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AN ANALYSIS OF THE FEASIBILITY OF USING GREEN INFRASTRUCTURE IN PUBLIC BUILDINGS ON THE EXAMPLE OF A KINDERGARTEN LOCATED IN CENTRAL POLAND

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ABSTRACT: The article describes the possibility of using green infrastructure for rainwater management on the example of an existing kindergarten building located in central Poland in the town of Skierniewice in the Łódź Voivodeship. The article shows solutions for the use of green infrastructure objects such as green roofs, infiltration basins and rain gardens, which, in addition to their technical function, have a positive impact on the facility's users. These devices were dimensioned based on rainfall intensity determined using the PMAXTP model for 15-minute rainfall with a probability of occurrence of p=0.2. The individual devices for rainwater management were analysed in terms of reducing rainwater runoff into the sewage system, and the course of calculations for the selection of specific solutions was presented. The findings lead to the conclusion that the implementation of the described solutions enables a reduction in the volume of rainwater discharged into the sewage system by 53%.

KEYWORDS: rainwater management, public utility facilities, rain garden, green roof, infiltration basin

Introduction

One of the effects of the continuously progressing urbanisation is a significant increase in impervious surfaces. This problem particularly affects areas of large cities and leads to the degradation of the hydrological system of these areas, acceleration of surface runoff, reduction of natural retention and of infiltration of water into the ground. In addition, the increasingly rapid climate change, accompanied by droughts and floods, is observed in recent years (Kotowski et al., 2016; Pendergrass & Hartmann, 2014). Changes in the distribution of precipitation throughout the year and the increasingly frequent lack of snow cover in the winter season are observed almost everywhere in the world (Szklarek, 2020).

The analysis of the above factors leads to the need of rational management of water resources, including sustainable rainwater management. A large number of urbanised area have a conventional system of draining areas for stormwater or combined sewers. However, there are many alternative ways of draining areas using, among others, the so-called blue-green infrastructure, allowing for increased retention or infiltration of water into the ground. These solutions can be applied in residential areas, service areas and public spaces. The use of on-site rainwater management facilities is particularly important in public spaces that show the right direction for change and educate the public.

There are also other benefits, for example, social ones, of using even small green infrastructure facilities, especially on school grounds (Iojă et al., 2014; Jaszczak et al., 2018; Shakya & Ahiablame, 2021).

The paper analyses the possibilities of local actions related to rainwater management on the example of a newly built kindergarten building without facilities for modern rainwater management. The analysis includes changes consisting of the introduction of an extensive green roof to the object, two rain gardens in the ground and an infiltration basin. The purpose of the calculations carried out in the article was to evaluate the local projects related to rainwater management for public facilities in the context of relieving the urban sewage system, benefits for the environment and educational values of the adopted solutions.

The article focuses on educational facility buildings because the described rainwater management methods improve the aesthetics of the surroundings, increase vegetation, and align with the principles of sustainable development. Moreover, from an early age, the users of these facilities are educated on important issues related to proper rainwater management.

An overview of the literature

The concept of rainwater management

Unfortunately, there is often still a belief among the general public that rainwater is not useful and should be drained away as quickly as possible. Such thinking causes people to forget the value of precious raindrops.

The Second UN World Congress in Rio de Janeiro in 1992 was a watershed moment in changing thinking about the nature of proper rainwater management in built-up areas (Wojciechowska et al., 2016). One of the four documents adopted at the conference was "Agenda 21", which included a chapter on the protection and management of natural resources to ensure sustainable and balanced development. This chapter addressed the agenda of, among other things, the protection and management of water resources. The subsequent Rio+20 UN Conference on Sustainable Development was held in 2012. It aimed to identify problems resulting from rapid economic development and population expansion. It highlighted the problem of access to drinking water and the management of water resources.

Over the years, different concepts of rainwater management have been developed in many countries. The table below (Table 1) lists a selection of concepts with a brief description of them (Wagner & Krauze, 2014; Sowińska-Świerkosz & García, 2022; Secretariat of the Convention on Biological Diversity, 2009; Szulczewska, 2018).

DOI: 10.34659/eis.2025.92.1.861

Table 1. Rainwater management concepts

Name	Assumptions
Low Impact Development, LID	Consideration of landscape specificity in measures, use of on-site precipitation, use of landscape retention and technical solutions.
Sustainable Urban Drainage Systems, SUDS	Use of environmentally friendly technical solutions for rainwater management in urban areas, reduction of pollutants and rainwater runoff from built-up areas.
Green Infrastructure, GI	An approach based on using the attributes of the natural environment to manage and reuse rainwater. The GI can be a component of SUDS.
Water Sensitive Urban Design, WSUD	The aim is to make the water cycle in the city more similar to the natural water cycle under natural conditions and to ensure cooperation in activities between urban planners, architects and environmental engineers.
Nature-Based Solutions, NbS	Actions arising from global changes to preserve biodiversity and human well-being through sustainable management and nature-inspired solutions, such as using rainwater or treated water instead of drinking water for irrigation.
Ecosystem-Based Adaptations, EbA	A subset of NbS relative to fast-changing climate. It involves the use of biodiversity, for example, to reduce the consequences of intense rainfall events while ensuring co-benefits.
Name	

Source: authors' work based on Wagner and Krauze (2014), Sowińska-Świerkosz and García (2022), Secretariat of the Convention on Biological Diversity (2009) and Szulczewska (2018).

From the above descriptions, it can be seen that the main objective of all concepts is related to environmental protection.

Applied solutions for rainwater management

A new way of thinking and a broad knowledge of stormwater management initially prevailed in countries such as the United States, Canada and Australia. This was due to the rapid urbanisation in these countries. Among European countries, Germany, Great Britain and France are the most specialised in this field (Wagner & Krauze, 2014).

The conventional way to drain urbanised areas is to discharge rainwater to a collective stormwater drainage system or to a combined sewer, depending on the infrastructure of the area. In the case of heavy rainfall, the stormwater drainage system is often unable to receive and carry away the entire quantity of rainwater (Nowakowska et al., 2019). In addition, the use of such a solution results in limited groundwater recharge (Karczmarczyk & Mosiej, 2011). An alternative approach is to choose systems that use surface or groundwater infiltration to recharge groundwater, retain rainwater and also treat it. The table below (Table 2) lists examples of devices used for rainwater management, depending on the process they use.

