Impetus

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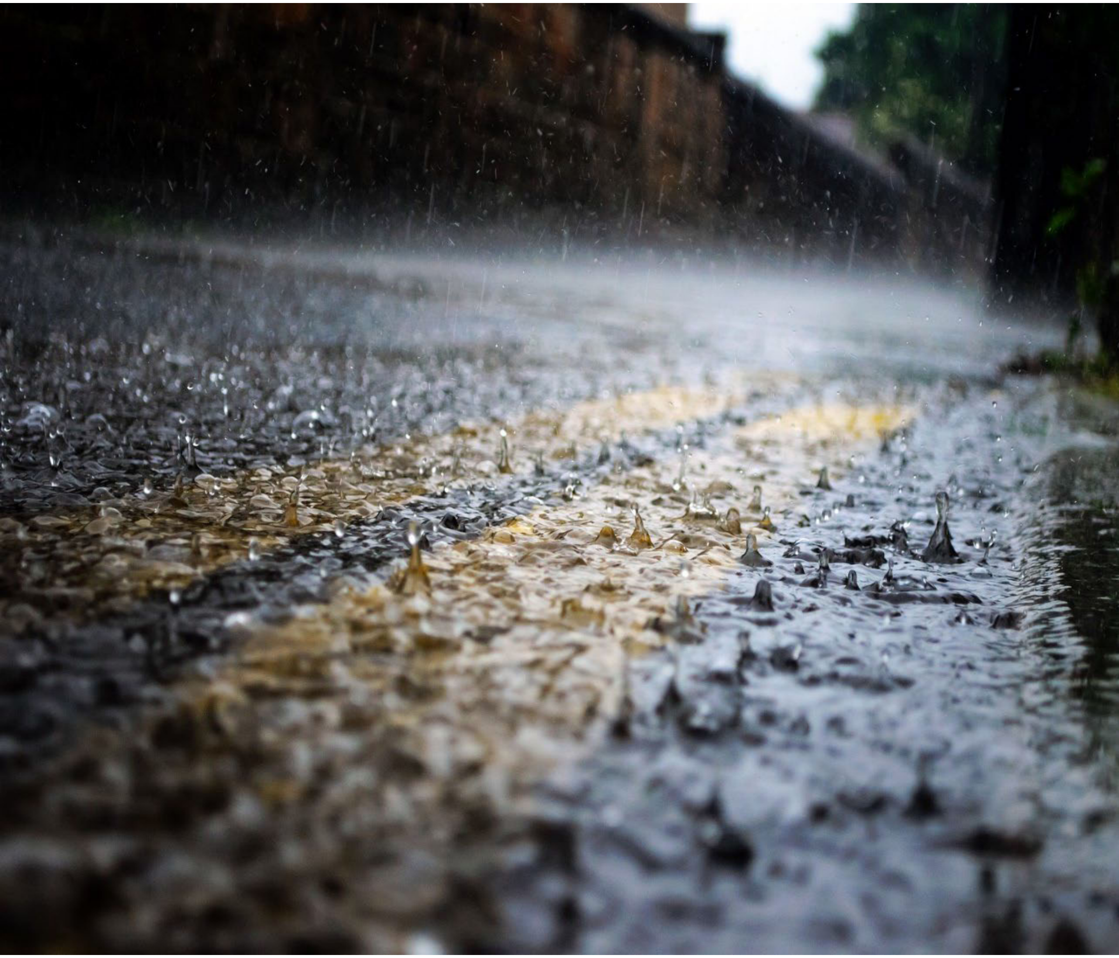
nature-based solutions for cities adaptation



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INTRODUCTION

As climate changes progress, stormwater management, especially in urbanized areas, in large cities will become more and more burdensome as the number of inhabitants increases. Water management is the most sensitive to progressive climate changes, regardless of the degree of urbanization or climatic zone. Unfortunately, the measures taken to decrease the impact on the climate are insufficient. We experience it through more frequent extreme weather events, such as flash floods and microbursts. Such extreme events will increase, which will result in increasingly troublesome periods of drought and heavy rains. Short and very intense rainfall and rapid runoff of stormwater during such an event cause the municipal infrastructure is not able to retain the appropriate amount of water and the existing sewage systems to become insufficient in terms of capacity, which leads to flooding and even urban floods. Due to the quick runoff, the greenery does not retain enough water for its functioning. At the same time, the stormwater runoff contains pollutants from the surface, causing the problem of water quality in the receivers: watercourses and reservoirs. The adaptation of cities to such phenomena requires a new approach, an approach involving the retention of stormwater, delaying its runoff, and simultaneous pretreatment. It is helpful to observe nature and use nature-based solutions using green infrastructure solutions based on vegetation.

