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The potential for sustainable rainwater management through domestic rainwater harvesting based on real rainfall

Ewa Burszta-Adamiak*[1)], Aleksandra Przybylska[2)]

[1)] Wrocław University of Environmental and Life Sciences, Institute of Environmental Engineering, Grunwaldzki Square 24, 50-363 Wrocław, Poland

[2)] Wrocław University of Environmental and Life Sciences (Graduate), Grunwaldzki Square 24, 50-363 Wrocław, Poland

* Corresponding author

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Abstract: Rainwater harvesting systems (RWHs) are identified as an alternative technology that is important for sustainable stormwater management through reuse, conservation, and reduce runoff. In recent years there has been a growth of studies on the effectiveness of RWHs. However, analyses of the system performance based on the site specific conditions are still limited. The aim of the study was to assess of the potential for rainwater reuse (householder's interest) and reduction of roof runoff by RWHs (an environment's perspective) assumed in a single-family building. Two performance indicators have been calculated i.e. water saving potential (*WSE*) and overall efficiency (*OE*). Four realistic scenarios (S1–S4) and three main non-potable water requirements were defined. The results of the study showed that *WSE* and *OE* varied depending on the type and size of the tank, the economic purpose, and the amount and irregularity of precipitation. The potential for the use of water stored in above-ground tanks for plant watering ranged from 62 to 82%. Underground reservoirs, with a larger capacity, were able to cover water requirements for this purpose up to 100%. However, the *OE* of tanks receiving runoff from the entire roof area were at low levels. Values of *OE* ranged from 3.7 to 6.8%, from 5.5 to 9.2%, and from 42.9 to 71.0%, for above-ground (S1 and S2) and underground (S3) and (S4) tanks, respectively. The results of the study may be useful for planning domestic rainwater harvesting systems and for comparison with practices in other countries.

Keywords: overfall efficiency, rainwater harvesting system, rainwater management, retention, water saving

INTRODUCTION

Stormwater management under the impact of climate change, urbanisation, demographic and economic development has become a challenge in urban areas. Therefore, rainwater harvesting systems (RWHs) are promoted in many cities as a measure of adaptation to climate change and make cities more resilient and sustainable (Raimondi *et al.*, 2023; Zhou *et al.*, 2023; Halder and Bose, 2024). These systems can be useful in reducing flood risk in urban areas by reducing runoff (Freni and Liuzzo, 2019; Hdeib and Aouad, 2023). Increasingly popular, rainwater harvesting systems help to save energy, eliminate the high costs of traditional water transport (Sá Silva de *et al.*, 2022; Ali and Sang, 2023) and reduce the need for drinking water treatment (Raimondi *et al.*, 2023; Abdullah *et al.*, 2024). Rainwater harvesting systems enable the collection and reuse of rainwater for non-potable uses. Analyses of the structure of water consumption for domestic purposes show that in households up to 50% of tap water could be replaced by rainwater, as some activities do not require drinking water quality (Hammes, Ghisi and Padilha Thives, 2020; Esmaeilishirazifard *et al.*, 2024). Rainwater obtained from rooftop catchments is the simplest and most common method of harvesting rainwater (Thomas *et al.*, 2014; Kolavani and Kolavani, 2020; Burszta-Adamiak and Spychalski, 2021) and even small rainwater tanks can be useful and effective (Lange *et al.*, 2012). In the studies of Kalavani and Kalavani (2020) potential for potable water saving was estimated at 16.91% using a tank size of 4 m^3. The studies of Ghisi (2006) demonstrated the potential for potable water savings among the five main Brazilian regions ranging from 48 to 100%.

