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Research paper

Management of rainwater as a barrier for the development of the City of Warsaw

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Abstract: The implementation of construction projects in Warsaw is associated with increasing difficulties in preparation, obtaining the relevant building permits and licences, partly due to the lack of water and sewage infrastructure and the inadequate management of rainwater in the city. All this leads to an increase in the cost of the construction projects undertaken. To illustrate a number of issues related to stormwater management in the city and the resulting problems, the study provides a number of different case studies, stylised facts and abductive conclusions to develop the best explanation for the existing problems. Specifically, the study presents the barriers to stormwater management in the city of Warsaw through an analysis of a hypothetical investment process (related to the Wawer Canal). The case studies analysed concern the deterioration of the "Bernardine Water" reservoir and the lack of appropriate investments in the Służewiecki Stream catchment, as well as a number of conflicting conditions in stormwater management in Warsaw. In contrast, examples of successful investments in stormwater management are also shown, e.g. Radex Park Marywilska, Stegny Południe settlement, Fort Bema settlement in Bemowo. In this way it is shown that with the right approach it is possible to carry out construction investments in water and wastewater infrastructure in an appropriate way, thus avoiding many stormwater management problems. The main conclusion of the study is that insufficient consideration of stormwater drainage issues in spatial planning will lead to further flooding and increasing water management problems.

Keywords: urbanization, urban flood, rainfall-run-off process, stormwater management, Warsaw city, land use

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1. Introduction

The implementation of construction projects is associated with difficulties in preparation, obtaining certain agreements and increasing costs for the built facilities, caused by the lack of water and wastewater infrastructure and inadequate stormwater management, among other factors [1–4]. The fact is that stormwater management in cities is one of the biggest challenges to sustainability in urban areas [5]. Indeed, there are areas that are at risk of flooding due to their natural conditions and where development poses some risks. In any case, there is much to suggest that these issues should be addressed, and this has not quite happened yet. In this highly simplified form, Fig. 1 shows a map of flood risk areas in and around Warsaw [3].

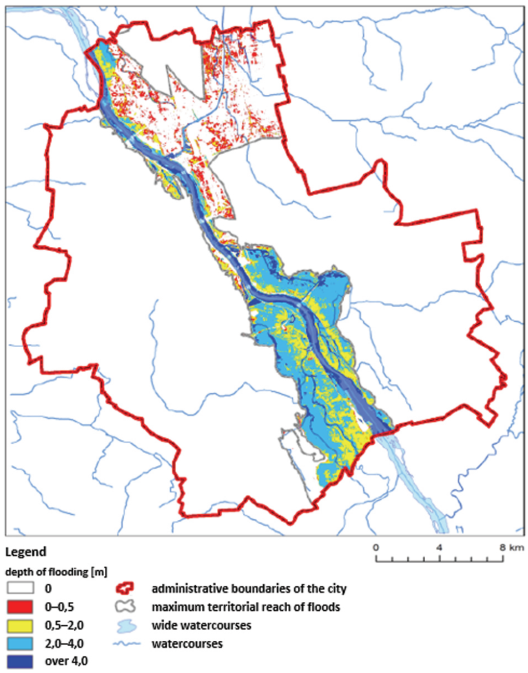

Fig. 1. The map of flood hazard zones in Warsaw and its surroundings

The risk is very high when houses are located in a flooded area. The situation is worse in the lowest lying areas, i.e., Czerniaków, Wilanów, Saska Kępa and Gocławek [3]. For years, there have been disputes about the spatial plans for these areas in connection with flood policies [3]. This is undoubtedly a major dilemma and local authorities have different positions on these issues. There was an idea to make the 100-year flood boundary mandatory in the local plans as an area with limited development. This was strongly protested by the communities. Nevertheless, new housing estates are constantly being built in these areas (both in Wilanów and Gocław) [3].

In turn, the local flooding risk can be illustrated by a corresponding map reflecting the actions and reports of local fire services (Fig. 2). This map is based on the reports of rainfall in the period 2008–2013 and shows the locations of actual floods in the mentioned period and the related deployments. The locations are marked with the corresponding GPS coordinates. This is very valuable material because it shows the actual extent of the phenomenon. As can be seen in Fig. 2, the map is densely dotted. In the five-year period there were reported 3128 such interventions.

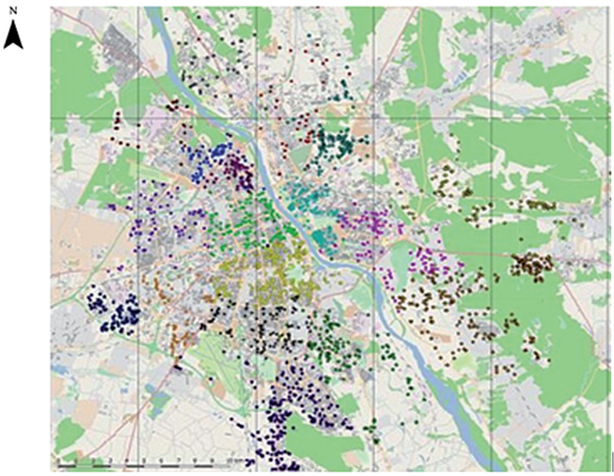

Fig. 2. Fire brigade reports of interventions due to heavy rainfall in Warsaw in 2008–2013

(**Note:** different colours of the dots indicate different fire brigade units. The report shows that most of the operations took place in the southern part of Warsaw and covered the catchment area of the Służewiecki Stream).

First-off it is important to note that organisational changes introduced by the Water Act, including the establishment of a new organisation called the State Water Holding Polish Waters in 2016, have complicated (rather than improved) water management in cities by excluding so-called “flowing waters” from their oversight [1]. However, this does not remove the obligation of local authorities to ensure the safety of their residents under the Local Government Act [1]. The conclusions drawn from the analysis of management in the city of Warsaw are also applicable to water management at the national level and can be used in the legislative process.

The provisions for stormwater management contained in spatial plans are mostly very patchy [6,7], and a coordination process is still required involving the Municipal Water and Sewage Works (MWiKW), the Office of Urban Greenery of the capital city of Warsaw, the district offices, the State Water Holding Company Polish Waters and the water companies. In fact, there are five entities instead of two [1,3]. The long list of agencies responsible for stormwater management is a consequence of shared responsibilities – and this is one of the flawed organisational elements that need to be simplified in the national legal system [1,3]. Due to the increasing frequency of urban flooding in recent years caused by local high intensity rainfall (with a monthly rainfall totals where heavy downpours of one or more days become a major factor), programmes have been developed at the national level and at the level of the capital city of Warsaw to set the direction of infrastructure development in view of the need to adapt to climate changes [3]. In July 2019, the City Council of the Capital City of Warsaw adopted the "Climate Change Adaptation Strategy for the Capital City of Warsaw until 2030 with an outlook until 2050" (hereinafter the Adaptation Strategy) [8]. The introduction to the Adaptation Strategy indicates that its implementation requires public participation in the form of civic participation. This provision is an invitation to the public to comment on issues that are not at the forefront of the strategy.

There are no references in the Adaptation Strategy to studies in the field of water and wastewater management strategy, such as the study commissioned by the Department of Architecture and Spatial Planning in 2016 entitled: "Characteristics and assessment of the functioning of the hydrographic system, with a special focus on drainage systems on the territory of the capital city of Warsaw, together with recommendations for the study of conditions and directions of development for the capital city of Warsaw and local plans" [9].

The study of conditions and directions for spatial development in the capital city of Warsaw fails to comprehensively assess water facilities and identify system solutions for wetlands – unsuitable for urbanisation [3, 6, 7]. These areas include southern Ursynów from the border between Pyry and Piaseczno, areas of Białołęka along the Długa River, fragments of Wawer and Wesoła, Targówek and Bemowo. In these particular places, large stormwater drainage networks are necessary for urban development, but local solutions should also be sought to retain rainwater where it occurs. In addition, the study fails to indicate the hierarchy of objectives and directions of implementation of postulates that address (among others) the following: (1) Flood protection of areas along the Vistula and near open water bodies that flow into the Vistula; (2) The revitalisation of existing hydrotechnical and water improvement facilities; (3) Stormwater drainage systems in the peripheral areas of Warsaw.

Moreover, the study of conditions and directions for the spatial development of the capital city of Warsaw does not take into account the retention basin for the Służewiecki Stream at the intersection of Sobieskiego Street and Wilanowska Avenue, which was planned in the previous study from 2007 as a "water treatment plant for the Służewiecki Stream", for which an area of 30,000 m^2, i.e. 3 ha, with a capacity of 90,000 m^3 to 120,000 m^3 was reserved. The hydrographical ground plan of the Służewiecki Stream catchment area is shown in Fig. 3.

