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# Water savings and reduction of costs through the use of a dual water supply system in a sports facility

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ABSTRACT

In sustainable urban management, rainwater, greywater, and groundwater are increasingly being considered as alternative water sources where quality drinking water is not required for the water supply. Current technological solutions allow for the use of dual water supply systems in both private and public buildings. The latter, due to the potential to better manage an alternative water source in a sustainable manner, are recommended for larger scale use. In this article, the function of a dual water supply system operating in a sports facility, including the collection and use of rainwater for non-potable purposes, was evaluated on the basis of technical, quantitative and financial data. The analyses were performed to determine the facility's water savings efficiency and cost reduction during period of 3 years. The results of the research prove that it is possible to manage rainwater for the benefit of the environment and achieve financial gain as a result of savings on charges for water from the municipal water supply and sewage disposal. While the findings of this study should encourage the use of rainwater in sports facilities, they also point to the need for properly designed of water storage tanks to maximise system efficiency.

## 1. Introduction

Water is an essential and multifunctional resource in the context of the urban economy. The rapid growth of urbanization worldwide, focusing on centralized and single-purpose urban water infrastructures, has led to a large portion of water resources being used by cities (Lewandowska & Szymańska, 2021; van Dijk, Lounsbury, Hoekstra, & Wang, 2020). In addition, forecasts of climate change, increasing pollution of fresh water resources, dwindling drinking water resources and growing a demand for them, point to the need to adopt measures to reduce water consumption (Kubicz, Pawełczyk, & Lochyński, 2018; Fialkiewicz et al., 2018; Haque, Rahman, & Samali, 2016; Li, Hai, Han, Mao, & Tian, 2020). On the other hand, cities can be seen as producers of secondary (their own) resources (rainwater, greywater). According to Agudelo-Vera, Leduc, Mels, and Rijnaarts (2012), these urban resources indeed comprise the key element of any future city design towards more resilient and selfsufficient cities. Therefore, contemporary debates on water management emphasise the need to implement solutions that contribute to a more sustainable management of urban resources. In sustainable cities, rainwater is treated not as a threat and problem to be solved, but as a valuable resource that should be included in circuits connecting sources and demand, intended to serve both residents and the urban environments. Preferred actions in this regard include investment in a decentralised multifunctional infrastructure (Gómez & Teixeira, 2017). Such infrastructure includes, among other things, dual water supply systems, that involve rainwater harvesting (Salimi & Al-Ghamdi, 2020). Rainwater harvesting furnishes water supply, acts as a substitute for high quality drinking water used for non-drinking purposes and reduces stormwater runoff as well as pollution of water bodies in cities. In analysing the impact of rainwater harvesting on urban flood risk, Jamali, Bach, and Deletic (2020) showed that extensive implementation of rain water tanks in the city can reduce flood costs up to approximately 30 %. The use of tap water for purposes that do not require drinking water, as in toilet flushing, cleaning of pavement, watering lawns and gardens, is neither environmentally nor economically justified. Therefore, rainwater, greywater, or even groundwater (Lani, Syafiuddin, Yusop, Adam, & Amin, 2018) can all be considered as alternative water resources given their wide range of uses. For these reasons, comprehensive solutions for the frugal use of drinking water, such as dual water supply systems, have become increasingly popular in recent years. This

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dual supply might be termed "potable" supply and "non-potable" supply. In the literature, despite the same assumption (dual supply), there are different definitions of these systems. Thus, Nguyen and Han (2014) considered the dual water distribution system as one consisting of both rainwater and groundwater. Dual water distribution systems in China refer to typical drinking water and high quality drinking water that are each supplied through separate pipe networks (Yang, Shen, Chen, Zeng, & Zhong, 2007). For the purposes of this article, a dual water supply system is defined as one consisting of both a public water network and an onsite rainwater harvesting system that provide sustainable water for potable and non-potable purposes, respectively.

The wide range of technological possibilities for water recovery allows for the application of this technology in both single- and multi-family buildings, public facilities, industrial plants, airports, and others. Due to its good quality and accessibility, rainwater is one of the most used sources of non-potable water (Ali, Zhang, & Yue, 2020; Imteaz, Shanableh, Rahman, & Ahsan, 2011). Rainwater harvesting is an important way of optimizing the usage of water resources and promoting sustainable development (Campos Cardoso, Cavalcante Blanco, & Duarte, 2020; Ghisi, Tavares, da, & Rocha, 2009). van Dijk et al. (2020) claimed that when strategically designed, financed, and implemented on a wider scale rainwater harvesting systems can meet infrastructure development needs for water supply and stormwater management. The use of rainwater harvesting systems (RWHS) for the protection of natural water resources can be seen as a response to the Sustainable Development Goals adopted by the United Nations General Assembly in 2015 [WWAP (United Nations World Water Assessment Programme), 2015]. The concept of sustainable development, including water management, is also referred to in the most important legislative documents at the national level, including the Polish Water Law Act (Journal of Laws 2017, item 1566) and the Polish Environmental Protection Law, 2001. Furthermore, rainwater harvesting systems are also considered a part of sustainable storm water management strategies, as implemented in many countries, e.g., Sustainable Drainage System (SuDS), the Sponge City, and Low Impact Development (LID) (Pour, Wahab, Shahid, Asaduzzaman, & Dewan, 2020).