With the growing interest in the use of rainwater harvesting tanks, it is important to gain knowledge of their performance under given meteorological conditions. This gives an idea of the extent to which the owner of rainwater harvesting systems can replace tap water, using stored rainwater, for various economic purposes. On the other hand, on a broader level, sewerage system managers, local decision-makers can get an idea of how much the use of these systems will improve the sustainability of our cities in terms of reducing rainwater runoff and improving water management. Most RWH systems have traditionally been installed on the single-family building level due to space for rainwater storage systems in this kind of building. Today, many cities have financial support programs for the purchase of rainwater harvesting systems. Although economic support and training to install rainwater harvesting systems are key factors for those systems' installation in Polish cities, recognition hydrological performance of RWH is still a challenging task. The potential for meeting domestic water demand using RWH systems in different climatic conditions varies widely. Most of the existing research with RWH has been carried out in countries where average annual rainfall is higher than in Poland, for example, in the North of Iran average rainfall ranging from about 523 to 1720 mm per year (Kolavani and Kolavani, 2020), in Brazilian regions with average annual rainfall from 1,100 to 2,998 mm (Santos dos and Farias de, 2017; Istchuk and Ghisi, 2022). The stormwater volume control performance of RWH is not only associated with rainfall patterns but also water demands and tank sizes. Although studies to date have used a wide range of tank sizes e.g. 1–70 m^3 (in intervals of 1 m^3) (Istchuk and Ghisi, 2022), not all of these tank sizes have been used in practice. To achieve maximum benefit from a rainwater tanks at a given location, it is desirable to analyse the system performance based on the site specific conditions (e.g. local rainfall and loss characteristics) and other relevant design parameters (Rahman *et al.*, 2023). From the authors' knowledge as well as from analyses conducted by other authors, a gap exists in the research in this field for Poland's conditions (Fioramonte *et al.*, 2022).

The aim of this research is to evaluate the potential for rainwater reuse (water saving) and reduction of roof runoff by rainwater harvesting systems assumed in a single-family building in Wrocław (Poland). The results of these analyses allow us to answer two questions: (1) to what extent rainwater stored in retention tanks can cover the water demand for a given economic purpose, and (2) how rainwater retention in the tanks affects the reduction of roof runoff depending on the size of the tank and installation requirements. The answer to the first question is important from the point of view of the householder's interests, while the second is relevant from an environmental perspective and provides knowledge of how much the use of these systems contributes to improving the sustainability of our cities in terms of improved water management.

MATERIALS AND METHODS

CASE STUDY

The analysis included roof runoff from a single-family building. Four realistic (most commonly practiced) scenarios of rainwater use were assumed in the calculations, with a separation of variants that took into account different ways of calculating the unit water demand standard. Three main non-potable water requirements (plant watering, outdoor cleaning, and toilet flushing) were investigated in this research. The total roof area taken for analysis was 140 m^2. This area is representative of the size of the roofs of buildings, located in single-family housing estates. The roof slope was 30°. The roof runoff coefficient was assumed to be 0.95. The number of residents living in the building is four. Above-ground and underground retention tanks were included in the analysis. Daily water consumption for toilet flushing per person was assumed to be 0.038 $m^3 \cdot M^{-1} \cdot d^{-1}$ (Sakson, 2018).

RAINFALL DATA

Rainfall data measured minute by minute with a laser disdrometer manufactured by the German company OTT MESSTECHNIK GmbH&Co.KG was used as input data for our calculations. Based on these rainfall data, individual rainfall events were created. Individual rainfall events were separated from the continuous rainfall records by a minimum dry weather period of 6 h. This definition of a rainfall event is widely accepted in urban hydrology calculations and has been used in studies by, among others Gong *et al.* (2019) and Zhang *et al.* (2021). From the point of view of engineering applications, the use of this increased level of detail (with the use of data with less widely spaced temporal resolutions), is important, as it allows a more accurate and realistic assessment of the performance of the RWH system (Ortiz, Barros Barreto de and Castier, 2022).