Table 2. Examples of devices used for rainwater management

Processes used	Types of equipment
Surface rainwater infiltration	Infiltration basins and tanks
	Infiltration trench
Underground rainwater infiltration	Infiltration boxes and chambers
	Soakaway wells
	Rigole
Retention of rainwater	Filtration basin
	Retention tanks
	Retention and filtration tanks
	Green roofs

Processes used	Types of equipment
Treatment of rainwater	Rain gardens
	Filtration trench
	Sedimentation ponds
	Filter drainage channel
	Rainwater sedimentation tanks
	Separators of petroleum derivative substances

Source: Słyś (2013).

In addition to the above-mentioned devices, the economic use of rainwater has become common for mainly residential buildings in certain countries. Having a proper installation with a storage tank and purification devices, it is possible to reuse the collected water for flushing toilets or watering plants in gardens. This saves water from being drawn from the water mains (Madzia, 2019; Campisano & Lupia, 2017).

In addition, the use of permeable surfaces has become extremely common in areas such as roads and car parks. Concrete grids or openwork lawn grids allow water to infiltrate through the natural material layers below (e.g. gravel or sand), which then seeps into the ground. Permeable materials can also be placed on top of infiltration boxes (Wagner & Krauze, 2014).

Examples of solutions for educational buildings around the world

An extremely interesting example of rainwater management combined with treatment of grey wastewater on an educational site is the Sidwell Friends private school in Washington, D.C., founded in 1883. The school is known for its "Lead in the light" strategic plan. It urges free speech on any subject while respecting all people. It also attaches importance to active environmental management. It tries to raise awareness of how our actions directly affect the life of the planet. The school has been recognised by The U.S. Green Building Council, an organisation that promotes sustainable design, for its efforts in applying environmentally friendly solutions (Sidwel Friends, n.d.).

In 2006 the school's own gymnasium building was renovated. A new part was added to the existing building and many ecological solutions were applied to the school premises. These include the management of rainwater and grey sewage generated in the building (Figure 1).

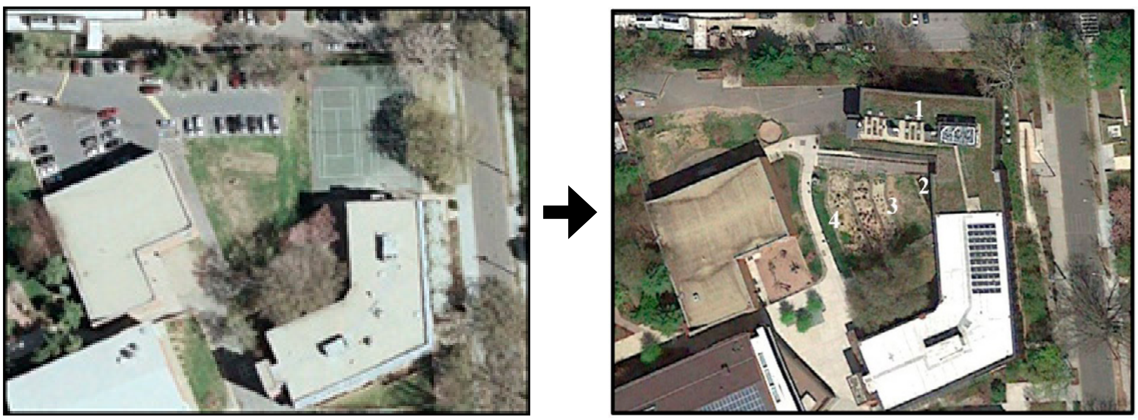

Figure 1. The site of the Sidwell Friends Middle School facility in Washington before and after the upgrade; 1 – green roof; 2 – retention pond; 3 – rain garden; 4 – constructed wetland

Source: authors' work based on Google Earth Pro.

DOI: 10.34659/eis.2025.92.1.861

The building has a green roof, which itself already brings many benefits. It reduces the amount of sealed surfaces in the area and improves the natural water cycle. In addition, it positively affects the microclimate and minimises the 'urban heat island' effect. It also prevents the building from overheating. Excess water from the roof is drained into an underground reservoir and retention pond. During heavy rains, rainwater overflows into the rain garden, from where it infiltrates into the ground through a drainage system and feeds the underground groundwater. Thanks to this solution, only the excess water is discharged into the sewage system. In the courtyard of the school, there is also a three-stage hydrophytic system, which makes it possible to treat the grey sewage that is generated within the building, in order to reuse it as grey water for flushing toilets (Wojciechowska et al., 2016).

A second example of an educational institution that practices sustainable stormwater management is Loyola University in Chicago. The campus is home to the Institute for Sustainability, which educates students in environmental issues, brings together scientists from various disciplines, and conducts research to address the planet's current environmental problems. Loyola is recognised as a leader in smart water management and conservation. The campus itself is located near Lake Michigan. The university strives to care for the environment in every aspect (environmental, social and economic). In addition to water conservation, activities such as recycling and composting, the use of alternative energy sources, growing local food on school grounds, and ensuring biodiversity and ecosystem protection are carried out on its premises. All this demonstrates the university's commitment to sustainability and makes us confident to call its grounds a "green campus" (Loyola University Chicago, n.d.).

Rainwater management is being carried out on the campus, along with conservation of drinking water and a ban on the sale of bottled water. Students are urged to use reusable bottles and fill them on campus at specially designated stations.

In recent years, Chicago has been struggling with increasingly violent and heavier rainfall. Appropriate rainwater management on campus has become an ideal solution to the ongoing climate change. The university has green roofs, underground storage tanks for excess rainwater and rain gardens.

Permeable paving stones have been used on the campus to allow rainwater to soak into the ground. This recharges the groundwater. Infiltration occurs relatively quickly because Loyola is mainly located on permeable soil – sand. Excess rainwater from the roofs is drained into underground reservoirs. Some of the water, after being filtered, is used to water vegetation on the campus and flush the toilets. There are currently 10 green roofs on the college campus. All excess water from the campus surface is further directed to an underground biofiltration system and then to a rain garden. The plants in the garden and the layers of sand and gravel filter the water and removeit of pollutants. In addition, the campus provides a habitat for insects and birds and ensures the preservation of biodiversity. The excess clean water is then discharged through a 30-inch pipe into Lake Michigan. The pollution-free water no longer poses a threat to it (Figure 2).

