics and Functionality: The estate's architecture combines modern forms with functionality. The designers aimed to make the buildings aesthetically pleasing but also practical and comfortable for residents.

Nowe Żerniki is an example of how tradition can be harmoniously combined with modernity, creating a space that addresses the challenges of contemporary urban life. WuWa 2 is a project that emphasizes innovation, sustainable development, and high quality of life, becoming a model for future urban initiatives to follow.

Rainwater on Nowe Żerniki

A vital role in the Nowe Żerniki project is played by stormwater management, which is an essential element of the estate's sustainable development. Detailed information about the planned and implemented solutions was provided in an interview by Piotr Fokczyński, the former Director of the Department of Architecture and Building at the Wrocław City Office and the City Architect, who served as the main Coordinator of the Nowe Żerniki project. Under his leadership, a range of innovative technologies were introduced to ensure effective stormwater management, contributing to the ecological and economic functioning of the estate.

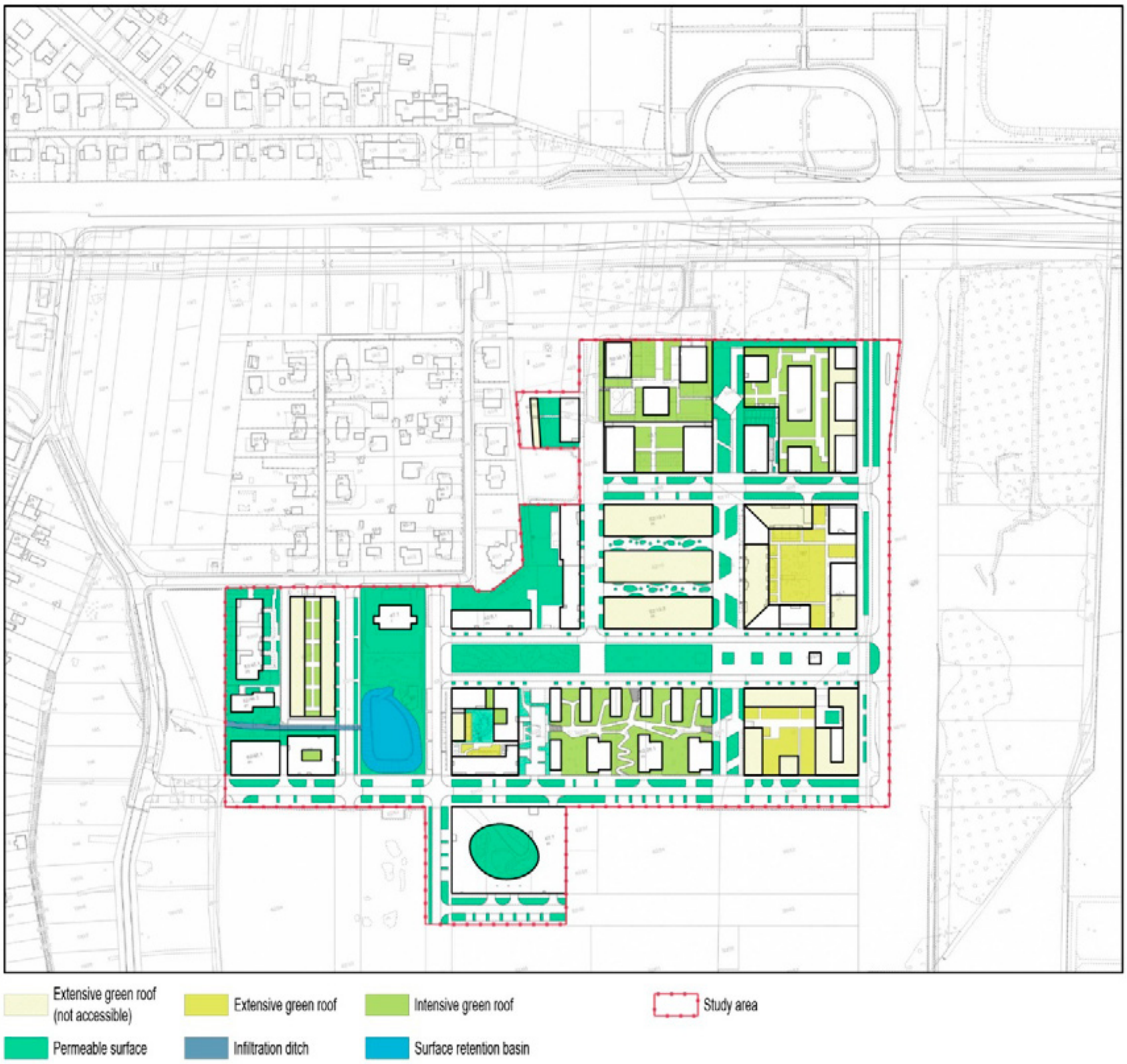

Figure 1. Studied area. Completed part of the Nowe Żerniki housing estate with an indication of the rainwater system

