

Decentralized Rainwater Management for Urban Resilience: Principles, Policy Context and a Case Study from Romania

Managementul descentralizat al apei meteorice pentru reziliența urbană: principii, context politic și un studiu de caz din România

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Abstract: *Urban areas face growing flood risks and hydraulic overloads due to climate change, urban densification, and the expansion of impervious surfaces. In this context, decentralized rainwater management is increasingly recognized as a valuable complement to conventional drainage systems. This paper outlines the principles and policy context of decentralized rainwater harvesting and infiltration, with a focus on nature-based and building-scale solutions that align with European water policies. The practical application of these approaches is illustrated through a case study of a decentralized rainwater harvesting and infiltration system implemented in an educational building in Cluj-Napoca, Romania. The findings demonstrate that such systems can reduce stormwater discharge, support non-potable water reuse, and improve urban water resilience.*

Key words: decentralized rainwater management; stormwater management; urban resilience; nature-based solutions; rainwater harvesting; infiltration systems

1. Introduction

Urban areas are facing growing water-related challenges driven by climate change, rapid urbanization, and the expansion of impervious surfaces. These factors lead to higher stormwater runoff volumes, increased flood risk, and greater pressure on centralized drainage and wastewater systems [1], [2]. As a result, urban water management is gradually shifting toward decentralized approaches that handle rainwater closer to its source [3].

Rainwater harvesting, retention, and infiltration systems can help reduce peak flows, support non-potable water reuse, and restore parts of the natural hydrological cycle in urban environments [3], [4]. European climate and water policies increasingly

support these types of solutions, particularly those based on natural processes and local implementation.

This paper explores the principles and policy context of decentralized rainwater management and presents their practical application through a case study of a building-scale rainwater harvesting and infiltration system implemented in Cluj-Napoca, Romania.

2. Principles and Design Aspects of Decentralized Rainwater Systems

2.1. Principles of Decentralized Rainwater Management in Urban Areas

Sustainable urban water management is increasingly shifting from conventional centralized drainage toward decentralized approaches. These methods handle stormwater close to where it falls. The change is driven by more frequent intense rainfall, urban surfaces becoming increasingly impermeable, and the limited capacity of existing sewer systems to handle peak flows [1], [2].

Unlike traditional systems, which focus mainly on moving water quickly, decentralized rainwater management seeks to reduce runoff volumes, smooth peak flows, and restore some natural hydrological processes that urban development has disrupted [5].

At the building level, these systems usually follow a simple sequence: collect, treat, store, and either reuse or infiltrate rainwater. By intercepting water locally, they lower the volume reaching combined sewers and treatment plants. This helps prevent sewer overflows and reduces hydraulic stress during heavy rainfall [5], [6]. Even if only part of the roof is connected, these systems can still significantly help manage runoff and urban flooding.

2.2. Collection, Treatment, and Storage Considerations

The performance of decentralized rainwater systems depends on local conditions. Factors such as climate, roof size, roof material, and surrounding environment all play a role. Rainfall intensity, seasonal changes, and previous dry periods influence how water flows into the system. Roof materials may release particles or dissolved substances, so proper treatment before reuse is essential [7], [8].

In many urban buildings, only a portion of the roof can be used for rainwater collection. In these cases, the design focuses on flexibility and reliability rather than maximizing harvested water. For non-potable uses, simple treatments such as sedimentation, flotation, and granular filtration are common. They remove solids and coarse contaminants effectively while keeping operation straightforward [6], [9].

Storage tanks serve two functions. They store water for reuse and act as hydraulic buffers, smoothing out variations in inflow while aiding natural sedimentation.

Tanks may be placed above or below ground, depending on space and structural constraints. Controlled overflow paths are essential to safely handle excess water during heavy rainfall and prevent localized flooding [6].

2.3. Infiltration and Nature-Based Approaches in Decentralized Systems

In cities with many impermeable surfaces, infiltration is key. Retention-infiltration systems allow water to slowly percolate into the soil. This supports groundwater recharge and reduces surface runoff [5], [10]. Compared with direct discharge into sewers, infiltration helps balance the urban water cycle and reduces downstream hydraulic stress [2], [5].