CHARACTERISTICS OF SCENARIOS AND VARIANTS

Analyses of the effectiveness of domestic tanks were performed for four scenarios (S1–S4), in which additional solution options – variants (V1–V2) were listed (Tab. 1). In the case of scenarios 1 and 2 (S1 and S2), due to the installation of above-ground tanks requiring clipping to only one downpipe, the volume of rainwater runoff from 1/4 of the roof area was considered (the building had four downpipes). The capacity of the above-ground tanks was 0.36 m^3. This is the most commonly used capacity of this type of tank on private properties. When installing underground tanks (scenarios S3 and S4), where it is possible to connect all the downpipes to a single system supplying runoff to the tank, runoff from the total roof area (140 m^2) was included in the calculations. The garden area for watering plants is 45 m^2, of which 40 m^2 was occupied by crops such as celery, leek, parsley, currants, blueberries and raspberries. The remaining 5 m^2 were used for ornamental plants. For these conditions, the optimal capacity of the underground tank, storing water for watering the garden according to calculations made using hydraulic calculators for selecting tanks is 2 m^3. In variant 1 (S1 and S3, V1), the unit standard of water demand was taken as the average value calculated on the basis of actual invoices for water consumption, recorded at a water meter installed outside the building (3 $dm^3 \cdot m^{-2} \cdot d^{-1}$). This water meter takes into account water consumption only for household purposes performed within the building. On the other hand, in variant 2 (S1 and S3, V2), the unit water demand refers to the applicable national legal regulations on the determination of average standards of water consumption (Rozporządzenie, 2002), and was adopted at the level of 2.5 $dm^3 \cdot m^{-2} \cdot d^{-1}$.

FREQUENCY AND PERIOD OF HARVESTED WATER USE

The frequency of watering the garden was assumed every three days in the period from 15 Apr to 15 Jun and 16 Aug to 15 Sept (the beginning and end of the growing season, respectively) and every two days in the period from 16 Jun to 15 Aug (the middle of the growing season). The analysis of water demand also took into account the heights of precipitation (≥6 mm), which were considered to be those that provided a sufficient volume of water for watering (after their occurrence, no additional watering with rainwater from the tank was needed). The adopted value resulted from observations during the period of analysis of the behaviour of property owners of single-family houses, who carried out garden maintenance in the climatic conditions of Wroclaw. In scenario 2 (S2), for each variant (V1 and V2), water consumption for cleaning works outside the building was assumed at the level of 6 $dm^3 \cdot d^{-1}$ of works. The frequency of their performance was assumed once a week. The period of performance of cleaning works was assumed from 1 Apr to 31 Oct in each year. Outside this period, the usual low air temperatures in Poland preclude outdoor work for which rainwater could be used. Scenario 4 (S4) assumes the use of rainwater for flushing toilets in a residential building using an underground rainwater storage tank with a capacity of 4.5 m^3. The period of rainwater demand for this purpose was assumed to be the entire year, i.e. from 01 Jan to 31 Dec.

A summary of the input data and assumptions made in the analysed scenarios and variants is summarised in Table 1.

HYDROLOGICAL PERFORMANCE INDICATORS

The analysis was conducted on particular scenarios of rainwater demand and the rainwater tank capacities based on the water balance concept. It is noteworthy that, among the papers that evaluate the performance of rainwater harvesting systems this is the most widely used method of analysis (Fioramonte *et al.*, 2022; Ortiz, Barros Barreto de and Castier, 2022). Hydrological performance of rainwater harvesting systems was analysed by assessing the extent to which rainwater is used to meet water demands for defined economic needs (owner's interest). The article also undertook an evaluation of the impact of rainwater retention on the reduction of roof runoff depending on the size of the tank and installation requirements (environmental aspect). For this purpose two performance indicators have been calculated as a measure of the hydrological performance of the infrastructure, i.e. the water saving potential and overall efficiency.