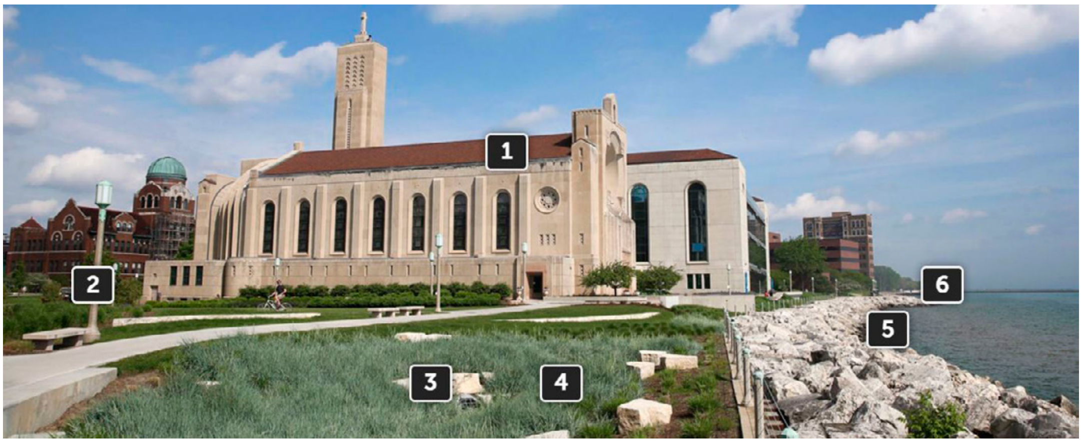

Figure 2. Rain garden application at Loyola University; 1 – rainwater from the entire campus is discharged into the local stormwater drainage system; 2 – an underground biofiltration system; 3 – a rain garden; 4 – native plants for biodiversity; 5 – a pipe carrying excess water to the lake; 6 – Lake Michigan

Source: Loyola University Chicago (n.d.).

DOI: 10.34659/eis.2025.92.1.861

The solutions described above can be used as examples for the planned modernisation of drainage systems in smaller and larger educational facilities.

Examples of solutions for educational buildings in Poland

The Sendzimir Foundation, which focuses on retention and infiltration in urban areas, provides examples of Polish schools with green infrastructure facilities, specifically schools located in Warsaw. Various devices serving both educational and technical functions have been installed on the premises of the schools described below.

As an example, six schools in Warsaw were highlighted where green infrastructure facilities were constructed, including rain gardens, rainwater tanks, green walls, permeable surfaces, and infiltration basins. The motivation for building these facilities was not only to create model solutions but also to address the issue of waterlogging in the areas surrounding the buildings (Fundacja Sendzimira, 2025) (Figure 3).

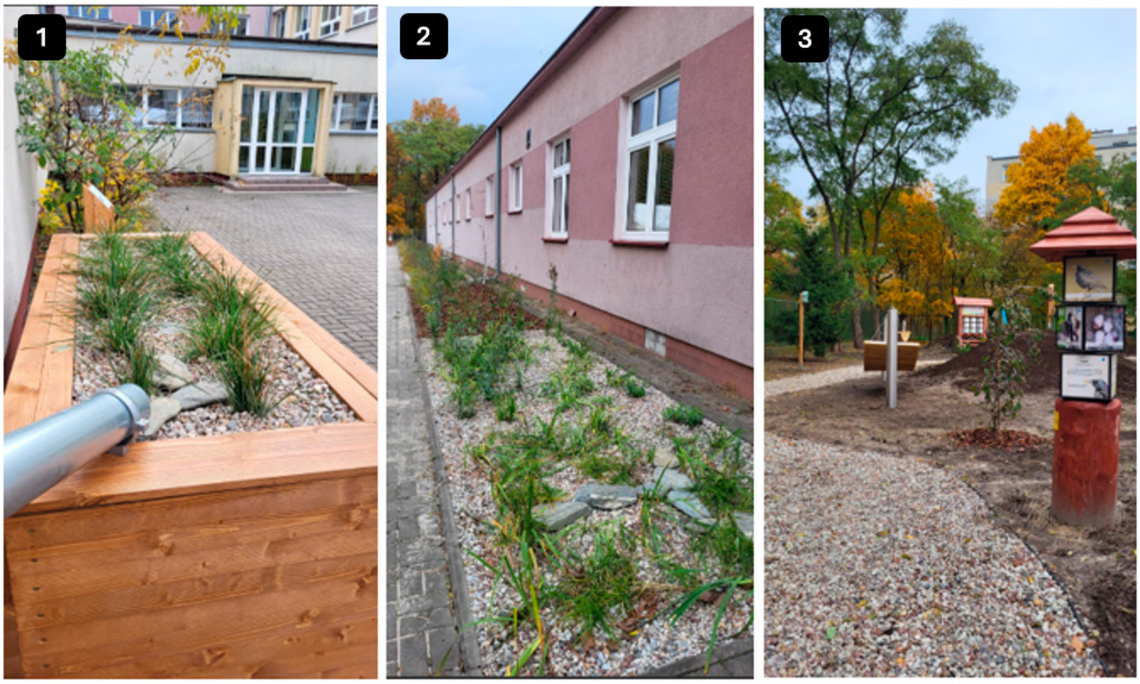

Figure 3. Solutions implemented at Primary School No. 195 in Warsaw; 1, 2 – Rain gardens, 3 – Gravel permeable surface

Source: Warszawa Wawer (n.d.).

Research methods

General characteristics of the kindergarten building

The kindergarten where the modernisation of the drainage system is planned is located in central Poland, more precisely in the north-eastern part of Lodz Voivodeship. The selected facility has inclusive branches and is considered to be one of the most modern kindergartens in the Lodz Voivodeship. In April 2018, construction of the new kindergarten premises began on the site of the old building, and the new building was officially opened at the beginning of 2019.

The new facility is a single-storey building. The total area of the kindergarten grounds is 1.45 ha. Although the kindergarten has gained a new, modern building with interesting landscaping of the plot, no green or blue infrastructure elements are foreseen on the site. The current development of the nursery school grounds includes (Figure 4):

- The main building,
- 2 playgrounds,

- a toboggan hill,
- sensory garden with a shelter,
- 131 parking spaces, including 5 for the disabled,
- hardened surfaces (pavements and roads),
- green areas.

Figure 4. The site of the Kindergarten in Skierniewice; 1 –main building; 2 – playground; 3 – parking spaces

Source: authors' work based on Google Earth Pro.

The existing site drainage system

The current drainage of the kindergarten area takes place in a conventional manner (Okraska, 2017). Rainwater, partially from the roof of the building and from the majority of car parks and other sealed surfaces (pavements, roads, playgrounds), is discharged into the existing rainwater drainage system and the existing combined sewer system. Rainwater from the area of the fire road, part of the pavements and 4 parking spaces in the eastern part of the kindergarten area, as well as partially from the building roof, is discharged in a surface manner to the surrounding lawns (Figure 5).