The decision was clearly negative in terms of hydrological conditions and land use preferences, but it is quite possible that this decision was influenced by the complex legal situation in which the State Water Holding Company Polish Waters is the manager of the stream and the landowner is a developer [1]. A hypothetical investment process is discussed in section 2.1.2 (case study II), where some conflicting conditions related to stormwater management in Warsaw are explained. The area designated for the treatment plant on the Służewiecki Brook is shown below in Fig. 4.

Moreover, the study on the conditions and directions of spatial development of the capital city of Warsaw lacks a specific provision on the preferences for the construction of local stormwater drainage systems in the outskirts of the capital city of Warsaw – which

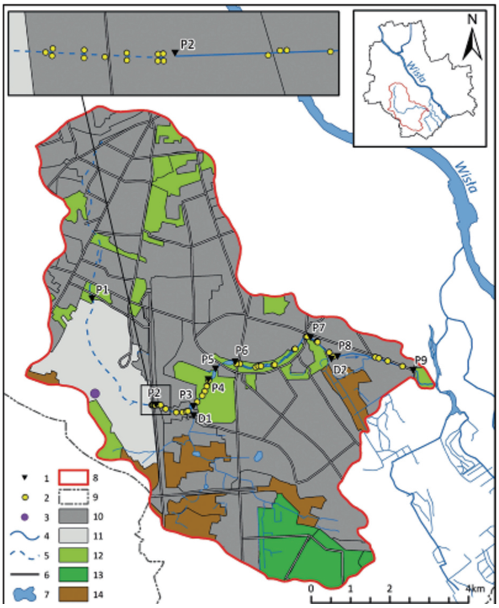

Fig. 3. Hydrographic layout of the Służewiecki Stream catchment area

Legend: 1 – measurement site, 2 – sewer outlets, 3 – meteorological station, 4 – watercourses, 5 – underground channel, 6 – roads, 7 – water bodies, 8 – catchment area, 9 – Warsaw city limits, 10 – built-up areas, 11 – Warsaw Chopin Airport, 12 – municipal greenery, 13 – forest, 14 – agriculture areas

Fig. 4. The area at the intersection of Sobieskiego Street and Wilanowska Avenue designated in the 2007 study for the treatment plant on the Służewiecki Stream

should be reflected in the water management costs incurred by the city of Warsaw in connection with stormwater management [3, 6, 7].

In 2019, an underground wastewater reservoir with a capacity of 80,000 m^3 was opened within the "Czajka" Wastewater Treatment Plant for the retention of wastewater in the event of accumulated stormwater inflow, at a cost of PLN 100.0 million [10]. Thus, the retention capacity of 1 m^3 of a basin costs PLN 1250. Considering the limited capacity of the sewage network to the city treatment plants, it is necessary to change the city's policy of building local stormwater management systems and giving preference to property owners who retain rainwater on their own land. The current situation, where rainwater is transported together with domestic sewage 20 km from Upper Mokotów to the "Czajka" wastewater treatment plant, is based on a vision from the past, when operating costs were not a factor in urban planning, and requires gradual correction by managing rainwater at the place where it is generated (after rainfall and downpours) [11]. The case of draining rainwater from a roadway in Żwirki i Wigury St. into an evaporation ditch can serve as an example of a suitable solution. The system works well, there is no local flooding in this particular location. More about stormwater management can be found in section 2.1.2 Case study II.

Based on the above, the remainder of the article will provide an overview and critical analysis of selected elements of stormwater management in Warsaw so that certain shortcomings of the overall system can be identified. The paper poses a number of questions that are considered to be relevant to the topic, while attempting to find and identify appropriate solutions. In particular, it aims to demonstrate how the city manages its water facilities, highlighting barriers to designing a rainwater and wastewater management system and addressing the need to align stormwater infrastructure with an investment strategy in the context of climate change.

2. Research method

In order to illustrate a number of urban stormwater management issues and the problems that arise from them, the study uses various case studies and Pierce's abductive reasoning to develop the best explanation [12]. In other words, the hypotheses contained in the introduction is supported in the form of various case studies and stylised facts, which is in line with scientific principles and this type of research method [13].

2.1. How does the City of Warsaw manage its water facilities?

First of all, the responsibilities of the authorities must be defined, i.e. which waters fall under the jurisdiction of the State Water Holding Polish Waters and which fall under the jurisdiction of the City of Warsaw. According to Article 212 (1) of the Water Act, the State Water Holding Polish Waters is responsible for flowing and underground waters. Therefore, such water facilities as the Służewiecki Stream and the Wawer Canal – which flow directly into the Vistula – are managed by the above-mentioned institution. Article 126(1)(3) of the Water Act allows the local government to manage flowing waters on the basis of a special agreement [14, 15]. In other words the City of Warsaw can implement strategies to protect its residents from local flooding on the basis of specific agreements; but such agreements do not exist or are unlikely to materialise. The two bodies disagree on many issues, such as the assessment of liability for the failure of pipelines or the procedure for the adoption of charges for water and wastewater, where the MPWiK is obliged to seek the approval of the State Water Holding Company Polish Waters in the event of changes to charges. Until the introduction of the Water Rights Act, responsibilities in this area lay with Warsaw's councillors. In the current administrative system of Warsaw City Hall, there is no special priority for water management, which is reflected in the fact that it is managed by the Municipal Green Spaces Office, which, according to its statute, "performs statutory tasks related to (. . .) parks, green spaces, squares, boulevards (. . .)". In summary, the unfavourable distribution of legal responsibilities for the city is overlaid by the poor management of water facilities in Warsaw, as this article shows with concrete examples.

2.1.1. Case study I. Examples of degradations, negligence and inadequate investments

At the beginning of the 20th century, there were a number of hydraulic structures from Pulawska Street to Lake Czerniakowski, namely Pilsudski Fort, Sielecki Canal, Bernardine Water and Czerniakowski Canal with Lake Czerniakowski (Fig. 5), which lost their hydraulic connections due to road infrastructure, which was a big mistake [16, 17].

Fig. 5. A section of the hydrographic network of the Lower Mokotow district

Today Lake Czerniakowski is drying up [16] and the area of the reservoir "Bernardine Water" at Idzikowskiego Street is overgrown with reeds and is called "weed patch" (i.e. weed area). A fragment of the hydrographic network in Lower Mokotów showing the reservoir "Bernardine Water" in Mokotow is shown in Fig. 5. Canoes were still seen floating on this reservoir in the 1960s and early 1970s, so it is worth considering the reasons for its deterioration. In the 1980s, according to historical photographs, the reservoir "Bernardine Waters" (with the background of EC Siekierki – the third stack was built in 1997) was full of water and the surrounding area was a place of recreation. This area in the context of the time can be seen in the following photos (Fig. 6). The hydrological changes of the Bernardine Water Reservoir are shown in Fig. 7.

What were the causes of the degradation of the reservoir? To understand the causes, it is useful to refer to the following local spatial plans, which allow to reconstruct the history of this reservoir: 1) Municipal Spatial Plan for the Sielce – Beethovena Area, adopted by Resolution No. XCIV/2412/2014 of the Council of the Capital City of Warsaw on 6 November 2014; 2) Municipal Spatial Plan for the Area of the Intersection of Sikorskiego

Fig. 6. Bernardine Waters Reservoir from a photo taken in the 1990s

Fig. 7. The present landscape of the former Bernardine Water reservoir

and Sobieskiego Streets, adopted by Resolution No. XCIV/2807/2010 of the Council of the Capital City of Warsaw of 9 November 2010. An extract from this specific municipal spatial plan is shown in Fig. 8.

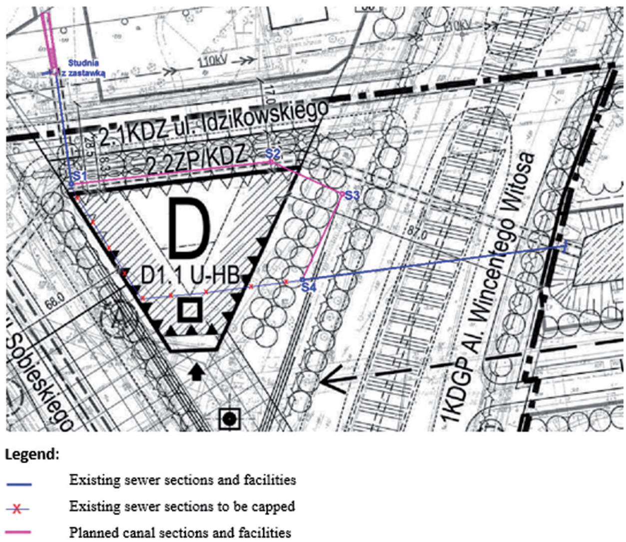

Fig. 8. Fragment of the municipal spatial plan for the area of the intersection of Sikorskiego Ave. and Sobieskiego St.