CLIMATE CHANGE EFFECTS ON RAIN EVENTS

Climate change brings about more frequent and longer heat waves, an increased probability of droughts and floods, and many changes in the dynamics of atmospheric phenomena. As a result of the increase in the concentration of greenhouse gases in the Earth's atmosphere and the accumulation of energy in the Earth's climate system, we are now seeing an increase in the temperature of the lower atmosphere (troposphere). Following the standards of the World Meteorological Organization (https://public.wmo.int/en), air temperature is measured at meteorological stations at a height of 2 m above the ground. For each station, we determine the climatic average for a specific reference period and the anomaly. The global mean of such anomalies is called the mean surface temperature anomaly of the Earth. Its change indicates an average change in air temperature near the planet's surface (which often means, in simplified terms, a change in average temperature) (Budziszewska et al., 2021).

In the chart (Figure 1), the average temperature anomalies fluctuate from year to year, which is a symptom of natural weather variability.

However, when we take into account long-term changes, it turns out that from pre-industrial times to 2017, the temperature has already increased by an average of 1 ± 0.2 ° C (IPCC, 2018). The last five-year (2015 – 2019) and ten-year

(2010 – 2019) periods were the warmest such periods in the history of measurements (WMO, 2020).

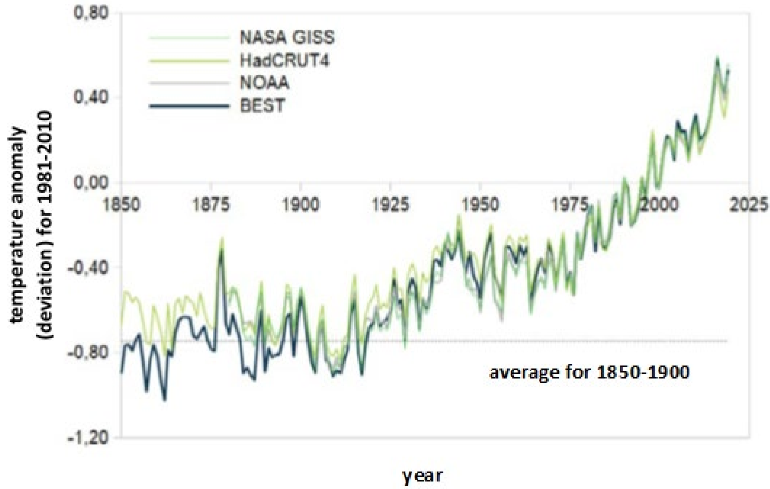

Figure 1. Changes in the mean surface temperature of the Earth relative to the reference period 1981–2010, in degrees Celsius. The chart shows the results of the analyzes of four different research teams. The dashed line shows the average value for the years 1850 – 1900 (an approximation of the state for pre-industrial times).
Source: NASA GISS », Had- CRUT4 », NOAA », BEST»

In the case of precipitation, globally, we are not dealing with a clear trend as in the case of temperature. It is true that global warming is conducive to stronger evaporation of water from the Earth's surface, and hence to rainfall (it is estimated that it may increase globally by approx. 7% per degree of warming, Trenberth, 2011), but where and how much rain falls depends on only from the amount of water vapor entering the atmosphere, but also from (Budziszewska et al., 2021):

- topography (for example, in the case of a humid mass of air passing over the mountains, rain may be expected on the windward slope, and not necessarily on the leeward slope and behind the mountains),
- distance from the ocean (the farther into the continent, the less moisture is available),
- typical velocities and directions of air masses and ocean waters,
- type of surface (ocean, rock, forest, etc.).

Projections (Figure 2) indicate that future changes in annual precipitation totals will often not significantly exceed their natural variability, but the more greenhouse gases are emitted into the atmosphere, the clearer they will be. Further increases in precipitation totals are expected in the mid-latitudes and polar regions, and drops are expected around the tropics (IPCC, 2021).

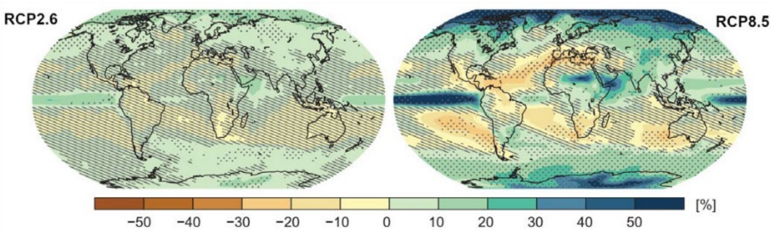

Figure 2. Projections of changes in mean annual precipitation totals in% for the period 2081 to 2100 compared to 1986 to 2005, in the RCP2.6 (left) and RCP8.5 (right) scenarios. Dots indicate places where changes significantly exceed the natural variability of precipitation in a given area, and dashes - places where changes are small compared to the natural variability.
Source: *IPCC (2013).*

RECOMENDATIONS

In 2009, it was developed as one of the first joint documents, the so-called White Book. Adaptation to climate change: A European Framework for Action (COM WHITE PAPER, 2009), which defines the goals and means of preparing a coherent climate change adaptation strategy for EU countries (Gajewska et al., 2019).