Rainwater from the roof of the building and from the impervious surfaces located in the southern part of the kindergarten area (car parks and roads) is discharged through a ϕ200 connection to the existing rainwater drainage channel. Rainwater is discharged through downpipes to the sewers, and then to the retention channel made of PP pipes with a diameter of 500 mm. Due to the limitation of discharge to 5 dm^3/s, the retention capacity of pipelines with a total capacity of 66.2 m^3 is planned to be used. In order to limit the discharge, a flow regulator is used. In addition to the rain manholes in the car park area, sedimentation wells integrated with oil separators are planned.

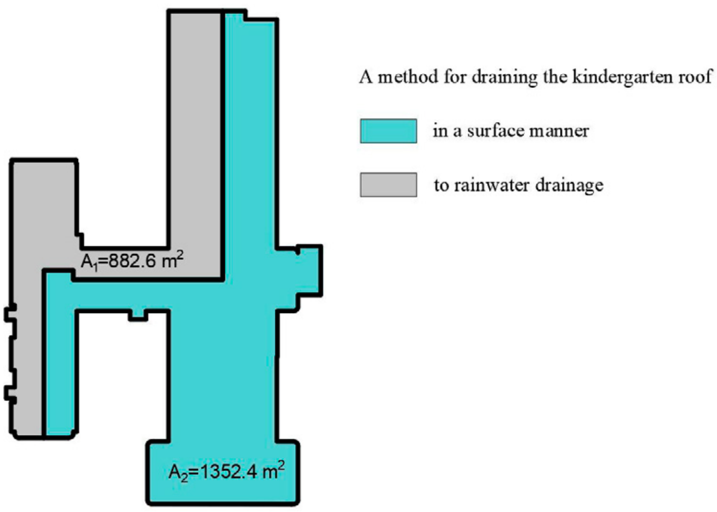

Figure 5. A method for draining the kindergarten roof

Rainwater from the car park and roads located in the northern part of the kindergarten grounds is discharged through a ϕ150 connection to the existing combined sewer. Due to discharge limits of up to 1.5 dm^3/s, the retention capacity of 200 mm and 400 mm diameter pipelines, with a total capacity of 3.0 m^3, is planned to be used. A flow regulator is used to limit the discharge.

The concept for upgrading the drainage system of the kindergarten area using green infrastructure

During the development of the concept for the modernisation of the drainage of the kindergarten grounds, the following main considerations were taken into account:

- The current utilisation of the nursery school premises,
- land configuration,
- ground and water conditions,
- current drainage of the area.

The modernisation concept assumes the introduction of the following elements for rainwater management (Figure 6):

- A green roof (extensive),
- two rain gardens in the ground (sealed with foil), with drainage chambers,
- an infiltration basin.

The Figure 6 details the areas from which rainwater will be managed by introducing green infrastructure facilities into the nursery grounds.

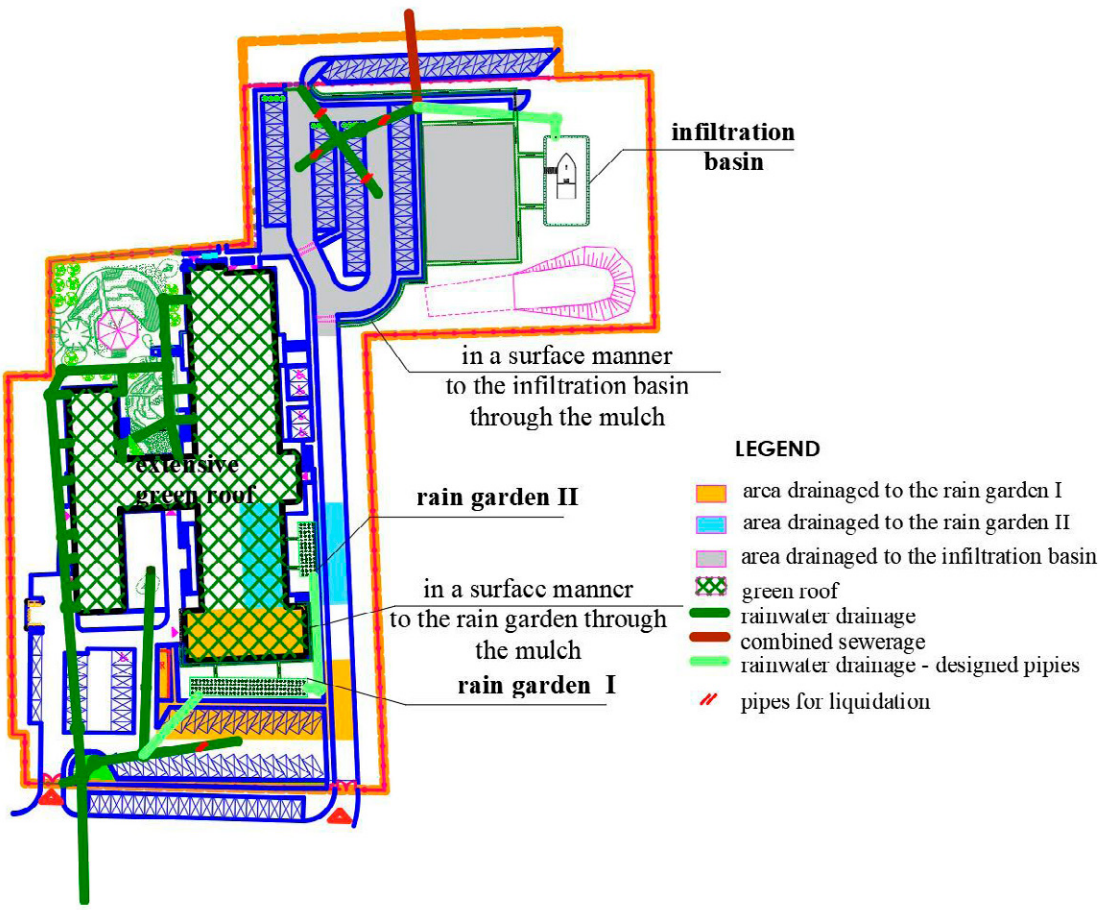

Figure 6. The management of rainwater from specific surfaces through the introduction of green infrastructure
Source: authors' work based on Okraska (2017).

Calculation of green infrastructure facilities

For the calculations related to the dimensioning of devices, it is necessary to calculate the authoritative rainfall intensity for the analysed area. For the calculations, the PMAXTP model (Bisaga et al., 2022) was used; the calculations were carried out for Td = 15 min and p = 0.2 for the city of Lodz, the authoritative rainfall intensity was 175 $dm^3/(s·ha)$.