Until the 1990s, rainwater from the area along Puławska Street in the section from Wilanowska Avenue to Królikarnia, referred to as the "pod Krokwią" area, was discharged into the hydrographic system: Dabrowski's Legions Moat, Sielecki Canal, with water distribution to Sielecki Pond and Bernardine Water. In the 1990s, the connection between the Sielecki Canal and the Bernardine Water was severed. A foundation for a building was erected on the site of the former collector. Currently, the reservoir is periodically fed by surface runoff from the surrounding part of the park. In late September and early October 2021, the water level was about 20 cm on the Witos Avenue side. The reservoir is overgrown with reeds and tall grasses. This area is neglected and no conservation work has been done there for a long time (cleaning, dredging to return it to the city as a recreational area). The above-mentioned urban land-use plan orders (since 2010) to restore the connection and to divert part of the water flowing through the Sielecki Canal to the Bernardine Water reservoir, which is shown in the following extract from the illustration of the above-mentioned urban land-use plan.

Today, several years after the adoption of the municipal spatial development plan (the spatial development plan was adopted in 2010), the area is fenced off and there is an investor who wants to develop the area. The question remains why the pipeline feeding the Bernardine Water reservoir is not being pursued. First of all, that it is really a priority investment, because currently the water from the "Pod Skarpą" area flows into the combined sewer system via Sielecki Park. It is easy to calculate that the city is losing money by delaying the revitalisation of the reservoir. Since the reservoir has an area of 0.8 hectares according to the environmental impact assessment for the Northern Sadyba Municipal Spatial Plan, its retention capacity is at least 8000 m^3 at a water depth of 1.0 m [17]. The value of the unused reservoir – including the costs for the construction of the reservoir at the Czajka wastewater treatment plant – amounts to PLN 10.0 million. The cost of this project will certainly not exceed PLN 10 million and MPWiK should be able to implement it within its budget. It is worth recalling here that MPWiK bought PLN 300 million worth of bonds from the Municipal Cleaning Company (MPO) [11, 18, 19]. The money spent by MPWiK to finance the purchase of MPO bonds could have been used for proper stormwater management in the capital city of Warsaw.

The failure to rehabilitate the Bernardine Water reservoir in over 25 years deserves to be looked at critically. In the context of some negligence, it is worth asking questions about the use of existing water facilities. On the other hand, all the activities concerning Lake Czerniakowski seem relevant (and going in the right direction). Between 2010 and 2020, the Mokotów District Office commissioned a series of expert studies to characterise the deterioration of this water body – mainly due to the limited inflow of surface water. In December 2020, the Office of the Capital City of Warsaw commissioned an expert study to identify the need for reconstruction of water facilities in the area – which implies a reduction of stormwater inflow to the Czajka wastewater treatment plant. In this context, the need to drain rainwater from the neighbouring housing estate (after its pre-treatment) should also be mentioned; such a solution would be many times cheaper than treating diluted faecal wastewater. In general, the sewage network in Warsaw should be modernised so that there are no more combined sewers. Warsaw's wastewater treatment plants should only treat municipal wastewater and not diluted municipal wastewater.

One of the scientific questions posed in the introduction was whether the City of Warsaw has a specific investment strategy to adapt stormwater infrastructure to climate change? In this context, it is important to note that a number of investments have been made along the Vistula River in recent years, including the Vistula Boulevards, Praga Boulevards and Czerniakowski Harbour. A flood gate to Praski Harbour has been built [3, 20, 21]. Before

2016, the flood protection dams in Wilanów and Białołęka were rebuilt, and in 2021 the raising of the flood protection dams was combined with the modernisation of a section of road from the Śląsko-Dąbrowski Bridge to the Gdański Bridge. The situation is different for investments in the watercourses that flow into the Vistula. They are managed by the State Water Holding Polish Waters, e.g. the Wawer Canal and the Służewiecki Stream, as well as the watercourses managed by the City of Warsaw (district offices), such as the Bielański Brook, the Kępa Potocka, the Sielecki Canal, the Brudnowski Canal, the Grabowski Ditch and the Jeziorki Ditch. Unfortunately, there is no discernible investment plan for these facilities at the municipal level within a time frame of 2–5 years. This is largely due to the dispersed responsibilities in water management; there are three decision-makers: the State Water Holding Polish Waters, the City of Warsaw and the district offices. Given the dispersed responsibilities, it is difficult to manage the relevant infrastructure. Individual projects to modernise or reconstruct facilities by individual districts do not come through under the specific funding procedures provided by the city administration and by the State Water Holding Polish Waters. It should also be emphasised that the central authorities are cutting the revenues of self-governments (cities and municipalities) and the "Polish Deal" will deprive Warsaw of more than PLN 1 billion in revenues. The State Water Holding Polish Waters does not have sufficient funds, and as long as it does not start collecting fees and charges for the use of the environment, this situation will not change. Since the legal and organisational changes under which the State Water Holding Polish Waters was established, sufficient start-up funding for this new institution has not been secured, i.e. at least the funds that were held jointly by the dissolved institutions.

The Wawer Canal, which drains the districts of Wesoła and Wawer (managed by the State Water Holding Polish Waters) and whose sections in Anin and Międzylesie are partly on private land, is particularly neglected. This matter needs to be clarified. The activities of the current manager are limited to occasional cleaning and maintenance work. It should be emphasised that MPWiK pays considerable funds to the State Water Holding Polish Waters for the use of the so-called flowing waters and part of these funds should be transferred (returned) to the account of the City of Warsaw. To date, these funds have not been collected because no significant investment has been made in watercourses classified as "flowing waters". In other words, the MPWiK does not receive funds for the maintenance of these canals, streams and drainage ditches because it does not collect funds from the City of Warsaw, which in turn does not receive them from the State Water Holding Company Polish Waters. This can be seen as a square circle.

It is also worth mentioning that significant funding from the Cohesion Fund under the Operational Programme Infrastructure and Environment (OPI&E) 2014–2020 was allocated for investments under the project "Water Supply and Wastewater Treatment in Warsaw". These funds were used to modernise wastewater treatment plants and build new wastewater networks, but stormwater facilities remained a secondary focus. Currently, water facilities identified in local spatial plans are not being implemented. An example of this is the lack of modernisation of the sewers of Ursynów, which the MPWiK is obliged to implement by Resolution No. XI /315/2007 of the Warsaw City Council of 14 June 2007 on the adoption of the Local Spatial Plan for the Służewiecki Valley Park [22]. The scope of the required reconstruction includes the reconstruction of stormwater outfalls from the storm sewers to treat them prior to discharge into the stream by: (a) reconstruction of the terminal sections within the plan area; (b) installation of oil separators with sediment traps and grates at the outlet sections; (c) discharge of the water treated in the separators into bypass ponds with the function of infiltration basins, as shown in the plan. However, none of the above provisions have been implemented to date.

The evidence that the runoff from the storm sewer system, for which the MPWiK is responsible, pollutes the Służewiecki Brook is shown in Fig. 9 [3]. It shows a water inflow with a heavy load of so-called suspended solids (despite the fact that the water from the inflow flows over a distance of 1.5 kilometres in an open channel where the sedimentation process takes place).

Fig. 9. Pollution of the Wolica Canal at the confluence with the Służewiecki Stream

2.1.2. Case study II. Barriers to stormwater management in the City of Warsaw

When it comes to stormwater management in Warsaw, there are several cases that indicate that there are inherently contradictory conditions that make it impossible to implement the necessary economic solutions [3]. Many of these cases discredit the existing system of financing urban water facilities. To prove this, it is sufficient to consider an exemplary (hypothetical) investment process for the construction of a water retention basin such as the Wawer Canal. A brief description of such a hypothetical investment process can be found in Table 1.

