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Analysis of the potential for increasing water retention in road pavements on public roads in cities: a case study based on the Old Town of Płock

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Abstract: The contemporary development of cities necessitates the implementation of modern systems, particularly with regard to the drainage of rainwater and melted snow from road surfaces. Due to the prevalent use of paved surfaces in urban areas, it is crucial to explore solutions that facilitate water retention at the point of occurrence. A key element is the use of biologically active surfaces. When designing specific solutions, it is vital to first review the current water and road regulations. An analysis based on these regulations was conducted to investigate the potential for increasing water retention in pedestrian buffer lanes in the Old Town area of Płock.

Keywords: water retention; road construction; biologically active surfaces; permeable surfaces

1. Introduction – water retention in the city

The contemporary development of cities, in terms of both infrastructure and urban planning, requires the implementation of modern and integrated systems. In urban environments, one fundamental element that influences the safety of pedestrian and vehicular traffic is the drainage of rainwater and meltwater from road surfaces. Hardened surfaces such as roads, sidewalks, and parking lots impede water percolation into the underlying soil, leading to its desiccation [1–3]. Water that is not managed at the point of precipitation is directed to municipal sewer systems, which, during intense rainfall, become overloaded both quantitatively and qualitatively, failing to fulfill their intended purpose. This creates a hazard for traffic and leads to flash floods and inundations. Therefore, it is crucial to seek solutions that allow for local water management, which not only relieves the burden on wastewater treatment plants but also reduces associated costs. Additionally, locally retained water can serve as a natural source of nutrients for vegetation during periods of drought [4–6]. Importantly, due to climate change and the increasing frequency of extreme weather events, including droughts, water availability in Poland is decreasing. According to 2020 research by the Central Statistical Office, an inhabitant of Poland has three times less water than residents of other European countries [7].

Retention and slowing down the runoff of water can be achieved through various methods, one of which is small-scale retention. This involves storing rainwater and meltwater in the ground, on its surface, as well as in natural and artificial reservoirs. Additionally, it encompasses the water resource accumulated through these methods. The use of small-scale retention offers numerous benefits, primarily ecological, such as improving the microclimate and providing conditions for vegetation growth, as well as social, aesthetic, and financial advantages [8]. In urban environments, it can be implemented in various ways. One approach is to increase permeable surfaces in road lanes by replacing hardened surfaces with biologically active surfaces or alternative permeable pavements [9, 10].

As defined in the Regulation of the Minister of Infrastructure [11], the term "biologically active area" refers to "an area with a surface arranged in a way that ensures natural plant vegetation and the retention of rainwater, as well as 50% of the surface of terraces and roofs with such a surface, and other surfaces ensuring natural plant vegetation, with a surface area of not less than 10 m^2, and surface water on this area." Consequently, parking lots are also considered biologically active areas, provided that openwork grids or pavers are used on their surface. The function of these permeable surfaces involves draining and infiltrating rainwater and meltwater into the soil layers through specially prepared substrates.

The application of such methods is highly advantageous. Among them, we can cite the reduction of negative consequences of floods and droughts in cities, the creation of a correlating blue-green city infrastructure consisting of retention ponds, basins, green roofs, and facades. These not only contribute to water retention but also facilitate the improvement of sewage systems, elevate groundwater levels, reduce maintenance costs for urban greenery, and enhance the city's aesthetics [12]. Moreover, according to NFOŚiGW (data from 2020), in Poland, since 2014, a total of 1.5 million m^3 of rainwater has been retained in cities thanks to rainwater management [2].

Figure 1 illustrates the differences in the water cycle between natural and built environments. In built-up areas, rapid surface runoff accounts for 55% of rainwater. There is also slight evaporation at 30%, as well as a small and slow level of infiltration, which constitutes 15%. In the case of permeable surfaces, the amount of runoff is reduced to 10%. Additionally, 50% of this water is released into the atmosphere, and 40% is retained in the soil through infiltration. The remainder is detained on plant surfaces due to evaporation and interception.