The green roof

An extensive green roof is proposed for the entire roof area of the kindergarten building (2235 m^2). The choice of roof type is mainly due to its use on an existing building. The weight of the selected solution is between 50 kg/m^2 and 170 kg/m^2, while intensive roofs cause much greater loads on the building structure and are best anticipated already at the design stage of the building. It was therefore assumed that the kindergarten building is adapted to the additional load resulting from the construction of an extensive roof. An extensive roof is also easy to maintain and does not require regular irrigation, reduces noise, and enhances the aesthetic value of the building (Getter & Bradley Rowe, 2006).

The shape of the kindergarten's roof, as well as its slope of between 8 and 15%, does not pose any restrictions to the retrofit. There is no fear of water residue (a danger for roofs with a slope of less than 2%). In this case, there is no need for anti-slide protection of the roof layers either, as it is recommended for slopes above 15° (26.8%, respectively). This is a standard roof, with mineral wool insulation and waterproofing in the form of roofing felt.

The PN-92 B-01707 standard was used to calculate the design flow in rainwater drainage pipes and connections before and after the application of the green roof (Eq. 1).

$$q_d = \psi \cdot A \cdot \frac{I}{10000} \left[\frac{dm^3}{s}\right], \quad (1)$$

where:
q_d – calculation flow,
Ψ – runoff coefficient [-],
A – drainage area [m^2],
I – authoritative rainfall intensity [$dm^3/(s·ha)$].

The runoff coefficient was assumed to be 0.95 for the standard roof, and 0.6 for the green roof. Then, the annual approximate volume (Eq. 2) of the rainwater drained from the roof surface of the building was calculated for the two variants. The calculations were made for the average annual precipitation for the city in which the facility is located (528.3 mm).

$$V_d = A \cdot \psi \cdot H \; [m^3], \quad (2)$$

where:
V_d – rainwater volume,
A – drainage area [m^2],
Ψ – runoff coefficient [-],
H – average annual precipitation [m].

Calculation for a variant without the green roof

The total volume of rainwater discharged from the roof surface per year was calculated (V_{d1} = 1121.71 m^3). Rainwater from 882.6 m^2 of the roof is discharged into the sewage system. Meanwhile, the remaining area of the roof, i.e. 1352.4 m^2, is discharged in a surface manner through downpipes. The volume of water discharged from the roof to the sewerage system per year was calculated (V_{d2} = 443.00 m^3). The volume of water discharged annually via surface run-off pipes is the difference between the total volume of rainwater collected from the roof and that discharged into the sewerage system and amounts to 678.71 m^3.

DOI: 10.34659/eis.2025.92.1.861

Calculations for the green roof option

The total volume of rainwater drained from the green roof area per year was calculated (V_{d3} = 708.45 m^3). The volume of water discharged annually from the roof to the sewerage system was subsequently calculated (V_{d4} = 279.77 m^3). In this case, the volume of rainwater discharged annually via surface run-off pipes is 428.68 m^3.

In Table 3 the calculation results obtained for both variants are presented.

Table 3. The summary of calculation results for the building roof

Parameter		Variant		Difference
		Without a green roof	With a green roof	
Design flow in stormwater drainage pipes and connections		44.80	28.30	16.50
Volume of water discharged from the roof per year Vd [m3]	Total	1 121.71	708.45	413.26
	In a Surface manner	678.71	428.68	250.03
	To stormwater drains	443.00	279.77	163.23

Advantages of the solution

The use of an extensive green roof allows for the management of 413.26 m^3 of rainwater per year, which constitutes approximately 37% of the volume of rainwater drained from the roof before the introduction of green infrastructure. The amount of rainwater directed to the stormwater drainage system will decrease by 163.23 m^3 and 250.03 m^3 of rainwater previously discharged to the surface will be managed. The design flow in rainwater drainage pipes and connections will decrease by 16.50 dm^3/s.

The infiltration basin

In order to modernise the drainage of the northern part of the kindergarten grounds, it is proposed to construct an infiltration basin. For safety reasons, it was assumed that the filling of the infiltration basin could not exceed 0.3 m. The facility is planned to be grassed over, which, among other things, will enhance the water purification process. The slope of the basin is planned to be inclined 1:2. The inflow to the infiltration basin would be carried out on the surface. For safety reasons, an emergency overflow has been planned so that excess rainwater during heavy rain can be discharged into the stormwater drainage system.

It was assumed that the surface drained by the basin would be the area of the court, as well as car parks and roads in the northern part of the kindergarten area. The filtration coefficient of the soil in the location of the basin was assumed as 10^{-5} m/s (for fine-grained sand/clayey sand). In order to determine the dimensions of a particular device, the required retention volume must be selected. For this purpose, the following formula was used (Eq. 3) (Słyś, 2008):

$$V_w = \left[q \cdot (F_0 \cdot \psi + F_w) \cdot 10^{-7} - F_w \cdot \frac{k_f}{2}\right] \cdot 60 \cdot T_d \ [m^3], \tag{3}$$

where:
V_w – retention volume [m^3],
q – rainfall intensity [dm^3/s·ha],
F_0 – size of the drained area [m^2],
Ψ – surface run-off coefficient [-],
F_w – area of the rainwater infiltration facility [m^2],
k_f – soil filtration coefficient [m/s],
T_d – rain duration [min].

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Data:

Drainage area:

- court area: F_{01} = 600 m^2, Ψ_1 = 0.25,
- parking space area: F_{02} = 775 m^2, Ψ_2 = 0.3 (openwork slab + lawn),
- area of access roads and pavements: F_{03} = 1396 m^2, Ψ_3 = 0.6 (polbruk),
- total reduced area (Eq. 4):

$$F_z = F_0 \cdot \psi \; [m^2], \tag{4}$$

Assumptions:
F_w = 200 m^2 : assumed available space for an infiltration basin,
$k_f = 10^{-5}$ m/s : soil filtration coefficient.

The rainfall intensity q was calculated according to the PMAXTP model for the rainfall duration T_d from 5 to 240 min (every 5 min) and for p = 0.2. For the given intensities, the retention volume of the device was calculated. From the results given, the maximum value of V_w = 31.03 m^3 for T_d =170 min was selected.

For a given volume, the filling of the infiltration basin was calculated (Eq. 5) assuming an area of 200 m^2.

$$h = \frac{V_{wmax}}{F_w} = 0.16 \; m. \tag{5}$$

After calculations, the dimensions of the infiltration basin were assumed to be 20x10 m and its depth 0.25 m. The maximum filling of the basin will be 0.16 m.

The basin is to be located at the site of the existing playground, which is to be rebuilt.