In the case of such a hypothetical investment process, the associated risk would be so great as to be inconsistent with the management standards indicated in the accepted methods of construction project management. Therefore, when considering such a process, it should be dispensed with as it is contradictory in its assumptions, as it meets the needs of the city but is not a priority investment in the implementation of the State Water Holding Polish Waters and is therefore not feasible.

Table 1. Hypothetical investment process related to the Wawer Canal

Characteristics of the watercourse	– Character of the watercourse – flowing waters managed by the State Water Holding Polish Waters; – During heavy rainfall, water rises from the canal and causes flood damages.
Characteristics of the area and estimated costs of implementation	– According to the Study of Conditions and Directions of Spatial Development of the Capital City of Warsaw, the area is designated for a retention basin of 1.0 hectare; – Legal status: private land owned by a developer; estimated cost of purchase at PLN 1000/m^2 = approx. PLN 10.0 million; – Land adjustment for the retention basin – approx. PLN 3.0 million; – Construction of an impoundment (weir) for water retention, cost – approx. PLN 3.0 million; – Total cost of the investment – approx. PLN 16 million.
The investment can be realised under the following conditions	– The State Water Holding Polish Waters qualifies the participation in the implementation of this investment in the multi-annual budget (to some extent it explains why such an investment is unrealistic); – The Marshal of the Voivodeship must include the investment in the Regional Operational Programme for Mazowieckie Voivodeship; – Warsaw City Council must include the investment in the strategy and study and approve the expenditure in the multi-year financial plan and annual plan (the agreement and adoption of the last study for the capital city of Warsaw took over 10 years); – The above-mentioned entities are obliged to sign an agreement on participation and division of their responsibilities, i.e. such an agreement determines the party that finances the preparation of the relevant documentation, acquires the land and carries out the necessary adjustment works in connection with the financing of the construction works and the restoration of the watercourse in a given area (the fulfilment of this condition is also unlikely, as the entities that bear the diluted responsibility do not have a common interest in signing the agreement); – The above bodies must appoint a replacement investor; – Resolutions of the Warsaw City Council are required to amend the City's Spatial Plan Study and the intended expenditure; the resolutions may be overruled by the Regional Chamber of Accounts as the intended appropriations relate to the regulation of the facility managed by the State Water Holding Company Polish Waters.

2.1.3. Case study III. Examples of successfully completed investments

In addition to urban stormwater management systems, there are also local solutions that need to be applied in the area of family homes, housing associations and businesses of all kinds. This is a very important aspect that brings many benefits to the actors described above. Spatial plans would have to prescribe the construction of retention reservoirs for housing developments in open or closed (underground) form. Water from such reservoirs would be used to irrigate plants, trees, shrubs and grass in the housing estate in summer, as well as for fire-fighting and recreation, and would create a local microclimate, especially in hot weather. It is worth mentioning how a similar problem with water management was solved by the Business Park Marywilska office and warehouse centre at 34 Marywilska St. in Warsaw [4, 23, 24]. The Żerań-Eastern area hosts many important industrial enterprises, e.g. Chłodnie Warszawskie SA, but does not have a stormwater drainage system, although it is located 1.0 km from the Żerań Canal. A combined sewer with a diameter greater that 0.4 m runs through the property and receives domestic wastewater, which can hardly be discharged. During stormy rains, diluted faeces flooded the area, as is currently the case in Warsaw in the eastern part of the Wilanów district after every major storm. During storms and heavy rains, the area was systematically flooded with rainwater. The water entered the warehouses, and in the car parks it stood between 20 and 40 cm high. To prevent this, retention basins were built at the lowest points, from which the excess water was drained via separators and degreasers into an open retention basin (with an area of 200 m^2) and a system of absorption wells with submersible pumps (*Flica*). The system currently includes 20 absorption wells with a capacity of about 10 m^3 each and a sealed underground rainwater storage tank with a capacity of 200 m^3 (in a modern office building) and a rainwater-fed aerated pond with a water cascade. The total retention capacity is 1500 m^3. The owner of the land has obtained a water right permit for the development works. The works were carried out with their own funds. After all these developments, the biggest storms no longer cause flooding in the area. The example of Marywilska Business Park very aptly illustrates an alternative way of stormwater management within the city.

Another example is the water system in the Stegny Południe housing estate in Warsaw, which is supplied with rainwater (Fig. 10–11) [25].

Fig. 10. Park with a water reservoir in Sardyńska St.

Fig. 11. Retention and evaporation basin in Stegny

The investment was made in 2006 by the inter-company housing cooperative "ENERGETYKA" and consisted of the construction of a retention and evaporation basin for the rainwater of the Stegny Południe housing estate, which consists of two interconnected basins – a grassed basin Z1 and a proper retention and evaporation basin Z2. The area next to the basins has a recreational function. The construction of the basins is made of reinforced concrete – the slab is divided into fields of max. 20×20 m, reinforced concrete walls and canopies (concrete B-37 W8, F150 was used). The facility was built partly with the help of EU funds.

It is worth mentioning the example of the construction of one of the largest housing estates in Warsaw, namely the construction of the Fort Bema housing complex in the Warsaw-Bemowo district [3], which took place in 1999–2011, where an area of 148 hectares was allocated for urban development and land use, and residential buildings were constructed (approximately 200,000 m^2 of usable and residential space + services) [3, 23]. This area is located on the edge of the Vistula basin and flows into the Bemowo forest and further into the Kampinos primaeval forest. In this area there is a separate system for sanitary and storm water drainage. The solution for stormwater management in this project was worked out with the municipality (now district) of Bemowo, with the participation of MPWiK and the authorities of the City of Warsaw, by diverting stormwater into the ditch of Fort Bema, which is part of the 19th century fortress complex with an area of 222,000 (i.e. 22.2 hectares). The entire project was carried out in the following manner: (1) in the area of the residential settlements affected by the ditch revitalisation, the local spatial plan was approved by the resolution of the Municipal Council of Warsaw-Bemowo, No. XIX /127/01 of 6 December 2001, which noted the revitalisation of the ditch with rainwater from the residential settlements as an appropriate solution [3]; (2) the drainage system was constructed by the developer after consultation with the Voivodeship Conservator and the Bemowo Municipal Office, having previously re-planned the stormwater catchment area for 14,980,000 (i.e. 1498 hectares) and reached an agreement with the MPWiK. The realisation of such a scenario was possible because the interests of the state-owned enterprises, the municipality of Bemowo and the developer were combined [3].

In summary, a number of water reservoirs can be built in the city and integrated into residential development. They will be of great value to the city, but especially to its inhabitants. They can also be considered interesting tourist attractions. After the revitalisation of the Fort Bema ditch, which has a minimum water level of about 0.5–0.6 m deep, the Warsaw-Bemowo District Office created a natural recreational reservoir for the inhabitants (with water bikes) [4]. After the construction of the reservoir with a capacity of 1,457 m^3 and the widening and deepening of the Służewiecki Stream, rainwater no longer causes local flooding (although such flooding was quite frequent before the reconstruction and affected Śródziemnomorska Street, house basements and housing estates on the other side of Wilanowska Avenue, among others). All these changes had a positive effect. Today, rainwater no longer causes flooding even during the strongest storms, as it did along the Służewiecki Brook from the intersection of Sikorskiego Street with Wilanowska Avenue to the intersection of Wilanowska Avenue with Sobieskiego Avenue.

3. Discussion

Rapid urbanisation increases the risk of flooding in large cities like Warsaw, as rainwater runoff is impeded [26–30]. In extreme cases, this can even lead to a multiplication of the volume of surface runoff [26–30] and an increase in the frequency of local flooding [3, 29].

In general, the recommendations and procedures for checking the frequency of storm and sewer overflows for drainage systems are laid down in the hydrological standard PN-EN 752:2008 [31–35]. In practise, these recommendations are rarely applied due to lack of adequate input data and appropriate modelling methodology [3, 35]. Some methodologies exist, but none meet expectations [35]. Unfortunately, combined sewer systems are not fully reliable and are subject to periodic disturbances, e.g. due to the intense nature of rainfall, which cannot be fully predicted (especially in the long term). The standards currently in force in Poland for drainage of built-up areas (safe design) provide for socially acceptable frequencies of maximum stormwater discharges per specified area (Table 2). Table 2 shows that the frequency in the above standard for residential areas is 1 flood per 30 years. One way to protect against flooding is to safely dimension drainage systems.

