

Role of rain gardens in stormwater management (Kecskemét, Hungary)

Edit Hoyk

John von Neumann University, Faculty of Horticulture and Rural Development, Hungary;
HUN-REN CERS IRS, Hungary / hoyk.edit@nje.hu

Krisztián Szórá

Bács-Kiskun County Government Office, Agricultural and Rural Development Support
Department, Hungary / szoratkrisz@gmail.com

Kenő Zsolt Farkas

HUN-REN CERS IRS, Hungary / farkas.jenozsolt@krtk.hun-ren.hu

Abstract

Today, urban climate adaptation is unthinkable without green and blue infrastructure. This includes the development of an urban stormwater management system, one element of which is rain garden. In our work, we investigated the potential of rain gardens in Kecskemét, one of Hungary's most populous cities, which is particularly vulnerable to drought. These low impact developments can help to effectively counter the negative effects of climate change, such as urban flash floods. We have developed an experimental rain garden which can collect rainwater from the roof of a family house. We planted it with some plants with different tolerances to prevent run-off. We also selected a critical point in the city of Kecskemét, where flash flooding during heavy rainfall is a problem. We examined the possibility of converting available green spaces into rain gardens to retain rainwater collected at the lowest point of the area as efficiently as possible. To do this, we used the QGIS (Quantum Geographic Information System) to analyze the different sectors, the topography and slope, and the typical runoff direction. The aim of our study was to determine how much amount of the rainfall could be retained and stored temporarily by converting the green areas of the sample area into rain gardens.

Key words: climate adaptation, Hungary, Kecskemét, rain garden, stormwater management

Introduction

Climate changes are particularly intense in the Danube-Tisza Interfluve, including Kecskemét. Due to the rise in average annual temperatures and weather extremes, the Sandridge region has been struggling with drought for decades. One of the main problems is the uneven distribution of precipitation. In some areas of Hungary, the daily rainfall has increased by more than 2 mm over the last 50 years, reflecting an increase in the intensity of showers (KSH; mean: Central Statistical Office)).

In urban areas, soil properties are significantly different from the natural conditions of the past. Soils with poor water management are less able to absorb water from rainfall, further increasing the risk of erosion. Increasing the amount of water retained is a key objective of water management. Four methods can be used to achieve this: rainwater harvesting, infiltration, water storage and drainage. The natural hydrological cycle of urban areas could be restored through rainwater management, which is of great importance for the sustainable development of our cities (Zeng et al. 2007; Schuetze – Chelleri, 2013; Suleiman, 2021; Dods, D. – Schmidt, R. 2012). However, the conscious spatial retention of rainwater is mostly unresolved and good practices are limited.

Municipalities are more exposed to the impacts of climate change, and changes in the natural water cycle due to urbanization exacerbate the problems (Osheen – Singh, 2019). The effect of paved surfaces in blocking water infiltration from evaporation is an obstacle to the development of a near-natural climate. During the urban water cycle, more than half of the precipitation runs off, leaving insufficient water for evaporation (Osheen – Singh, 2019). Rainfall can cause flooding by running off smooth paved surfaces in a short period of time. Moreover, these flash floods mix with urban pollutants. Nature-based solutions can be an effective way to address these problems (Chen et al., 2016; Castonguay et al., 2018), including the use of methods such as water retention with vegetation, green roofs and rainwater harvesting (porous pavement, bioretention cells and green roofs) (Bradford – Denich, 2007; Berland et al., 2017).

Among the nature-based solutions, rain gardens (also known as bioretention systems) are now widely used to reduce non-point source pollution from urban areas (Malaviya et al., 2019; Tang et al., 2015; Zang et al., 2020). As a consequence of increasing urbanization, flash floods threaten the population of many cities. The traditional way to manage urban flooding is to build sewer systems, but these are quite costly. Therefore, rain gardens are a financially viable solution to rainfall problems, although their applicability may be modified by soil and catchment characteristics (Ishimatsu et al., 2017; Boguniewicz-Zabłocka – Capodaglio, 2020). For this reason, there is a need to investigate the characteristics of optimally designed rain gardens in many countries and municipalities through field experiments (Alyaseri et al., 2021).