A children's play area in the form of a ship is planned to be located within the basin. After heavy rains, the water remaining in the basin for 1–2 days, together with the ship, would be an interesting educational and recreational element for children. The educators would have an opportunity to emphasise the importance of taking care of water resources and rainwater harvesting during the outdoor play. This element would also enrich the aesthetic value of the facility.

The annual approximate volume of rainwater discharged from the court and the sealed surfaces from the northern part of the nursery grounds was then calculated. In this case, the following formula was used (Eq. 6):

$$V_{pn} = F_z \cdot H \; [m^3], \tag{6}$$

where:
V_{pn} – annual volume of rainwater,
F_z – reduced area,
H – average annual precipitation [m].

Data:

The drainage area:

- court area: F_{01}= 600 m^2, Ψ_1= 0.25,
- parking space area: F_{02} =775 m^2, Ψ_2 = 0.3 (gegrid + lawn),
- area of access roads and pavements: F_{03} = 1396 m^2, Ψ_3 = 0.6 (polbruk),
- total reduced area (Eq. 4):

$$V_{pn} = 1220.10 \cdot 0.5283 = 644.58 \; m^3 \; .$$

Advantages of the applied solution

The retention volume of the infiltration basin was determined on the assumption that the total volume of rainwater from the northern part of the kindergarten area will be utilised in it. In this way, in the case of heavy rainfall, only the excess water will be discharged into the sewer system. This

DOI: 10.34659/eis.2025.92.1.861

means that approximately 644.58 m^3 less rainwater will enter the combined sewer annually. The rainwater will be managed in the place where it occurs. Moreover, this solution is associated with low modernisation costs and is certainly cost-effective for existing facilities with developed land.

In-ground rain gardens

Rain gardens are another example of systems that enable the collection of rainwater from impervious surfaces (Borel et al., 2015). This solution has many advantages, including the ability to treat rainwater from parking lots, provide flood protection, and counteract the effects of climate change (Siwiec et al., 2018). Rain gardens do not require a large available surface area or significant financial investment (Dunnett & Clayden, 2007).

On the territory of the kindergarten, it is planned to locate two rain gardens, to which rainwater will be directed through surface mulch from part of the roof, parts of the access roads, pavements and part of the car park. Due to the close proximity of the gardens to the buildings, the use of foil-lined rain gardens is envisaged. The water stored there in case of dry weather will be used for the vegetation processes of the plants.

Rain garden I

Data:

q = 175 $dm^3/(s \cdot ha)$,

T_d = 15 min.

The drainage area:

- part of the building roof (surface drainage): F_{01} = 0.0258 ha, Ψ_1 = 0.6 (green roof),
- area of parking spaces: F_{02} = 0.0138 ha, Ψ_2 = 0.3 (openwork slab + lawn),
- area of access roads and pavements: F_{03} = 0.0217 ha, Ψ_3 = 0.6 (polbruk),
- total area reduced according to formula (Eq. 4):

$$V_{k1} = 0.06 \cdot 0.0326 \cdot 175 \cdot 15 \cong 5.13\ m^3.$$

Due to the available space, garden dimensions of 26x4 m were adopted.

Rain garden II

Data:

q = 175 $dm^3/(s \cdot ha)$,

T_d = 15 min.

The drainage area:

- part of the building roof (surface drainage): F_{01} = 0.0273 ha, Ψ_1 = 0.6 (green roof),
- area of access roads and pavements: F_{02} = 0.0119 ha, Ψ_1 = 0.6 (polbruk),
- total area reduced according to formula (Eq. 4):

$$V_{k2} = 0.06 \cdot 0.0235 \cdot 175 \cdot 15 \cong 3.70\ m^3.$$

Due to the available space, garden dimensions of 12 x4 m were adopted.

In order to estimate the benefits of the solution, the annual indicative total volume of rainwater discharged into the rain gardens was also calculated (Eq. 7).

$$V_{ogr} = F_z \cdot H\ [m^3], \tag{7}$$

where:

V_{ogr} – annual volume of rainwater,

F_z – reduced area [m^2],

H – average annual precipitation [m].

Analogous calculations of the volume of rainwater discharged to the gardens on an annual basis were carried out, taking into account the previous method of rainwater discharge. The rain garden II will receive the rainwater that was previously discharged in a surface manner, while the rain garden I will receive the water that was previously discharged into the sewerage system (from the surface of

DOI: 10.34659/eis.2025.92.1.861

car parks – 0.0138 ha) and the water that was previously discharged in a surface manner (from 0.0475 ha).

The table below (Table 4) summarises the results of the volume of managed rainwater per year in the rain garden area.

Table 4. Summary of the results regarding the volume of managed rainwater per year in the rain gardens

	per year [m^3]		Rainwater in a rain garden [m^3]
	Rainwater previously discharged into the sewage system	Rainwater previously discharged by surface water	
I	21.87	150.57	172.44
II	-	124.26	124.26
I+II	21.87	274.82	296.69

Advantages of the applied solution

The two rain gardens will enable the management of a total of approximately 296.69 m^3 of rainwater per year. The water is drained from a part of the roof, parts of the roads and pavements and a fragment of the car park in the southern part of the kindergarten area. Thanks to the applied solution, approx. 274.82 m^3 of rainwater previously discharged on the surface will be managed and infiltrated into the ground, whereas approximately 21.87 m^3 less water from the parking places will be discharged into the sewage system.

Summary and conclusions

The outlined concept for the modernisation of the kindergarten's drainage system brings many positives. In order to determine the benefits of using green infrastructure facilities, an analysis was carried out on the volume of rainwater entering the sewage system before and after modernisation. The tables below (Tables 5–6) summarise the results of calculating the volume of rainwater discharged annually from specific parts of the kindergarten area before modernisation and after the introduction of green infrastructure into the area of the kindergarten.