Table 2. Calculated precipitation and flood events

Computational rainfall frequency [in C years]	Land use	Flood occurrence frequency [in C years]
1 in 1	rural areas	1 in 10
1 in 2	residential areas	1 in 20
1 in 5	city centres, service and industrial areas	1 in 30
1 in 10	underground transport facilities, street crossings, etc.	1 in 50

The appropriate design of combined sewers in relation to their dimensioning for adequate design rainfall frequencies has been discussed in the works of W. Blaszczyk [37, 38], P. Błaszczyk [39] and A. Kotowski [40, 41], among others. There are two types of flood risks to which a city like Warsaw is exposed, namely (1) flooding by the Vistula River and (2) flooding in the city caused by heavy rainfall and the lack of an adequate combined sewerage system. Regarding the first type of risk, up to 25% of the city is at risk of periodic flooding [42]. However, this risk is not perceived as high and, moreover, can be controlled to some extent in advance. There are protective dams that provide protection against 100-year and even 1,000-year water [42]. In their study, A. Magnuszewski, M. Gutry-Korycka, and Z. Mikulski [43] presented the flood levels (a.k.a. high water stages) observed in the Warsaw section of the Port Praski profile over the last 200 years. In the time period studied, the maximum flow occurred during the flood of 1844 and was 8250 $m^3 \cdot s^{-1}$. Theoretically, the flood of 2010 was caused by a flow of 5899 $m^3 \cdot s^{-1}$, preceded by a dike breach at four locations on a section of the upper Vistula [43]. The risk is very high when houses are located in such a flooded area. The situation is worst in the lowest lying areas, i.e. Czerniaków, Wilanów, Saska Kępa and Gocławek. For years there have been disputes about the spatial plans for these areas in the context of flood policy. As for the second type of risk, namely the possibility of local flooding due to heavy rainfall, this risk occurs most frequently in the summer season [44]. In short, it is not easy to determine the exact places and times when heavy rains will occur and to predict how long they will last. It is also not easy to identify the so-called bottlenecks in the combined sewer system that are associated with the occurrence of intermittent rainfall. This is a multi-dimensional problem and one can rarely rely on complex simulations, hydrographs or simulation tests of the respective sewer infrastructure. In highly urbanised areas with high runoff coefficients, large volumes of water do not have time to drain during heavy rainfall, causing sewer systems to fail and water to flood streets and cause localised flooding. The level of urbanisation in Warsaw is already so high that this issue has become a real problem for the future infrastructural development of the city. The case studies in this article contain examples of failures (sections 2.1.1 and 2.1.2), but also examples of appropriate solutions (section 2.1.3). However, a number of failures of a systemic and legal nature (at the level of the competent authorities) have also been committed over the years, which are also very clearly highlighted in the article. The fact is that the lack of appropriate changes in hydrological legislation becomes a bottleneck that hinders or even prevents the further development of the city. Therefore, the adoption of the necessary solutions in this area is strongly recommended. A.H. Roy, S. Wenger and T. Fletcher point out that modern stormwater management policies, which aim at rapid removal of stormwater to protect human health and property, but have little regard for the protection of aquatic ecosystems, are not an appropriate approach [45, 46]. The problem affects all large cities, but there are already appropriate stormwater management methods that consist of minimising impervious surface and maximising infiltration of stormwater. These methods include Low Impact Development (LID) and Sustainable Drainage Systems (SuDS). LIDs are building systems and practises that use or mimic natural processes in construction and thus have the least impact on existing landscapes. SuDS, in turn, are different types of drainage solutions that mimic natural environmental processes related to stormwater retention to minimise the negative impacts of urbanisation on surface water management. The best known SuDS solutions are natural vegetation, trees, permeable pavements, bioswales, wetlands, detention basins, green roofs and rain gardens. Recently, there has been increasing talk about the concept of sponge cities [47–49]. SuDS allow for stormwater management that resembles processes found in nature, greatly facilitating runoff management and volume control, reducing infiltration of pollutants into groundwater, and complementing traditional methods of direct discharge of surface water (via a network of suitable pipes and channels) to the sewer system. Modern stormwater management methods such as Water-Sensitive Urban Design (WSUD) and Real-Time Control (RTC) [3] are also worth mentioning. In short, WSUD is a type of stormwater management that focuses on minimising environmental impacts and improving the recreational attractiveness and aesthetics of the city [3]. It can be seen as a somewhat holistic approach to engineering and spatial design that integrates the urban water cycle into the context of urban planning and incorporates the different areas of stormwater management, including groundwater management, wastewater management, water recycling, water storage and water supply, into the design of an integrated management of the urban water cycle [3]. The main objective of WSUD is to reduce the impact of urbanisation on the natural urban water cycle. Godyń et al [50] argue that the commonality of SuDs and WSUD concepts is to solve the problems of stormwater management in the context of ecological challenges and provide living solutions that are compatible with natural processes in the environment [50]. Regarding the implementation of SuDS and WSUD in Warsaw, there is no comprehensive study that examines the knowledge on this topic. The knowledge is very fragmented and scattered. Only a few papers by different authors contain topics on this subject [51–54]. However, some sources suggest that Warsaw is not a leader in promoting these types of solutions [55]. In this context, it is also worth mentioning government initiatives such as the My Water programme (which runs until 2024), which aims to protect water resources by increasing the retention of water on individual properties and using captured rainwater and snowmelt. The aim of this programme is to reduce the amount of rain and snowmelt water discharged into drains, drainage ditches, adjacent areas and roads. Such initiatives deserve to be seen in a positive light, especially in the context of climate change and the resulting increasingly prolonged droughts followed by heavy and torrential rains.

In turn, RTC is a management system for the combined sewer network that allows for optimised control of the entire network in real time to improve its efficiency. It analyses data and controls the available infrastructure (gates, pumps, valves, weirs, other equipment, etc.) to improve its performance. To date, Warsaw does not have an intelligent RTC system, such as those used in some cities around the world, e.g., Dresden, Philadelphia, Tokyo or Minneapolis. However, there are indications that the municipality has looked into this issue and plans to follow the path that leading cities have already taken in the field of real-time sewer network control. The deadline for the introduction of such an intelligent, self-learning control system for the combined sewer network of the Polish capital is scheduled for January 2023 [56]. This introduction is taking place at present as part of a project to expand and modernise the wastewater transport system. The task is not easy because the combined sewer network in Warsaw is one of the longest in Europe. It consists of a system of pipes and pumping stations controlled by automated processes. In response to the challenges described in the adaptation strategy document, and against the backdrop of climate change, the city authorities (together with MPWiK) have taken on the difficult task of modernising the entire system and implementing modern, environmentally friendly solutions [56]. This is all the more important as it allows for the automation and centralisation of the entire management of wastewater infrastructure across Warsaw – something that has been lacking in stormwater management in such a large and constantly developing city as the capital of Poland. To better understand the existing stormwater management problems in the context of possible improvements, it is useful to use a SWOT analysis (Table 3):

Based on the examples described above, all decisions on spatial plans and development conditions should be linked to an overview of hydrological systems for suitable locations and a possible commitment to create low-impact developments and SuDS facilities in places where relevant hydrological systems are at risk. Modern technologies offer the possibility of checking the degree of urbanisation of a specific place in relation to green areas very easily. One such technology is machine learning based classifiers that can be used to calculate the ratio of urbanised to green areas for specific locations. More specifically, there is a method called Support Vector Machines (SVM) that allows features to be extracted from multispectral images and these classification results can then be used for further analysis. It is worth noting that SVM is one of the artificial intelligence methods (along with Bayesian Networks (BNs), Artificial Neural Networks (ANN) [57, 58] and Directional Acyclic Graphs (DAGs) [59] that is used to solve many engineering problems [60]. SVM and machine learning are suitable for identifying impervious surfaces such as roads, roofs, pavements, etc. Many local governments use impervious surfaces to calculate stormwater runoff for a property. There is a technique consisting of an object-oriented feature extraction method and the ArcGIS Pro Classification Wizard to accomplish such a task. Using a multispectral image (an orthophoto with a high-resolution image with 6 inch pixels) containing a near-infrared band it is possible to perform a detailed feature

Table 3. SWOT Analysis of the current state of stormwater management in Warsaw

Strengths	Weaknesses
– Relatively early recognition of the problem of water management in Warsaw in the early 2000s, including the preparation of a hydrological report led by a number of renowned hydrological scientists; – Strong scientific centres researching the cause of the problem, e.g. under the leadership of Prof. Banasik and Prof. Barszcz – outstanding specialists in the field of hyrdrology; – The Council of Ministers adopted in 2013 the document "Strategic Adaptation Plan for Sectors and Areas Vulnerable to Climate Change to 2020 with Prospects to 2030"; – Adoption by the Warsaw City Council of a related strategy entitled: "Climate Change Adaptation Strategy for the Capital City of Warsaw until 2030 with an Outlook to 2050" (in July 2019); – The launch of the 'My Water' programme, which recognises the problem of stormwater management in Warsaw and provides matching funds for grants to purchase, supply, construct, install and commission equipment to manage snowmelt and stormwater on individual properties; – Implementation of the Adaptcity project, which involves the development of the climate change adaptation strategy for Warsaw. The scope of work under this project included determining the changes in the following parameters characterising the surface of the city of Warsaw: biologically active area, water-permeable and water-impermeable areas, building density, albedo of the active area, temperature of the active area, NDVI indices; – Numerous individual water projects and corresponding investments in the field of stormwater management carried out by private individual investors (on an individual level).	– Stormwater management in the city of Warsaw has to some extent become an obstacle to the further development of the city; – Controversial water legislation that complicates many problems in realising construction investments, etc.; – Lack of adequate RTC system in the city and late decision on the relevance of its implementation as part of an integrated stormwater management system; – Unfavourable external climatic factors, as evidenced by the increasing annual average rainfall. The most difficult climatic situation concerns the southern part of Warsaw.

