Chapter 3

The Impact of Rainwater Harvesting System Location on Their Financial Efficiency: A Case Study in Poland

Agnieszka Stec and Daniel Słyś

Abstract Natural water resources of Poland are among the lowest in Europe. In addition, the intensive development of urbanized areas and the associated increase in water demand necessitate the need to look for alternative sources. However, limiting the amount of resources available for use does not go hand in hand with the development of ecological awareness of society, which has the greatest attention still attached to the financial criterion. Considering this, the studies have been conducted to determine the cost-effectiveness of the rainwater harvesting system (RWHS) in a single-family house located in selected Polish cities where rainfall varies in height. Financial analysis for four different variants of the water supply system in the building in question has been done using the Life Cycle Cost (LCC) Methodology. The results show that RWHS financial performance varies widely, but it has also been found that the variant in which rainwater will be used to flush toilets, wash, and water the garden is characterized by the lowest LCC costs irrespective of tank capacity, number of users, and the location of RWHS system. The study also examines the impact of the capacity of the rainwater storage tank on the tap water savings. Depending on the installation variant these savings ranged from 11– 40% for Zakopane, 10–25% for Warsaw and Katowice, and 10–28% for Koszalin.

Keywords Stormwater management · Rainwater harvesting · Sustainable urban drainage · Life cycle cost

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3.1 Introduction

Water is one of the most important environmental resources that determine human existence. However, over the years, freshwater resources have been overexploited due to anthropogenic activities. This has led in many regions of the world to a state in which their quantity and quality are not adequate to ensure proper social and economic development. Existing water shortages, which are caused not only by the poor management of its resources, but also by growing demand, changing climate, and intensive urbanization, are now becoming one of the world's major problems (Li et al. 2010). Climate change, which is the result of natural factors and human activity (Stern and Kaufmann 2014), has influenced precisely the quantity and intensity of precipitation resulting in an increased occurrence of extreme weather events (Kaźmierczak and Kotowski 2014). Significant amounts of water, which, as a result of intense rainfall, fall into a given area in a short time, only slightly supply that part of the water resources that can then be used. Such precipitation, combined with the sealing of the terrain resulting from urbanization, creates intensive surface runoff, which contributes to an increase in flood risk (Todeschini 2016; Lu et al. 2014; Du et al. 2012). Intensity of surface runoff also causes significant hydrological changes in the catchments and hydraulic ones in sewage systems (Pochwat et al. 2017; Kim et al. 2015; Słyś and Stec 2013).

The actions are taken, especially in urban areas, for an introduction and an implementation of sustainable water and wastewater management (Hoang and Fenner 2016; Willuweit and O'Sullivan 2013). This is a strategy whose primary purpose is to maintain water resources in a state of order that is economically and socially possible for present and future generations (Water Frame Directive). The most commonly used "end-of-pipe" rainfall management model is not compatible with this strategy. There is a tendency toward a more integrated and sustainable approach that takes into account the changes in the rainwater flow regime, the protection of natural water resources, and the need to adapt technical infrastructure to modern urban water management standards (Palhegyi 2010; Mitchell 2006; CIRIA 2000). It is implemented, among others, by using facilities and equipment that are part of the sustainable urban drainage system (SUDS) and low impact development (LID) (Campisano et al. 2017; Fletcher et al. 2013). These solutions are based mainly on the processes of retention and infiltration of precipitation into the ground. The use of such objects are retention reservoirs (Starzec et al. 2015; Stec and Słyś 2014; Słyś and Dziopak 2011) green roofs (Burszta-Adamiak and Stec 2017; Poorova et al. 2016; Czemiel-Berndtsson 2010), bio-retention systems, infiltration trenches and basins (Liu et al. 2014; Hirschman et al. 2008; Hatt et al. 2009).