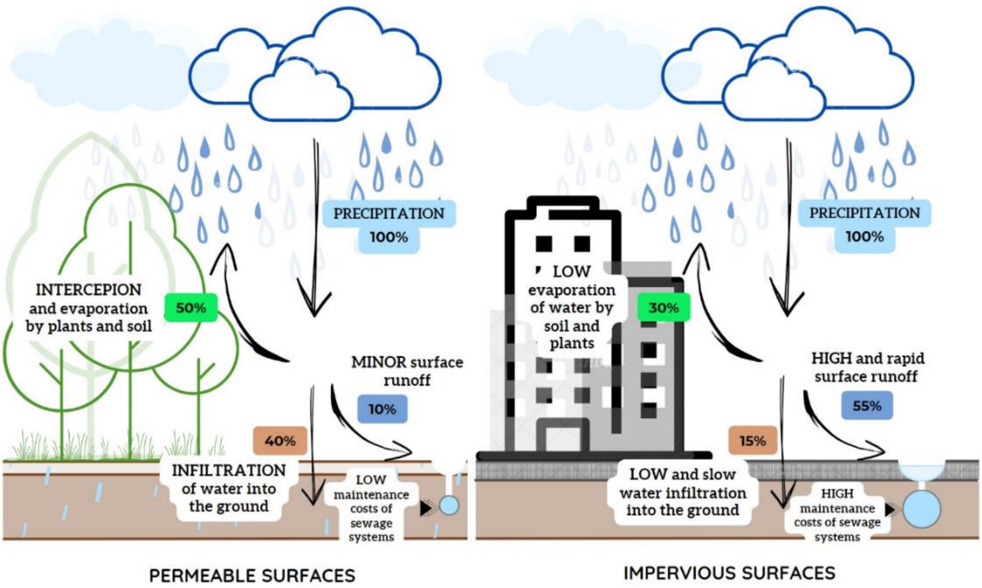


Fig. 1. Comparison of water circulation in natural and built environments [13]

It should also be noted that improper management of greenery in cities, its absence, or limited extent contribute to the formation of urban heat islands. This climatic phenomenon is characterized by higher air temperatures in cities compared to surrounding areas. It arises from the specific functional-spatial structure of cities, such as the accumulation of artificial surfaces, a limited share of urban greenery, and reduced ventilation. Materials like concrete, asphalt, and brick absorb more sunlight than they reflect, releasing energy and raising the surrounding temperature [14]. This situation detracts from the comfort of city residents and the proper functioning of the city.

However, it is important to emphasize that any actions regarding the possibilities and methods of draining water from road lanes, as well as their management and retention, must be preceded by a thorough analysis of applicable regulations and legal provisions.

2. Rainwater management in the city

With the development of cities, there has been a long-term process of collecting and discharging most of the rainwater into rivers. While this approach protected urban areas against flooding after each rain, it also led to unfavourable climate changes, including drought. Water plays an invaluable role in the lives of city residents, making it essential to restore balance and improve the quality of their lives as soon as possible.

One major negative effect of the lack of greenery and water in cities is the formation of so-called heat islands, which make the air feel hotter, particularly noticeable at night when asphalt or concrete release stored heat. This phenomenon can be mitigated by the presence of numerous lawns or trees. Additionally, greenery should be watered with rainwater or water from natural reservoirs to conserve high-quality tap water. Existing streets should also be unsealed by using hardened but rain-permeable surfaces.

Water, regardless of its origin, must be managed in cities, ideally at the point of rainfall. However, the progressive expansion of the urban fabric and the proliferation of asphalt roads and paving stone surfaces increase the area of impermeable surfaces, leading to the overloading of the rainwater drainage system. Flooded streets, submerged vehicles, and houses are the results of excessive surface sealing. Such a large volume of rainwater flow causes the overflow of streams into which it is discharged, leading to flooding of properties nearby.

In urban areas, efforts should be made to expand the so-called green-blue infrastructure, comprising green areas, properly designed watercourses, rain gardens, and retention reservoirs that can be intentionally flooded during rainfall.

The use of rainwater involves collecting it in advance, storing it before use, and often cleaning it. Utilizing rainwater in rain gardens or ponds can also be considered a means of maintaining the environment surrounding humans. The simplest example of using rainwater is to collect it, even in a makeshift tank, and then use it to water the garden [15–17].

Rainwater management systems designed for the infiltration process can be categorized into several types, each utilizing a different method:

- surface infiltration,
- infiltration with surface retention,
- infiltration with underground retention.

Surface infiltration is defined as percolation through a permeable surface without excess water or prior water accumulation. This permeable surface may be reinforced and/or covered with greenery. This process is typically implemented in green areas and on permeable surfaces.