Decentralized systems work well with nature-based solutions (NBS). NBS rely on natural processes to address environmental challenges. By combining infiltration, retention, and natural filtration, rainwater systems can restore some pre-urban hydrology while providing co-benefits, such as flood mitigation, water conservation, and increased urban resilience [8], [11].

These systems are modular and scalable, making them suitable for retrofitting existing buildings and adapting to various urban settings. When integrated into broader urban water strategies, they complement conventional drainage and help create more resilient, adaptive, and sustainable water systems.

3. Alignment with Eu Climate and Water Policies

The management of urban rainwater has become increasingly important in the European Union, as cities face growing pressure from climate change, urban densification, and more frequent extreme rainfall events. As a result, urban water management is no longer based only on centralized wastewater treatment. It now includes broader approaches such as stormwater control, local retention, and the partial restoration of natural hydrological processes [12], [13].

These priorities are reflected in the European Green Deal, which sets the objective of climate neutrality by 2050 and promotes resource efficiency, pollution prevention, and more resilient infrastructure across environmental sectors [13]. In practice, reducing the amount of stormwater entering sewer networks is seen as an important step in limiting hydraulic overloads and improving system performance.

A key regulatory element supporting this transition is the revised Urban Wastewater Treatment Directive (UWWTD, 2024). It requires cities to develop integrated urban water management plans that explicitly address stormwater runoff [14], [15]. The directive promotes measures such as retention, infiltration, and green infrastructure. These solutions help reduce inflows into sewer systems, lower the risk of overflows, and avoid the unnecessary treatment of relatively clean rainwater [14].

At the same time, the European Union supports the use of nature-based solutions (NBS) in urban water management. The European Commission defines NBS as cost-effective approaches based on natural processes. In practice, they support rainwater

retention, soil infiltration, and the partial recovery of natural hydrological functions [8]. Their increasing use in European strategies shows a broader move toward infrastructure that can address several challenges at once, including flood control, water reuse, and environmental protection [16].

Support for these approaches is also provided through research and innovation programs such as Horizon Europe, Biodiversa+, and the NetworkNature platform [8]. These initiatives help translate research into practical applications and encourage wider adoption in urban areas. In this context, decentralized rainwater harvesting and infiltration systems offer a practical way to reduce stormwater discharge, reintegrate water into the natural cycle, and improve resilience at building and neighborhood scale [5].

Figure 1 summarizes how European climate objectives, water policies, and decentralized stormwater solutions are connected. It shows how policy directions and nature-based approaches come together in practical measures such as rainwater harvesting, local retention, and infiltration.

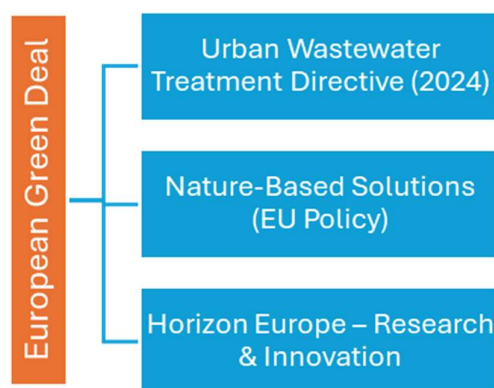


Fig. 1. Alignment of EU Climate and Water Policies Supporting Decentralized Stormwater Management

4. Case Study — Decentralized Rainwater Harvesting and Infiltration System in an Urban Educational Building (Romania)

To better understand the role of low-energy, decentralized water solutions in urban environments, a pilot rainwater harvesting and infiltration system was implemented in an educational building in Cluj-Napoca, Romania. The building was selected as a pilot site due to its existing role as a testing platform for sustainability-oriented research, including energy performance evaluation, indoor environmental monitoring, and carbon-related analyses—conditions that made it particularly suitable for implementing and assessing a decentralized water management solution.