Table 5. Volume of drained rainwater per year from all sealed surfaces in the kindergarten area before modernisation

Drained nursery area	Volume of rainwater discharge per year before modernisation [m^3]	
	Method of site drainage	
	To the sewerage system	In a surface manner
Roof of the building	443.00	678.71
Northern part (car parks, pavements, access roads, playing field)	644.58	-
Eastern part (road, pavement, car park)	-	278.00
Southern part (car parks, roads, pavements, playground)	47912	-
Total	1 566.70	956.71
	2 523.41	

Table 6. Volume of managed rainwater per year, achieved through the introduction of green infrastructure

Type of modernisation	Volume of managed rainwater per year, due to the introduction of green infrastructure [m^3]	
	Rainwater previously discharged into the sewerage system	Rainwater previously discharged by surface water
Green roof	163.23	250.03
Infiltration basin	644.58	-
Rain gardens	21.87	274.82
Total	829.68	524.85
	1 354.53	

After carrying out the calculations, it was found that after the introduction of green infrastructure in the area of facilities in the form of a green roof, an infiltration basin and two rain gardens, rainwater drained from sealed surfaces will be managed in the amount of 1 354.53 m^3 per year, which is about 54% of the total volume of rainwater drained from all sealed surfaces before modernisation. 829.68 m^3 less water, i.e. reduced by approx. 53% will be discharged into the rainwater and combined sewerage system. The rainwater previously discharged as surface water will be safely managed, thanks to the green infrastructure, in the amount of 524.85 m^3, i.e. reduced by approx. 55%.

Apart from the benefits associated with the increased infiltration of the rainwater into the ground, relieving the municipal sewage system and improving the microclimate, the proposed modernisation will enrich the aesthetic value of the facility and enable the increased ecological awareness of children and their carers staying at the kindergarten. These actions can also minimise the effects of climate change, counteract the occurrence of drought and prevent flooding associated with the increasingly frequent occurrence of sudden and heavy rainfall.

The development of a modernisation concept also highlights the importance of introducing green or blue infrastructure elements as early as the urban drainage design stage. This allows for greater freedom in the location of equipment and a reduction in costs.

Cost analyses were carried out in Portugal, taking into account the costs of retrofitting, the life cycle of the facilities and the financial benefits of green infrastructure facilities. As an example of the analysis for two facilities, it was found that the use of green roofs reveals negative cash flows at the beginning and the end of the facility's life (Almeida et al., 2021).

Similar analyses were also conducted in Austria, identifying the issue of a lack of integration of green infrastructure with existing school buildings. Here, the authors also described the life cycle of selected facilities, methods of financing, and implementation of the systems. The problem of high costs associated with advanced greening systems was also identified (Teichmann et al., 2023).

The modernisation presented here is an example of local actions related to rainwater management. It is worth noting, however, that only the implementation of a responsible environmental policy and the creation of a subsidy programme encouraging the design and use of blue-green infrastructure will bring tangible benefits on a global scale. It has been noted that the problems associated with the introduction of such facilities into the existing structure of educational facilities is described in literature, e.g. in two schools in Melbourne, Australia, despite successful execution, implementation problems were identified at the level of financing, execution and subsequent use of the facilities. Additionally, the successful implementation of the green infrastructure facilities has been defined as a technical and social achievement (Onori et al., 2018).

In Poland, the first installations for sustainable rainwater management in educational institutions are being developed, for example, in several schools in Warsaw. Analyses are also being conducted to explore the possibility of building green roofs on the Morasko Campus of the Adam Mickiewicz University in Poznań (Jawgiel & Zajączkowski, 2016). However, there is a lack of in-depth analyses related to the design, construction, and operation of such facilities in Polish case studies.

In the face of ever-increasing urbanisation and ongoing climate change, this is becoming an extremely important and conscious step to protect the environment and water resources for us and our future generations.

DOI: 10.34659/eis.2025.92.1.861

The contribution of the authors

Conceptualisation, E.B., D.B. and B.K.; literature review, E.B. and D.B.; methodology, E.B. and D.B.; formal analysis, E.B. and D.B.; writing, E.B. and D.B.; conclusions and discussion, E.B., D.B. and B.K.

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

References

Almeida, C., Teotónio, I., Silva, C. M., & Cruz, C. O. (2021). Socioeconomic feasibility of green roofs and walls in public buildings: The case study of primary schools in Portugal. The Engineering Economist, 66(1), 27-50. https://doi.org/10.1080/0013791X.2020.1748255

Bisaga, W., Bryła, M., Kaźzmierczak, B., Kielar, R., Kitowski, M., Marosz, M., Miętek, B., Ozga-Zieliński, B., Tokarczyk, T., & Walczykiewicz, T. (2022). *Modele Probabilistyczne Opadów Maksymalnych o Określonym Czasie Trwania i Prawdopodobieństwie Przewyższenia*. Projekt PMAXTP. Institute of Meteorology and Water Management-National Research Institute: Warsaw. (in Polish).

Borel, V., Myers, M., & Giraud, D. (2015). *Coastal California Rain Gardens*. https://escholarship.org/uc/item/2bm3j1sj

Campisano, A., & Lupia, F. (2017). A dimensionless approach for the urban-scale evaluation of domestic rainwater harvesting systems for toilet flushing and garden irrigation. Urban Water Journal, 14(9), 883-891. https://doi.org/10.1080/1573062X.2017.1279192

Dunnett, N., & Clayden, A. (2007). *Rain gardens – Managing water sustainably in the garden and designed landscape*. Timber Press. https://www.researchgate.net/publication/230887824_Rain_Gardens_Managing_water_sustainably_in_the_garden_and_designed_landscape

Fundacja Sendzimira. (2025, November 15). *Szkoła przyjazna klimatowi*. https://sendzimir.org.pl/projekty/szkola-przyjazna-klimatowi (in Polish).

Getter, K. L., & Bradley Rowe, D. (2006). The Role of Extensive Green Roofs in Sustainable Development. HortScience, 41(5), 1276-1285. https://doi.org/10.21273/HORTSCI.41.5.1276

Ioja, C. I., Gradinaru, S. R., Onose, D. A., Vanau, G. O., & Tudor, A. C. (2014). The potential of school green areas to improve urban green connectivity and multifunctionality. Urban Forestry & Urban Greening, 13(4), 704-713. https://doi.org/10.1016/j.ufug.2014.07.002

Jaszczak, A., Vaznonienė, G., & Vaznonis, B. (2018). Green infrastructure spaces as an instrument promoting youth integration and participation in local community. Management Theory and Studies for Rural Business and Infrastructure Development, 40(1), 37-49. https://www.researchgate.net/publication/323817486_GREEN_INFRASTRUCTURE_SPACES_AS_AN_INSTRUMENT_PROMOTING_YOUTH_INTEGRATION_AND_PARTICIPATION_IN_LOCAL_COMMUNITY

Jawgiel, K., & Zajączkowski, D. (2016). Potencjał kampusu UAM Morasko w aspekcie zagospodarowania dachów zielona infrastrukturą. Acta Scientiarum Polonorum Formatio Circumiectus, 15(4), 181-192. https://acta.urk.edu.pl/pdf-102912-34299?filename=POTENCJAL%20KAMPUSU%20UAM.pdf

Karczmarczyk, A., & Mosiej, J. (2011). Racjonalne zagospodarowanie wód opadowych na terenach o zwartej i rozproszonej zabudowie. *Ekoinnowacje na Mazowszu. Poradnik transferu technologii w ochronie środowiska. Cz. II – Gospodarka wodna [Dokument elektroniczny].* (in Polish).