The infiltration process with surface retention includes features such as absorption basins (infiltration), absorption reservoirs, absorption moguls, and ditches, as well as rain gardens and green roofs.

The infiltration process combined with underground retention involves devices and facilities such as absorption wells, drainages, infiltration boxes, and drainage chambers [15, 18, 19].

3. Legal and formal conditions and examples of water retention and infiltration solutions

Legal regulations concerning water management are outlined in the Water Law Act of July 20, 2017 [20]. Additionally, the document "Guidelines for the Design of Drainage Devices for Rural Roads and Streets" (WR-D-71), recommended in 2023 by the Minister of Infrastructure, is significant [21]. This document establishes principles for protecting water resources and their responsible management, considering the needs of environmental protection, people, and the economy. It defines the concepts of rainwater and meltwater as water resulting from atmospheric precipitation and describes ways to manage them. Following the consent of the relevant authorities, this water can be discharged into rain or general drainage systems, drainage ditches, or various retention systems. In urban areas, these actions involve water services and require water permits. The document details the possible amount of rainfall infiltrated into the ground or into atmospheric waters, a description of works or structures that can directly reduce natural water retention in a specific area, and the amount of water discharged from hardened areas to retention facilities, thus determining the fees for reducing biologically active surfaces. However, these fees are not applicable if the water from a specific area is managed using water retention and infiltration devices. Nevertheless, the act does not provide more detailed solutions regarding water management in road lanes or methods of local retention. This lack of specific guidelines poses challenges for designers and investors, who are required to take particular actions in response to climate change effects.

When undertaking the task of increasing biologically active surfaces in the road lanes of public roads to enhance natural water retention, it is crucial to maintain the appropriate technical parameters of the road and its components. Regulations governing the shaping of road lanes are found, among others, in the Regulation of the Minister of Infrastructure of June 24, 2022, on technical and construction regulations for public roads [22]. According to this document, if specific conditions are not clearly stipulated, roads should be built and designed in accordance with established patterns and standards, as well as Polish Standards. Road elements include the roadway, shoulder, drainage devices, road signs and signals, and traffic safety devices. For pedestrian use, a pedestrian path, a combined pedestrian and bicycle path, or a shoulder with at least one sidewalk is delineated. In exceptional cases, a minimum width of 1.0 m is permitted. Supporting or buffer lanes are also designed according to their specific purpose. The minimum width of a sidewalk must be 1.8 m, and only in exceptional cases is a width of no less than 1.0 m allowed. Roads designated for bicycles, combined pedestrian and bicycle use, and carriageways also accommodate the movement of bicycles, electric scooters, personal transport devices, and muscle-powered vehicles. The minimum width for a pedestrian and bicycle road, if not located on a bridge or viaduct, should be at least 3.0 m; otherwise, a width of no less than 2.5 m is acceptable. In special cases, larger widths are permissible.

In the road lanes of public roads, impermeable surfaces are commonly used, which prevent the penetration of water and oxygen into the soil. As a result, most water from atmospheric precipitation flows directly into municipal drainage systems. The primary goal in managing rainwater and meltwater is to limit their flow and retain them where they fall [8, 23]. Sustainable water management in urban areas can be achieved through so-called de-concreting, which involves replacing sealed surfaces in road lanes with green strips or permeable surfaces. However, it is important to ensure a minimum sidewalk width of 1.8 m for pedestrians, unless regulations require an increase due to the pedestrian traffic intensity on a specific route.

A good example of de-concreting road lanes is seen in the city of Płock. Figure 2 illustrates the changes made to one of the streets, where a section of concrete block pavement was replaced with small green strips, allowing the free flow of rainwater into the ground.

Fig. 2. De-concreting on Bielska Street in Płock

In the road lanes of public roads, the possibilities for implementing such solutions are somewhat limited. This limitation is due, among other factors, to the presence of parking spaces in these areas. To avoid eliminating these parking spaces, alternative permeable surfaces are used. Their function involves the penetration of water into the ground through small pores on their surface, which vary depending on their structure and purpose.