A rainwater harvesting system consists of three basic elements: a collection area, storage facilities, and a conveyance system. A rainwater harvesting system is simpler to make than a greywater recovery system, and as a result, a rainwater harvesting system is usually a cheaper solution. As rain falls periodically and unevenly, not to mention the difficulty of predicting its quantity and intensity, it is thus necessary to build large storage tanks. Greywater, on the other hand, is obtained constantly, which allows access to it on a regular basis. Despite these inconveniences, the use of rainwater for economic purposes seems promising. This is due to the increase in charges for tap water and sewage collection, which thus increases the profitability of using rainwater. Additionally, worth noting, is that dual installations do not reduce the comfort of water use. No less important is the argument for the protection of water resources, which is becoming increasingly important in a society with growing pro-ecological awareness. In particular, positively evaluated by investors are the systems used in large-area facilities, e.g., sports facilities, commercial facilities, or airports, where a large amount of water is consumed. Therefore, it is important to define the measurable benefits, i.e., reduction in tap water consumption and economic dimensions, achieved as a result of applying pro-ecological solutions. The literature shows different levels of water saving efficiency when using rainwater harvesting systems. As the research shows, the efficiency range can be from 17 % to 100 % (Ali et al., 2020; Muthukumaran, Baskaran, & Sexton, 2011; Palla, Gnecco, Lanza, & La Barbera, 2012; van Dijk et al., 2020). In the aforesaid studies, water saving efficiency is defined as the water supplied by the rainwater harvesting system divided by the sum of water demand for the period under consideration. Such a large span in the scope of water savings efficiency results from at diversification of climate zone, rainfall event characteristics, roof type, roof slope, surface from which rainwater is collected, water consumption in buildings, building type, etc. The evaluation of the financial profitability of rainwater harvesting systems considers various aspects. Domènech and Saurí (2011); Matos, Bentes, Santos, Imteaz, and Pereira (2015) and Sousa, Silva, and Meireles (2018) assessed the financial viability of RWHS by means of the payback period. In a study by Juliana, Kusuma, Cahyono, Kardhana, and Martokusumo (2017), the construction, installation, maintenance, and operational costs were taken into account. Lani et al. (2018), in their evaluation of the economic benefits of the RWHS used several economic indicators, including percentage of reliability, return on investment, net present value, and benefit-cost ratio. Zhang, Polyakov, Fogarty, and Pannell (2015) used the hedonic price method to show the influence of a rainwater harvesting system on the real estate value. A significant number of studies have confirmed the potential of rainwater harvesting as an alternative source to potable water. However, most of them refer to the functioning of these systems at a household scale (Haque et al., 2016; Kolavani & Kolavani, 2020; Palla, Gnecco, & La Barbera, 2017; Sheikh, 2020). Research on efficiency in terms of the functioning of investments on a larger scale, which is periodically used by several hundred recipients, is still very limited. There is a potential to use rainwater harvesting systems specifically for large-scale buildings. These buildings offer large catchment areas (roof surface), from which rainwater is discharged to retention tanks. In large-area facilities, water consumption is usually high, which requires managers of these facilities to pay high water bills on a monthly basis. One of the main reasons for this knowledge gap is probably the lack of realistic data from water management monitoring in such facilities. These empirical data on system operation are needed, for instance, to optimize the design of rainwater tanks and allow for improved modeling by taking into account the multiple objectives of rainwater harvesting systems including water saving and stormwater management (Campisano et al., 2017; Şahin & Manioğlu, 2019). The lack of information on the potential benefits of rainwater harvesting systems and their water savings efficiency has discouraged city dwellers and decision makers from adopting these systems. According to Imteaz et al. (2011), a proper analysis of rainwater harvesting systems' effectiveness while paying attention to finding an appropriate design for the storage capacity of rainwater retention tanks would amplify the benefits of these systems, thereby raising the level of acceptance and confidence in the use of rainwater within the community. In Europe, rainwater harvesting systems are being installed in many countries even though studies on their performance are still scarce and mostly based on hypothetical cases exploring the environmental and water reduction aspects (Geraldi & Ghisi, 2017; Lopes, Marques, Dornelles, & Medellin-Azuara, 2017; Palla et al., 2012). The purpose of this study is to quantify the potential of harvesting water through assessment of the real possibilities of using rainwater for utility purposes with reference to a dual water supply system operating in a sports facility. As part of the research, water saving efficiency calculations were made and the annual rainwater retention rate was determined. Additionally, the impact of the amount of precipitation on the possibility of rainwater retention was analyzed while financial savings (reduction in water bills) resulting from a rationed management of rainwater in the facility were determined. It is expected that the results of the research will allow the environmental and economic benefits of dual water supply systems in a sports facility to be made known and thus contribute to the adoption of rainwater harvesting practices in cities. Furthermore, the study results could also be helpful to designers dealing with the optimization of system configuration using rainwater (proper tank storage capacity according to the amount of rainfall and water consumption patterns) in sports facilities.

## 2. Research methodology

### 2.1. Case study

The sports facility is located in south-western Poland. It was built as a

Euro 2012 facility. The area of the stadium plot is just over 164,000 $m^2$ while the facility building rises to about 39 m. The pitch, which has an area of 7140 $m^2$ is covered with natural grass. The stadium has a capacity over 47,000 covered seats and offers 9000 $m^2$ of space for rent in addition to sports and cultural events that are organised there. In the analysed years, the premises were rented by 17 companies employing a total of approximately 500 people. Due to the great interest in the facility, the stadium also organises guided tours for individuals or groups. According to facility managers, approximately 3000 people visited the stadium each day in the period 2014–2016. The facility has a dual water supply system. Water is supplied to the stadium building from the external public water network and is used in toilets to supply washbasins and flush toilets, showers and in catering kiosks (washbasins, sinks, catering equipment), as well as in medical rooms if necessary. In addition, the facility has 4 rainwater retention tanks with a total volume of 1297.3 $m^3$, of which 60 % is permanently reserved for rainwater (778.38 $m^3$). The rainwater runoff is collected from the roof over the crown of the stadium, with an area of 38 141 $m^2$. Drainage of the roof is carried out in a vacuum system. In case of lack of rainwater in the tank, it is possible to supplement it with groundwater. The water replenishment system works automatically. Rainwater surplus is directed through emergency overflows to the external sewage system. The system is equipped with water meters that measure the amount of stored rainwater, the amount taken from the groundwater, and the amount of mains water supplied to the rainwater control unit when necessary. The water stored in the tanks is treated as non-potable water and is used for flushing toilets and urinals as well as for watering the turf. The stadium's water supply system, is presented in Fig. 1.