Searching for alternative sources of water, in terms of the rapidly increasing population in the world and the intensification of the urbanization process, is becoming a key issue to ensure the right quantity and quality of water to meet hygienic and human health needs (Ait-Kadi 2016). Nearly 54% of the world's population now lives in urban areas, but it is projected to increase to 66% in 2050 (UN 2014), thus increasing water demand by 55% (OECD 2012). The most urbanized regions in the world are the USA (82%), South America (80%), and Europe (73%). Taking into account that cities absorb almost 70% of the world's resources, the measures are needed to reduce their excessive use. Modern urban water management should be based on sustainable consumption, based not only on available freshwater resources but also on alternative sources of water such as rainwater and gray water (An et al. 2015; Hyde 2013). In recent years, the concept of sustainable homes with reduced demand for water and energy has become increasingly popular (Stec et al. 2017; Kaposztasova et al. 2016; Zelenakova et al. 2014; Stec and Kordana 2015).

Of the possible alternative sources of water, rainwater for hygienic reasons is the most socially acceptable source (Marleni et al. 2015; Hurlimann and Dolnicar 2010). Rainwater harvesting systems have been used all over the world for many years, both for potable and non-potable use (Lopes et al. 2017; Gwenzi et al. 2015; Fewkes 2006). However, in the vast majority of cases, rainwater replaces non-potable water, particularly for toilet flushing (Jones and Hunt 2010; Słyś and Stec 2014; Devkota et al. 2015a), greening and arable fields (Devkota et al. 2015b; Unami et al. 2015; Ghimire et al. 2014), cleaning and laundering work (Morales-Pinzón et al. 2014; Angrill et al. 2012). The effectiveness of these systems depends on many factors, including rainfall, roof size, demand for non-potable water, building type, and tank capacity, which is the main component of RWHS (Vieira et al. 2014; Santos and Taveira-Pinto 2013; Imteaz et al. 2012; Słyś et al. 2012; Ghisi 2010). Commercial rainwater utilization systems are often used in combination with the gray water recycling system, which, due to the uneven distribution of rainfall over the year, has a positive effect on the improvement of the water supply system from alternative water sources (Fonseca et al. 2017; García-Montoya et al. 2015; Morales-Pinzón et al. 2015; Proença and Ghisi 2013).

Rainwater harvesting is not a new technology, but because of the environmental and financial benefits of its use, it is in constant interest among many researchers in the world. In recent years, the cost-effectiveness of using rainwater harvesting systems has been analyzed by, among others (Ghisi and Ferreira 2007; Liang and Van Dijk 2011; Rahman et al. 2010; Ghisi et al. 2014; Wang and Zimmerman 2015). The tap water savings that can be obtained by replacing it with rainwater are very different depending on the climatic conditions and the technical and hydraulic parameters of the RWHS and the building (Ghisi et al. 2007; Abdulla and Al-Shareef 2009; Haque et al. 2016; Markovic et al. 2014; Palla et al. 2012; Khastagir and Jayasuriya 2010). For example, Kuller et al. (2015) set tap water saving at 58% for a large Amsterdam airport. Ghisi (2006), in turn, presented research results showing tap water reductions ranging from 48 to 100% for residential buildings in different regions of Brazil. A similar study was conducted for petrol stations where rainwater was used to wash cars. Water savings in this case ranged from 9.2 to 57.2, 32.7% on average (Ghisi et al. 2009a, b). Ward et al. (2012) have set the tap water savings for toilets in a large office building located in the UK which is 79%.

Taking into account that rainwater harvesting systems are rarely used in Poland, and this is mainly due to the public's belief in the ineffectiveness of installing these solutions, in the paper, the research has been conducted to determine the financial efficiency of RWHSs for a single-family building located in various cities in Poland.

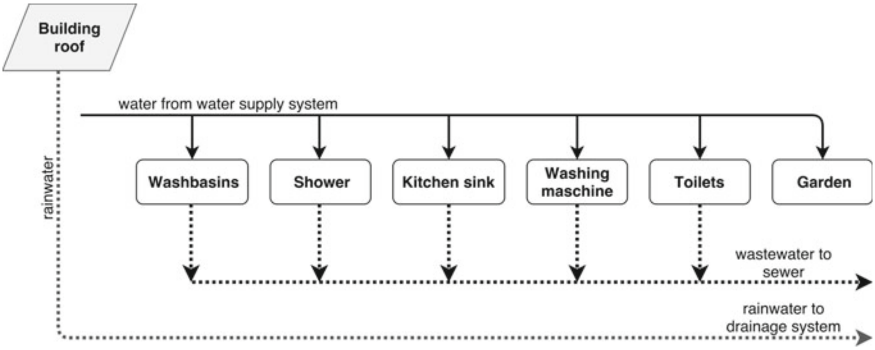

Fig. 3.1 Diagram of system operation in Variant 0 (*Source* Authors)