Considering the initial conditions of the land designated for the planned investment, it is important to note several factors, including the lack of stormwater drainage systems (both existing and planned), a high groundwater level, and three existing open drainage ditches. Additionally, a significant factor was the planned high density of development and the introduction of hardened communication surfaces, resulting in the loss of substantial natural retention capacity and soil permeability. At that time, no existing legal regulations, such as those related to lost retention, are present today.

With the above considerations in mind, the conceptual phase was preceded by comprehensive and detailed geotechnical and hydrotechnical studies. This allowed for the precise planning of the stormwater management system based on the existing resources and conditions, creating a comprehensive solution for the entire area. Given the initial conditions and the need for a comprehensive solution, the planning phase involved detailed geotechnical and hydrotechnical studies, enabling precise stormwater management planning based on existing resources and conditions. The planned system comprises interconnected solutions, ranging from local rainwater collection on individual plots, emergency connections to more prominent local system elements in the form of open reservoirs, to emergency overflows utilizing the Ługowina catchment area (a stream that is a left tributary of the Oder River). Below are the key assumptions and solutions for stormwater management implemented in the estate, along with a brief description:

DOI: 10.34659/eis.2025.93.2.956

Underground Retention Tanks: Each residential block has an underground retention tank with sufficient capacity to collect and retain rainwater from the entire block. This water is then used to irrigate green areas during dry periods. Each tank also has an overflow buffer that redirects excess water to surface retention tanks.

Surface Retention Tanks: Two surface retention tanks have been created in the completed part of the estate. Their primary function is to collect and retain rainwater from public spaces within the estate, including streets and squares, through the internal stormwater drainage system. Additionally, due to their capacity, they serve as emergency backups in case the underground tanks overflow (in an emergency scenario, these tanks can accommodate over 10% of the volume of the underground tanks).

Internal Stormwater Drainage System: The internal stormwater drainage system, implemented along communication routes, connects the other elements of the structure, including underground retention tanks, surface retention tanks, and drainage ditches.

Drainage Ditches: Existing drainage ditches have been integrated as a crucial element of the overall system, utilizing the natural surface water layout. They are kept open channels for as long as possible and only canalized in critical areas. These ditches lead water to surface retention tanks and further to the stream (Ługowina).

Ługowina Stream: Running along the investment area, the stream is the natural drainage for rainwater. It is currently used for the emergency discharge of excess water from the system, specifically from the surface retention tanks, considering the natural geometry and layout of the catchment area, including drainage ditches.

Extensive Green Roofs: Most buildings feature extensive green roofs, which, in addition to their aesthetic and insulating benefits, increase the system's retention capacity.

Intensive Green Roofs: In one of the residential blocks, intensive green roofs are planned to incorporate urban farming and community gardens. This solution, as with extensive green roofs, enhances the system's retention capacity. However, it is a supplementary solution due to the limited number of applications.

Permeable Surfaces: An additional concept element includes using permeable surfaces in park areas and sports greens. These surfaces reduce surface runoff by absorbing water, thereby decreasing the rainwater flowing directly into the stormwater drainage system and drainage ditches.

The solutions described above collectively form a cohesive and comprehensively planned stormwater management system, which can serve as a model solution for other urban estates. By integrating various technologies and practices, Nowe Żerniki effectively minimizes the negative impact on the natural environment while reducing operational costs.

At the same time, the described system has proven its effectiveness during operation, having experienced only one failure. During a heavy rainstorm, the drainage ditches did not effectively channel rainwater from the streets to the surface retention tank and further to the Ługowina stream. As a result, water overflowed the street edges and entered the underground garages. The cause of the failure was the neglect of one section of the drainage system, where vegetation blocked the flow. It was determined that the failure was due to maintenance oversight rather than a flaw in the functioning of the planned system itself. It is also essential to consider the elements evaluated during the planning stage but not included in the final concept. A significant solution not implemented due to financial considerations was using rainwater in buildings' systems. The retained and stored rainwater was intended to be filtered and reintroduced for reuse. The planned system's efficiency assumed the utilization of 100% of the retained rainwater, which would have significantly reduced the operational costs of the buildings. However, considering the potential maintenance challenges of this advanced solution, none of the developers decided to implement it.