Table3 [cont.]

Opportunities	Threats
– Implementation of the relevant systems: real-time control (RTC), sustainable drainage systems (SuDS), Water-Sensitive Urban Design (WSUD) systems; – The government's "My Water" Programme and other similar programmes; – Realisation of a number of initiatives identified and described in the Adaptacity programme (related to the city's adaptation to climate change); – Future support of the city and its authorities for water initiatives of private investors as presented in this article (e.g. Radex Park Marywilska, Stegny Południe settlement, Fort Bema settlement Bemowo); – Implementation of SuDS and WSUD projects in Warsaw.	– Further aggravation of the negative climatic factors; – Failure to address many of the problems diagnosed and outlined in this article, including the neglect of the Służewiecki stream catchment area; – The pursuit of further irrational spatial planning policies leading to increased urbanisation; – The reluctance of investors to invest due to, among other things, restrictions on stormwater management and difficulties in obtaining the relevant building permits and licences with regard to stormwater management policies.

extraction of impervious surfaces. More specifically, the band combination of the image can be changed so as to highlight its relevant features such as vegetation, roads, etc. In Fig. 12 it can be seen that with a colour-infrared band combination it is very easy to highlight vegetated areas in the environment.

Fig. 12. Classification for impervious surfaces with machine learning SVM method

The combination of colour and infra-red seems to be well suited for what is to be identified, as man-made features are clearly different from vegetation.

In summary, society should work at all costs to develop and implement a sustainable urban stormwater management system that protects the health of people and their properties while helping to maintain natural, functioning ecosystems in the catchment.

4. Conclusions

The article deals with the issue of stormwater management in the city of Warsaw, which has in some ways become an obstacle to the further development of the city. It manifests itself in the fact that construction specialists face serious problems in the preparation and implementation of construction projects when it comes to making certain arrangements related to hydrological constraints. Another problem is the rising construction costs caused by the lack of water and sewage infrastructure and inadequate stormwater management. In order to show that the city of Warsaw is managing water resources inadequately, several case studies were analysed to highlight the sources of inefficiency in the water system and the causes of management failures. Specifically, the case studies covered in the article deal with: (1) the deterioration of the Bernardine Water reservoir and the lack of adequate investments in the Służewiecki Stream catchment; (2) the contradictory (conflicting) conditions of stormwater management in Warsaw. To illustrate the contrast, some examples of successful investments in stormwater management are also presented, e.g. Radex Park Marywilska, Stegny Południe housing estate, Fort Bema housing estate in Bemowo. The fact is that insufficient consideration of stormwater drainage issues in spatial planning will lead to further flooding and water management problems.

The article highlights that there are appropriate stormwater management practises such as Low Impact Development (LID), SuDS and WSUD that aim to minimise impervious surface and maximise infiltration of stormwater. It is also worth noting that an improvement in the overall stormwater management situation can also be expected from the completion of the currently implemented RTC system, which is scheduled for completion in the first quarter of 2023 [3]. In addition, the article points to the need to link all land use planning and development condition decisions to a review of the hydrological systems for the sites in question, and possibly to require environmentally sustainable development (LID and SuDS) if certain sustainable hydrological systems are threatened. This is relatively straightforward as modern technologies such as ArcGIS software and the Support Vector Machines (SVM) method make it easy to check the degree of urbanisation of a site in relation to green spaces. Further relevant conclusions, required legal and regulatory changes and recommendations are listed in Table 4 below.

Table 4. Summary of important conclusions, required regulatory changes, and recommendations

Important conclusions

– Water streams (of secondary order) in urban areas must be managed by local authorities (a single authority).
– Charges for the discharge of sewage and rainwater must be levied by municipalities/cities in a certain proportion to the size of the catchment area. For watercourses such as the Wawer Canal, which flows through three municipalities, for example, the watercourse could be managed by a municipal water company established by these municipalities.
– Rainwater retention facilities built by investors and private individuals in the city should receive certain subsidies resulting from fees for discharged rainwater and fee reductions for the so-called management of rainwater on one's own property.

– To remove barriers to development in the city, it is necessary to build stormwater infrastructure in the outskirts of the city.
– When adopting resolutions on development conditions and adopting local spatial development plans, the management of rainwater on one's own property through the construction of above-ground and underground watertight reservoirs should be provided for and arranged together with the management of local green spaces, which, in addition to their basic functions, will provide recreational spaces for residents and a specific microclimate on warm days.
– Without a solution to the problem of rainwater flooding of the areas of the capital city of Warsaw and without the construction of sewerage and storm water drainage systems, further development of housing (mainly low-rise buildings) on the territory of the capital city of Warsaw will be practically limited and even impossible in some areas on the outskirts of the city.
– Polders should be created on the tributaries of the Vistula to Warsaw. In addition, there are recognised experts in this field who proposed the creation of five polders in the Mazowieckie Voivodeship. They were planned in the following places: Puławy, Kozienice, Prażmów and Stężyca.
– In a period of up to 5 years, the city of Warsaw can be protected from stormwater flooding if the recommendations listed in this article are followed.

Required legal and regulatory changes

– Amendment of the Water Law Act in relation to the jurisdiction of the State Water Holding Company Polish Waters, so that the capital city of Warsaw and other cities can effectively manage the so-called "flowing waters" and receive budgetary subsidies or charge fees for the discharge of these waters into rivers and lagoons, etc.
– Amendment of the statutes of Warsaw districts with regard to their power to manage stormwater in their territory.
– Amendment of the Water Rights Act in relation to monitoring of watercourses – recording of pollutants, including the power to control discharges from which stormwater is discharged from MPWiK.

Recommendations

– There is an urgent need to conduct periodic inventory of water facilities.
– Detailed maps should be prepared for areas with unfavourable structural conditions in Warsaw.
– There is a need to develop a catalogue of best practises for stormwater management on the territory of the capital city of Warsaw and their obligatory use.
– It is necessary to create a geoportal with information and analyses carried out during the implementation of the task in question, so that representatives of all institutions involved in stormwater management have access to this database.

References

[1] J. Sobieraj, *Wpływ Polityki Gospodarczej, Środowiskowej i Prawnej na Zarządzanie Procesem Inwestycyjnym w Budownictwie Przemysłowym*. Radom, Poland: ITE-PIB, 2019.

[2] J. Sobieraj, *Investment Project Management on the Housing Construction Market*. Madrid, Spain: Universitas Aurum Grupo Hespérides, 2020.

[3] J. Sobieraj, M. Bryx, D. Metelski, "Stormwater Management in the City of Warsaw: A Review and Evaluation of Technical Solutions and Strategies to Improve the Capacity of the Combined Sewer System", *Water*, 2022, vol. 14, pp. 1–41; DOI: 10.3390/w14132109.

[4] J. Sobieraj, "Impact of spatial planning on the pre-investment phase of the development process in the residential construction field", *Archives of Civil Engineering*, 2017, vol. 63, no. 2, pp. 113–130; DOI: 10.1515/ace-2017-0020.

[5] A.F. Vasconcelos, A.P. Barbassa, M.F. dos Santos, M.A. Imani, "Barriers to sustainable urban stormwater management in developing countries: the case of Brazil", *Land Use Policy*, 2022, vol. 112, art. ID 105821; DOI: 10.1016/j.landusepol.2021.105821.