The calculation of the water saving potential (*WSE*, in %) is accomplished through the relationship between the total volume of rainwater collected and reuse (RW) and the total water demand (WD) (Souza de and Ghisi, 2020).

$$WSE = \frac{RW}{WD}100\% \tag{1}$$

where: RW = the amount of rainwater collected and reused (m^3), WD = the total water demand (m^3).

The overall efficiency (*OE*) of the system is calculated as the ratio between the amount of rainwater collected and reused (RW, in m^3) and the volume of rainwater that potentially could have entered the system (roof runoff (*RR*), in m^3) (Kapli *et al.*, 2023). Rainwater that was not used for its stated economic purpose and drained from the tank due to its limited capacity, rainfall irregularity, etc., was treated as overflow (*OF*), or "lost" water from the perspective of sustainable rainwater management.

$$OE = \frac{RW}{RR}100\% \tag{2}$$

Accordingly, the analyses of water demand for the assumed economic purposes took into account the use of rainwater retained in the tank and reuse (RW), and the consumption of tap water (TW) during periods when there was no water in the tank. For periods when there was no rainwater demand or it was less than the volume of *RR* there were excess *OF*, which were calculated from the following relationship:

$$OF = 100\% - OE \tag{3}$$

Table 1. Characteristics of the analysed scenarios and variants

Parameter	S1		S2		S3		S4
	V1	V2	V1	V2	V1	V2	
Roof total area (m^2)	140		140		140		140
Part of the roof from which runoff was discharged into the tank (%)	25[1)]		25[1)]		100		100
Type and capacity of tank (m^3)	aboveground tank, capacity – 0.36				underground tank, capacity – 2.0		underground tank, capacity – 4.5
Purposes for which rainwater was used	watering, plants within the building		watering, plants and cleaning work within the building		watering, plants within the building		flushing toilets in the building
Period of rainwater harvesting for the aforementioned purposes	from 15 Apr[2)] to 15 Sep		from 1 Apr to 31 Oct		from 15 Apr[2)] to 15 Sep		from 1 Jan to 31 Dec

[1)] The rainwater runoff from the roof is directed to the tank via a single drain pipe (installation requirements).
[2)] The period adopted in accordance with the Ordinance of the Minister of Infrastructure of January 14, 2002 on the determination of average norms of water consumption (Rozporządzenie, 2002).
Explanations: S = scenario, V = variant.
Source: own elaboration.

RESULTS AND DISCUSSION

RAINFALL CHARACTERISTICS

In terms of the number of individual rainfall events, the analysed years were similar. There were 157 individual rainfall events in 2019, 159 in 2020 and 161 in 2021. However, the amounts of rainfall, its duration as well as its frequency of occurrence were different. The longest duration of precipitation of 23.40 h was recorded in 2020. The highest number of days without precipitation (253) occurred in 2019 and 2020. According to the classification of Kaczorowska (Kaczorowska, 1962; Tomczyk and Bednorz, 2022), assessing the deficiency or excess of precipitation relative to the multi-year norm (1991–2020), the years selected for analysis varied in terms of pluvial conditions. The year 2019 was classified as wet, 2020 as extremely wet, and 2021 as pluvially normal. The driest months in 2019 were April and June. In 2020 and 2021, the warm season (June–July) saw numerous instances of violent and unusually intensive precipitation, causing localised flash floods and flooding. Heavy rainfall also occurred in 2020 in October.

THE WATER SAVING POTENTIAL

In the S1 scenario, identical to S2, the *RW* retention tank received water from 1/4 of the roof due to limitations in the ability to connect all the downpipes to a single above-ground tank with a present capacity. The total volume of *RR* that resulted from rainfall occurring in 2019–2021 was in range from 17.93 to 27.99 m^3. As shown by the results of the analyses summarised in Table 2, the volumes of water stored in the 0.36 m^3 tank were not sufficient to cover the total water requirements for plant watering (S1) as also for plant watering and cleaning (S2).