Another set of solutions abandoned at the initial stage included landscape features such as absorbent mounds and rain gardens. The deciding factor in their exclusion was the land consumption of these solutions. Their implementation and regulatory requirements concerning elevation differences would have consumed too much space.

One of the critical aspects influencing stormwater management was the issue of building surface area. In most residential blocks, almost the entire area was designated for development, including elevated parking structures, often constructed at ground level due to the high groundwater levels. This approach drastically reduced the biologically active surface area and, consequently, the site's

DOI: 10.34659/eis.2025.93.2.956

retention capacity. Other factors conditioning and determining the work on the system concept (besides the nearly complete development of the plot) included the existing layout of drainage ditches, the high groundwater level, guidelines from the entities carrying out the investments, and, consequently, the efficiency of the planned system. While the recreational usability of system elements was an essential aspect of the design process, it was not the primary determinant.

Recreational usability of the implemented system

The previously described model approach to stormwater management in the studied housing estate exemplifies how contemporary cities can implement sustainable and efficient water resource management solutions by utilizing existing natural conditions. The estate's designers ensured that the stormwater infrastructure not only fulfilled technical functions but also served as recreational spaces for residents. For example, the surface retention basins and green areas were designed to promote outdoor relaxation and recreation. One such basin is located near the Community Center, which additionally serves as a recreational area, providing a space for relaxation and community events and enabling nature observation and ecological education.

Efforts were also made to protect local fauna by transforming the retention basin into a wintering habitat for amphibians through appropriate shaping and vegetation selection. Due to ongoing climate changes, the constructed surface retention basins have recently periodically taken on the form of dry retention basins.

Table 3. Recreational usability index of the studied system (RUI-S)

	Recreational usability index of the element (RUIE)	Total area of the element in the system [ha] – weight	Recreational usability index of the element in the system
Extensive green roof	18	0.38	6.8
Intensive green roof	23	0.92	21.2
Street inlet	16	-	-
Permeable surface	16	2.41	38.6
Permeable openwork surface	15	-	-
Infiltration trench	14	-	-
Rain garden	25	-	-
Absorbent mound	21	-	-
Infiltration ditch	20	0.04	0.8
Surface infiltration basin	24	-	-
Evaporation basin	22	-	-
Constructed wetland	26	-	-
Dry retention basin	22	-	-
Surface retention basin	26	0.45	11.7
Recreational usability index of the system (RUI-S)			79.1
low usability			63-76.8
moderate usability			76.9-90.7
high usability			90.8-109.2

DOI: 10.34659/eis.2025.93.2.956

In Table 3., utilizing the developed and discussed tool, the analysis of the recreational usability of the stormwater management system in the Nowe Żerniki estate are presented, considering each element's retention capacity. These results are discussed in the following section of the article – the discussion.

Discussion/Limitation and future research

Discusion

It should be noted that the implemented system elements generated a recreational usability index (RUI-S) considering retention capacity at 79.1 points, with the possible score range being from 63 to 109.2 points. Given the scoring ranges, the recreational usability of the implemented system can be described as moderate. It is important to note that out of the eight types of system elements, five can be considered in terms of recreational usability. The remaining elements are purely technical solutions that supplement the system but are essential for its functioning (e.g., underground retention tanks and the internal stormwater drainage system). Additionally, solutions such as surface retention tanks and drainage ditches significantly impacted the assessment, as they are key components of the system with high recreational usability.

Considering both the character and the assumptions of the stormwater management system concept, one could consider: covering standard roofs with the intensive green roofs alongside replacing the extensive green roofs with intensive green roofs (4.18 ha of extensive green roofs in total) and changing some permeable surfaces into rain gardens (reducing permeable surfaces to 1.75 ha and introducing 0.66 ha of rain garens). Changing these properties of system elements can increase the recreational usability index to 153.1 points, indicating a high recreational usability for the entire system (in such system high usability starts from 153 points). At the same time, as mentioned, the system is based on a limited number of solutions with diverse technical and landscape characteristics. However, their combination creates a cohesive and comprehensive system that transcends property boundaries. In summary, the stormwater management system implemented within Nowe Żerniki serves as a model solution in terms of both the comprehensiveness and innovativeness of the solutions introduced and their recreational usability.

The discussed concept of constructing a stormwater management system is illustrated by the example of a new housing estate, which is being developed in line with the idea of sustainable development and is treated as a model estate. However, even this space has not achieved the highest level of RUI-S with the current development method (although this can be improved, as outlined above). Therefore, focusing efforts on efficient stormwater management is necessary to ensure multifunctionality in the built systems, including retention and recreational functions. The developed indices (RUI-E, RUI-S) will be helpful in this effort, as their ease of use can encourage the planning of efficient systems, thereby contributing to climate care, environmental protection, and quality of life.