One example is mineral-resin surfaces, which consist of a combination of natural aggregates such as quartz and resin. After bonding, these materials form a porous structure that allows water to penetrate into the ground, thereby hydrating nearby vegetation. This type of surface is laid on a previously prepared substrate consisting of several layers: drainage, leveling, and load-bearing. These layers influence the durability and mechanical strength of the surface, as well as its resistance to weather conditions and abrasion. Perforated concrete slabs or blocks are also used. The empty spaces in these slabs of various shapes are filled with small aggregates or seeded with grass. Such surfaces are characterized by high load-bearing capacity and durability. Examples of such applications are presented in Fig. 3a-3d.

Fig. 3. Example of the application of surfaces a) TerraWay, b) EKOWAY, c) HanzaVia, d) Domino Eco on Kazimierza Wielkiego Street in Płock

The solutions presented limit surface runoff, enabling the management and retention of water at the point of its occurrence, thereby reducing the volume entering municipal sewer systems. The amount of water accumulated using these methods depends on the type of soils, their geotechnical properties, filtration capacity, and water permeability. The water retained in the soil layers will subsequently be utilized by plants and released into the atmosphere as water vapor, which positively impacts both the climate and the urban environment.

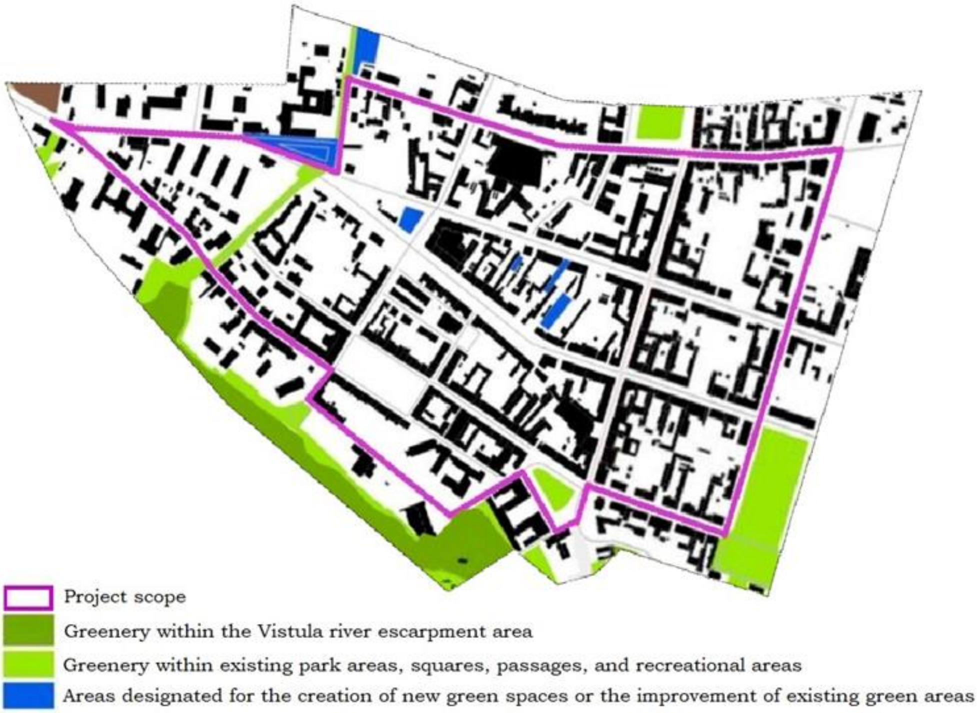
Figure 4 illustrates the process of replacing the pavement around trees on Kazimierza Wielkiego Street in Płock. The traditional concrete block pavement was replaced with selected permeable surfaces (as shown in Fig. 3). This measure has created better conditions for vegetation growth, increased soil moisture levels, and enhanced water retention, while still preserving the existing parking spaces near the trees.

Fig. 4. Photos from the replacement of the pavement around trees on Kazimierza Wielkiego Street in Płock