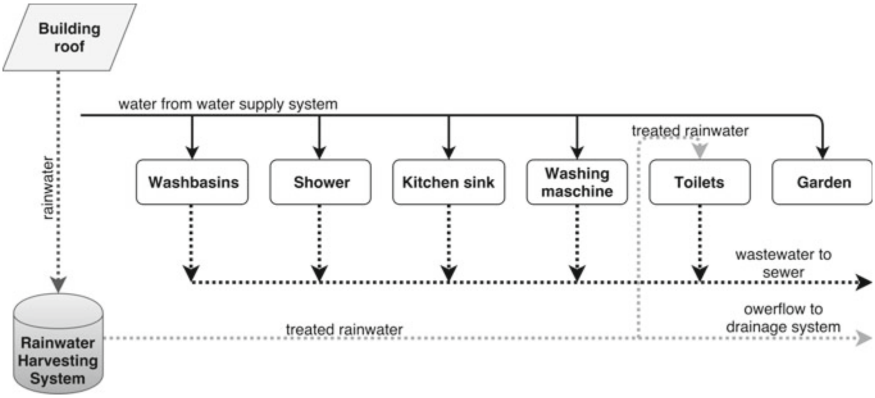

Fig. 3.2 Diagram of system operation in Variant 1 (*Source* Authors)

3.2 RWHS Simulation Model

The simulation model developed by Słyś (Słyś 2009) was used to determine the use of rainwater in the analyzed building. The model algorithm is based on daily water balance. It was assumed that the rainwater from the roof would flow through the pipe system to the retention tank located in the vicinity of the building. Then, by means of a pumping system rainwater from the tank will be transported to the internal installation for use as non-potable water.

In order to determine the influence of changes in operating parameters of the internal water supply and sewerage system on the financial effectiveness of the project, the cost-effectiveness studies of the analyzed variants of the installation were made for different values. The study included a variable number of inhabitants and different capacities of the retention tank. Installation systems that have been analyzed are shown in Figs. 3.1, 3.2, 3.3, 3.4, and 3.5.

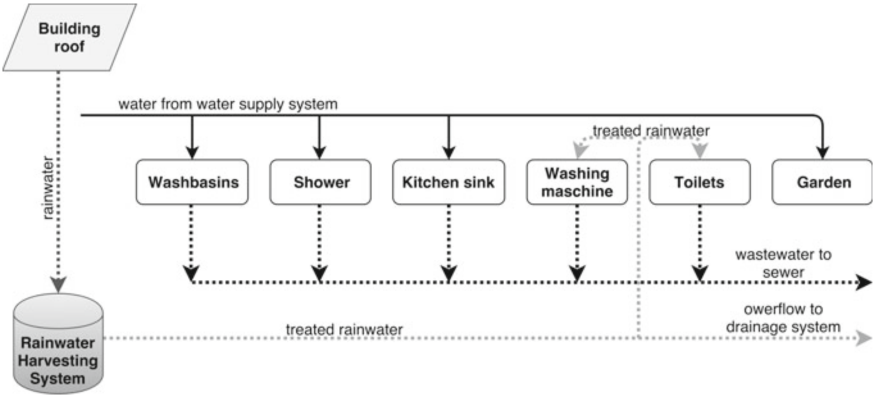

Fig. 3.3 Diagram of system operation in Variant 2 (*Source* Authors)