In 2021, the City of Kecskemét prepared its Climate Strategy, in which the principles of stormwater management based on water retention were formulated, such as (1) reducing runoff factors by increasing green areas, (2) applying regulations at the property level for the retention and delayed discharge of stormwater and (3) promoting different types of utilization (e.g. siccation, evaporation) (Climate Strategy of Kecskemét, 2021). In connection with this, we investigated areas in Kecskemét which are particularly sensitive to flash floods, to find out the suitable locations for the development of rain gardens. These are the lowest points in the area, which can effectively retain and use the collected rainwater. To identify them, the topography and slope of the land and the typical run-off direction were examined. Our aim was to identify how the conversion of suitable green areas in the area into rain gardens could retain or temporarily store a larger proportion of the rainfall. The experience and calculations gained from the construction of the experimental rain gardens will allow us to estimate the potential role of rain gardens in the recovery of rainwater in each area.

Material and methods

Kecskemét is located on the Danube-Tisza Interfluve, which is particularly vulnerable to climate change. Due to the extremes of warming forecast for the Carpathian Basin, an increase in the number of heat-wave periods and heat-wave days is expected. The extreme effects will be more pronounced in this region. The average temperature in the county has risen by 3.5°C between 1991 and 2019 (KSH – Central Statistical Office). The heat island effect is mainly felt in the densely built-up urban areas and the crowded, heavily paved city centre, where the air often does not cool below 20°C even at night. In July and August, average temperatures reach 30°C and can reach up to 37°C on the hottest summer days. According to climate models, the region will become an extremely dry area by the end of the century (Climate Strategy of Kecskemét, 2021).

It should be noted that the climate change does not necessarily mean less rain. As regards the precipitation situation, the 10-year average precipitation has not decreased and has even increased somewhat. The number of days with precipitation, however, shows a different trend. This indicates an uneven distribution of precipitation. It is not that rainfall is decreasing, but that a significant proportion of rainwater falls in large quantities at the same time. Testing the suitability of rain gardens was approached from two directions. From one side, we set up a small experimental rain garden in which we tested the viability of different plants. From the other side, we delimited an area of almost 1.5 km² in the city centre of Kecskemét, where experience shows that excess rainfall during rainstorms is a regular problem.

To test the suitability of plants for rain gardens, we set up a small rain garden in the garden of a family house in Kecskemét. This rain garden is able to collect and use water run-off from the roof. The soil of the rain garden contains a 50-50% mixture of the original soil and a loose compost with a high organic matter content. The compost produced in the composting plant of the water company of Kecskemét wastewater treatment plant (Bácsvíz Zrt). After planting the plants, the surface without plant cover was covered with wood mulch. Mulching serves several purposes: it prevents the soil in the rain garden from drying out, reduces transpiration losses, protects against deflation and prevents weeds from overgrowing.

The plants planted are composed of species suitable for rain gardens (*Carex nigra*, *Lythrum salicaria*, *Mentha aquatica*, *Symphytum officinale*) and species more tolerant of dry conditions (*Tradescantia virginiana*, *Echinacea purpurea*, *Festuca amethystina*, *Festuca pallens glauca*). The rain garden has an area of 3 m², in which a total of 44 plants have been planted. This gives a density of approximately 14.6 plants per m². The plants were selected partly from traditional ornamental plants and partly from plants considered to be native to the area, without invasive plants.

The catchment areas in the city centre of Kecskemét, the direction of precipitation runoff, and the ratio of paved surfaces to green areas were investigated using the QGIS geographic information system. The field experience was used to investigate the feasibility of creating rain gardens on green areas in the study areas to collect water run-off from paved surfaces and building roofs. For ease of management, the study area was divided into twelve smaller sections.

Using geospatial data, the main runoff directions and topography factors in each sections were investigated. The location of the utility network and the sewer network were also taken into account. The green areas in the study area were delimited using the MePAR system (Farm Parcel Identification System), and areas that could potentially be converted into rain gardens were analysed separately. The size of the planned rain gardens was estimated based on the ratio of paved to unpaved areas, from which the amount of water the rain gardens would be able to retain was calculated.

By comparing the precipitation data from Kecskemét, it is possible to determine how much of the annual precipitation the planned rain gardens would be able to collect in the sample area, and to calculate how much of a certain amount of rainfall (e.g. 10 mm per hour) the rain gardens would be able to receive.

Results

Viability of the experimental rain garden vegetation

The rain garden, planted with plants of two categories, functioned well within six months of its establishment. Water drained from the roof through the gutters is fully collected and retained by the rain garden, both during short periods of heavy rainfall and on longer days with steady rainfall.