In March 2012, the online Climate-ADAPT platform (http://climate-adapt.eea.europa.eu) was launched in cooperation with the European Environment Agency and the European Commission dealing with climate change. The platform presents a database and information on the policies of the European Union and individual countries. It also presents scientific reports, the latest data on adaptation efforts in the EU, and useful tools to support the policy process (Gajewska et al., 2019).

In 2013, the EU Strategy for adaptation to climate change was developed (COM 0216 final, 2016). It presents the current state of work and indicates methods of supporting the activities of the Member States, among others. by adopting comprehensive adaptation strategies and financial support for their implementation (Gajewska et al., 2019).

Three years later, in 2016, the Paris Agreement (Paris Agreement, United Nations Framework Convention on Climate Change, 2016) was developed, which is to strengthen the United Nations Framework Convention on Climate Change, drawn up in New York on 9 May, 1992. the goal of responding to the threats of climate change in the context of sustainable development and poverty eradication efforts. The effectiveness of the action is to be based on mutual trust and, in line with Article 2 of the Agreement, on helping richer countries to poorer countries (Gajewska et al., 2019):

- limiting the increase in the global mean temperature to a level well below 2 ° C above the pre-industrial level;
- making efforts to limit the temperature rise to 1.5 ° C above pre-industrial levels, recognizing that this will significantly reduce the risks and impacts of climate change; increasing the ability to adapt to the negative effects of climate change and fostering climate resilience and low greenhouse gas emissions development in a way that does not endanger food production;
- ensuring that financial flows are consistent with the path to low greenhouse gas emissions and climate-resilient development.

According to the Baltic Marine Environment Protection Commission (HELCOM Recommendation 23/5-Rev.1, 2021) from June 2021, a reduction in discharges from urban areas must be ensured by proper management of stormwater systems. Unsuitable sewerage systems can cause highly polluted runoff from urban areas which is eventually discharged into the receiver (e.g. The Baltic Sea). The Helsinki Commission (HELCOM) recommendation stands for specific stormwater planning, and reduction of discharge from urban areas through proper stormwater management, especially high-risk storm waters. These objectives should be supported by integrated stormwater management, assessment of local stormwater impact, green infrastructure planning, and green technologies. Green technologies include Water Sensitive Urban Design (WSUD) developed in the 1990s in Australia. The objective of WSUD is to manage water balance, maintain or improve water quality, and preserve water-related ecosystem services. This particular approach to stormwater management aims to address the entire urban water cycle at all scales and densities. Water Sensitive Urban Design is a part of a larger group of solutions based on nature (Abbott et al., 2013; Ballard et al., 2015; Dickie et al., 2010; Digman et al., 2012; Fletcher et al., 2015; Graham et al., 2012; HELCOM Recommendation 23/5-Rev.1, 2021, Kasprzyk et al., 2022).

Nowadays, increasing urbanization and the harmful effects of climate change have influenced the water balance, resulting in unfavorable events such as flooding, droughts, and heat stress (European Environment Agency, 2015; IPCC, 2014a, 2014b). Implementing Nature-based Solutions (NBS) can help, treat, and infiltrate stormwater that runs off roofs and impermeable surfaces and potentially into the subsurface (Venvik and Boogaard, 2020). Green infrastructure, especially rain gardens and swales, creates permeable pavements to restore water balance by capturing, retaining, and improving the infiltration capacity in urban areas. In addition, such systems can better treat stormwater runoff, restore groundwater levels, increase soil moisture to alleviate drought impacts, and lower temperatures by evapotranspiration. Nevertheless, in practice, predicted infiltration capacities are usually not met, often for unknown reasons (Atanasova et al., 2021; Katsou et al., 2020; Oral et al., 2020; Veldkamp et al., 2021; Venvik and Boogaard, 2020).

The International Water Association (IWA) developed the Principles for Water Wise Cities to inspire change amongst urban and local leaders and catalyze a shift in the current water management paradigm to make cities more resilient and liveable (International Water Association, 2016).

According to the IWA Principles Water Wise Cities (2016) the Five Building Blocks to Deliver Sustainable Urban Water (Figure 3) are:

(1) a shared vision moves stakeholders from defending solutions for their specialties to defining a set of common drivers for the greater benefit of the urban community. A shared vision is an essential prerequisite for ensuring sustainable reforms and the implementation of new policies and strategies.

(2) governance and institutions provide the framework for urban stakeholders to work together, working across silos to integrate water in all urban services at the building, neighborhood, metropolitan, and catchment scales. Policies provide incentives for urban stakeholders to unlock the synergies across sectors, maximizing the benefits of water to cities.

(3) knowledge and capacities – implementing the sustainable urban water vision start with the existing capacities and competencies of the different urban stakeholders. • Upgrading existing educational programs with contents related to sustainable management of urban resources and urban resilience, with an integrated approach

and a balance to both technological and social challenges.

- To fully realize the vision, increased capacities and competencies are needed, through sharing success stories from other cities, learning to work differently with new tools, pooling resources, and opening to other sectors' approaches and methods.