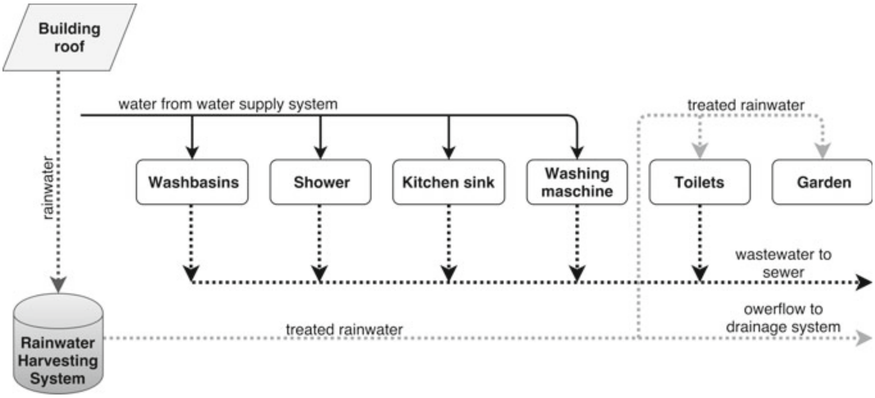

Fig. 3.4 Diagram of system operation in Variant 3 (*Source* Authors)

3.3 Financial Analysis

Making investment decisions solely on the basis of the initial investment outlays can lead to the choice of a wrong solution that will generate high operating costs in the future. Therefore, in the research the method of financial effectiveness assessment has been applied, which allows to determine costs in the whole life cycle. The use of Life Cycle Cost (LCC) analysis in evaluating different investment options enables to compare capital-intensive comparisons and thus allows the selection of the optimal solution, the implementation of which requires the lowest cost over the life cycle of the investment. The Life Cycle Cost Methodology takes into account the initial investment expenditure INV incurred in year 0, the KE operating costs resulting from the use of the solution over a longer period of time as well as the residual value of the RV which is the remaining value at the end of the study period (Fuller

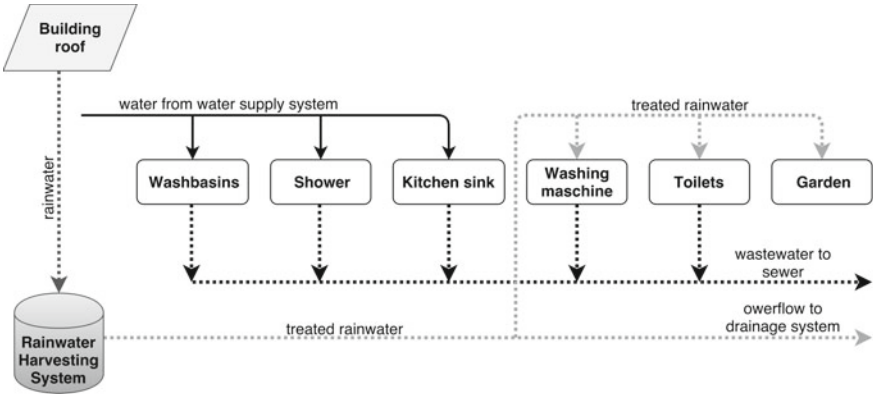

Fig. 3.5 Diagram of system operation in Variant 4 (*Source* Authors)

and Petersen 1996). Cash flows occurring in the following years are discounted. Due to the difficulty of determining the RV, especially during long periods of the analysis, according to the guidelines contained in the work (DOE 2014), the residual value of the RV system need not be determined in quantifiable terms. Considering this, financial costs were omitted, as was the case with other authors (Rahman et al. 2012). Therefore, the LCC analysis for *k* investments variants performed using the formula (1).

$$\mathrm{LCC}_k = \mathrm{INV}_k + \sum_{t=1}^{T} (1+r)^{-t} \cdot \mathrm{KE}_{kt} \tag{1}$$

where:

LCC_k	Total cost of *k*-variant of installation, €;
INV_k	Investments of *k*-variant of installation, €;
KE_{kt}	Operating costs in the year *t* of *k*-variant of installation, €;
T	Duration of the LCC analysis, years;
r	Constant discount rate;
t	Another year of the system use

In the studies conducted, the initial investment outlays of INV_k were estimated on the basis of cost estimates for each of the variants, which included the purchase and assembly costs of the individual components. In turn, the annual operating costs of KE_{kt} which included the cost of purchasing water from the water supply network, the costs of discharging sanitary sewage, and rainwater to the sewage system were calculated for each of the investment options analyzed using the current unit prices set by the network managers in each city. The variants that include the use of the RWHS system in the cost of the $\mathrm{KE}_{\mathrm{kt}}$ also determine the cost of purchasing the electricity used to drive the rainwater pump from the tank to the installation. The data for the

Fig. 3.6 Location of case study cities in Poland (*Source* Authors)

tests are summarized in Table 3.1. The discount rate *r* was set at 5%, which is in line with the assumptions adopted by other research authors who have analyzed RWHS financial performance (Roebuck et al. 2011; Ghisi and Oliveira 2007).