4. Analysis of the possibilities to increase water retention in road strips of public roads in the Old Town of Płock

The Old Town of Płock is the oldest part of the city, located on the right bank of the Vistula River in the city center. It covers an area of 0.83 km² and is situated at an elevation of approximately 47.0 meters above sea level. This area is characterized by compact, low-rise buildings, predominantly in the form of tenement houses. It is a historic district of the city, bounded by the streets: Piekarska, Kazimierza Wielkiego, Okrzei, Kwiatka, Kolegialna, Sienkiewicza, and Kościuszki. Nearby neighborhoods include Kolegialna and Tysiąclecia [24]. For research purposes, the area of the Old Town has been expanded to include a section of the Kolegialna neighborhood. The boundaries of this area are defined by the streets: Archbishop A. J. Nowowiejskiego, Ostatnia, Królewiecka, 1 Maja, Plac Obrońców Warszawy, T. Kościuszki, Plac G. Narutowicza, Teatralna, Piekarska, Ks. Prał. S. Wyczałkowskiego, and Kazimierza Wielkiego. Additionally, the project also considers the streets: H. Sienkiewicza, Bielska, J. Kwiatka, Kolegialna, S. Okrzei, Staromiejska, Synagogalna, Jerozolimska, Zduńska, and S. Małachowskiego. This area has a limited amount of green spaces, mainly concentrated in small squares, such as Narutowicza Square, and experiences high pedestrian and vehicular traffic. Due to the scarcity of space for green plantings, vegetation is primarily found along the streets. The scope of the study area is depicted in Fig. 5.

a)



b)

Fig. 5. Scope of the study (a), marked research area on Google Maps (b) [24, 25]

The conducted research aimed to analyse the possibilities of increasing the retention and infiltration of rainwater and meltwater in urbanized areas, which would contribute to reducing the risk of floods and inundations, among other benefits. For this purpose, an inventory of green areas along each street was conducted, the width of buffer zones, including sidewalks, was measured, and the location of existing parking spaces in the research area was identified. Based on the collected data and a review of available market solutions, areas were designated for so-called "de-concreting," and the use of permeable surfaces was planned. A minimum sidewalk width of no less than 1.8 meters was assumed, while the width of green belts and permeable surfaces was set at a minimum of 1.5 meters. In the locations of existing parking spaces, the replacement of impermeable surfaces with permeable ones was designed.

Table 1 presents detailed information about the existing and planned biologically active areas and permeable surfaces for each road section. After implementing the project, the greatest increase will be seen in the road sections of J. Kwiatka, a segment of Kolegialna Street, Królewiecka Street, and H. Sienkiewicza Street. On J. Kwiatka Street, the segment of Kolegialna Street, and Królewiecka Street, permeable surfaces will constitute a larger part, while biologically active surfaces will be smaller.

Table 1. Comparison of existing and planned permeable surface areas for individual road sections

Road corridor	Class	Length [m]	Total area [m^2]	Existing biologically active areas [m^2]	Planned biologically active areas [m^2]	Planned permeable surfaces [m^2]
abp. A. J. Nowowiejskiego	Z	356.3	6351.5	349.6	245.5	56.8
Ostatnia	L	326.9	4506.6	204.7	386.7	461.1
Królewiecka	L	558.7	9917.2	141.4	573.7	1573.5
H. Sienkiewicza	Z	702.5	13 304.9	1263.7	634.3	1370.5
section St. Bielska	L	366.2	6100.1	220.3	300.8	194.1
section St. 1 Maja – sq. Obrońców Warszawy	L	589.8	10 450.3	752.6	456.5	1187.3
J. Kwiatka – section St. Kolegialna	Z	780.0	19 588.2	1253.2	331.7	2406.8
S. Okrzei	L	181.3	2464.7	347.6	19.6	108.8
Staromiejska	D	119.6	973.9	12.0	0.0	0.0
Synagogalna	D	120.9	1455.1	81.7	0.0	125.8
Jerozolimska	D	114.8	1088.6	2.6	0.0	0.0
Zduńska	D	208.4	2130.2	0.0	0.0	0.0
S. Małachowskiego	D	165.0	1911.4	128.2	8.8	89.3
section St. T. Kościuszki	L	230.9	4273.4	72.0	153.8	809.2
sq. G. Narutowicza	D	-	8582.7	1770.6	33.7	755.7
section St. Kazimierza Wielkiego	L	552.6	8574.3	595.8	172.4	1588.2
Teatralna	L	112.4	1546.2	8.8	145.6	143.9
	Sum	5486.3	103 219.3	7204.8	3463.1	10 871.0

Currently, the surveyed area encompasses a total of 7,204.8 m² of biologically active areas, constituting 6.98% of the total surface area of road sections on public roads in this area. The research demonstrated the possibility of increasing these areas by 3,463.1 m², or about 50% (which represents 3.36% of the total surface area of road sections on public roads). Additionally, the replacement of 10,871 m² of surfaces in buffer zones for pedestrian roads was designed, accounting for 10.5% of the total surface area of road sections. Consequently, over 20% of the surface area of road sections will enable water infiltration and retention in the soil, thereby reducing surface runoff. The percentage breakdown of surfaces in the project area is presented in Fig. 6.