The area experiences strong seasonal variation in precipitation (see Fig. 2), with limited rainfall in winter and higher intensities during summer—patterns also reported

across many European regions and cited as a key motivation for adopting localized stormwater capture and storage strategies [12].

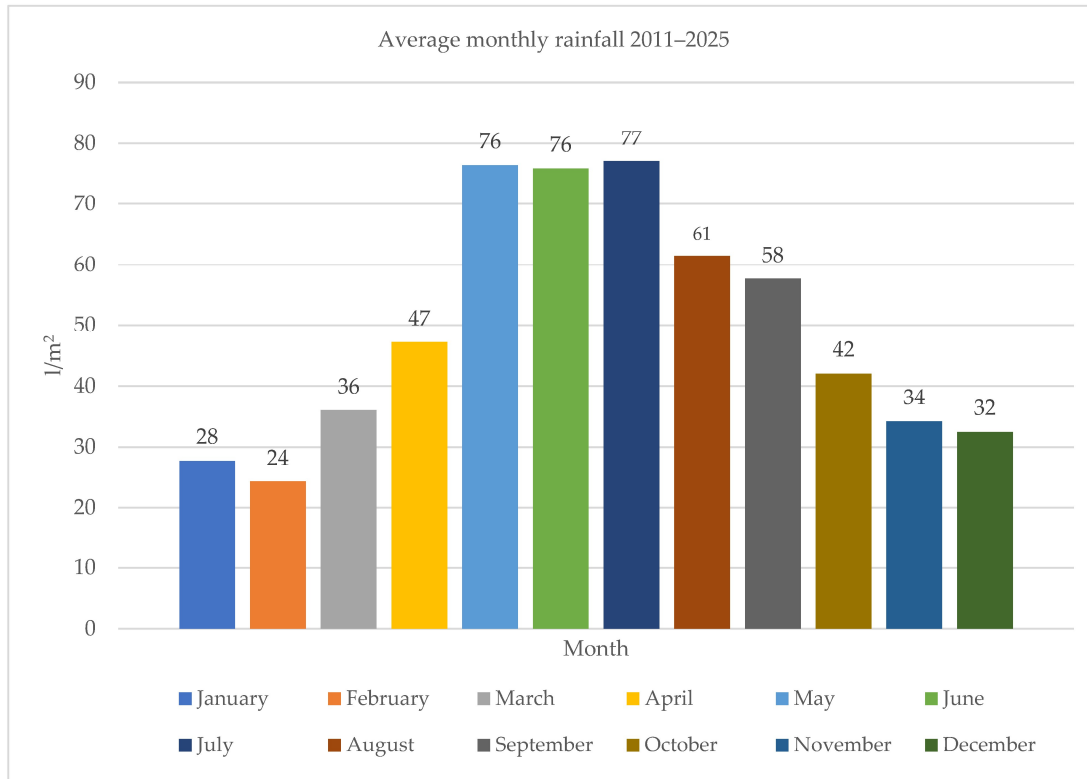


Fig. 2. Average monthly rainfall in Cluj-Napoca (2011–2025)
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These climatic conditions influenced both the sizing and operation of the system. The installation was designed as a compact, building-integrated unit combining sedimentation, granular filtration, storage for non-potable use, and controlled infiltration into the soil. This general configuration (see Fig. 3) aligns with established design principles for urban rainwater harvesting systems, where multi-stage treatment is recommended to improve water quality and ensure reliable reuse.

Collected rainwater was reused for applications such as irrigation and outdoor cleaning, while surplus water was directed to an infiltration unit, helping to reduce stormwater discharge to the municipal sewer system and supporting shallow groundwater recharge. Even though the system was connected to only part of the roof area, it still lowered peak flows during heavy rainfall events—a behavior also noted in other urban stormwater studies and particularly relevant in dense urban environments.