3.4 Study Case

The climate of Poland is defined as the transitional climate of temperate warm zone. It is characterized by high variability of weather and a significant variation of the seasons in successive years. Precipitation shows a high dependence on surface configuration. The average rainfall in the country is about 600 mm, but the rainfall ranges from less than 500 mm in the central part of Poland to almost 800 mm on the coast and over 1000 mm in the Tatras. The highest sums of precipitation fall in the summer months and in this period are 2–3 times higher than in winter. Taking into account the variation in precipitation levels in Poland, four cities located in different parts of the country were selected for the research. Their location is shown in Fig. 3.6.

On the basis of the daily rainfall totals from the period 2003–2012, which was used for simulation studies, the average annual precipitation for each of the selected cities was determined. Table 3.2 summarizes the values of these data.

Research aimed at determining the financial efficiency of the rainwater harvesting system (RWHS) depending on the location of the system was carried out for a single-family house located in four Polish cities. It is a one-storey building with a shower,

Table 3.1 Data used in the calculation of LCC costs (*Source* Authors)

Parameter	Parameter value
Investments	
The cost of purchasing and installing the RWHS with the tank 2 m^3 $INV_{RWHS\text{-}2}$	€1.631
The cost of purchasing and installing the RWHS with the tank 3 m^3 $INV_{RWHS\text{-}3}$	€1.938
The cost of purchasing and installing the RWHS with the tank 4 m^3 $INV_{RWHS\text{-}4}$	€2.151
The cost of purchasing and installing the RWHS with the tank 5 m^3 $INV_{RWHS\text{-}5}$	€2.600
The cost of purchasing and installing the sanitary systems INV_0	€1.891
Operating costs	
The annual increase in electricity prices $i._e$	4%
The annual increase in the prices of purchase of water from the water-pipe network i_w	6%
The annual increase in the prices of rainwater discharge to the sewage network i_r	4%
The annual increase in the prices of sanitary sewage discharge to the sewage system i_s	6%
The cost of purchasing electricity in the year 0 c_e	0.139 €/kWh
The cost of purchasing water from the water-pipe network in Katowice in the year 0 c_w	1.375 €/m^3
The cost of sanitary sewage discharge to the sewage network in Katowice in the year 0 c_s	1.960 €/m^3
The cost of purchasing water from the water-pipe network in Koszalin in the year 0 c_w	0.844 €/m^3
The cost of sanitary sewage discharge to the sewage network in Koszalin in the year 0 c_s	1.173 €/m^3
The cost of purchasing water from the water-pipe network in Warszawa in the year 0 c_w	1.073 €/m^3
The cost of sanitary sewage discharge to the sewage network in Warszawa in the year 0 c_s	1.638 €/m^3
The cost of purchasing water from the water-pipe network in Zakopane in the year 0 c_w	0.565 €/m^3
The cost of sanitary sewage discharge to the sewage network in Zakopane in the year 0 c_s	1.577 €/m^3
Analysis period T	20 years
The discount rate r	5%

Table 3.2 Amount of rainfall in the years 2003–2012 in selected cities (*Source* Authors)

City	Year										
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Average
	Annual rainfall H, mm										
Katowice	510	512	694	727	464	550	574	552	459	412	545
Zakopane	924	1098	1156	875	1166	1111	1250	1600	980	806	1097
Warszawa	545	520	514	482	593	547	653	789	601	537	578
Koszalin	614	834	743	611	972	738	757	801	696	824	759