[6] Miasto Stołeczne Warszawa, "Studium uwarunkowań i kierunków zagospodarowania przestrzennego Warszawy wraz z późniejszymi zmianami". [Online]. Available: https://architektura.um.warszawa.pl/studium2006. [Accessed: 10 Apr. 2022].

[7] M. Zdancewicz, *The Spacial Policy Of Warsaw; Office of Architecture and Spatial Planning of the Capital City of Warsaw*. Warsaw, Poland: City Hall, 2007.

[8] A. Kassenberg, W. Szymalski, L. Drogosz, M. Bugaj, I. Jakubczak, *Strategia adaptacji do zmian klimatu dla miasta stołecznego Warszawy do roku 2030 z perspektywa do roku 2050*. Warsaw, Poland: Instytut na Rzecz Ekorozwoju/Urząd m.st. Warszawy, 2019.

[9] M.St. Warszawa, *Charakterystyka i ocena funkcjonowania układu hydrograficznego, ze szczególnym uwzględnieniem systemów melioracyjnych na obszarze m.st. Warszawy wraz z zaleceniami do Studium uwarunkowań i kierunków zagospodarowania m.st. Warszawy i planów miejscowych*. Warsaw, Poland: Biuro Architektury i Planowania Przestrzennego Urzędu m.st. Warszawy, 2015.

[10] Portal Funduszy Europejskich, "Nowy zbiornik retencyjny dla Warszawy". [Online]. Available: https://www.funduszeeuropejskie.gov.pl/strony/wiadomosci/nowy-zbiornik-retencyjny-dla-warszawy/. [Accessed: 21 Apr. 2022].

[11] J.A. Oleszkiewicz, E. Kalinowska, P. Dold, et al., "Feasibility studies and pre-design simulation of Warsaw's new wastewater treatment plant", *Environmental Technology*, 2004, vol. 25, pp. 1405–1411; DOI: 10.1080/09593332508618472.

[12] G. Paul, "Approaches to abductive reasoning: an overview", *Artificial Intelligence Review*, 1993, vol. 7, pp. 109–152; DOI: 10.1007/BF00849080.

[13] R.K. Yin, "Validity and generalization in future case study evaluations", *Evaluatio*n, 2013, vol. 19, no. 3, pp. 321–332; DOI: 10.1177/1356389013497081.

[14] K. Dąbrowska, Ł. Trybułowski, M. Butkiewicz, et al., "Zarządzanie krajową gospodarką wodną od 2018 roku", *Budownictwo i Inżynieria Środowiska*, 2018, vol. 9, pp. 109–115.

[15] Internetowy System Aktów Prawnych, Ustawa Prawo wodne z dnia 20 lipca 2017 roku (Dz. U. 2017 poz. 1566, 2180). [Online]. Available: https://isap.sejm.gov.pl/isap.nsf/ByKeyword.xsp?key=wodne{%}20prawo. [Accessed: 24 Apr. 2022].

[16] I. Kabzińska, "The dying of Czerniakowskie Lake, the dying of quiet. From a hi-fi to a lo-fi soundscape", *Etnografia Polska*, 2019, vol. 63, no. 1-2, pp. 113–132; DOI: 10.23858/EP63.2019.007.

[17] J. Kręgiel, *Prognoza Oddziaływania na Środowisko Projektu Miejscowego Planu Zagospodarowania Przestrzennego Sadyby Północnej*. Warsaw, Poland: Pracownia Urbanistyczno-Architektoniczna ANNELI, 2008.

[18] PF Projekt, Retention Tanks at the Czajka Wastewater Treatment Plant. [Online]. Available: https://www.pfprojekt.pl/en/czajka.html. [Accessed: 25 Apr. 2022].

[19] J. Koszewska, Ł. Kuzak, "Exogenous NaHS Treatment Alleviated Cd-induced Stress in Ocimum basilicum Plants through Modulation of Antioxidant Defense System", *Journal of Water and Land Development*, 2021, vol. 50, pp. 1–9; DOI: 10.24425/jwld.2021.137688.

[20] K. Guranowska-Gruszecka, M. Kordek, "Port Praski in Warsaw–Plans and Reality", *Studia KPZK*, 2018, vol. 188.

[21] D.E. Zając, *A water tram stop at the Prague Port in Warsaw*. Warsaw, Poland: Warsaw University of Technology (Faculty of Architecture), 2021.

[22] Miejscowy plan zagospodarowania przestrzennego Parku Dolina Służewska. [Online]. Available: http://www.siskom.waw.pl/zagospodarowanie/park-dolina-sluzewska/uchwalenie/mpzp_DolinaSluzew_tekst.pdf. [Accessed: 21 Apr. 2022].

[23] J. Sobieraj, D. Metelski, "Project Risk in the Context of Construction Schedules – Combined Monte Carlo Simulation and Time at Risk (TaR) Approach: Insights from the Fort Bema Housing Estate Complex", *Applied Sciences*, 2022, vol. 12, no. 3, art. ID 1044; DOI: 10.3390/app12031044.

[24] D. Blesinger, D. Krawczyk, F. Linnebacher, et al., *Revitalisation and Refurbishment in Construction*. Warsaw, Poland: Civil Engineering Faculty of Warsaw University of Technology, 2017, pp. 111–122.

[25] AC Alsima Construction, "Stegny – Zbiornik retencyjno-odparowujący". [Online]. Available: http://www.alisma.pl/alisma/idm,623,stegny-zbiornik-retencyjno-odparowujacy.html. [Accessed: 25 Apr. 2022].

[26] D. Anderson, *Effects of urban development on floods in northern Virginia.* Washington, D.C., USA: US Government Printing Office, 1970.

[27] J.F. Bailey, W.O. Thomas, K.L. Wetzel, T.J. Ross, *Estimation of flood-frequency characteristics and the effects of urban-ization for streams in the Philadelphia, Pennsylvania area. U.S. Geological Survey Water-Resources Investigations Report 87-4194*. Harrisburg, Pennsylvania, USA: Philadelphia Water Department, 1989.

[28] A.H. Roy, S.J. Wenger, T.D. Fletcher, et al., "Impediments and solutions to sustainable, watershed-scale urban stormwater management: lessons from Australia and the United States", *Environmental Management*, 2008, vol. 42, pp. 344–359; DOI: 10.1007/s00267-008-9119-1.

[29] C.P. Konrad, *Effects of urban development on floods*. Tacoma (WA), USA: U.S. Geological Survey–Water Resources, 2003.

[30] Z. Xu, G. Zhao, "Impact of urbanization on rainfall-runoff processes: case study in the Liangshui River Basin in Beijing, China", *Proceedings of the International Association of Hydrological Sciences*, 2016, vol. 373, pp. 7–12; DOI: 10.5194/piahs-373-7-2016.

[31] B. Kaźmierczak, A. Kotowski, A. Dancewicz, "Weryfikacja metod wymiarowania kanalizacji deszczowej za pomocą modelu hydrodynamicznego (SWMM) w warunkach wrocławskich", *Ochrona Środowiska*, 2012, vol. 34, pp. 25–31.

[32] J. Hakiel, "Designing drainage systems–possible application of advanced calculations and hydrodynamical modeling", *PhD Interdisciplinary Journal*, 2015, vol. 1, pp. 167–174.

[33] M. Hajdukiewicz, D. Kowalski, "Porównanie metod obliczeniowych do wymiarowania kanalizacji deszczowej", *Gaz, Woda i Technika Sanitarna*, 2018, vol. 1, pp. 9–11.

[34] A. Kotowski, M. Nowakowska, "Standards for the dimensioning and assessment of reliable operations of area drainage systems under conditions of climate change", *Technical Transactions*, 2018, vol. 1, pp. 125–139; DOI: 10.4467/2353737XCT.18.010.7961.

[35] J. Kanclerz, S. Murat-Błażejewska, K. Dragon, S. Birk, "Wpływ urbanizacji w strefie podmiejskiej na stosunki wodne w zlewniach małych cieków", *Inżynieria Ekologiczna*, 2016, vol. 46, pp. 94–99; DOI: 10.12912/23920629/61470.

[36] M. Nowakowska, A. Kotowski, *Metodyka i zasady modelowania odwodnień terenów zurbanizowanych*. Wrocław, Poland: Oficyna Wydawnicza Politechniki Wrocławskiej, 2017.

[37] W. Błaszczyk, "Spływy deszczowe w sieci kanalizacyjnej (wytyczne do normatywu)", *Gaz, Woda i Technika Sanitarna*, 1954, vol. 9, pp. 262–271.