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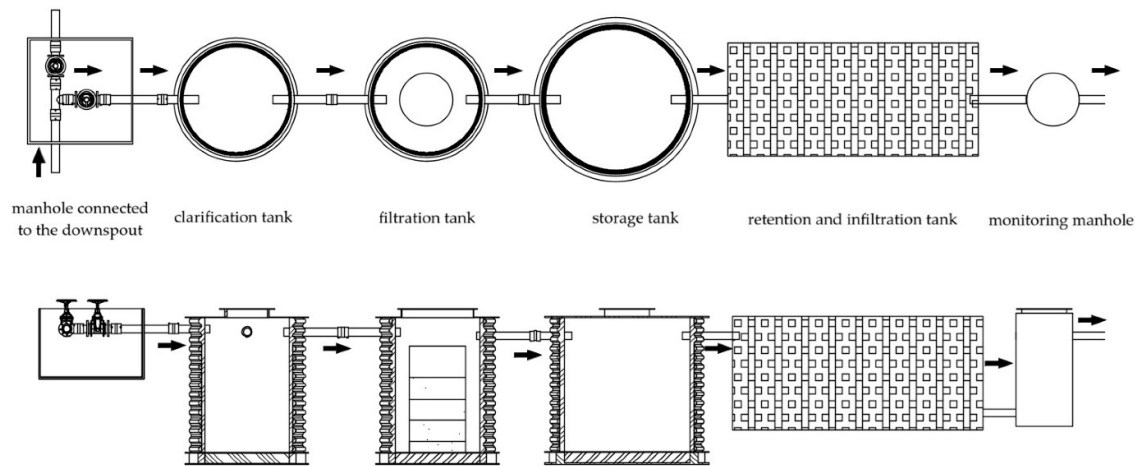


Fig. 3. Functional schematic of the AmZEB system. Reproduced from Deac et al., Water 2026, 18, 731, CC BY 4.0.

Water-quality monitoring performed during contrasting seasons showed clear improvements in parameters such as turbidity and ammonium. This is consistent with findings from the broader literature, which indicates that combining sedimentation with granular media filtration can significantly enhance rainwater quality when systems are properly maintained. Although the treated water did not satisfy drinking-water criteria due to low mineral content and pH variability, it remained suitable for non-potable purposes, reflecting common practice in similar applications [12].

From a hydraulic perspective, one of the most relevant observations was the reduction in stormwater discharge to the combined sewer network. Diverting runoff—even from just 15–30% of the roof—helped ease pressure on local infrastructure during intense rainfall. This aligns with recent European policy directions, including the updated Urban Wastewater Treatment Directive (UWWTD 2024), which requires integrated stormwater management measures and encourages decentralized approaches to reduce overflow events and improve climate resilience [12], [13].

A simplified economic assessment showed that the system resulted in avoided stormwater discharge fees under local tariff conditions. While the financial impact at pilot scale was modest, scaling the system across the full roof—or deploying similar units in multiple buildings—would likely increase both hydrological and economic benefits. Previous analyses across Europe support this, noting that larger catchment surfaces and higher storage capacities significantly improve system performance [16].

Beyond water reuse and reducing runoff, the system also helps restore some of the natural hydrological processes that are often disrupted in highly impervious urban areas. By encouraging local infiltration, it supports groundwater recharge and helps limit peak flows during rainfall events. These functions are increasingly highlighted in European urban adaptation strategies, where decentralized and nature-based approaches are seen as key elements in improving the resilience of built environments [16].



Fig. 4. Aerial view of the completed AmZEB pilot rainwater-harvesting system. Reproduced from Deac et al., *Water* 2026, 18, 731, CC BY 4.0.

Although the pilot system has already shown clear technical and environmental benefits, it is still at an early stage of implementation. Additional monitoring is planned, including continuous flow measurements and more extensive water quality analysis, in order to better understand its long-term performance and identify opportunities for further optimization [12].

This case study shows that decentralized rainwater systems can be effective even at a relatively small scale. The results indicate multiple benefits, such as reducing pressure on centralized infrastructure, supporting non-potable water reuse, and improving local water balance. At the same time, the project offers a useful reference for Eastern European cities, where similar solutions are not yet widely implemented but could provide significant advantages in the future.