We found that the water collected and retained by the rain garden not only benefits the plants planted, but also improves the water supply to other plants nearby, suggesting a more even water balance in the area.

The nutrient content of the compost mixture used is adequate, as shown by the rapid regeneration of the plants and their spectacular and rapid growth. Soil life has also intensified, arthropods have appeared, plants have flowered and are growing healthily (Fig. 1).

Species proposed as rain garden plants have developed less spectacularly in the sum of the species. Of the plants used, the survival of *Carex nigra* without irrigation is questionable. However, *Mentha aquatica* is considered to be permanently established. The more drought tolerant plants proved to be more viable, all of which can survive without irrigation.



Figure 1.: Plants and environment of the experimental rain garden / Source: own photo

Rain garden potential of the Kecskemét study area

In the study area, which was divided into twelve sections, the available spatial data were used to calculate the green areas of the area, the number of planned rain gardens and their area. For the planned rain gardens, the potential water retention capacity of the planned rain gardens was calculated using a depth of 60 cm.

The rain gardens planned for the area would be able to hold more than 1500 m³ of rainwater. This would be roughly equivalent to collecting the average of 10 mm of rainwater falling on the area at any one time. However, the excess rainwater from further away, especially from the higher ground to the north-east, should also be taken into account. At the same time, the amount of water collected in storm drains should be taken into account.

Our measurements suggest that a significant proportion of the rainwater generated during a heavy rainfall event (e.g. 10 mm/day) could be effectively stored by a rain garden system in the area. And a more intense storm event of the same magnitude (10 mm/h) would allow the drainage system to drain the rainfall from the area continuously due to the lower load.

It is worth noting that increasing the depth of the rain gardens increases the water retention capacity proportionally. Therefore, the values we have calculated represent the lower limit of the rain gardens' rainwater harvesting capacity, i.e. the potential may be higher. Based on the calculations carried out in the study area, the characteristics of the rain gardens that can be developed, their potential water retention capacity and a classification raingarden suitability can be seen on Table 1:

Table 1.: Characteristics and water retention capacity of the rain gardens designed for the sample area / Source: Own

Sections	Area (m ²)	Area of rain gardens (m ²)	Potential water retention (m ³)	Rain garden suitability classification
I.	4359	555	155,4	2
II.	9426	1100	308	1
III.	5827	925	259	1
IV.	5206	145	40,6	2
V.	11731	215	60,2	1
VI.	4266	800	224	3
VII.	9722	97,5	27,3	1
VIII.	6330	240	67,2	1
IX.	8276	348	97,4	1
X.	5447	515	144,2	3
XI.	13313	100	28	1
XII.	54600	455	127,4	3
Total	138503	5495,5	1538,74	

The rain garden suitability classification based on the possibilities of design options is as follows:

1. The area is ideal for a rain garden. If implemented, little construction work would be required.
2. The area is suitable for a rain garden but would not be able to collect large amounts of water, as only a small rain garden could be constructed, but without costly works.
3. The area could be used for rain gardens, but this would require major landscaping and construction works.

Discussion

Based on the study area in Kecskemét and the experimental rain garden studies, it can be concluded that in one of the most critical zones of Kecskemét in terms of runoff, flash flooding problems could be reduced or even eliminated by the use of rain gardens.

With the method we use, it is possible to identify the critical points in each city, not only in Kecskemét, but also in the rest of the world. If it can be determined that rain gardens or other green-blue infrastructure elements can improve stormwater management in the area, then it is advisable to proceed with the design with the involvement of experts.

By involving different experts, systems thinking can be implemented and the most effective decisions can be made by analysing the environment. The design should be carried out in such a way that the different green-blue infrastructure elements are interlinked and integrated (Ferreira et al., 2024). A theoretically ideal method is obviously not feasible everywhere, but efforts should be made to implement as many sustainable solutions as possible (Kuitert – van Buuren, 2022).

Native vegetation should also be favoured in rain gardens and other green spaces. Obviously, this is not always possible, but the use of invasive species should be avoided. It is true that undemanding tree species with high growth potential and tolerance of urban environments, such as *Ailanthus* and *Celtis occidentalis*, are more successful than *Quercus robur*, but they carry serious risks. They pose a risk by altering the natural ecosystem of the area and control is a costly and resource-intensive task. Therefore, the spread of these species in urban environments must be inhibited (Francis – Chadwick, 2015).