[38] W. Błaszczyk, M. Roman, H. Stamatello, *Kanalizacja,* vol. I. Warsaw, Poland: Arkady, 1974.

[39] P. Błaszczyk, D. Igielski, B. Osmulska-Mróz, *Zasady planowania i projektowania systemów kanalizacyjnych w aglomeracjach miejsko – przemysłowych i dużych miastach*. Warsaw, Poland: Wyd. Instytut Kształtowania Środowiska, 1983.

[40] A. Kotowski, "Wybrane aspekty wymiarowania i sprawdzania przepustowości kanałów deszczowych i ogólnospławnych", *Forum Eksploatatora*, 2006, vol. 1, pp. 18–25.

[41] A. Kotowski, *Podstawy bezpiecznego wymiarowania odwodnień terenów*. Warsaw, Poland: Wydawnictwo Seidel–Przywecki, 2015.

[42] Z. Bartosik, "Zagrożenie powodzią na terenie Warszawy", presented at Conference of the Parliamentary Group for the Development of Waterways entitled "Warsaw's comeback to the Vistula River", Warsaw, Poland, 9 October 2017.

[43] A. Magnuszewski, M. Gutry-Korycka, Z. Mikulski, "Historyczne i współczesne warunki przepływu wód wielkich Wisły w Warszawie. Część I", *Gospodarka Wodna*, 2012, vol. 1, pp. 9–18.

[44] M. Miętus, M. Marosz, J. Filipiak, et al., *Klimat Polski 2020*. Warsaw, Poland: IMGW-PIB, 2021.

[45] D. Booth, C. Jackson, "Urbanization of aquatic systems – degradation thresholds, stormwater detention, and the limits of mitigation", *Journal of the American Water Resources Association*, 1997, vol. 33, no. 5, pp. 1077–1090; DOI: 10.1111/j.1752-1688.1997.tb04126.x.

[46] C. Arnold, C. Gibbons, "Impervious surface coverage – the emergence of a key environmental indicator", *Journal of the American Planning Association*, 1996, vol. 62, pp. 243–258; DOI: 10.1080/01944369608975688.

[47] T.T. Nguyen, H.H. Ngo, W. Guo, et al., "Implementation of a specific urban water management-Sponge City", *Science of the Total Environment*, 2019, vol. 652, pp. 147–162; DOI: 10.1016/j.scitotenv.2018.10.168.

[48] H. Li, L. Ding, M. Ren, C. Li, H. Wang, "Sponge city construction in China: A survey of the challenges and opportunities", *Water*, 2017, vol. 9, no. 9, art. ID 594; DOI: 10.3390/w9090594.

[49] H. Jia, Z. Wang, X. Zhen, M. Clar, S.L. Yu, "China's sponge city construction: A discussion on technical approaches", *Frontiers of Environmental Science & Engineering*, 2017, vol. 11, pp. 1–11; DOI: 10.1007/s11783-017-0984-9.

[50] I. Godyń, A. Grela, D. Stajno, P. Tokarska, "Sustainable rainwater management concept in a housing estate with a financial feasibility assessment and motivational rainwater fee system efficiency analysis", *Water*, 2020, vol. 12, no. 1, pp. 151; DOI: 10.3390/w12010151.

[51] M.P. Barszcz, "Influence of applying infiltration and retention objects to the rainwater runoff on a plot and catchment scale–case study of Służewiecki Stream subcatchment in Warsaw", *Polish Journal of Environmental Studies*, 2015, vol. 24, pp. 57–65; DOI: 10.15244/pjoes/29197.

[52] T.P. Sobol, *Urban Waterscape. Architecture's Response to Changing Water Levels on the Example of Siekierki Area in Warsaw*. Warsaw, Poland: Warsaw University of Technology, 2018.

[53] M. Wojnowska-Heciak, M. Suchocka, B. Grzebulska, M. Warmińska, "Use of structural soil as a method for increasing flood resilience in Praga Północ in Warsaw", *Annals of Warsaw University of Life Sciences–SGGW. Horticulture and Landscape Architecture,* 2019, vol. 40, pp. 15–28; DOI: 10.22630/AHLA.2019.40.2.

[54] A. Bus, A. Szelągowska, "Green water from green roofs – the ecological and economic effects", *Sustainability*, 2021, vol. 13, no. 4; DOI: 10.3390/su13042403.

[55] M. Marzuchowska, M. Żebrowski, "Miasto Gąbka – Czyli Jak Wycisnąć Więcej Korzyści z Naszych Miast?". [Online]. Available: https://obserwatorium.miasta.pl/miasto-gabka-czyli-jak-wycisnac-wiecej-korzysci-z-naszych-miast/, [Accessed: 5 Aug. 2022].

[56] MPWiK, "Inteligentny System Sterowania Siecią Kanalizacyjną w Stolicy". [Online]. Available: https://www.mpwik.com.pl/view/inteligentny-system-sterowania-sieci-kanalizacyjn-w-stolicy. [Accessed: 5 Aug. 2022].

[57] M. Juszczyk, "Analysis of labour efficiency supported by the ensembles of neural networks on the example of steel reinforcement works", *Archives of Civil Engineering*, 2020, vol. 66, no. 1, pp. 97–111; DOI: 10.24425/ace.2020.131777.

[58] N.A. Jasim, S.M. Maruf, H.S. Aljumaily, F. Al-Zwainy, "Predicting index to complete schedule performance indicator in highway projects using artificial neural network model", *Archives of Civil Engineering,* 2020, vol. 66, no. 3, pp. 541–554; DOI: 10.24425/ace.2020.134412.

[59] J. Sobieraj, D. Metelski, "Private Renting vs. Mortgage Home Buying: Case of British Housing Market – A Bayesian Network and Directed Acyclic Graphs Approach", *Buildings*, 2022, vol. 12, no. 2; DOI: 10.3390/buildings12020189.

[60] G. Straż, A. Borowiec, "Evaluation of the unit weight of organic soils from a CPTM using an Artificial Neural Networks", *Archives of Civil Engineering*, 2021, vol. 67, no. 3, pp. 259–281; DOI: 10.24425/ace.2021.138055.

Gospodarowanie wodami opadowymi jako bariera rozwoju miasta stołecznego Warszawy

Słowa kluczowe: bariery rozwoju miasta, podtopienia, proces spływu wód opadowych, urbanizacja, zarządzanie wodami opadowymi, zlewnia Potoku Służewieckie, zagospodarowanie przestrzenne miasta

Streszczenie:

Realizacja inwestycji budowlanych w Warszawie wiąże się z coraz większymi trudnościami w przygotowaniu, uzyskaniu odpowiednich pozwoleń i zgód budowlanych, częściowo z powodu braku infrastruktury wodno-kanalizacyjnej oraz niewłaściwego zagospodarowania wód opadowych w mieście. Wszystko to prowadzi do wzrostu kosztów podejmowanych przedsięwzięć budowlanych. Aby zilustrować szereg kwestii związanych z gospodarką wodną w mieście i wynikającymi z niej problemami, w opracowaniu przedstawiono szereg różnych studiów przypadków, stylizowanych faktów i abdukcyjnych wniosków w celu opracowania najlepszego wyjaśnienia istniejących problemów. Bardziej szczegółowo, badanie przedstawia bariery w gospodarce wodami opadowymi w mieście Warszawa poprzez analizę hipotetycznego procesu inwestycyjnego Kanału Wawerskiego. Analizowane studia przypadków dotyczą: degradacji zbiornika wodnego Bernardyńska oraz braku odpowiednich inwestycji w zlewni potoku Służewieckiego, a także szeregu wewnętrznie sprzecznych uwarunkowań w gospodarce wodami opadowymi w Warszawie. Dla kontrastu pokazano również przykłady udanych inwestycji w gospodarkę burzową, np. Radex Park Marywilska, osiedle Stegny Południe, osiedle Fort Bema na Bemowie. W ten sposób wykazano, że przy odpowiednim podejściu można w odpowiedni sposób realizować inwestycje budowlane w zakresie infrastruktury wodno-ściekowej, co pozwoli uniknąć wielu problemów związanych z gospodarką wodami opadowymi. Głównym wnioskiem z badania jest to, że niedostateczne uwzględnienie w planowaniu przestrzennym zagadnień związanych z kanalizacją deszczową będzie prowadzić do dalszych powodzi i narastania problemów związanych z gospodarką wodną.

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