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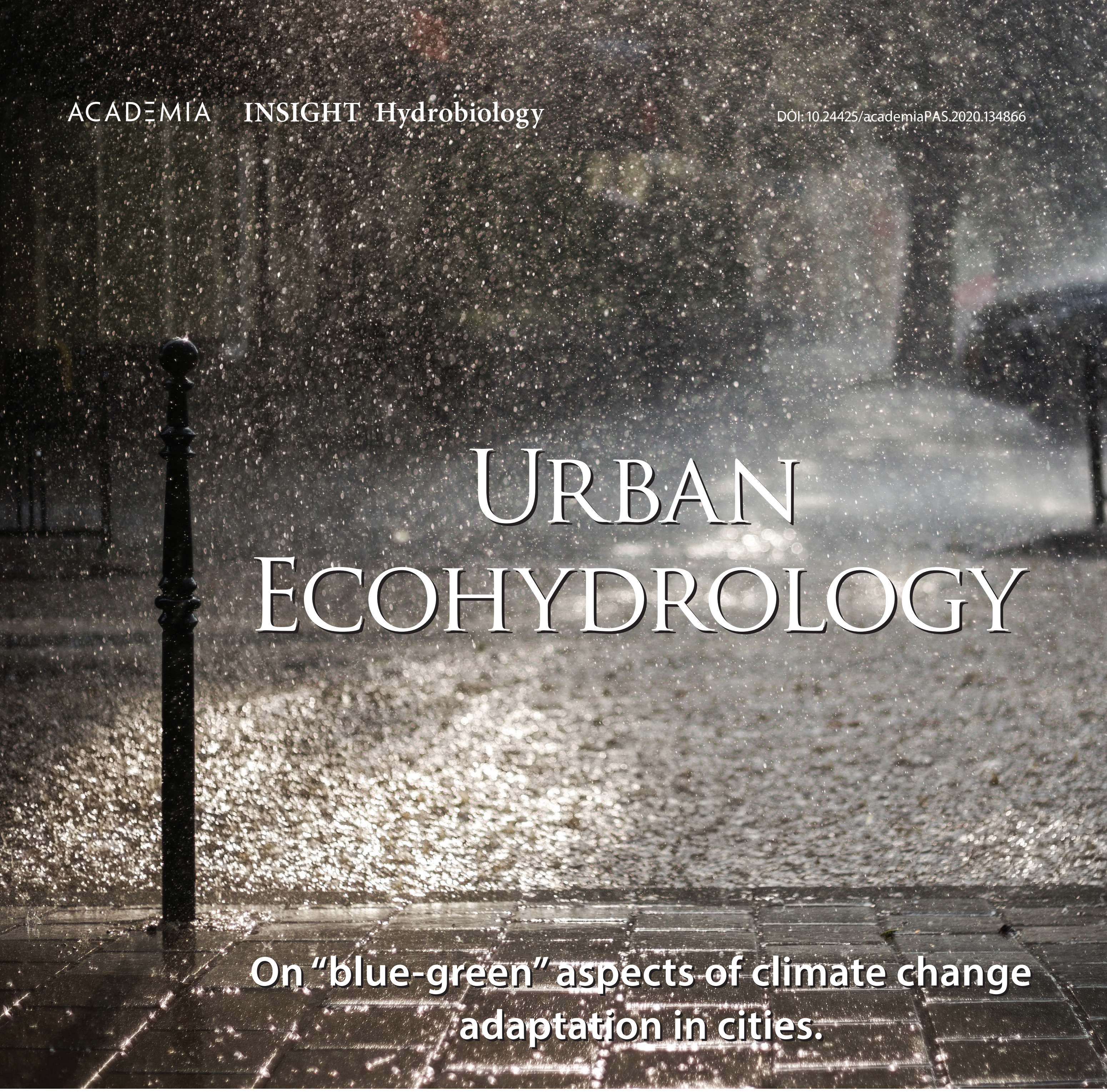

Urban Ecohydrology

On "blue-green" aspects of climate change adaptation in cities.

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Today's world is highly urbanized. In 2008, for the first time in history, the urban population started to account for over 50% of the world's population. Right now the figure is above 55% (or 72% in the EU) and by 2050 it may further rise to over 68% of the world's population of then nearly 10 billion. However, this projection is not set in stone – ongoing climate change could impose serious limitations on the rapid growth in world population numbers, due to unstable climate conditions. Consequently, cities, which are not only densely populated but also characterized by highly concentrated infrastructure and capital as well as intensive economic, cultural, and social development, are one of the key "vulnerable areas" that require climate change adaptation measures.[1] In Poland, all cities with more than 100,000 inhabitants[2] as well as some smaller towns[3] have already adopted comprehensive strategies and detailed action plans related to climate change adaptation.