The use of more efficient water management methods should also be encouraged in areas with detached houses. Rain gardens are an excellent tool for this purpose: not only can residents meet their rainwater retention obligations, but an aesthetic rain garden can also be an ornamental feature of the property, and it can also have a positive effect on the water management of the soil on the plot, reducing the need for irrigation. The example of the experimental rain garden shows how the goal can be achieved with little effort and great efficiency. Considering the size of the housing estates in Kecskemét, the residents of the garden houses could play a decisive role in improving urban stormwater management. It would be important to make it understood and enforced that rainfall should not be drained away but used and stored. In addition, it is worth considering abandoning the use of lawns that require intensive care in addition to irrigation (Ignatieva et al., 2020). These lawns are only viable where the climate allows (e.g. UK). In continental climates, a mix of native grasses, which are more diverse and much less demanding, would be more appropriate for gardens.

Summary

In this article, we explored the potential of rain gardens as green-blue infrastructure elements for stormwater management. Increasing urbanisation is leading to an increasing proportion of built-up, paved surfaces. The sewerage network, built decades ago, is finding it increasingly difficult to cope with heavy rainfalls. Today, with the focus on environmental awareness, we need to find ways to store and use the large quantities of rainwater that periodically appear. One solution to this is the use of near-natural methods such as rain gardens.

Rain gardens function in a similar way to natural forest soils: their loose, organic-rich soil with good water retention capacity stores large quantities of collected water and gradually releases it into the environment. Rain garden plants filter the water with their root systems and evaporate the absorbed moisture to improve the local climate.

To learn more about how rain gardens work, we set up a small-scale rain garden in the garden of a family house. Two groups of plants were investigated: one group was selected from plants that had never been in a rain garden experiment. These consist of plant species that prefer wetter habitats. The other group of plants was selected from species that are specifically drought tolerant.

As a result of the experiment, it was found that the first group of plants is less viable than the second group of plants in a rain garden on sandy soils, but they are applicable. However, they are more effective as rain garden plants in more compacted soils.

For our study in an urban environment, we chose an area of Kecskemét that is highly susceptible to flash floods. Here, heavy and irregular showers often cause flash floods. The area was divided into twelve sections to investigate the potential of green areas as rain gardens. Using QGIS, we analysed the characteristics of the areas. These were complemented by our field experience.

It was found that, if 60 rain gardens were constructed in the study area of about 1.5 km², at least 1.5 million litres of rainwater could be retained during average rainfall events. During more significant rainfall events, the load on the area's stormwater drainage network would be reduced, which would reduce the likelihood of flash floods. The water stored in rain gardens would also be used days or weeks later: it would be purified and released into urban soils, and evaporation from rain garden vegetation would cool the urban environment, reducing the heat island effect.

Sustainable use of green-blue infrastructure elements increases the efficiency of stormwater management, making the city more resilient. Urban design should be more careful to ensure that the proportion of paved surfaces does not increase more than the proportion of green surfaces. The use of near-natural solutions is a more cost-effective and sustainable way to focus on water conservation, as water-sensitive urban design is an appropriate method for climate adaptation.