### 2.2. Characteristics of meteorological conditions

The stadium is located in a temperate transitional climate zone. This climate is influenced by both oceanic and continental air masses. The average value of the air temperature for the multiannual period (1971–2000) is 8.7 °C. According to one report (Central Statistical Office, 2019), the warmest month of the year is July while the coldest month is January. The annual precipitation for the multiannual period (1971–2000) is 569 mm. In recent years, the range of annual precipitation sums varied greatly, with the highest precipitation usually recorded in the summer months. The annual sum of precipitation was 624.8 mm in 2014, 451.7 mm in 2015, and 853.3 mm in 2016. A comparison of monthly precipitation levels for the period 2014–2016 against the multiannual period 1971–2000 is presented in Fig. 2. Monthly precipitation levels for the period 2014–2016 were obtained from the Provincial Environmental Protection Inspectorate, while monthly sums of multiannual precipitation were based on data published by the Central Statistical Office (2019).

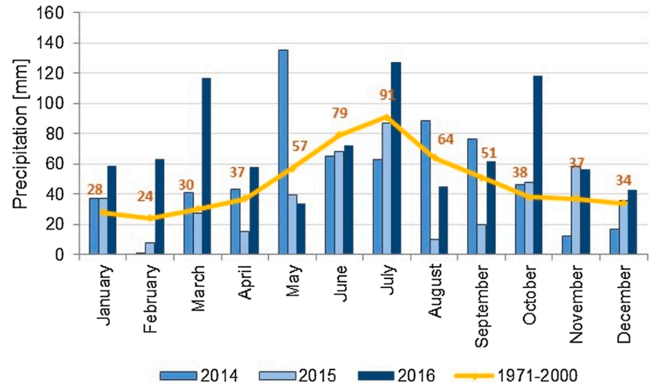


**Fig. 2.** Monthly sum of precipitation for the period 2014–2016 vs multiannual period 1971–2000.

### 2.3. Water and cost reduction

The analysis of possibile ways to reduce water consumption using alternative sources of water supply to the aforesaid facility was performed on the basis of data received from the facility management company. The calculations were based on the following assumptions: 1. The amount of water from the water supply system used by the athletes to shower, as well as for washing dishes and preparing meals in catering outlets located on the premises of the facility was the same with or without the rainwater retention tanks. Since, for these purposes, it was necessary to use water from the municipal water supply system (with potable water properties) 2. The consumption of rainwater and groundwater from one's own intake for flushing toilets and watering the turf is equal to the amount of water stored in the tanks; 3. The volume of sewage discharged is equal to the total consumption of tap water for all the above purposes and the amount of water stored in tanks used for flushing the toilets; 4. The use of water for irrigating the turf is unrelated to sewage discharged to the sewer system.

The water saving efficiency is defined as the ratio of the total annual amount of water supplied from the rainwater tanks and groundwater intake to the total amount of water demand (Ali et al., 2020; Haque et al., 2016). The study also defined the annual rainwater retention rate in the facility, in terms the ratio of the total annual volume of rainwater accumulated in the tanks (the difference between the volume of rainwater runoff from the roof and the volume of water discharged through the overflow to the sewer system) to the total volume of rainwater runoff that occurred during rainfall in a given year. This indicator determines the actual volume of rainwater that was used for utility purposes in the analyzed facility. A correlation analysis using the Statistica software was carried out to assess the relationship between the precipitation level and the volume of water reaching the overflow. The level of linear dependence between the examined variables was determined by means of the Pearson coefficient. The value of the correlation coefficient is in the

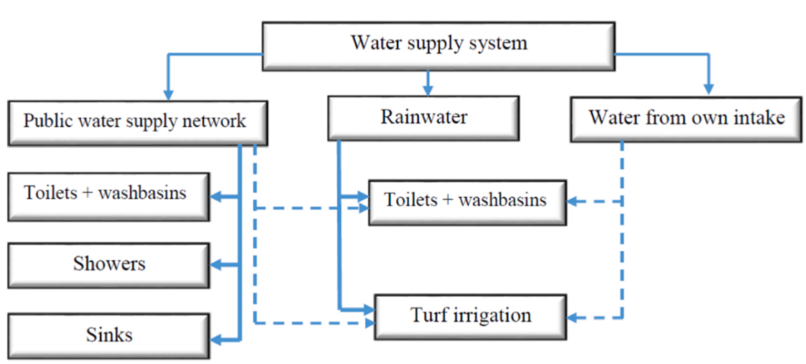


**Fig. 1.** Water supply system in the sports facility (own elaboration).

closed range of [-1, 1]. The higher its absolute value, the stronger is the linear dependence between the variables.

To determine any saving (water cost reduction), the water and sewage prices valid for the analyzed period were used, on the basis of which invoices were issued to the company by the water supply and sewage company. The analyses were carried out on a monthly basis for the period 2014–2016. At the end of each month, the total volume of rainwater used for domestic purposes as well as the amount of water taken from the water supply system and from the groundwater intake located in the stadium area were compared. The toilets, showers and catering outlets are the sources of sanitary sewage in the stadium area. The amount of sewage discharged was accepted on the basis of invoices issued to the company managing the stadium by the water supply company. The cost reduction was determined after taking into account two variants: 1. The real situation that currently prevails in the stadium (selected non-food purposes, i.e., flushing of toilets and irrigating the turf using water supplied by the rainwater tank, with the rest being supplied from the public water supply network); and 2. Assuming there is no dual installation in the facility, i.e., all water consumed in the stadium is supplied by the public water supply network. The difference in water and sewage bills/public water supply cost between variant 1 and variant 2 represents the financial saving for the month. Converted from Polish zloty (PLN) to Euro, the average currency data from 07/2020 to 8/2020: 1 PLN is equal to 0.22 Euro.