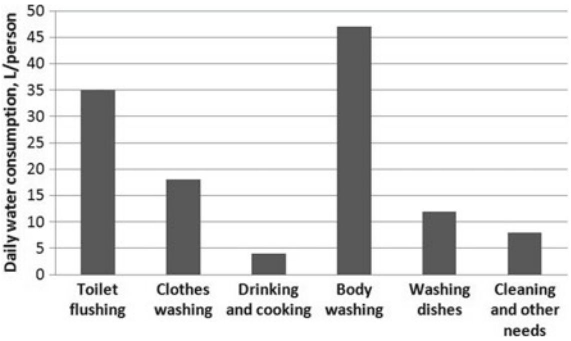

Fig. 3.7 Daily structure of water consumption in the analysed building (*Source* Authors)

2 washbasins, 2 toilet bowls, a washing machine, and a sink. It was assumed that the characteristics of water consumption in individual cases were the same for all users of the installation. The daily structure of water consumption in this building is shown in Fig. 3.7. It was also assumed that in the period from May to September three times a week the garden of 500 m^2 would be watered in the amount of 2.5 dm^3/m^2.

In order to determine the optimum capacity of the retention tank to achieve the greatest savings in tap water, tanks of 2, 3, 4, and 5 m^3 were considered for the research. Simulation studies were conducted using 10-day historical rainfall data (2003–2012) collected from meteorological stations located in four selected Polish cities (Fig. 3.6). Different RWHS location allowed to determine the impact of precipitation on the reduction of water consumption from the water supply and the cost-effectiveness of the system in Poland.

The following data was used in the study:

- Building roof surface $F = 150$ m^2;
- Garden surface $F_g = 500$ m^2;
- Number of inhabitants $M = 3, 4, 5$ persons;
- Average unit water requirement for toilet flushing $q_t = 35$ L/person/day;
- Average unit water requirement for washing $q_w = 18$ L/person/day;
- Average unit water requirement for garden watering $q_g = 2.5$ L/m^2/day (May to September, 3 times a week);
- Daily water requirement for toilet flushing $V_t = q_t \cdot M$;
- Daily water requirement for washing $V_w = q_w \cdot M$;
- Daily water requirement for garden watering $V_g = q_g \cdot F_g$;
- Runoff index of a drained surface $\psi = 0.9$;
- Number of days of water retention in a tank during a period of drought $t = 7$ days.

Table 3.3 LCC calculations for a building located in Katowice (*Source* Authors)

Tank capacity V, m^3	Variant	Life Cycle Cost, €		
		3 Occupants	4 Occupants	5 Occupants
2	0	22,198	25,539	28,879
	1	21,826	24,671	27,639
	2	21,117	23,995	27,019
	3	19,915	23,055	26,334
	4	19,695	22,924	26,190
3	0	22,198	25,539	28,879
	1	21,971	24,700	27,573
	2	21,091	23,869	26,858
	3	19,699	22,813	26,070
	4	19,439	22,651	25,926
4	0	22,198	25,539	28,879
	1	22,074	24,741	27,548
	2	21,091	23,797	26,757
	3	19,574	22,682	25,938
	4	19,302	22,521	25,802
5	0	22,198	25,539	28,879
	1	22,444	25,073	27,833
	2	21,398	24,027	26,976
	3	19,784	22,890	26,152
	4	19,513	22,743	26,034

3.5 Results and Discussion

The obtained LCC values for different rainwater harvesting system locations are shown in Tables 3.3, 3.4, 3.5, and 3.6. When analyzing these results, it can be seen that the variant in which rainwater will be used to flush toilets, wash, and water the garden (Variant 4) is characterized by the lowest LCC costs irrespective of the volume of the tank, the number of inhabitants, and the location of the RWHS system. This is due to the largest reduction in water consumption from the water supply and the resulting savings. It was also found that the traditional variant (Variant 0) in any of the analyzed cases was not the most financially advantageous solution, even though its use was associated with the lowest initial investment INV_0.

Comparing the total LCC values for the location of the RWHS system in different Polish cities, the highest costs were obtained for the investment located in Katowice (Table 3.3). These results from the fact that the unitary water supply and sewage disposal costs in the city are the highest among all analyzed cities.