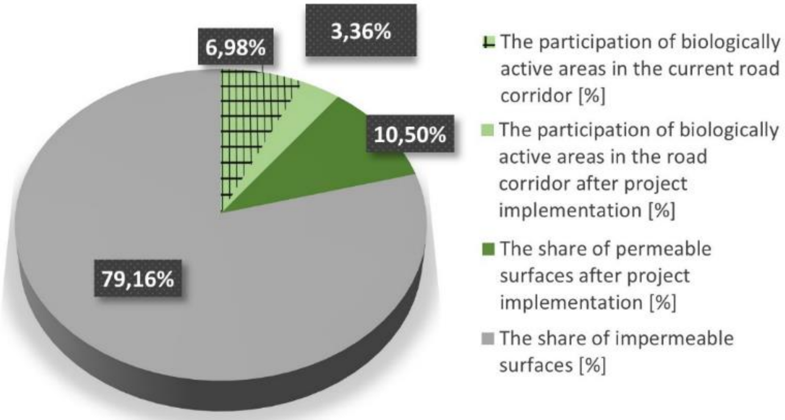


Fig. 6. Comparison of surfaces in the project area

As shown in Fig. 7, the largest share of biologically active areas characterizes the road sections of G. Narutowicza Square, S. Okrzei Street, and H. Sienkiewicza Street, while the smallest share characterizes Zduńska Street, Jerozolimska Street, and Staromiejska Street. The analysis indicates that the streets with the greatest potential for increasing biologically active areas are Ostatnia Street and Teatralna Street, where the surface area of biologically active areas can increase by approximately 9% relative to their total surface area. The introduction of permeable surfaces offers the greatest potential for increasing biologically active areas, with their share in the total surface area of individual road sections reaching up to approximately 18%. This percentage share of permeable surfaces is achievable on the surveyed sections of T. Kościuszki and Kazimierza Wielkiego Streets. The research demonstrates that, in the majority of analyzed road sections, the surface area of biologically active areas and permeable surfaces can reach up to 30% of the total surface area. However, some road sections, often very narrow and heavily urbanized, lacking or having minimal existing biologically active areas, do not have the potential for their introduction or expansion. Unfortunately, these sections also lack the possibility of introducing permeable surfaces. In the surveyed area, they constitute approximately 15% of all streets, including Staromiejska, Jerozolimska, and Zduńska Streets.