## 3. Results and discussion

### *3.1. The facility water consumption*

Fig. 3a–d show the consumption of tap water and rainwater over a period of 3 years (2014–2016) at a sports facility. In 2014 (Fig. 3a), the highest consumption of tap water occured in June and amounted to 611 $m^3$ while the lowest consumption was in January (206 $m^3$). On the other hand, the month in which the largest volume of rainwater was used in facility premises (for toilet flushing and turf irrigation) was March (1647 $m^3$). The least amount of rainwater used for domestic purposes in 2014 was in July (459 $m^3$). In 2015 (Fig. 3b), the consumption of tap water was higher than in 2014. Water taken from the water supply system was highest in the months of May (1196 $m^3$) and November (1065 $m^3$), with the lowest use in January (167 $m^3$). Rainwater was also used at the most in May (971 $m^3$) and at the least in January (474 $m^3$). In 2016 (Fig. 3c), most water was used in July (995.2 $m^3$) and November (839 $m^3$), with the least use in January (480 $m^3$). In the case of rainwater, most of the water was used in July (912 $m^3$), with the least use in October (403 $m^3$). Fig. 3d shows the consumption of tap water and rainwater for individual years of the analysed period. The least water was used in 2014 (4188 $m^3$ of tap water and 8484 $m^3$ of rainwater). The years 2015–2016 were similar in terms of total water consumption (15,974 $m^3$ in 2015 and 15,497 $m^3$ in 2016). In 2016, however, the amount of rainwater used was higher (8329 $m^3$) compared to 2015 (8096 $m^3$). In case of a lack of rainwater in the tanks (e.g., during long periods without rain), water

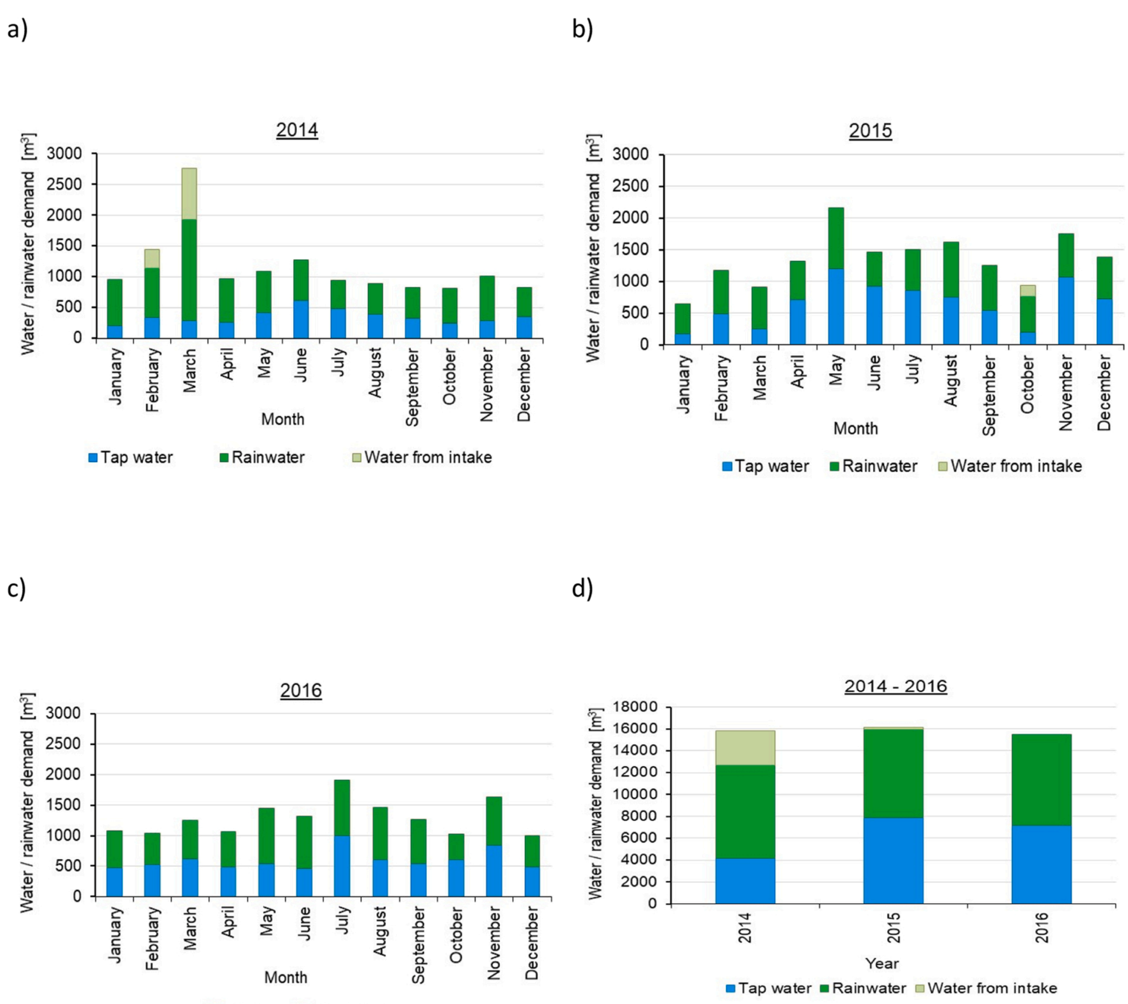


**Fig. 3.** Water consumption for utility purposes in a sports facility: a-c) in individual months, d) in the period 2014–2016.

was drawn from a groundwater intake into the tanks and only from there was it used for flushing toilets and watering the turf. In 2014 and 2015, it was necessary to use the groundwater, 1142.21 $m^3$ and 160.61 $m^3$, respectively. In 2016, it was sufficient to collect the runoff from the roof (without taking water from the intake) and distribute it for use throughout the facility.