Table 2. Use of rainwater in scenario 1 and scenario 2

Parameter	Scenario (S), variant (V)	Value in		
		2019	2020	2021
Roof runoff (*RR*, in m^3)	S1, V1, S1, V2	21.33	27.99	17.93
	S2, V1, S2, V2	21.33	27.99	17.93
Demand for water (*WD*, in m^3) *WD* = *RW* + *TW*	S1, V1	6.44	6.16	6.30
	S1, V2	6.83	6.61	6.61
	S2, V1	6.63	6.35	6.49
	S2, V2	7.02	6.80	6.51
Use of rainwater (*RW*, in m^3)	S1, V1	5.04	4.58	4.20
	S1, V2	5.55	4.10	4.49
	S2, V1	5.23	4.54	4.47
	S2, V2	5.77	4.63	4.47
The water saving potential (*WSE*, in %)	S1 ,V1	**78.3**	**74.4**	**66.7**
	S1, V2	**81.3**	**62.0**	**67.9**
	S2, V1	**78.9**	**71.5**	**68.9**
	S2, V2	**82.2**	**68.1**	**68.7**

Source: own study.

Therefore, it was necessary, during periods of rainwater shortages in the tank, to use *TW*.

In scenarios 3 and 4, runoff was obtained from the total roof area, i.e. 140 m^2. It is noteworthy that in the years 2019–2021, for which analyses were carried out, there was no need to take tap water, as the applied tank capacity in the S3 made it possible to fully cover the demand for watering plants with stored rainwater and the *WSE* was 100% (Tab. 3). Analyses for water demand in the S4 were conducted for the entire year due to the daily demand for water for flushing toilets. It is noteworthy that despite the fact that the lowest rainfall occurred in 2021, the rainwater utilisation rate in S4 was high (91.8%).

Table 3. Use of rainwater in scenario 3 and scenario 4

Parameter	Scenario (S), variant (V)	Value in		
		2019	2020	2021
Roof runoff (*RR*, in m^3)	S3, V1, S3, V2	85.24	111.97	71.71
	S4	85.24	111.97	71.71
Demand for water (*WD*, in m^3) *WD* = *RW* + *TW*	S3, V1	6.44	6.16	6.30
	S3, V2	6.83	6.30	6.61
	S4	55.48	55.63	55.48
Use of rainwater (*RW*, in m^3)	S3, V1	6.44	6.16	6.30
	S3, V2	6.83	6.30	6.61
	S4	52.57	48.08	50.93
The water saving potential (*WSE*, in %)	S3, V1	**100.0**	**100.0**	**100.0**
	S3, V2	**100.0**	**100.0**	**100.0**
	S4	**94.8**	**86.4**	**91.8**

Source: own study.

The degree of use of rainwater (*RW*) and tap water (*TW*) to meet the economic needs identified in the various scenarios and variants is summarised in Table 4.

Table 4. Degree of coverage of economic needs by rainwater (*RW*) and tap water (*TW*)

Scenario, variant	Value in		
	2019	2020	2021
S1, V1	78.3% *RW* + 21.7% *TW*	74.4% *RW* + 25.6% *TW*	66.7% *RW* + 33.3% *TW*
S1, V2	81.3% *RW* + 18.7% *TW*	62.0% *RW* + 38.0% *TW*	67.9% *RW* + 32.1% *TW*
S2, V1	78.9% *RW* + 21.1% *TW*	71.5% *RW* + 28.5% *TW*	68.9% *RW* + 31.1% *TW*
S2, V2	82.2% *RW* + 17.8% *TW*	68.1% *RW* + 31.9% *TW*	68.7% *RW* + 31.3% *TW*
S3, V1	100% *RW* + 0% *TW*	100% *RW* + 0% *TW*	100% *RW* + 0% *TW*
S3, V2	100% *RW* + 0% *TW*	100% *RW* + 0% *TW*	100% *RW* + 0% *TW*
S4	94.8% *RW* + 5.2% *TW*	86.4% *RW* + 13.6% *TW*	91.8% *RW* + 8.2% *TW*

Source: own study.