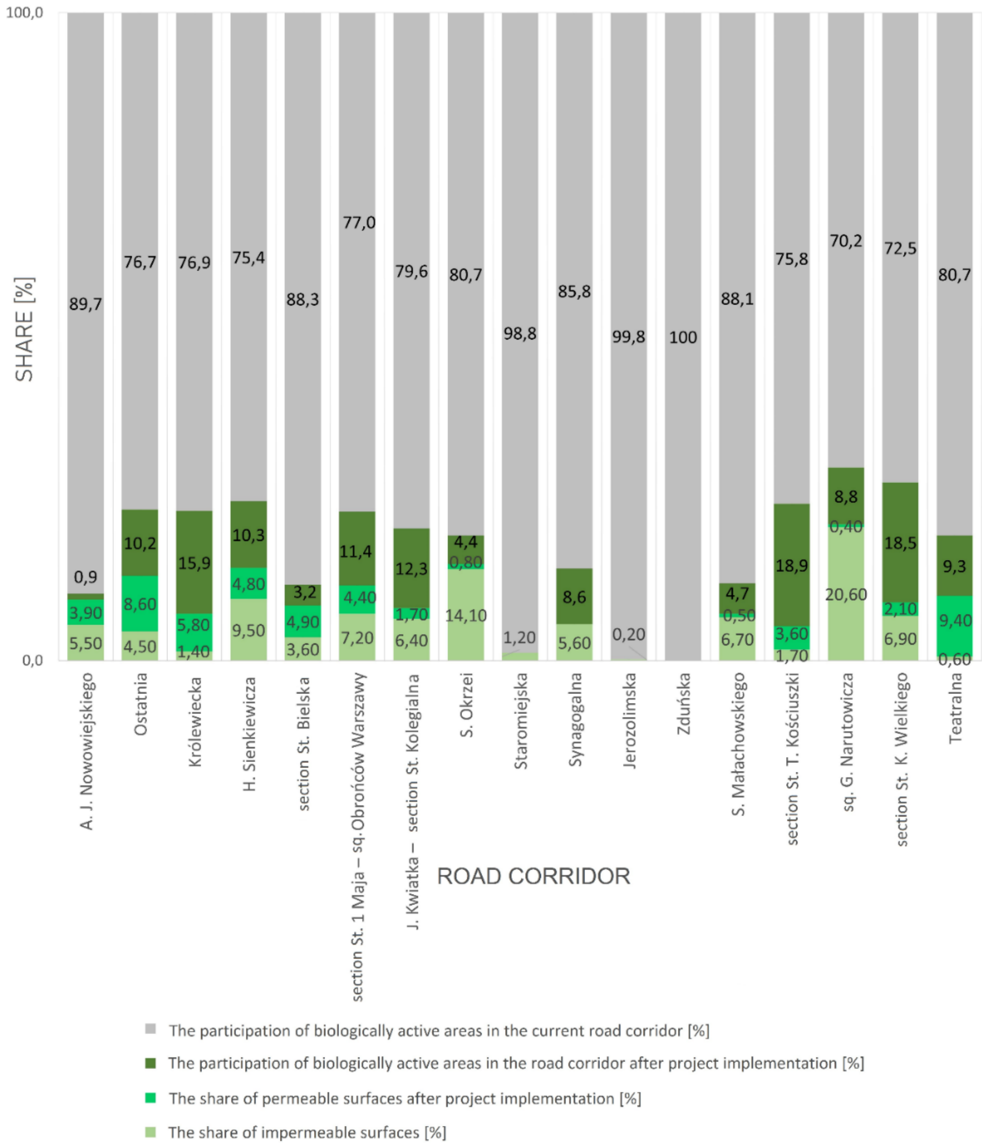


Fig. 7. Ratio of impervious to permeable surfaces in the road lanes of public roads

5. Summary

The modern development of cities necessitates the implementation of advanced and integrated systems. One of the key elements affecting safety in pedestrian and vehicular traffic in urban environments is the proper drainage of rainwater and meltwater from road lanes. Traditionally paved surfaces of roads, sidewalks, and parking lots impede water penetration into the soil, potentially leading to drought and overloading sewage systems during heavy rainfall. A solution to this issue is the use of small retention, which involves storing rainwater and meltwater on the soil surface or in tanks. Retaining water at its point of rainfall brings many ecological, social, and financial benefits, particularly in the context of climate change and decreasing water availability in Poland. One method to increase water retention is to replace traditional road surfaces with permeable surfaces, allowing water to penetrate the soil. The use of mineral-resin surfaces or perforated concrete slabs can enhance retention in urbanized areas.

The analysis of the possibilities of increasing water retention in the road lanes of public roads in the Old Town of Płock has led to the design of modern solutions. These improvements have increased the area of biologically active areas by approximately 50% compared to existing areas. Additionally, alternative permeable surfaces were applied in buffer lanes for pedestrians, constituting about 10% of the total area of road lanes. As a result, this has led to over 20% of the total area consisting of biologically active areas and permeable surfaces in the surveyed area.

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References

[1] Craul, P.J. "Urban soils: an overwiew and their future", in Watson G.W., Neely D. (red.), *The landscape below ground*. Savoy: International Society of Arboriculture, 1994.

[2] *The volume of water stored as part of the activities co-financed by Measure 2.1.5 of the Operational Programme Infrastructure and Environment 2014-2020, based on data from the National Fund for Environmental Protection and Water Management*.

[3] *Regulation of the Minister of Infrastructure of 15 July 2021 on the adoption of the Drought Impact Mitigation Plan*. Journal of Laws of 2021, item 1615.

[4] Kronenberg, J., "Bariery dla utrzymania drzew w miastach i sposoby pokonywania tych barier" in Bergier T., Kronenberg J. (ed.), *Przyroda w mieście. Usługi ekosystemów – niewykorzystany potencjał miast*. Fundacja Sendzimira, Kraków 2012 (in polish).