6. Conclusions

Decentralized rainwater management provides an effective approach for addressing multiple challenges related to urban stormwater, particularly in the context of climate change and increasing urban impermeability. By managing precipitation near its source, these systems can reduce runoff volumes, lower hydraulic stress on sewer networks, and support the reuse of water for non-potable purposes.

The case study demonstrates that building-scale rainwater harvesting and infiltration systems can deliver meaningful benefits, even when only a portion of the roof area is connected. These benefits include decreased stormwater discharge, improved local water balance, and enhanced urban resilience. The AmZEB system illustrates how decentralized solutions can align with current European water and climate policies while remaining practical for existing buildings.

Overall, building-level rainwater harvesting and infiltration represents a scalable, practical, and policy-aligned strategy for sustainable urban water management. This approach is particularly relevant for cities in Eastern Europe, where adoption remains limited but the potential impact is significant.

References

- [1] A. Bahri, "Integrated Urban Water Management," Global Water Partnership, 2012.
- [2] Y. Qin, "Urban flooding mitigation techniques: A systematic review and future studies," *Water*, vol. 12, no. 12, 2020.
- [3] M. Garrido-Baserba, D. Sedlak, M. Molinos-Senante and others, "Using water and wastewater decentralization to enhance the resilience and sustainability of cities," *Nature Water*, vol. 2, p. 953–974, 2024.
- [4] L. R. N. P. Rentachintala, M. G. M. Reddy and P. K. Mohapatra, "Urban stormwater management for sustainable and resilient measures and practices: a review," *Water Science and Technology*, vol. 85, no. 4, pp. 1120–1140, 2022.
- [5] K. Wartalska, M. Grzegorzek, M. Belcik, M. Wdowikowski and A. Kolanek, "The Potential of RainWater Harvesting Systems in Europe – Current State of Art and Future Perspectives," *Water Resources Management*, vol. 38, p. 4657–4683, 2024.
- [6] A. Campisano, D. Butler and others, "Urban rainwater harvesting systems: Research, implementation and future perspectives," *Water Research*, pp. 195–209, 2017.
- [7] J. Mao, B. Xia, Y. Zhou and others, "Effect of roof materials and weather patterns on the quality of harvested rainwater in Shanghai, China," *Journal of Cleaner Production*, vol. 279, 2021.
- [8] European Commission, "Nature-based solutions research policy," [Online]. Available: https://research-and-innovation.ec.europa.eu/research-area/environment/nature-based-solutions/research-policy_en.
- [9] A. Tokar, D. Foriș, D. Tokar and P.-A. S., *Hidraulica*, vol. 4, pp. 51–58, 2020.
- [10] Y. Qin, Y. He, J. E. Hiller and G. Mei, "A new water-retaining paver block for reducing runoff and cooling pavement,," *Journal of Cleaner Production*, vol. 199, pp. 948–956, 2018.
- [11] N. Kabisch, H. Korn, J. Stadler and A. Bonn, "Nature-Based Solutions to Climate Change Adaptation in Urban Areas—Linkages Between Science, Policy and Practice," in *Nature-Based Solutions to Climate Change Adaptation in Urban Areas. Theory and Practice of Urban Sustainability Transitions*, 2017.
- [12] A. Deac, D. V. Mureșan, C. A. Iacob and T. V. Chira, "Towards Sustainable Urban Water Management: A Case Study on Rainwater Harvesting in Romania," *Water*, vol. 18, no. 6, p. 731, 2026.
- [13] M. Salvetti, "Going from energy efficiency to climate neutrality on the way to decarbonizing the wastewater sector," *Nature Water*, vol. 2, 2024.
- [14] European Commission, "Wastewater treatment and management," [Online]. Available: https://knowledge4policy.ec.europa.eu/water/topic/wastewater-treatment-management_en.
- [15] Florence School of Regulation, "Decarbonizing the Wastewater Sector: A Path to Climate Neutrality," 2025. [Online]. Available: <https://fsr.eui.eu/decarbonizing-the-wastewater-sector-a-path-to-climate-neutrality/>.
- [16] European Parliament, "European Water Resilience Strategy A10-0073/2025," European Parliament, Brussels, 2025.