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Cities are extremely complex and spatially diverse socioecological systems, so their adaptation to climate change likewise poses a complex challenge. Such adaptation comprises numerous types of action, introducing changes in vulnerable sectors of the economy as well as in administration, municipal services, and even the social system. However, what serves as a point of departure for all adaptation measures is attempting to mitigate the effects of extreme climate events that hinder the functioning of cities, such as heat waves, droughts, and urban floods. This goal can only be achieved in an economically efficient way by unleashing the potential inherent in the environment or natural capital. Thanks to the links between natural capital and what are known as "ecosystem services," those who live in cities may draw numerous benefits from natural processes. These benefits include the regulation of the local microclimate, the stability of the local water cycle, and water self-purification in urban rivers.

In order for this to happen, cities need well-functioning ecosystems, in other words ones that are non-degraded, integral, and resilient. Unfortunately, the very idea of urban development has meant considerable landscape transformations, resulting in changes in the structure of the original natural system. Natural areas have become downsized, fragmented, and mostly replaced by urban development, and the processes taking place in the environment (including ecosystem services) have been lost permanently or replaced with municipal infrastructures to serve the needs of city dwellers. Consequently, the quality of the natural environment in today's cities (natural capital) is often low, which impacts negatively on the health and comfort of inhabitants as well as on their living conditions (social capital), in addition to increasing the costs of the functioning of cities (economic capital). These boundary conditions are accompanied by the ever-more strongly felt effects of climate change, which not only augment the negative consequences of urbanization but also weaken the natural environment, which is the main factor behind adaptation to ongoing changes.

In their climate change adaptation efforts, local governments are relying increasingly on knowledge and practices in the field of urban ecohydrology, which aims to boost the resilience of the natural system in cities in response to anthropogenic stress (or stress caused by human activity) and ultimately to improve the quality of life in cities. Ecohydrology is based on a fundamental principle that provides for the mutual regulation of hydrological and biological processes and aims to improve the condition of the environment and optimize processes that are beneficial from the perspective of specific ecosystem services.

Water in urban areas

Cities are complex mosaics of different human-altered areas and ecosystems of varying levels of quality, ranging across the urbanization gradient, from areas dominated by grey infrastructure (such as city centers) to semi-natural areas (for example suburban forests). The impervious surfaces found in these mosaics (buildings, roads, sidewalks, streets, and squares) alter the water cycle in local landscapes to a fundamental degree, a situation that was described as far back as in the 1960s with the arrival of a new branch of science called urban hydrology. Stormwater no longer sinks into the ground where it falls, but instead runs off concrete surfaces into the sewerage system and then

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[1] COM (2013) 216 final. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. An EU Strategy on adaptation to climate change, https://ec.europa.eu/transparency/regdoc/rep/1/2013/EN/1-2013-216-EN-F1-1.Pdf

[2] The project "Let's feel the climate!", http://44mpa.pl

[3] For example the CLIMCITIES project of climate change adaptation in small and medium-size cities, www.climcities.ios.gov.pl/projekt

directly into water receivers or wastewater treatment plants. In extreme cases (with imperviousness reaching 75–100%), this produces even 95% stormwater runoff. Rapid runoff causes flash floods, which pose a problem for most big cities. Heavy rainfall can paralyze traffic in a matter of 15 minutes, causing material damage and personal injuries and possibly even endangering people's lives. Storm drains and city-wide sewage systems were once expected to protect inhabitants from such threats. Unfortunately, systems that were designed more than 100 years ago are not always able to do their intended jobs today – most of them were built with less intensive rainfall and less impervious catchment areas in mind. Ongoing climate change may further exacerbate this situation. Although detailed precipitation projections are uncertain and vary depending on the assumed scenario of carbon dioxide emissions and the climate model, we can say with a high degree of likelihood that intensive rainfall and therefore flash flooding in cities will occur more and more frequently in the future.

> Climate forecasts are predicting roughly similar temperature changes: temperatures are expected to rise, with warm spells and heat waves expected to be more frequent and last longer.