Kotowski, A., Wartalska, K., & Nowakowska, M. (2016). Generalized Analytical Method of Overfall Storm Water Retention Reservoir Sizing. Ochrona Środowiska, 38(1), 45-52. https://www.researchgate.net/publication/302579628_Generalized_Analytical_Method_of_Overfall_Storm_Water_Retention_Reservoir_Sizing (in Polish).

Loyola University Chicago. (n.d.). www.luc.edu

Madzia, M. (2019). Reduction of Treated Water Use through Application of Rainwater Tanks in Households. Journal of Ecological Engineering, 20(9), 156-161. https://doi.org/10.12911/22998993/112495

Nowakowska, M., Wartalska, K., Kaźmierczak, B., & Kotowski, A. (2019). Verification of the Stormwater Drainage System Overloads in Wroclaw for an Assessment of Climate Change Effects. Periodica Polytechnica Civil Engineering, 63(2), 641-646. http://dx.doi.org/10.3311/PPci.12668

Okraska, J. (2017). Wielobranżowy projekt budowlany i wykonawczy przedszkola [Projekt]. (in Polish).

Onori, A., Lavau, S., & Fletcher, T. (2018). Implementation as more than installation: a case study of the challenges in implementing green infrastructure projects in two Australian primary schools. Urban Water Journal, 15(9), 911-917. https://doi.org/10.1080/1573062X.2019.1574842

Ozga-Zieliński, B. (Ed.). (2022). *Modele probabilistyczne opadów maksymalnych o określonym czasie trwania i prawdopodobieństwie przewyższenia – projekt PMAXTP*. Warszawa: Instytut Meteorologii i Gospodarki Wodnej – Państwowy Instytut Badawczy. (in Polish).

Pendergrass, A. G., & Hartmann, D. L. (2014). Changes in the Distribution of Rain Frequency and Intensity in Response to Global Warming. Journal of Climate, 27, 8372-8383. http://dx.doi.org/10.1175/JCLI-D-14-00183.s1

Secretariat of the Convention on Biological Diversity. (2009). *Connecting Biodiversity and Climate Change Mitigation and Adaptation: Report of the Second Ad Hoc Technical Expert Group on Biodiversity and Climate Change.* https://www.cbd.int/doc/publications/cbd-ts-41-en.pdf

Shakya, R., & Ahiablame, L. (2021). A Synthesis of Social and Economic Benefits Linked to Green Infrastructure. Water, 13(24), 3651. https://doi:10.3390/w13243651

Sidwell Friends. (n.d.). www.sidwell.edu

Siwiec, E., Erlandsen, A. M., & Vennemo, H. (2018). City greening by rain gardens – costs and benefits. Environmental Protection and Natural Resources, 29(1), 1-5. https://doi.org/10.2478/oszn-2018-0001

Słyś, D. (2008). *Retencja i infiltracja wód deszczowych.* Rzeszów: Oficyna Wydawnicza Politechniki Rzeszowskiej. (in Polish).

Słyś, D. (2013). *Zrównoważone systemy odwodnienia miast*. Wrocław: Dolnośląskie Wydawnictwo Edukacyjne. (in Polish).

Sowińska-Świerkosz, B., & García, J. (2022). What are Nature-based solutions (NBS)? Setting core ideas for concept clarification. Nature-Based Solutions, 2, 100009. https://doi.org/10.1016/j.nbsj.2022.100009

Szklarek, S. (2020). Susze już nas nie opuszczą. Wodociągi – Kanalizacja, 6, 8-10. (in Polish).

Szulczewska, B. (2018). *Zielona infrastruktura – czy koniec historii?* Warszawa: Wydawnictwo PAN. (in Polish).

Teichmann, F., Korjenic, A., Sreckovic, M., Veit, H., & Hartmann, D. (2023). Financing Green Infrastructure in Schools: A Case Study in Austria. Sustainability, 15(20), 14985. https://doi.org/10.3390/su152014985

Wagner, I., & Krauze, K. (2014). *Jak bezpiecznie zatrzymać wodę opadową w mieście? Narzędzia techniczne. Zrównoważony Rozwój – Zastosowania nr 5: woda w mieście*. Kraków: Fundacja Sendzimira. (in Polish).

Warszawa Wawer. (n.d.). https://wawer.um.warszawa.pl/

Wojciechowska, E., Gajewska, M., & Matej-Łukowicz, K. (2016). *Wybrane aspekty zrównoważonego gospodarowania wodami opadowymi na terenie zurbanizowanym.* Gdańsk: Politechnika Gdańska. (in Polish).

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ANALIZA MOŻLIWOŚĆ ZASTOSOWANIA OBIEKTÓW ZIELONEJ INFRASTRUKTURY W BUDYNKACH UŻYTECZNOŚCI PUBLICZNEJ NA PRZYKŁADZIE PRZEDSZKOLA POŁOŻONEGO W CENTRALNEJ POLSCE

STRESZCZENIE: Artykuł opisuje, na przykładzie istniejącego budynku przedszkola zlokalizowanego w centralnej Polsce w miejscowości Skierniewice w województwie łodzkim, możliwości wykorzystania zielonej infrastruktury do zarządzania wodami opadowymi. W artykule przedstawiono rozwiązania w zakresie zastosowania elementów zielonej infrastruktury, takich jak zielone dachy, niecki infiltracyjne i ogrody deszczowe, które poza funkcją techniczną korzystnie wpływają na użytkowników obiektu. Urządzenia te zostały zwymiarowane na podstawie natężenia opadów określonego przy użyciu modelu PMAXTP dla deszczu trwającego 15 minut i prawdopodobieństwie wystąpienia p=0.2. Poszczególne urządzenia do zarządzania wodami opadowymi zostały przeanalizowane pod kątem redukcji odpływu wód deszczowych do systemu kanalizacyjnego, a także przedstawiono przebieg obliczeń doboru konkretnych rozwiązań. W konkluzji oceniono, że wdrożenie opisanych rozwiązań pozwala na zmniejszenie objętości wód opadowych odprowadzanych do kanalizacji o 53%.

SŁOWA KLUCZOWE: zagospodarowanie wód opadowych, obiekty użyteczności publicznej, zielony dach, ogród deszczowy, niecka infiltracyjna

DOI: 10.34659/eis.2025.92.1.861