(4) planning tools – delivering water wise-cities require planning tools to assess the inter-relationships between land use planning decisions and all components of urban water systems. The tools include models that analyze the bio-physical and socio-economic consequences of different system options, at a range of scales. These tools, developed and used by cross-sectoral teams, allow for assessing risks, identifying benefits and co-benefits of projects, defining levels of service, ensuring ownership by stakeholders, and enabling public participation and engagement.

(5) implementation tools – regulations can drive innovation and incentives. If based on quality assurance, equity, transparency, accountability, and sound financing, they can provide a solid frame for stakeholders to invest in sustainable urban water. Financial tools, linked to rigorous asset management plans, enable long-lasting improved service levels with a well-maintained infrastructure. Financing tools, which value the ability of solutions to adapt to changes or recover from disasters, allow cities to adopt more efficient solutions and transition towards systems requiring smaller and more frequent investments.

Figure 3. Principles for the Water Wise Cities (International Water Association, 2016)

The Four Levels of Action: 1 – Regenerative Water Service (e.g. replenish waterbodies and their ecosystems, reuse and use diverse source of water), 2 – Water Sensitive Urban Design (e.g. enable regenerative water service, design urban space to reduce flood risk, 3 – Basin Connected Cities (secure water resources and plan for drought mitigation, plan for extreme events), 4 – Water Wise Communities (e.g. transdisciplinary planning teams, empowered citizens).

SUSTAINABLE STORMWATER MANAGEMENT IN CITIES

Urbanization is one of the causes of floods. The construction and sealing of the surface cause changes in the water balance, which in turn increases the size of maximum outflows. Therefore, cities are increasingly threatened by floods caused by the overflow of water from the river bed (snowmelt, storm floods) or resulting from heavy, torrential rains, the so-called rainfall floods (Gajewska et al., 2019).

Figure 4. New Orleans flooding after Katrina hurricane (Pixabay)

In addition to excessive sealing of the surface, the main causes of rainfall floods in the city (Figure 4, Figure 5) include limiting the area of green areas, cutting down trees, technical problems related to insufficient capacity of the sewage system, blocked culverts and ditches, changes in the topography as a result of new projects and accumulation of water in places without drainage. Diagnosing problems and identifying their areas of occurrence, i.e. sensitive areas exposed to such floods, is the first step in good planning (Gajewska et al., 2019).

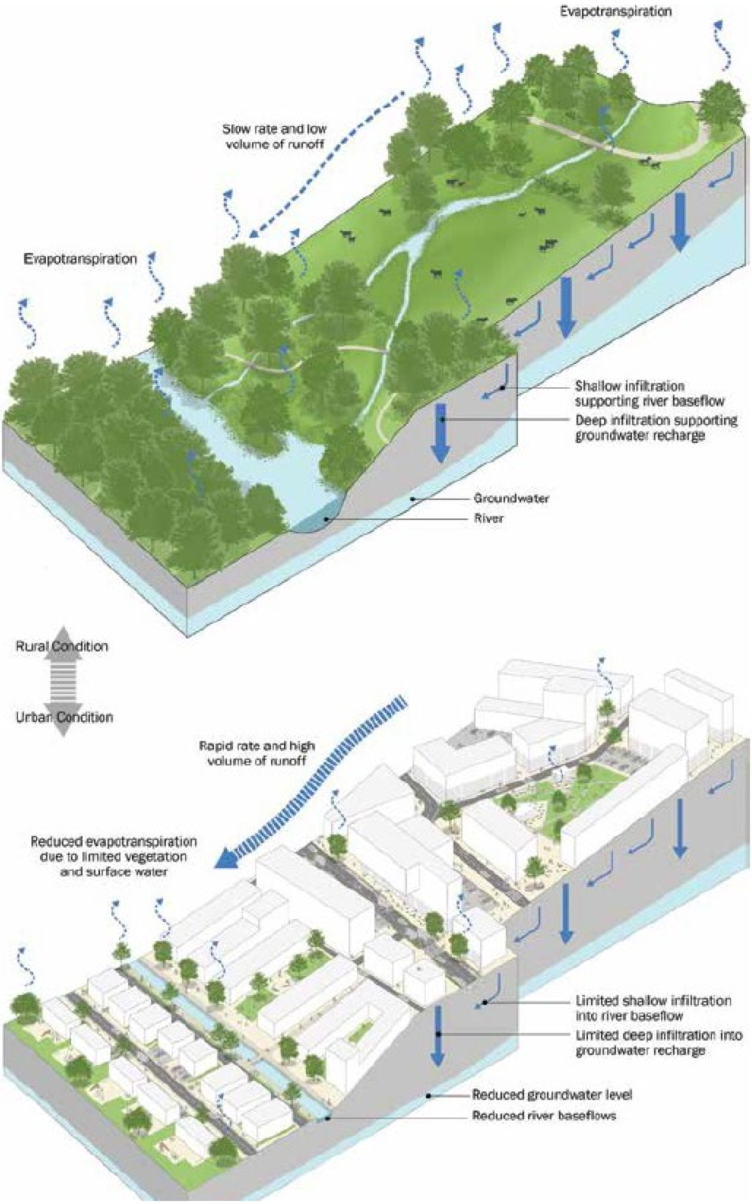

Figure 5. Impacts of urbanization on a catchment (The SuDS Manual, CIRIA)

In recent years, more and more often urbanized areas experience flooding and urban floods - the so-called flash floods, i.e. sudden local floods. The main cause of these recurring situations is the expansion of cities and the replacement of permeable areas - e.g. green areas - with impermeable ones. In addition, the observed climate changes tend to increase the frequency of extreme phenomena, such as long periods of drought or short-term high-intensity rainfall (Gajewska et al., 2019).