The construction of effective stormwater management systems that provide retention and recreational functions should not be limited to new urban housing estates. Such systems can also be built in less favourable conditions, such as small spaces, already-developed areas, and post-industrial, railway, or military sites. The flexibility provided by the tool allows for adaptation and customization to meet the needs of users and spaces. Many studies and tools focus on the technical aspects of stormwater management (primarily considering retention functions), which is insufficient in contemporary conditions. In contrast, the developed mechanism places primary importance on recreational functions and often includes landscape value. Consequently, with limited space resources in cities, a well-constructed system meets the requirement for multifunctional space use and addresses the challenges associated with climate change.

Limitations and difficulties

The issue of rainwater retention has garnered significant interest in both scientific research and implementation and legislative activities. These initiatives are undertaken by research institutions, local and governmental authorities, and private individuals. Consequently, at the outset of their research, the authors were able to build upon a well-established theoretical foundation. However, the

DOI: 10.34659/eis.2025.93.2.956

recreational value of retention solutions is typically regarded as a secondary or supplementary concern – it has not yet been parameterized in previous studies. Throughout the research process, the authors encountered several difficulties and limitations.

The first difficulty was the diversity of units and parameters used to assess individual components when determining the RUI-E (Recreational Use Index – Element). This variability complicated the direct comparison of component parameters and the assignment of uniform weight to each, which affected the tool's flexibility in allowing users to evaluate each component independently. As a result, it was necessary to limit the assessment of individual parameters by adopting an index-based approach and assigning each component a numerical value ranging from 1 to 3. This approach allows users to evaluate the components independently in the future (Table 1).

Another difficulty was the universal weight determination for each element within the system when calculating the RUI-S (Recreational Use Index – System). It was crucial to ensure that the adopted method did not favour any specific component of the RUI-E, which posed a significant challenge. As a result, a simplified approach was adopted, whereby the weight of each element was assigned based on its total surface area within the system (Table 3).

An additional limitation of the original RUI-S index was its inability to support direct comparisons between different locations, as the results were context-specific and relative to the analyzed area. Hence, the tool has been extended to include an contribution form of the index – RUI-S% – which enables normalization of results and allows for comparative evaluations across independent sites. This enhancement significantly increases the analytical potential of the tool, facilitating its application in cross-site assessments regardless of differences in area or spatial characteristics.

The limitations above introduced in the presented research, on the one hand, allowed for its simplification and easy, intuitive use of the proposed tool. On the other hand, they open up opportunities for further research and its development.

Directions of future work

As mentioned earlier, when developing the discussed tool, the authors aimed to simplify its operation as much as possible. RUI-E, RUI-S, and the defined usability range thresholds are automatically calculated based on established formulas. This approach aims to optimize the tool's usability process and shift the user's focus towards the design process rather than the tool's operational mechanics.

The proposed tool can be of use not only to designers but also to researchers. The tool's key feature for designers is its simplicity and intuitive nature, which is essential as it is one of many tools utilized throughout the design process. On the other hand, researchers may be more interested in analyzing the impact of individual measures and parameters of each system component on the overall recreational value. As such, several potential areas for further research into the tool's development can be identified:

- Incorporating explicit assumptions for measures of individual components, which could facilitate planning the system's structure based on the available budget.
- Parameterization of measures for individual components, allowing for the automation of system structure planning.
- Considering the ratio of available land area to the surface area of individual components as an additional factor in system structure planning.

Additionally, it would be valuable to consider incorporating the following aspects:

- Consideration of population density in the studied area.
- Integration of solutions implemented through private initiatives as system structure components.

At this stage, the tool is based on spreadsheets, which, although they enable calculations and modifications, may reduce its intuitiveness in everyday use. Developing a dedicated tool in the form of an application or software could significantly streamline the work of both designers and researchers by providing greater ease of use and automating design processes.

Conclusions

Issues related to the necessity of focusing on safety, and the economic, social, landscape, and recreational use of rainwater are a consequence of striving for sustainable development and meeting the challenges posed by global climate change. At the same time, it should be noted that there is a lack of a systemic/holistic approach to the construction of retention systems that would consider the recreational/relaxation function as a determinant for the system; this can lead to the underutilization of the full potential of these areas.