[5] Kupryś-Lipińska I., Kuna P., Wagner I., "Woda w przestrzeni miejskiej a zdrowie mieszkańców, Woda w mieście", *Zrównoważony Rozwój – Zastosowania*, nr 5, (2014). Available: https://sendzimir.org.pl/wp-content/uploads/2019/08/ZRZ5_str_51-59.pdf [Access: 27 Mar 2023]

[6] Lejcuś K. et al., *Katalog dobrych praktyk. Zasady zrównoważonego gospodarowania wodami opadowymi pochodzącymi z nawierzchni pasów drogowych*. Wrocław 2017. Available: http://44mpa.pl/wp-content/uploads/2018/04/Katalog-Dobrych-Praktyk-drogi.pdf [Access: 27 Mar 2023]

[7] *Resolution 92 of the Council of Ministers dated 10 September 2019 on the adoption of the "Assumptions for the Programme to Counteract Water Shortage for the Years 2021-2027 with a Perspective to 2030"*.

[8] *Urban Climate Change Adaptation Plan*. Available: https://www.gov.pl/web/klimat/mpa-44 [Access: 27 Mar 2023]

[9] *What is water retention? What does small-scale water retention involve? TerraCottem*. Available: https://terracottem.pl/co-to-jest-retencja-wodna-na-czym-polega-mala-retencja/ [Access: 27 Mar 2023]

[10] *Strategic Adaptation Plan for Sectors and Areas Vulnerable to Climate Change by 2020 with a Perspective to 2030*, Ministry of Environment, Warsaw, October 2013.

[11] *Regulations of the Minister of Infrastructure of 12 April 2022 on the technical conditions that buildings and their location should meet*. Journal of Laws 2002, No. 75, item 690.

[12] Wagner I., Krauze K., Zalewski M., "Błękitne aspekty zielonej infrastruktury", *Zrównoważony Rozwój – Zastosowania*, vol. 4, (2013), pp. 145-155. Available: https://www.teraz-srodowisko.pl/media/pdf/aktualnosci/1576-Blekitne-aspekty-zielonej-infrastruktury.pdf [Access: 27 Mar 2023]

[13] *Guidelines for rainwater management in single-family housing areas, Aquanet Retention*. Available: https://www.aquanet-retencja.pl/wp-content/uploads/2021/05/AQ-Retencja-Wytyczne.pdf [Access: 27 Mar 2023]

[14] *Urban heat island, Climate 2.0. Knowledge Base on Climate Change*. Available: https://klimada2.ios.gov.pl/miejskie-wyspy-ciepla/ [Access: 27 Mar 2023]

[15] Bąk, J., Królikowska, J., "Proekologiczne zagospodarowanie wód opadowych", *Inżynieria na rzecz ochrony środowiska*, (2016), pp. 247-258.

[16] Geiger W., Dreiseitl H., *Nowe sposoby odprowadzania wód deszczowych*. *Poradnik*. Bydgoszcz: Oficyna Wydawnicza Projprzem – EKO, 1999.

[17] Losch H.A., *Woda deszczowa dla domu i ogrodu. Do it yourself*, Warszawa: Arkady, 1998.

[18] Wojciechowska E., Gajewska M., Żurkowska N., Surówka M., Obarska-Pempkowiak H., *Zrównoważone systemy gospodarowania wodą deszczową*, Wydawnictwo Politechniki Gdańskiej, Gdańsk 2015

[19] Królikowska J., Królikowski A., *Wody opadowe. Odprowadzanie, zagospodarowania, podczyszczanie i wykorzystanie*, Wydawnictwo Seidel – Przywecki Sp. z o.o. 2012

[20] *The Water Law Act of 20 July 2017*. Journal of Laws 2017, item 1566.

[21] *Guidelines for the Design of Drainage Devices for Rural Roads and Streets (WR-D-71)*, Ministry of Infrastructure, 2023.

[22] *Regulation of the Minister of Infrastructure of 24 June 2022 on technical and construction regulations concerning public roads*, Journal of Laws 2022, item 1518.

[23] *Retention. Retain the Water. Water Shortage Prevention Program*, Ministry of Infrastructure, Warsaw 2021.

[24] *Climate Adaptation Plan for the City of Płock until 2030*. Available: http://rozwojmiasta.plock.eu/wp-content/uploads/2018/09/MPA-Pojekt_PLOCK_konsultacje.pdf [Access: 27 Mar 2023]

[25] *Google Maps*. Available: https://www.google.com/maps/ [Access: 27 Mar 2023]