The natural water cycle is disturbed by urban development (Wojciechowska et al., 2015; Wojciechowska et al., 2017). Water infiltration (infiltration) and evapotranspiration decrease, and surface runoff increase significantly. The consequences include not only flooding and sudden urban floods, but also a reduction in groundwater supply and a change in the microclimate in the cities. In addition, surface runoff discharges pollutants from the catchment area, from streets, roofs, industrial sites, or gas stations, and transports them to rainwater drainage pipes or directly to surface waters.

Another way to solve the problem may be to treat rainwater in urban areas as a raw material that can be reused for irrigation in green areas during drought or used in industry. This requires the appropriate design of retention areas in relation to green or industrial areas. Retention and accumulation of rainwater in open tanks also have a positive effect on the microclimate of the place, especially during periods of drought and hot days (Gajewska et al., 2019).

NBS DEFINITION AND CIRCULAR ECONOMY ASPECTS

Nature-based Solutions (NBS) are "Actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (IUCN) (Figure 6).

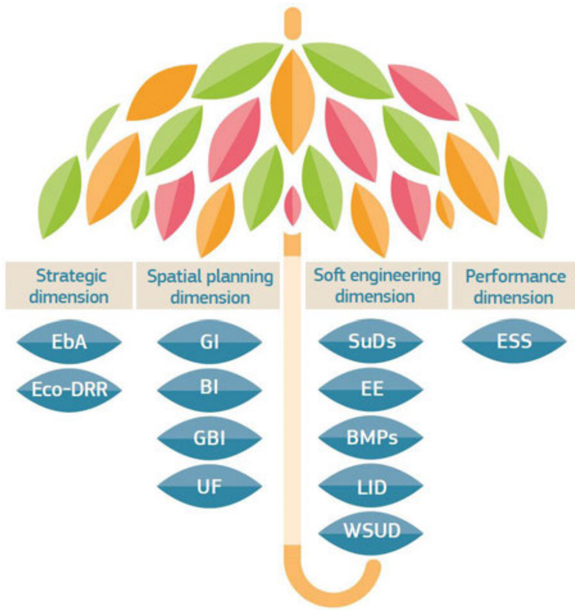

Figure 6. Nature-based solutions as an umbrella concept and the relation of NBS to key existing concepts. EbA = ecosystem-based adaptation; Eco-DRR = ecosystem-based disaster risk reduction; GI = green infrastructure; BI = clue infrastructure; GBI = green-blue infrastructure; UF = urban forestry; SuDS = sustainable urban drainage systems; EE = ecological engineering; BMPs = best management practices; LID = low-impact design; WSUD = water-sensitive urban design; ESS = ecosystem services (European Commission, 2021)

According to European Commission they are "Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions."
(https://research-and-innovation.ec.europa.eu/research-area/environment/nature-based-solutions_en)

Nature-based solutions must therefore benefit biodiversity and support the delivery of a range of ecosystem services (Figure 7).

Provisioning	Regulating	Cultural
Products humans obtain from ecosystems: • Food • Raw Materials e.g. wood, fuel, fibre • Medicine • Fresh Water	Services nature provides that **regulate** the environment: • Air Quality • Climate • Water Purification • Waste Treatment • Disease and Pest Control • Pollination • Extreme Events Moderation	**Non-material** benefits of nature for humans: • Recreation e.g. tourism • Aesthetic Values • Religious and Spiritual Values • Mental and Physical Health • Education

Supporting
The underpinning services that enable all other services to function – encompasses both human and ecosystem needs: • Photosynthesis • Nutrient Cycling • Soil Formation

Figure 7. Categories and examples of ecosystem service (Millennium Ecosystem Assessment, 2005)

Ecosystem services are the benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services, such as nutrient cycling, that maintain the conditions for life on Earth

Nowadays, Nature-Based Solutions (NBS) are developing as innovative multifunctional tools to maximize urban ecosystem services such as stormwater preservation, reduction of runoff and flood protection, groundwater pollution prevention, biodiversity enhancement, and microclimate control (Kasprzyk et al., 2022).