Overall, rainwater consumption was highest in 2014 and lowest in 2015. For tap water, the situation was the opposite. Tap water consumption was highest in 2015 and lowest in 2014. The aforesaid difference between rainwater and tap water consumption reflects the precipitation levels in these two years, in other words the highest tap water consumption was observed in 2015, which was the year with the lowest precipitation level. 2016 was a year with an "intermediate" level in terms of both tap water consumption and the level of rainfall. It is worth noting that the periodically high (higher than in other months of the year) tap water consumption (e.g., March 2014) is mainly influenced by the scheduling of sports and cultural events at the stadium. At that time, the number of people in the facility usually exceeded the average number of people using the sanitary facilities during days free of such events. As far as groundwater is concerned, the volume to be used is based primarily on decisions made by the facility managers. By analysing rainwater consumption in detail, taking into account the purpose for which rainwater was used (Fig. 4), it is clear that this water was mainly used for flushing toilets and, to a lesser extent, for irrigating the turf. This is due to the high demand for water by the aforementioned purposes, but also due most probably to the prevailing weather conditions. From the analyses of individual years, it can be concluded that toilet flushing was the dominant form of consumption (approximately 50–80 %) in years with high amounts of rainfall, i.e., in 2014 and 2016. In the dry year (2015), the water accumulated in the tanks in most months of the year was mainly used to irrigate the turf and, to a lesser extent, to flush the toilets. The exception is the period May-July 2014, when the rainfall was high, so the irrigation of the turf was organized in a natural way (supplied directly from precipitation), while the water accumulated in tanks was used to flush toilets. The use of rainwater to irrigate the turf, assuming that this activity did not generate outflows to the sewage system, allowed for a reduction in rainwater runoff of 13.0 % in 2014, 22.1 % in 2015, and 7.6 % in 2016. In other words, this amount of rainwater could be managed on-site without unnecessary dischange to the sewage system.

### 3.2. *Water saving efficiency and the annual rainwater retention rate*

The system’s water saving efficiency in the facility, taking into

**Table 1**
Water saving efficiency for individual months and in relation to the entire year in the analysed period 2014–2016.

| Month/Year | 2014 | 2015 | 2016 |
|---|---|---|---|
| January | 79 % | 74 % | 55 % |
| February | 77 % | 59 % | 50 % |
| March | 90 % | 72 % | 51 % |
| April | 74 % | 46 % | 55 % |
| May | 62 % | 45 % | 63 % |
| June | 52 % | 37 % | 65 % |
| July | 49 % | 43 % | 48 % |
| August | 57 % | 53 % | 59 % |
| September | 61 % | 57 % | 57 % |
| October | 69 % | 79 % | 42 % |
| November | 71 % | 39 % | 49 % |
| December | 57 % | 48 % | 51 % |
| Total | 70 % | 51 % | 54 % |

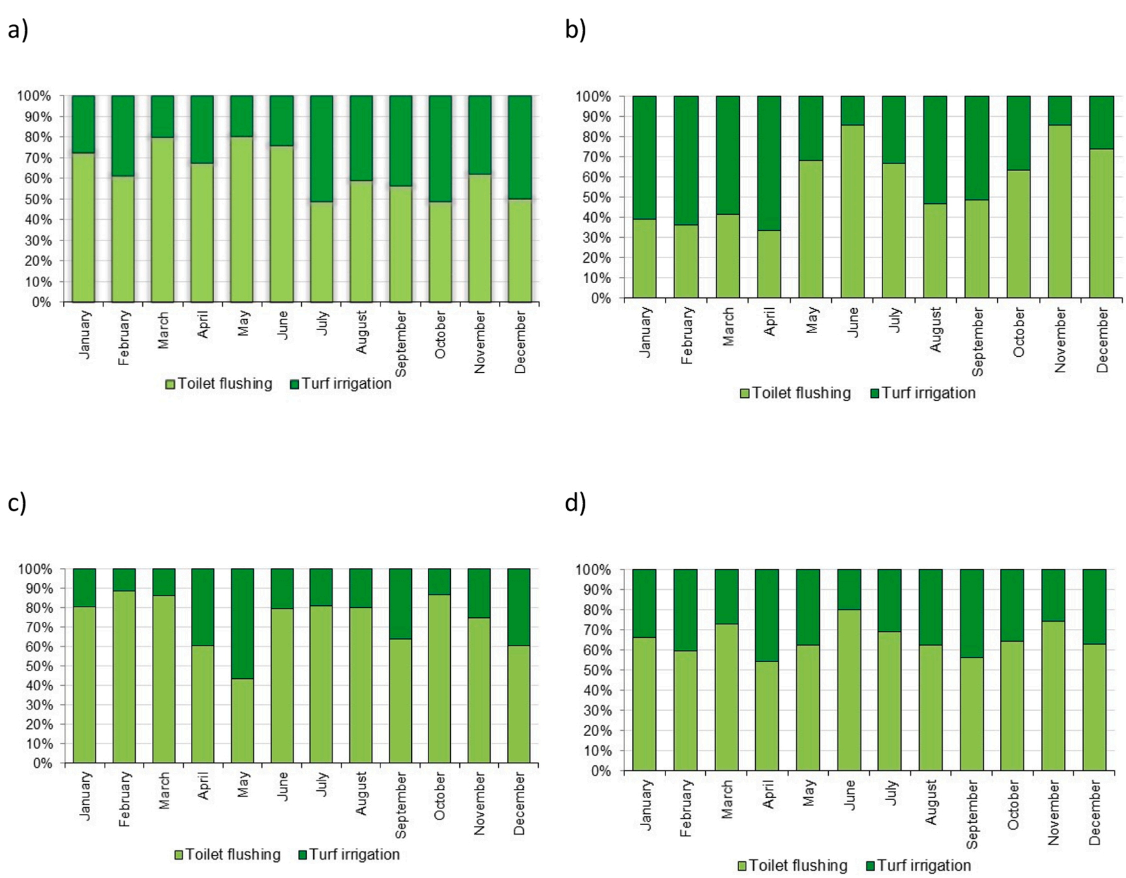


**Fig. 4.** Breakdown of water consumption by toilet flushing and turf irrigation and their share in monthly rainwater consumption: a) in 2014, b) in 2015, c) in 2016, d) in 2014–2016.

account the occasional water supply from the groundwater intake, was over 50 % in each of the analysed years (Table 1). However, the values of this parameter in individual months of the year were quite diverse. They ranged from 37 % (in June 2015) to even 90 % (in March 2014). The diversity of water saving efficiency had resulted from the different demands for water on a monthly basis, as well as the different levels of rainfall, that could be retained over time.