Ultimately, however, conventional sewers do manage to do their job and water is drained from cities after several hours or days. But drainage, in turn, intensifies other adverse phenomena. Cities drained of water heat up fast, often becoming what are referred to as urban heat islands. The temperatures in city centers are higher than those in the suburbs; the difference is usually several degrees Celsius, but it may periodically exceed even 10 degrees. Reduced green spaces further exacerbate this effect, because the transpiration of plants naturally lowers and stabilizes temperature, in addition to increasing air humidity. Desiccated and overheated cities translate into significantly higher rates of such diseases as asthma and inhaled allergies, cardiovascular disease, heat stroke, and so on. In addition, life in such cities may cause depressed mood, exacerbate health problems, and even cause premature death, especially in particularly vulnerable groups such as those with chronic vascular, cardiac, and respiratory diseases, children, and elderly people, as well as people who are socially excluded and those who live alone.

Climate models are relatively consistent in their predictions of temperature changes: temperatures are expected to rise, with warm spells (periods characterized by a maximum air temperature of more than 25°C) and heat waves (more than 30°C) expected to be more frequent and last longer. Also, we will face more frequent tropical nights (when the temperature does not fall below 20°C), which are particularly dangerous for people's health. The overlapping effects of urban heat islands and climate change could cause daytime temperatures in European cities to exceed 40–50°C, making it impossible for inhabitants to spend time outdoors. The first warning sign came with the heat waves that hit Europe in 2003 which, depending on estimates, caused from 30,000 to 70,000 premature deaths. The economic losses were estimated at over 13 billion euros.

Small urban rivers

Water runoff in cities affects small urban rivers especially strongly. Disproportionately large amounts of water make their way into rivers through sewer systems in a short period of time, causing the level of water in such rivers to surge abruptly – maximum flows may be even an order of magnitude greater that those found in natural conditions. In addition, urban rivers become contaminated by many pollutants such as suspended matter, heavy metals, dioxins, petroleum products, nutrients (chiefly nitrogen and phosphorus compounds, which cause increased growth of algae and water vegetation), chlorides, and so on. Such loads of pollutants are usually effectively reduced by separators and sedimentation tanks at sewage outflows. However, studies taken in the rivers in Łódź have shown that even when pollutant concentrations remain within statutory limits, the mixture of pollutants that reaches rivers may impact negatively on all trophic levels of the ecosystems, which destabilizes how they function and undermines the self-purification capacities of rivers (their capacity for metabolic processing of inflowing pollutants).

Most pollutants reach rivers within the initial stage of a rain event (the first flush effect), especially in cases of heavy rainfall. The amount of pollution increases the longer the rain-free period between rain events, as pollution accumulates on urban surfaces. More toxic effects are also observed during the winter, when there are more sources of pollution (such as low-stack emissions and chlorides in deicing agents), and the period of pollutant deposition is longer (snow buildup). Given the fact that climate change increases the likelihood of extreme rainfall, we may expect cities to have an even more negative impact on rivers in the fu-

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A heavily-degraded small urban river (the Karolewka River in Łódź):
(A) overburdened by stormwater drained from urban surfaces a moment after heavy rainfall (15 liters per square meter in 15 minutes);
(B) with a nearly empty channel after the outflow of the stormwater, 12 hours later

ture. How rivers react will depend on their condition: rivers in conditions close to natural may metabolize pollutants more effectively. If the biological structure of a watercourse is degraded, we should expect pollutants to remain present for longer and flow downstream, thus polluting other water bodies. We should also remember that water self-purification is relatively poor during the winter given the reduced metabolism of river organisms. It is then easy for an ecosystem's assimilative capacity to be exceeded, and the load of pollutants flowing into it may be greater than its ability to process such pollution in keeping with the kinetics of bioassimilation processes, which may lead to the degradation of such an ecosystem.

Climate change adaptation in cities

Climate change adaptation in cities involves attempts to reverse the degradation of the environment caused by urbanization and the local restoration of natural processes and ecosystem services. Urban ecohydrology applies solutions in the field known as "blue-green infrastructure" to achieve this goal. Blue-green infrastructure is part of a city's natural capital, resulting from the presence of green spaces (such as urban forests, agricultural land within cities, parks, squares, green spaces close to streets, and so on) as well as water resources (watercourses, ditches, reservoirs, wetlands, and so on). Blue-green infrastructure also encompasses man-made ecosystems and elements that have infrastructural functions, such as green roofs, green walls, green bus stops and green street furniture, as well as artificial areas for the infiltration, retention and purification of stormwater, as long as they incorporate nature-based solutions.