The essence of green in blue-green systems is to perform as many functions as possible: providing a place for recreation, ensuring food production, purifying air and water, supporting biodiversity, or air conditioning the area (cooling in summer, heating in winter). The collected rainwater is used by the "green" and its excess is to supply and increase the surface retention or, which is increasingly important, to restore the aquifer. Currently, greenery is planned in cities, but often it only serves an aesthetic function, e.g. trees in pots or planting shrubs and flowers in flower beds tightly separated from the inflow of rainwater, which does not ensure retention and proper management of rainwater. In such cases, neglect of watering by municipal services will lead to the death of these plants (Gajewska et al., 2019).

Principles of shaping integrated rainwater management systems (modified based on Januchț-Szostak, 2011):

1. Management of rainwater at the precipitation site, preferably on the surface of the land, to reduce surface runoff and increase retention and infiltration

2. The use of the natural properties of soil and plant material to slow and purify the runoff of rainwater and snowmelt.

3. Shaping water and plant ecosystems in close connection with the spatial composition and functional purpose of the place, to achieve multifunctionality:

- visual and functional attractiveness of the place,
- social acceptance and increase in environmental awareness of the inhabitants,
- biodiversity
- adaptation to climate change and minimization of the "heat island"

4. Necessity of multi-sector planning and participation of residents.

5. The need for multi-variant and multi-level planning enabling flexible adaptation to change weather conditions.

6. Taking into account the economic effects in the long term.

Among the above-mentioned principles, there is a need for residents to participate in planning processes, which is a necessary condition for social acceptance but also helps the residents to feel like co-hosts of the city. An important aspect of the planned solutions is the cost understood as investment and operating costs. The success of the approach is based on coordination of and communication between multidisciplinary teams instead of focus on individual benefits.

Nature-Based Solutions (NBS) have been proven to effectively mitigate and solve resource depletion and climate-related challenges in urban areas. The COST (Cooperation in Science and Technology) Action CA17133 entitled "Implementing nature-based solutions (NBS) for building a resourceful circular city" has established seven urban circularity challenges (UCC) that can be addressed effectively with NBS (Oral et al., 2021).

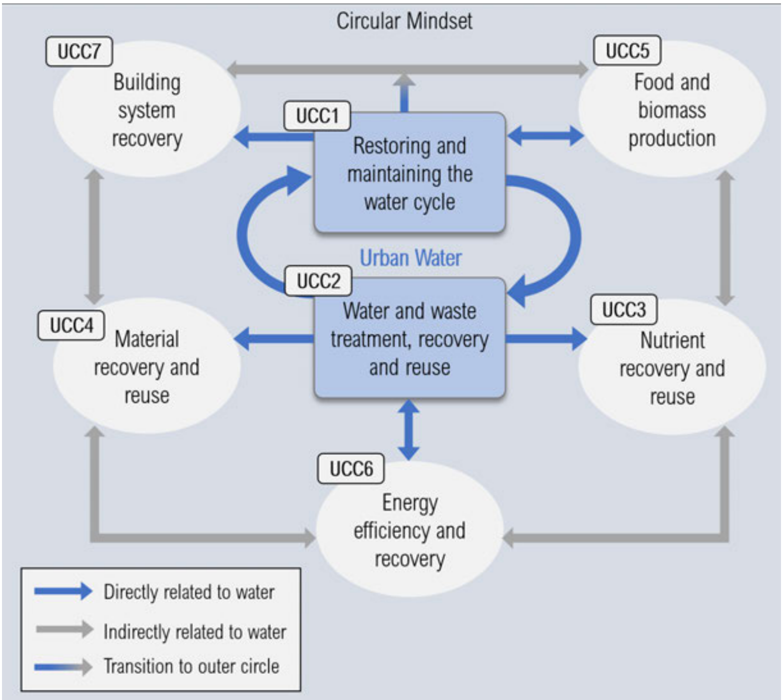

Figure 8. *Diagram illustrating the interconnections between the seven circularity challenges from the perspective of urban water. The two central challenges of our analysis are (UCC1) restoring and maintaining the water cycle, and (UCC2) water and waste treatment, recovery, and reuse (Oral et al., 2021)*

Within the CA17133 seven urban circularity challenges (UCC) were selected (Figure 8): (UCC1) Restoring and maintaining the water cycle; (UCC2) Water & wastewater treatment, recovery and reuse; (UCC3) Nutrient recovery and reuse; (UCC4) Material recovery and reuse; (UCC5) Food and biomass production; (UCC6) Energy efficiency and recovery; and (UCC7) Building system recovery. These seven UCCs provide a novel framework for discussing and planning a transition to circular cities (Oral et al., 2021).

Table 1. Case-based qualitative assessment of the 12 selected NBS units (Oral et al., 2021)

Category	NBS Unit	Total Circularity Score
Units for rainwater management	Infiltration trench	7
	Bioretention cell (Rain garden)	16
	Dry swale	6
	Riparian buffer	19
Vertical Green Infrastructure & Green Roofs	Extensive green roof	6
	Intensive green roof	15
Remediation, Treatment & Recovery	Treatment wetland	21
	Anaerobic treatment (for nutrient, VFA & methane recovery)	3
River Restoration	River restoration	24
	Coastal erosion control	2
Greening intervention + (Public) Green Space	Large urban park	14
NBS units for food & biomass production	Productive garden	12

The total circularity score achieved by an NBS unit for both UCC1 and UCC2 is calculated as the sum of all awarded marks (Table 1), excluding the enabling process "Treatment" within UCC1. 2 NBS units are classified into 3 classes of contribution based on the total circularity score for UCC1 and UCC2: high >20, medium 20–10, low <10 (Oral et al., 2021).