OVERALL EFFICIENCY

The stored rainwater in retention tanks was used for the domestic purposes designated in scenarios S1–S4. However, it should be remembered that in the case of using rainwater for watering greenery and cleaning works within the building, the water demand was periodic. It was limited to the growing season (in the case of irrigation) and to the warm season (temperature >15°C), when cleaning work can be done outside the building. In contrast, rainwater inflow to the tanks took place throughout the year (during the precipitation period). In addition, in the case of an above-ground tank, the inflow to the tank was from a single downpipe (common practice). In single-family buildings, there are usually four or more downpipes. That is, the runoff from the remaining downpipes must be handled in a different way, for example, through other solutions for local retention and infiltration or discharged into the sewer system.

The volume of water that did not fit into the aboveground and underground storage tanks and was discharged through an overflow was presented in Figure 1.

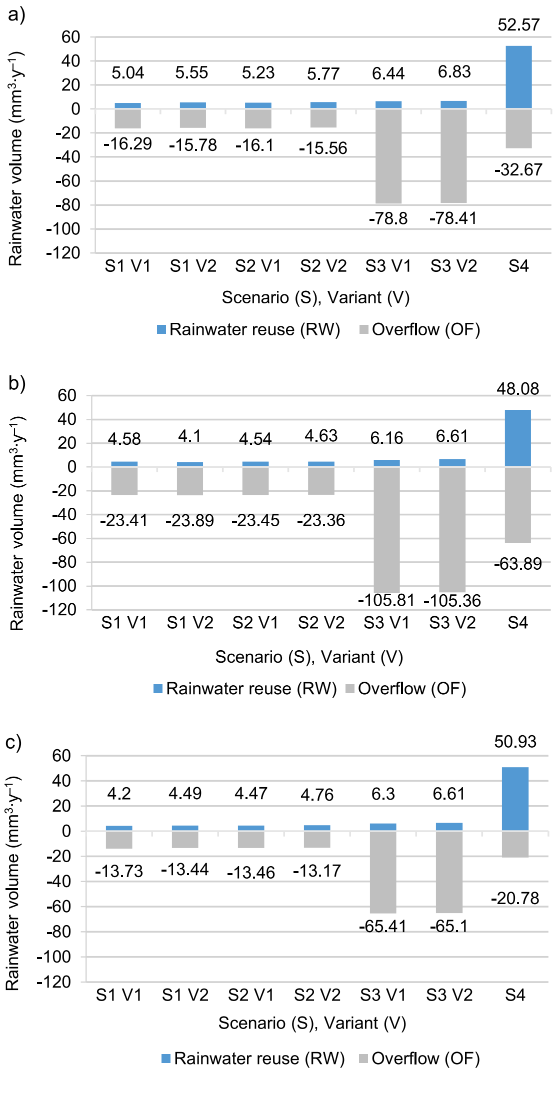

Fig. 1. The volume of rainwater (*RW*) that was used for domestic purposes and overflow (*OF*) against the inflow from part (S1 and S2) and the whole (S3 and S4) of the roof in: a) 2019, b), 2020, c) 2021; source: own study

On the basis of knowledge of the volume of water used versus the acquired inflow from the roof, calculations were made of the overall efficiency of the tanks. The results of these analyses are shown in Figures 2 and 3.