The accumulated water in the tanks (rainwater and periodically supplied with groundwater from the intake) made it possible to cover 70 % of the total water consumption in the facility in 2014, 54 % in 2016, and only slightly less in 2015 (51 %). The difference in results (approximately 16–19 %) obtained for the years 2014 and 2015 and 2016 may be explained by the use of groundwater from the facility's own intake in 2014. This water, together with rainwater, were taken into account in the calculation of system efficiency as being an alternative source of water to water from the municipal water supply system.

It is also worth noting that despite the lower amount of rainfall (by 47 %) in 2015 compared to 2016, the efficiency of the system decreased only slightly (by 3 %). It follows then that not all rainwater could be collected in the tanks installed in the facility. A significant part of the water was channelled through an overflow before being directed to the sewage system. The reason for this is that the capacity of the tanks was too small, hence incapable of retaining the entire volume of roof runoff during heavy rainfall. The least water was directed to the overflow in 2015, while the most water was directed through the overflow to the sewage system in 2016 (Fig. 5).

The results of the calculation of the annual rainwater retention rate in the facility, expressing the percentage share of the amount of rainwater retention in the tank to the total volume of roof runoff, showed that this parameter assumed its highest values for the year 2015 which amounted to 52 %, was slightly lower (40 %) for the year 2014, was lowest in 2016 (28 %) (Fig. 5). This means that such a percentage of rainwater was actually stored in the tanks and then used in the facility for utility purposes. The above calculations indicate a decrease in the rate of rainwater utilisation along with an increase in annual rainfall; in other words, here being observed is an increase in the volume of unused rainwater in the facility (considered as potential losses). The relation between the amount of rainfall and the volume of water going into the overflow is also confirmed by the correlation results between these parameters. The graphical interpretation of the correlation is what has become known as the so-called scatter plot, presented in Fig. 6 by means of the Statistica software.In this analysis the coefficient determining the level of linear dependence between the examined variables (Pearson's coefficient) was 0.9716, which indicates a strong positive correlation. The higher the amount of precipitation in a given month, the higher is the amount of water flowing through the overflow to the sewage system. Thus, the possibility of using rainwater in the facility would decrease.

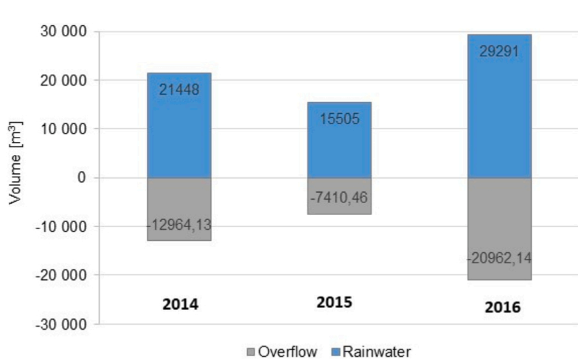


**Fig. 5.** Volumes of rainwater taken from the roof and discharged through an overflow to the sewage system in individual years of analysis.

### 3.3. Water cost savings

Fig. 7a–d shows the costs of charges incurred for water supply and sewage disposal for the three-year period of 3 years 2014–2016, including the accumulated rainwater and occasionally, water taken from the intake located in the area (current situation). The unit fee for each $m^3$ of water taken was in the range of 4.15 PLN-Polish zloty (0.93 €) to 4.48 PLN (1.01 €) while for sewage disposal it was 4.69 PLN (1.05 €) to 5.51 PLN (1.24 €). To present the reduction in charges on this account, the potential costs which the company would have to incur if the water and sewage management was based solely on the municipal water supply system (without the use of rainwater and from the intake) were also calculated. The compilation of these statements was based on data concerning the amount of water used from the municipal system, rainwater and groundwater from own intake in a given month over a period of 3 years (2014–2016). In the analyzed years, when using water from its own intake the company did not incur any charges on this account. Therefore, the calculations took into account the tariffs for water and sewage disposal in force in the analysed period, established by the water supply and sewage company, which issues invoices to the company. When determining reduction in the total water and waste water charge, also taken into account was the fact that in the case of rainwater intake for flushing, the reduction in charges can only be assumed for the tap water charge, while the waste water charge remains unchanged compared to option 1. In this case, despite the possibility of replacing tap water with rainwater, wastewater is generated and discharged into the sewage system. On the other hand, when using rainwater to irrigate the turf, the charges for sewage discharged were not taken into account in both analysed variants, as water infiltrates deep into the ground in this case.

Fig. 7a shows the costs of water consumption and sewage disposal in 2014. The highest fees were incurred in March which amounted to PLN 18,312.0 (€ 4111.4), while the lowest fees were paid in December (PLN 3,811.0/€ 855.6). If rainwater and occasionally water from the company's own intake had not been used, these costs would have increased significantly. For the above months, they would have amounted to PLN 30,233.0 (€ 6787.9) in March and PLN 6,925.9 (€ 1555.0) in December. Thanks to the use of alternative water sources, the reduction in costs for the aforementioned fees in particular months was between 32 % and 50 %. In 2015 (Fig. 7b), the company incurred the highest fees in May (PLN 17,072.4/3833.1 €) and November (PLN 13,664.9/3068.0 €). These fees were still lower by PLN 5561.1 (€ 12488.6) in May and PLN 3,359.2 (€ 754.2) in November compared to those that the company would have had to pay without using rainwater and water from the intake. The reduction in fees for individual months ranged from 24 % to 57 %. In 2016 (Fig. 7c), the company used water from the municipal water supply system as well as rainwater. In that year, there was no need to supplement the tanks with additional water from the company's own intake. A comparison of the two cost variants (actual use including rainwater) and hypothetical (without the use of ground or rainwater) showed that by collecting the roof runoff and using it to flush the toilet and irrigate the turf, the company had managed to save between 25 % and 51 % of the water and wastewater charges. A comparison of costs for each year showed that savings through the use of alternative water sources amount to approximately 50,000 PLN (€ 11,225.9). On average, the annual water cost reduction was 41 %, 39 %, and 33 % in 2014, 2015, and 2016 respectively (Fig. 7d). Thanks to the retention and use of rainwater instead of tap water for utility purposes, i.e., toilet flushing and turf irrigation, the sports stadium has saved PLN 154,250.8 (€ 34,632.7) on charges for water supply and sewage disposal over the three years analysed (2014–2016).