Due to the urban characteristics of the catchment area, the stormwater runoff can be affected by more than 700 different organic pollutants of anthropogenic origin, heavy metals, and trace inorganic compounds (Eriksson et al., 2007).

Table 2. General stormwater monitoring parameters including selected priority pollutants

Parameter	Unit	Range	Stormwater problem	
			Human	Aquatic
pH	–	3.9–7.9	MINOR	MINOR
Conductivity	μS/cm	25–2436		
BOD_5; COD	mg/L	2–36; 55–146	MINOR	MINOR
DO; total solids	mg/L	0–14.0; 76–36, 200	MAJOR	MAJOR
TSS	**mg/L**	**(13–937) 1–36 200**	**MAJOR**	**MAJOR**

Among the basic specifications of storm water quality, the most significant is the amount of total suspended solids (TSS) (Table 2), particularly in urban runoff (Gavrić et al., 2019), because many pollutants are attached to particulate matter (Liu et al., 2019). Solids are considered as an important transport agent – e.g. metal contaminants (Bibby and Webster-

Brown, 2005) – and in addition, the concentration of various pollutants can be strictly related to the number of suspended solids (Table 3) (Kasprzyk et al., 2022).

Table 3. Concentration of total suspended solids depending on the urban catchment area (Pictures source: Pixabay)

Type of catchment	Total suspended solids (TSS)
	6-230 mg/L
	STREETS – 61-320 mg/L Parking – 42-240 mg/L Motorways – 200mg/L
	City Center – 300-2000 mg/L Districts – 100-3000 mg/L Polish City – 98-933 mg/L

GOOD EXAMPLES

Rain gardens in Gdańsk (Poland)

Rain garden in definition is a planted depression designed to collect, store, infiltrate and filter stormwater runoff on a small-scale, especially in urban areas. It combines layers of organic sandy soil for infiltration and mulch to promote microbial activity. Native plants are recommended without the use of fertilizers and chemicals. Storm water runoff is drained, stored for a certain period, and then infiltrates into the ground soil. This NBS can have an above-ground overflow for excess water (URBANGREENUP (2018), UNALAB (2019), University of Arkansas Community Design Center (2010), The SUDS Manual CIRIA (2015) and Castellar et al. (2021)).

1. The rain garden (Goszczyńskiego) consists of 7 cascaded, it is fed by rainwater collected from the surface of the roadway. Three inlets in the curb allow surface runoff of rainwater to the facility, where it is collected and taken up by the root systems of planted plants (Gdańskie Wody).

Figure 9. Source: Gdańskie Wody

2. The rain garden (Stryjewskiego) consists of a depression in the terrain with plantings of properly selected plants.

Figure 10. Source: M. Gajewska

It is sustained with rainwater collected from the surface of the building rooftop. The facility collects and purifies rainwater, which relieves the urban rainwater drainage system.

Box rain garden in Gdańsk (Poland)

This NBS involves the use of planted containers such as pots, boxes, or planters, filled with artificial (technical) soilless substrate or soil. They can be placed individually or grouped on the ground and close to the building (NATURE4CITIES (2020) and Castellar et al. (2021)).

Figure 11. Source: Gdańskie Wody

The rain garden (Ugory) consists of 3 box gardens connected by cascades, it is fed by rainwater collected from the roof surface. In the last of the containers, there is an emergency overflow. The facility collects rainwater, which relieves the municipal rainwater drainage system, and has a positive effect on the microclimate (Gdańskie Wody).

Bioswale in Wrocław (Poland)

Swale is an open lined or unlined, slightly sloped, vegetated channel for treatment and conveyance of stormwater runoff. The main function is to treat stormwater runoff as it is conveyed, whereas the main function of a rain garden is to treat stormwater runoff as it is infiltrated. Bioswales require curb cuts, gutters or other devices that direct flow towards them. This NBS is often used to drain roads, paths or car parks while enhancing access corridors or other open spaces (URBANGREENUP (2018), NATURE4CITIES (2020), UNALAB (2019), University of Arkansas Community Design Center (2010), The SUDS Manual CIRIA (2015) and Castellar et al. (2021)).

The use of a part of a garden or plot of land through appropriate shaping and site preparation, enabling the creation of a collection site and temporary rainwater retention.

Figure 12. Source: Wrocławskie Inwestycje Sp. z o.o.

Bioswale Paddepoel, Groningen (The Netherlands)

Figure 13. Source: Floris C. Boogaard

Nature-friendly swales, rainwater gardens and infiltrating sidewalks are popular with municipalities and water offices which participate in the climate protection of cities, districts and villages. The research results are of great importance for all stakeholders in (inter)national cities that are involved in climate adaptation. SuDS is the most widely used method for storing stormwater and infiltrating in the Netherlands.