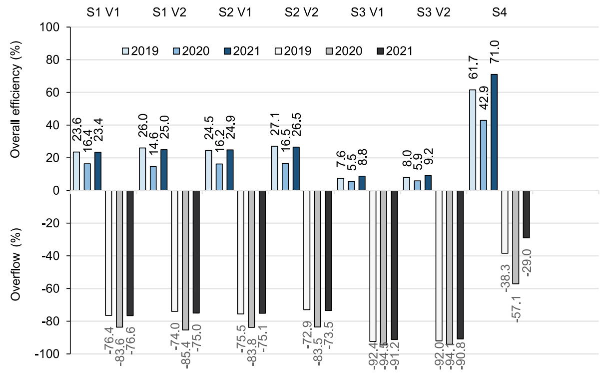

Fig. 2. Share of rainwater volume used for domestic purposes (*OE*) and "lost" in the form of overflows (*OF*) in relation to inflow from part (S1 and S2) and all (S3 and S4) of the roof area in 2019–2021; source: own study

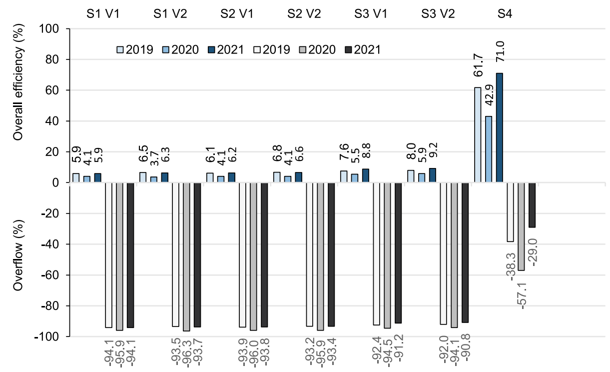

Fig. 3. Share of rainwater volume used for domestic purposes (*OE*) and "lost" in the form of overflows (*OF*) in relation to the inflow from the entire roof area in 2019–2021 for S1–S4; source: own study

DISCUSSION

In modern desirable rainwater management, the aim should be to manage rainwater runoff through local retention or infiltration, and private properties are the best place to implement these solutions. Studies have shown that in 2019–2021, the volume of water that can be harvested from a 140 m^2 roof is greater than the assumed water demand, so theoretically there should be no need to supplement the demand with tap water. However, depending on the size of the tank, the designated economic purpose and the irregularity of rainfall, part of the water demand had to be met by tap water.

In the case of rainwater harvesting systems, especially with the relatively small capacity of tanks, it is necessary to reckon with a high variability in the level of water demand coverage from year to year, which is related to the variable amount and characteristics of rainfall occurrence. Nevertheless, it is worth noting that when deciding on an aboveground water storage tank, the householder (owner) can cover the water demand for plant watering in the range of 62.0–81.3%, and including additional clean-up work up to 82.2%. Thus, from the householder's point of view, access to retained rainwater that he can use for designated household purposes seems satisfactory. Such a result contributes to seeing the benefits of having this type of solution from the owner's point of view. Increasing the efficiency of the use of retained rainwater seems to be possible when installing underground tanks. In this type of installation, it is possible to connect all the downpipes to a single system supplying runoff from the entire roof, so the runoff area as well as the volume of inflow, potentially usable, is top-down larger. However, despite the larger volume of runoff potentially usable in the studied underground tank in the S3 scenario, compared to the above-ground tank in S1, the volume of rainwater used for designated domestic purposes increased slightly. Comparing the two tanks with the same defined economic purpose (watering plants within the building), it can be observed that there was a difference of 1.5%. Thus, from the householder's point of view, one can't quite see the point of installing a more expensive underground tank when rainwater would only be used for watering plants. However, for another purpose, i.e. flushing toilets (S4), there is a need to install an underground tank, as the volume of water used is many times greater. The volume of water used to meet the needs specified for a family of four ranged from 48.08 to 52.57 m^3, allowing a *WSE* of 86.4–94.8%. Of course, for such a target, it should be remembered that rainwater requires pre-treatment before use, and the household sanitary system must be made dual, which makes the entire installation more expensive from the householder's point of view. Thus, despite the high potential for using rainwater for this purpose, investment and operating costs may be a barrier to this type of development. However, this issue requires separate analyses, which are beyond the scope of those presented in this article.