Adaptation measures in developed areas

Since cities are complex mosaics of ecosystems and developed land, adaptation expectations and measures differ across different urban districts. In areas characterized by the densest development, such as city centers, the most important measures are temperature regulation, drought mitigation, and the prevention of urban floods. Due to the density of development, flooding prevention is generally achieved with the help of grey infrastructure, whereas urban ecohydrology solutions as well as blue-green infrastructure and nature-based solutions play an auxiliary role and may prove relatively costly (for example, green roofs). Such solutions are also crucially important for temperature regulation. We can cite many examples of bold measures taken in cities in Western Europe that are worth emulating (such as Vienna in Austria as well as Copenhagen and Aarhus in Denmark) that rebuild entire streets, replacing concrete with green spaces and water and creating parks that are friendly and capture water. When the density of development in cities is reduced, their resilience in response to anthropogenic stress grows, and so do their adaptation potential and capacity to sustain their own ecosystem functions in blue-green infrastructure and nature-based solutions. Areas characterized by a medium density of development (such as residential estates with large areas of greenery) are more resilient and less expensive in terms of maintenance, and the natural system has a measurable and direct effect on the quality of life and the ecological safety of inhabitants (for example comfort in residential space and beneficial effects on health). In the least transformed areas (such as suburbs and urban forests), the natural systems are less affected by cities, which improves the condition of such systems. In addition, they are valuable areas of additional water retention, for example in rivers flowing into cities.

Adaptation measures related to small urban rivers

Urban rivers are potentially very valuable elements supporting adaptation, because they provide the basis for the natural systems in cities (for example the Blue-Green Network in Łódź), in addition to providing many other benefits (such as space for walks). However, urbanization pressure and decisions that led to their degradation have diminished this role to a substantial extent. The solutions in the sphere of blue-green infrastructure described above, which increase local stormwater retention, have a beneficial effect on the functioning of rivers, stabilizing the quantity, quality, and rapidity of the surface runoff that supplies them with water. Purification of stormwater that supplies rivers is equally important and may be achieved through natural processes. One example is the Sequential Sedimentation-Biofiltration System (SSBS), which was designed in Łódź and uses sedimentation, adsorption of phosphate ions in biogeochemical reactions as well as such biological processes as the assimilation of excess nutrients by vegetation, denitrification (the removal of nitrogen compounds from the ecosystem and their return into the atmosphere as a result of microbiological process) and the decomposition of organic matter. The system may also be supplemented by including various types of separators, creating a hybrid system that combines technological solutions with nature-based solutions. High-efficiency separators effectively reduce the concentration of suspended matter and petroleum products, whereas nature-based solutions, which are subtler in their mechanism of action yet more effective at low concentrations of pollutants, reduce the dissolved forms of nutrients.[4]

Another step towards improving the functioning of rivers in urban areas with simultaneous climate change adaptation in cities involves taking measures aimed at boosting stormwater retention in river channels and semi-natural (rehabilitated) river valleys to reduce the risk of floods. This could be achieved through the widening (often reclamation) of valleys or the construction of dry reservoirs (polders), which fill with water only in periods of heavy rainfall, protecting cities from flooding. In addition, retention can be increased through the rehabilitation of river channels and the restoration of their natural three-dimensional structure (differentiation of their cross section and longitudinal section, as well as re-meandering). This also increases the diversity of habitats, which form the basis for the shaping of the biological structure of ecosystems, thus enhance their biodiversity and bioproductivity as well as metabolic self-purification capacities. Such measures have been planned, for instance, in Radom as part of the LIFE project.[5]

Adaptation and mitigation

The average surface temperature on Earth is currently 1.1°C higher than it was in the pre-industrial period, and it is growing at a rate that is dangerously faster than we assumed four years ago (when the Paris Agreement was being signed), nearing the level of 1.5°C. When this boundary is crossed, we will most probably not be able to avoid the catastrophic consequences of global warming. Adaptive measures that reduce the extreme consequences of climate change are therefore necessary, and such possibilities are created by blue-green infrastructure, nature-based solutions, and urban ecohydrology. However, the effectiveness of adaptation measures depends on the quality of the natural system in cities and above all on efforts to prevent the global temperature from further rising and causing further climate disturbances. It is hard to answer the question of where lies the limit of the effectiveness of adaptation measures – deciding whether it should be set at the 1.5°C rise in temperature proposed in the report of the Intergovernmental Panel on Climate Change (IPCC).[6] After all, with the current rise of "only" 1.1°C, adaptation measures already often prove insufficient. In its recent report, the IPCC points out that in addition to adaptation measures, immediate mitigation action is needed to reduce the emissions of greenhouse gases into the atmosphere and the negative impact of human activity on climate as soon as possible.

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