References

- Alyaseri, I.; Zhou, J.; Morgan, S. Sustainable stormwater management using rain gardens in urban areas. *IOP Conf. Ser.: Earth Environ. Sci.* 2021, 779 012041 DOI: 10.1088/1755-1315/779/1/012041
- Berland, A.; Shiflett, S.A.; Shuster, W.D.; Garmestani, A.S.; Goddard, H.C.; Herrmann, D.L.; Hopton, M.E. The role of trees in urban stormwater management. *Landscape and Urban Planning* 2017, 162, 167-177. <https://doi.org/10.1016/j.landurbplan.2017.02.017>
- Bradford, A.; Denich, C. Rainwater Management to Mitigate the Effects of Development on the Urban Hydrologic Cycle. *Journal of Green Building* 2007, 2(1), 37-52. <https://doi.org/10.3992/jgb.2.1.37>
- Boguniewicz-Zabłocka, J.; Capodaglio, A.G. Analysis of Alternatives for Sustainable Stormwater Management in Small Developments of Polish Urban Catchments. *Sustainability* 2020, 12, 10189. <https://doi.org/10.3390/su122310189>
- Castonguay, A.C.; Urlich, C.; Iftekhhar, Md.S.; Deletic, A. Modelling urban water management transitions: A case of rainwater harvesting. *Environmental Modelling & Software* 2018, 105, 270-285. <https://doi.org/10.1016/j.envsoft.2018.05.001>
- Chen, Y.; Samuelson, H.W.; Tong, Z. Integrated design workflow and a new tool for urban rainwater management. *Journal of Environmental Management* 2016, 180, 45-51. <https://doi.org/10.1016/j.jenvman.2016.04.059>
- Dods, D.A.; Schmidt, R. Rain Gardens: Integrating Stormwater Management into Attractive Landscaping. *World Environmental and Water Resources Congress 2007: Restoring Our Natural Habitat*, 2012. [https://doi.org/10.1061/40927\(243\)43](https://doi.org/10.1061/40927(243)43)
- Ferreira, J.C.; dos Santos, D.C.; Campos, L.C.: Blue-green infrastructure in view of Integrated Urban Water Management: A novel assessment of an effectiveness index, *Water Research*, Volume 257, 2024, 121658. <https://doi.org/10.1016/j.watres.2024.121658>
- Francis, R.A. – Chadwick, M.A.: Urban invasions: non-native and invasive species in cities. *Geography*, Volume 100, 2015, Issue 3. <https://doi.org/10.1080/00167487.2015.12093969>
- Ignatieva, M.; Haase, D.; Dushkova, D.; Haase, A. Lawns in Cities: From a Globalised Urban Green Space Phenomenon to Sustainable Nature-Based Solutions. *Land* 2020, 9, 73. <https://doi.org/10.3390/land9030073>
- Ishimatsu, K.; Ito, K.; Mitani, Y. et al. Use of rain gardens for stormwater management in urban design and planning. *Landscape Ecol Eng* 2017, 13, 205–212. <https://doi.org/10.1007/s11355-016-0309-3>
- Kecskemét Megyei Jogú Város Klímastratégiája. *Kecskemét*, 2021. augusztus, p. 131. https://kecskemet.hu/uploaded_files/files/document/2022-02/Kecskem%C3%A9t_MJV_KI%C3%ADmastrat%C3%A9gi%C3%A1ja.pdf
- Kuitert, L. – van Buuren, A.: Delivering Blue-Green Infrastructure: Innovation Pathways for Integrating Multiple Values. *Frontiers in Sustainable Cities*, 2022, Volume 4. <https://doi.org/10.3389/frsc.2022.885951>
- Malaviya, P.; Sharma, R.; Sharma, P.K. Rain Gardens as Stormwater Management Tool. In: Shah, S.; Venkatramanan, V.; Prasad, R. (eds) *Sustainable Green Technologies for Environmental Management*. Springer, 2019, Singapore. https://doi.org/10.1007/978-981-13-2772-8_7
- Osheen; Singh, K.K. Rain Garden—A Solution to Urban Flooding: A Review. In: Agnihotri, A.; Reddy, K.; Bansal, A. (eds) *Sustainable Engineering*. Lecture Notes in Civil Engineering, vol 30. Springer, 2021, Singapore. https://doi.org/10.1007/978-981-13-6717-5_4
- Schuetze, T.; Chelleri, L. Integrating Decentralized Rainwater Management in Urban Planning and Design: Flood Resilient and Sustainable Water Management Using the Example of Coastal Cities in The Netherlands and Taiwan. *Water* 2013, 5, 593-616. <https://doi.org/10.3390/w5020593>
- Suleiman, L. Blue green infrastructure, from niche to mainstream: Challenges and opportunities for planning in Stockholm. *Technological Forecasting and Social Change*, 2021, 166, 120528. <https://doi.org/10.1016/j.techfore.2020.120528>
- Tang, S.; Luo, W.; Jia, Z. et al. Evaluating Retention Capacity of Infiltration Rain Gardens and Their Potential Effect on Urban Stormwater Management in the Sub-Humid Loess Region of China. *Water Resour Manage* 2016, 30, 983–1000. <https://doi.org/10.1007/s11269-015-1206-5>
- Zhang, L.; Ye, Z.; Shibata, S. Assessment of Rain Garden Effects for the Management of Urban Storm Runoff in Japan. *Sustainability* 2020, 12, 9982. <https://doi.org/10.3390/su12239982>
- Zeng, B.; Tan, H.; Wu, L. A New Approach to Urban Rainwater Management. *Journal of China University of Mining and Technology* 2007, 17(1), 82-84. [https://doi.org/10.1016/S1006-1266\(07\)60018-2](https://doi.org/10.1016/S1006-1266(07)60018-2)
- https://www.ksh.hu/stadat_files/kor/hu/kor0056.html