Bioswale Euvelgunne, Groningen (The Netherlands)

Figure 14. Source: Floris C. Boogaard

Swale biodiversity 7500 m²; rainfall of up to about 25 mm can be stored in a swale; this is located around the building and is landscaped beautifully. The swale has been sown with a flowery mixture for the benefit of biodiversity. An overflow has been installed to the sewage system.

Green roof University of Warsaw Library (Poland)

This NBS consists of implementing a great diversity of vegetation (higher variety than extensive GR) on rooftops. These spaces are normally accessible to the public for recreation, gardening, relaxation and socializing purposes. This NBS is usually heavier and has a deeper substrate (more than 20 cm) as compared to extensive systems. In addition, it requires higher installation and maintenance efforts such as regular irrigation and fertilisation but provides more biotopes and higher biodiversity (URBANGREENUP (2018), UNALAB (2019), NATURE4CITIES (2020), FFL (2002) and Castellar et al. (2021)).

Figure 15. Source: Dominika Wróblewska

A two level rooftop garden that covers 1 ha area. The upper part - views of Warsaw city, and numerous pathways of plants life, trees and pergolas. The lower part - a place to hide and relax with a pond. Both levels are connected by a cascade stream.

Rooftop farm in New York (USA)

This NBS involves basic, lightweight, planted systems that are implemented on the rooftop. The most common plants used are sedum, herbs, mosses, and grasses. The installation and maintenance are less expensive than that of intensive systems. The growth medium is relatively thinner (8-15 cm) than for intensive systems (URBANGREENUP (2018), UNALAB (2019), NATURE4CITIES (2020), Somarakis et al. (2019), FFL (2002) and Castellar et al. (2021)).

The project includes a one-acre green roof farm, an all-season greenhouse, 10,000 square foot orchard and food forest with dozens of fruit-bearing trees, and a 344,000-gallon underground cistern for recovering and recycling rainwater runoff.

Figure 16. Source: Greenroofs.com

Green metro entrance, Rotterdam (The Netherlands)

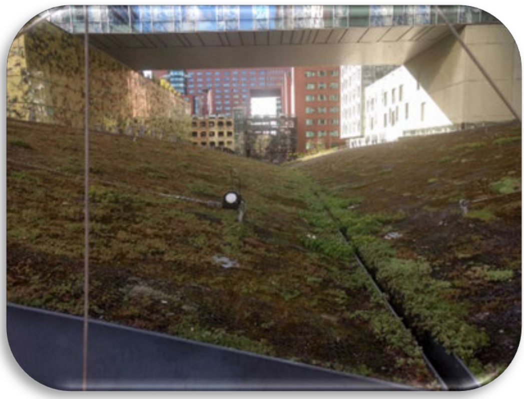

Figure 17. Source: Rick Heikoop

The location where the Rotterdam metro dives underground has been transferred in a park-like location amidst tall buildings.

Green wall Lombardijen, Rotterdam (The Netherlands)

This NBS is based on the application of climbing plants along the wall (in building facade or other types of walls). The wall is completely or partially covered with greenery and the plants can grow upwards. The climber plants are planted in the ground (soil) or in containers (filled with soil or substrate) and grow directly on the wall (direct systems), or climb using climbing-aids (indirect systems) that are attached to the wall (URBANGREENUP (2018), UNALAB (2019), NATURE4CITIES (2020), Manso and Castro- Gomes (2015) and Castellar et al. (2021)).

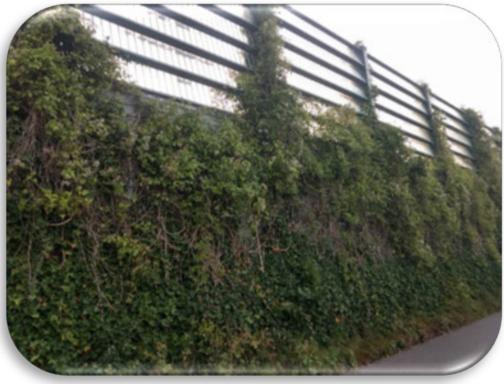

Figure 18. Source: Rick Heikoop

The railway tracks are hidden from the view from the apartments by a green 'wall'.

Floating houses, Rotterdam (The Netherlands)

Figure 19. Source: Rick Heikoop

Floating houses project in Nassau haven.

CONCLUSION

In adaptation activities related to flood protection, the retention functions, the introduction of a biologically active surface harmonizes with the functions of public space, as well as the tourist and recreational functions. The differentiation of the structure of such areas, their spatial composition, and equipment with small architecture, accessibility, and connection with neighboring areas significantly increases the rank of such solutions.

An example may be nature-based solutions that, when made available to residents, create public space and become an icon of cities, a tourist attraction. At the same time, they strengthen the city's natural system by linking water with green infrastructure and contribute to the preservation and development of biodiversity.

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