Most retention system elements can perform a dual recreational function-serving one role during dry periods and another during rainfall. In the context of increasing urban population density and limited space, particularly under climate change, the multifunctional use of available areas is crucial. Therefore, it becomes essential to create a system that allows for efficient use of space, considering its retention capacity and potential for recreational functions. The developed recreational usability indices for individual elements and the entire system serve this purpose.

Building a stormwater management system incorporating the recreational usability index allows for effective water resource management, enhances residents' quality of life, and diversifies the use of urban areas. The Nowe Żerniki estate, in light of conducted research and the evaluation of the system's recreational usability index (for the developed part of the area), meets the requirements for moderate recreational usability with an efficient retention system, while also having the potential to achieve high recreational usability. Maintaining and raising this index level for the undeveloped part of the estate is important. However, due to structural changes within the City Office, there is a concern that the subsequent stages of the estate's construction may not uphold the discussed standards.

The conducted research, which includes the developed index, is current and addresses challenges related to climate change, increasing urban populations, and the pursuit of compact city development. Future studies on combining retention and recreational functions should focus on the population density of a given area and the ratio of the system's surface area to the area designated for development. Considering the planned further development of the Nowe Żerniki estate under the established master plan, research can continue using the proposed tool what can be done by creating variant concepts for developing the stormwater retention system in newly developed areas. This is particularly relevant since the individual entities responsible for developing subsequent residential blocks will be able to decide on the system elements and methods for retaining rainwater within their blocks (while maintaining the main solutions of the holistic system).

In the light of contemporary climate changes, which have recently manifested through both droughts and sudden, prolonged, and intense rainfall leading to floods, as well as the anticipated imminent water deficit, the issue of stormwater management is gaining renewed importance. The shifting climate conditions make the effective planning of retention systems and their multifunctional use crucial for the sustainable development of cities. Tools that facilitate the design of such systems, like the one proposed in this article, are becoming increasingly relevant, supporting not only protection against the effects of extreme weather events but also enhancing the use of urban spaces for both retention and recreational purposes.

The contribution of the authors

Conceptualization, D.R., H.A., B.A. and T.B.; literature review, D.R. and H.A.; methodology, D.R., H.A., B.A. and T.B.; formal analysis, B.A. and T.B.; writing, D.R., H.A., B.A. and T.B.; conclusions and discussion, D.R., H.A., B.A. and T.B.

The authors have read and agreed to the published version of the manuscript.

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OCENA PRZYDATNOŚCI REKREACYJNEJ SYSTEMU GOSPODAROWANIA WODAMI OPADOWYMI NA OBSZARACH MIEJSKICH – STUDIUM PRZYPADKU WROCŁAWIA

STRESZCZENIE: W artykule przedstawiono możliwości budowy efektywnego systemu zrównoważonego zagospodarowania wód opadowych na obszarach miejskich, spełniającego funkcje rekreacyjne, na przykładzie osiedla Nowe Żerniki we Wrocławiu (Polska). Metodologia obejmuje badania desk research, kartograficzną analizę terenu, studium przypadku, metodę wskaźnikową i indywidualny pogłębiony wywiad. W badaniu zidentyfikowano brak holistycznego podejścia do systemów retencji, którego zadaniem jest integracja funkcji gromadzenia wody opadowej i funkcji rekreacyjnej, co w efekcie prowadzi do niedostatecznego wykorzystania przestrzeni miejskich. Ograniczenia badawcze, wynikające ze złożoności komponentów systemów retencyjnych, ominięto poprzez zastosowanie uproszczonych wskaźników RUI-E (wskaźnik użyteczności rekreacyjnej elementu) i RUI-S (wskaźnik użyteczności rekreacyjnej systemu). Uproszczenia takie pozwalają na intuicyjne korzystanie ze sporządzonych wskaźników, ale także otwierają możliwości dalszego rozwoju, w tym implementacji bardziej szczegółowych parametrów. Oryginalność/wartość polega na możliwości oceny atrakcyjności terenu z użyciem zaproponowanej procedury określenia przydatności rekreacyjnej systemu gospodarowania wodami opadowymi na obszarach miejskich. Jednocześnie może ona służyć jako narzędzie wspomagające projektowanie terenów miejskich. To z kolei czyni narzędzie przydatnym dla projektantów i badaczy nowych oraz istniejących inwestycji. W ramach badania stwierdzono, że użyteczność rekreacyjna systemu Nowe Żerniki była umiarkowana, z potencjałem poprawy.

SŁOWA KLUCZOWE: zarządzanie wodami opadowymi, systemy retencyjne, indeks rekreacyjny, tereny zielone, opady deszczu