Overall, the research results showed that the utilization of rainwater and groundwater (from time to time) as a supplement to the public water supply may have considerable benefits for the owner and environment, including reducing the water bills and pressure on the existing water resources and resource preservation. The main factors affecting

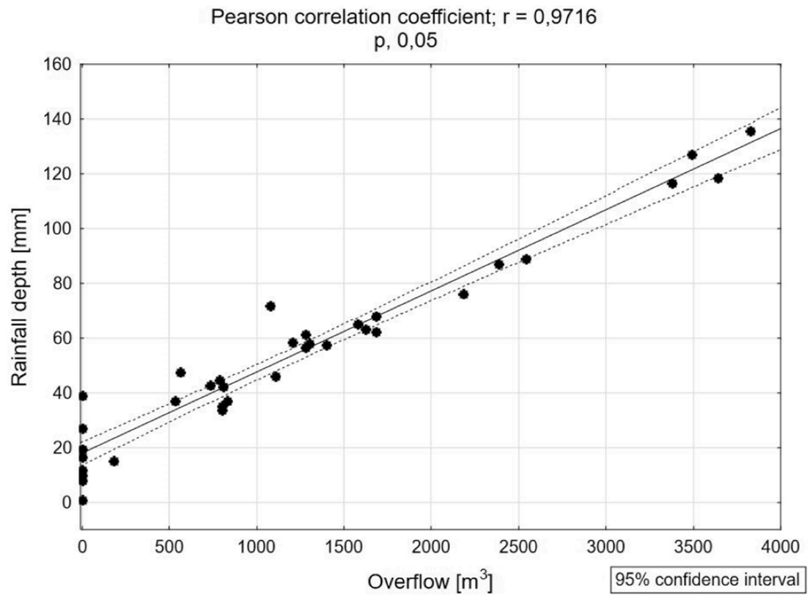


**Fig. 6.** Scatter plot of monthly rainfall depth and overflow for the 2014-2016 period.

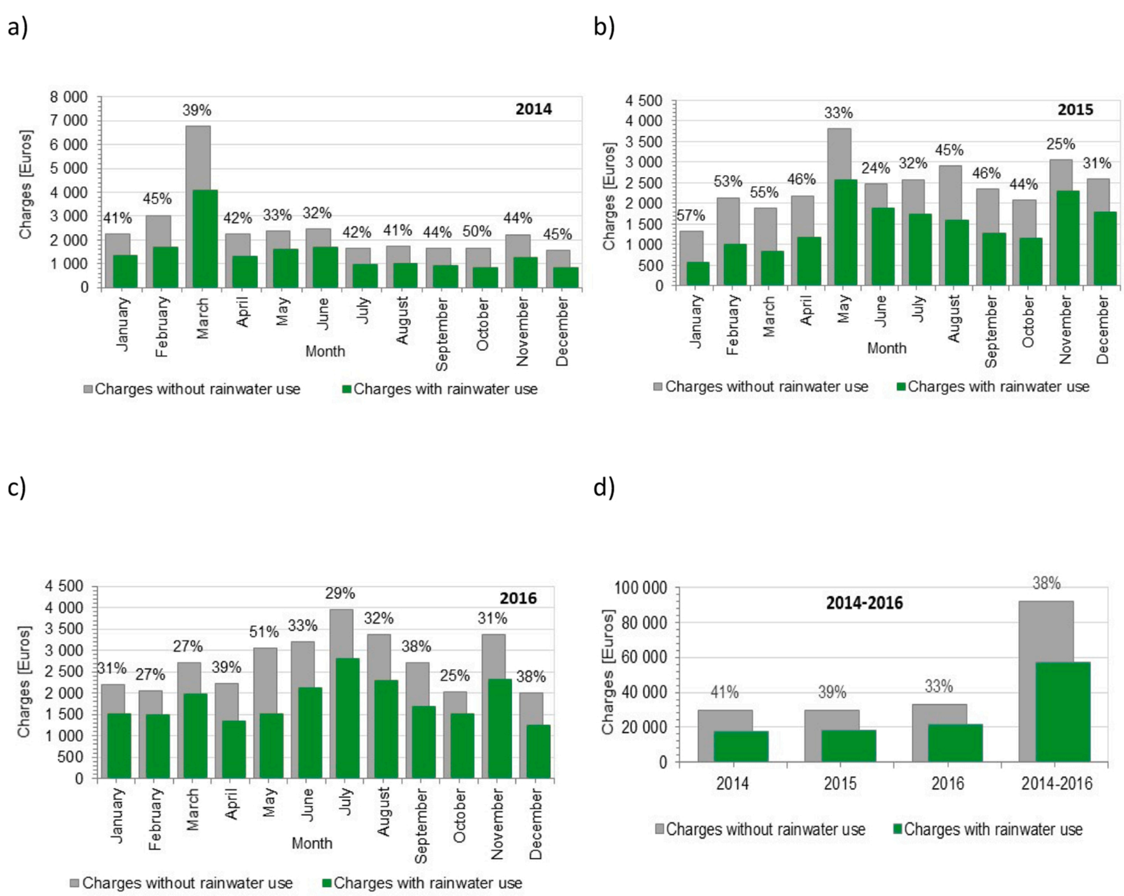


**Fig. 7.** Comparison (in %) of reduction inwater and wastewater bills (Euro, €) with and without rainwater use: a) in 2014; b) in 2015; c) in 2016; d) in 2014-2016 period.