Based on the results of the analysis of the total balance of inflow and outflow of rainwater, it is clear that a significant volume of rainwater from the tanks, despite the accomplishment of the assumed economic purposes, must be discharged through an overflow into the sewer system or otherwise managed on the property (Figs. 2, 3). In this situation, the installation of an above-ground tank is an investment that does not solve the problem of rainwater management on the property. In the current legal regulations, it is the owner's duty to safely capture rainwater and/or discharge it off the property into a sewer system. In the absence of a sewer system, it is the obligation of the property owner to manage runoff locally (within the boundaries of the property). Investment in an aboveground tank and used *RW* for watering greenery (S1) or watering greenery and cleaning work (S2) forces the householder to drain the excess runoff volumes from the remaining drain gutters in an alternative way. Assuming the same purpose of using the harvested *RW*, when installing an underground tank (S3), provision must also be made for draining the excess inflow *RW* volumes into the tank. The volume of unaccommodated *RW* in the retention tank can be discharged, for example, to retention-infiltration boxes, rain gardens or other systems that allow local management of runoff, and only eventually consider overflow to the sewer system. While in the case of using *in-situ* runoff management systems, the owner is acting in accordance with the principle of sustainable rainwater management, by discharging runoff in the traditional way into the sewer system, it does not contribute to relieving the burden on technical infrastructure systems and protecting cities from urban flooding. The rate of *RW* utilisation was satisfactory (42.94–71.02%), assuming daily demand and a large capacity tank accumulating *RW* from the roof (as was the case in the S4 scenario).

CONCLUSIONS

1. Analyses conducted for 2019–2021 showed that water saving potential and overall efficiency varied depending on the type and size of the tank, the economic purpose (water demand), and the amount and irregularity of precipitation.
2. In the case of aboveground tanks of relatively small capacity (commonly used in practice in not only Polish, but also European conditions), there are large losses of rainwater, as runoff from the entire roof area is much larger than the storage capacity of such tanks. The demonstrated runoff reduction rate in 2019–2021 for the aboveground tank was from four to about 7% per year. Nevertheless, from the owner's point of view, this is a desirable solution, since the degree of rainwater coverage of water requirements for watering plants and cleaning work amounted to 62.0–81.3%. For these reasons, above-ground tanks for local retention with a relatively small capacity and market price can serve as a way to cover the demand for rainwater used outdoors on private properties, but also as a tool to raise the environmental awareness of residents and increase their sense of responsibility for the use of available water resources.
3. The investment in an underground tank is justified both from the point of view of the householder's interest and from the environmental point of view in the case of daily water demand. Such a situation occurred in the S4 scenario. Householders were able to meet 86.4–94.8% of their water needs with rainwater. Thus, only a small percentage (5.2–13.6%) of the demand had to be met with tap water. In this scenario, also the smallest volume of rainwater of all scenarios had to be discharged through an overflow (29.0–57.1%). The rainwater utilisation of 42.9–71.0% can be regarded as a good potential for relieving the burden on sewerage systems, provided that such installations are used on a larger scale in cities.
4. The highest potential for rainwater use (water saving potential) was observed in 2019. This was due to the fact that precipitation was fairly evenly distributed, especially during the growing season of plants, where water demand was highest. Hence, the balance between inflow and outflow of water translated into a lower volume of overflows from the tank, and thus a lower volume of "lost" rainwater. Coverage of water demand, with rainwater, ranged from 78.3% for the S1 V1 scenario to 100% for S3 V1 and V2.
5. There was no need to draw tap water in the S3 scenario in 2019–2021, as the applied capacity of the underground tank made it possible to store enough volume of rainwater to cover the total (100%) water demand for plant watering.
6. Local retention should be applied in cities on a larger scale, especially since in recent years there are more and more areas with single-family housing. This is the only way to think nowadays about rainwater management in cities in a sustainable way, respecting water resources in the currently observed water-climate crisis.

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CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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