water savings and cost reduction during the operation of rainwater harvesting systems are the amount (particulary the regularity of rainfall on a given site), the proper selection of tank storage capacity, and the prices for water supply and sewage disposal. Equally important is the level of other charges that managers of such facilities would have to pay or be exempt from demonstrating the use of rainwater on their site. An analysis of the data from the sports facility showed that the water saving efficiency could be even higher if the storage capacity of tanks could handle it. The amount of generated runoff from the roof was higher than that actually used for the facility's utility needs. This is due to the limited capacity of those tanks which, in the case of high rainfall, were not able to retain the entire volume of rainfall for later stage. The research showed that in the years with low sums of precipitation, the amount of rainwater used in the facility compared to its supply during rainfall was high. However, it is worth noting that no system designed for the use of rainwater has been able to absorb 100 % of all runoff. Precipitation, unlike other types of media (tap water or greywater), is characterized by the periodicity of supply with quantitative and spatial diversity. The precipitation that occurs evenly throughout the year is much more favourable. Runoff from torrential rain goes to the sewage system via the overflow, and in the case of long breaks between rainfalls, tap water must be used. Therefore, when designing dual installations, precipitation parameters are adopted, which ensure a satisfactory system efficiency, taking into account the discharge of excess water through an overflow into the sewage system. Larger or extra reservoirs would provide better rainwater efficiency, but would be more expensive to build. Semaan, Day, Garvin, Ramakrishnan, and Pearce (2020), in an analysis conducted on the basis of a systematic literature review of domestic rainwater harvesting systems, identyfied the sizing of storage as the most important objective of optimization, even as sizing for cost is the most frequently implemented outcome of optimization. Additionally, field experience conducted by GhaffarianHoseini, Tookey, GhaffarianHoseini, Yusoff, and Hassan (2016) has shown that although high capacity storage tanks may increase the benefits of rainwater harvesting systems, limited space can often prevent their installation. Therefore, every project, including those made for utilities, must determine the optimal capacity for rainwater tanks that can provide a trade-off between reliability and savings. The literature includes studies in which rules for estimating the optimum tank capacity are proposed (Shadmehri Toosi, Danesh, Ghasemi Tousi, & Doulabian, 2020; Silva, Sousa, & Carvalho, 2015; Zhang, Zhang, Yue, & Jing, 2019).

Currently, in most cases at least, the only economic benefit of using these systems is a reduction in tap water consumption, and thus a reduction in fees from the municipal network and discharge into the sewage system. The conducted analyses showed that with the current fees, the facility can save as much as PLN 50,000 (€ 11,225.9) per year by managing rainwater in a sustainable manner. As these charges are likely to continue to increase in the foreseeable future, the use of rainwater systems could increasingly become economically attractive. In addition, reductions in fees for the discharge of rainwater to the sewage system, commonly used in many countries and calculated on the basis of the size of the sealed surface connected to the sewage system, may be an additional incentive for the use of rainwater systems. The possibility for partial financing of the construction of a dual installation would shorten the investment payback period, which would also certainly contribute to popularizing these pro-ecological solutions. Therefore, it is important to ensure adequate support from the state, as well as help from local governments in seeking funds for this purpose. The environmental benefits from implementing such systems are usually not weighed up in terms of financial benefits. However, they are an important element of environmental protection, even if it can a difficult argument in talks aimed at convincing investors about the advisability of using such a dual system. To appreciate the importance of those environmental benefits, environmental education of society at large, but above all decision-makers, investors, and designers has become a necessity. Making them regularly aware of the need to protect and ration the use of water resources may translate in the future into a number of installations that will allow for the sustainable management of rainwater. Dual water supply systems are certainly part of such installations.

## 4. Conclusions

Based on technical, quantitative, and financial data (fees for water and sewage), the article assesses the effectiveness of a dual system operating in a sports facility. In this facility, water and sewage management is based on the supply of tap water from the municipal network and the use of alternative water sources (rainwater and occasionally groundwater from its own intake) for utility purposes, that do not require drinking water quality, e.g. flushing toilets and irrigating the turf. The results of the research have shown that this type of technological solution of a pro-ecological nature allows for both the effective use of rainwater and reduction in water and sewage fees for this facility. The highest water saving efficiency (70 %) was achieved in 2014. In turn, the use of rainwater accumulated in water tanks was highest (52 %) in 2015. In the two remaining years of the analysis, in which the amount of total annual precipitation were higher, the possibility of using rainwater decreased, as the retention rate was 40 % for 2014 and 28 % for 2016. These results prove that during high rainfall, the existing tanks were not able to absorb the entire volume of the generated runoff, which meant that rainwater had to be directed through the overflow to the sewage system. This is also confirmed by the demonstrated correlation between the amount of rainfall and the amount of water discharged into the sewage system during rainfall. Retention and economic use of non-potable water resources in the facility contributed to saving up on tap water which brought financial benefits to the facility. In one sports stadium, the use of alternative water sources to supplement the public water supply system allowed for reducing the fees for water supply and sewage disposal by as nuch as 33–41%. On average, in the analysed period, the billed amounts were reduced by 38 %.The use of rainwater management solutions also translates into other profits, including environmental benefits, such as reduction in surface runoff, and thus relief for the sewage systems. The mere use of rainwater for irrigating the turf allowed for a reduction inrunoff by 13 % in 2014, 22 % in 2015, and 7.6 % in 2016. This corresponds to almost 8500 $m^3$ of rainwater being managed at the rainfall site during a period of three years. Despite the fact that in recent years the number of investments that take into account the implementation of dual systems is increasing, the needs in this area are much greater. The increasing prices of the municipal water supply and sewage disposal, as well as the prospect of obligatory charges for rainwater discharged from sealed surfaces into the sewage network, could only mean that these dual systems will become commonly used. Although from the investors' point of view, these are still very costly investments, whose return on investment is long-lasting (even several years), they are nonetheless necessary for strengthening sustainable water management. For these reasons, the help of the state or at least the local authorities, in providing aid in the form of subsidies, tax exemptions, or even technical advice is essential. This aid would go a long way in encouraging investors to put their money behind pro-ecological solutions, as in managing rainwater in a sustainable manner, thereby helping to protect the planet's precious yet limited water resources.

## Declaration of Competing Interest

The authors report no declarations of interest.

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