Table 3.4 LCC calculations for a building located in Koszalin (*Source* Authors)

Tank capacity V, m^3	Variant	Life Cycle Cost, €		
		3 Occupants	4 Occupants	5 Occupants
2	0	14,972	16,991	19,011
	1	15,334	16,998	18,707
	2	14,797	16,420	18,129
	3	13,637	15,451	17,392
	4	13,407	15,270	17,168
3	0	14,972	16,991	19,011
	1	15,535	17,139	18,813
	2	14,928	16,474	18,141
	3	13,602	15,398	17,327
	4	13,348	15,188	17,072
4	0	14,972	16,991	19,011
	1	15,687	17,238	18,882
	2	15,006	16,515	18,138
	3	13,590	15,375	17,302
	4	13,321	15,160	17,029
5	0	14,972	16,991	19,011
	1	16,083	17,616	19,212
	2	15,352	16,824	18,430
	3	13,883	15,669	17,576
	4	13,596	15,435	17,304

It was also noted that only for this system location when comparing Variant 0 and Variant 1 the second solution, regardless of tank capacity and number of installation users, was more profitable. Despite the fact that in this city the lowest rainfall (annual rainfall H = 545 mm) and the economic use of rainfall waters are limited, the amount of unitary charges c_w and c_s affect the increase of financial efficiency of Variant 1. In this case, increased investment expenditure, which depends on the volume of the tank were 46–58% higher than those of Variant 0, was compensated by the lower operating costs spent on the purchase of tap water and the discharge of sewage into the sewage system during the 20 years of operation of the RWHS. The exception is a case in which the installation is used by three inhabitants and the tank capacity is 5 m^3. In this situation, due to the low demand for non-potable water and the resulting negligible tap water savings and the high capital expenditure required to install RWHS with such a high capacity tank, Variant 0 is more financially advantageous.

In turn, the lowest cost of LCC was the use of RWHS in Koszalin (Table 3.4). This is mainly due to the relatively low unit costs for water supply and sewerage and an increased rainfall in this area (annual rainfall $H = 759$ mm). This has resulted in a decrease in the financial performance of Variant 1 in favor of Variant 0 for cases

Table 3.5 LCC calculations for a building located in Zakopane (*Source* Authors)

Tank capacity V, m^3	Variant	Life Cycle Cost, €		
		3 Occupants	4 Occupants	5 Occupants
2	0	16,125	18,270	20,415
	1	16,629	18,310	20,032
	2	15,928	17,502	19,192
	3	13,790	15,575	17,711
	4	13,496	15,420	17,397
3	0	16,125	18,270	20,415
	1	16,851	18,506	20,339
	2	16,106	17,601	19,193
	3	13,473	15,230	17,355
	4	13,152	15,045	16,994
4	0	16,125	18,270	20,415
	1	17,001	18,635	20,299
	2	16,227	17,691	19,228
	3	13,290	15,030	17,154
	4	12,951	14,836	16,768
5	0	16,125	18,270	20,415
	1	17,397	19,020	20,663
	2	16,597	18,032	19,550
	3	13,447	15,177	17,295
	4	13,093	14,976	16,898

where the installation is used by three or four people. Only when the installation is used by five people, Variant 1 is more cost-effective than the variant in which the installation is designed in the traditional way (Variant 0).

A similar relationship was observed for a building located in Zakopane (Table 3.5). Despite the fact that the highest precipitation reaches 1097 mm per year in the area, and their height could indicate the highest savings, the very low unit cost for purchasing water from the water supply network c_w reduces the financial efficiency of the RWHS system. The obtained LCC values for this location are close to the LCC costs set for the RWHS located in Koszalin, where the annual rainfall is significantly lower. However, comparing the LCC costs between Variant 0 and Variant 4, it was found that, depending on the capacity of the reservoir, the differences in these costs ranged from 9 to 10% for Koszalin and from 15 to 18% for Zakopane. An increase in the difference is due to the high fees for discharging rainwater into the sewage system that is required to be incurred at Variant 0 during the 20 years of building use. This is due to the high, compared to Koszalin, rainfall occurring during the year in Zakopane.

Table 3.6 LCC calculations for a building located in Warszawa (*Source* Authors)

Tank capacity V, m^3	Variant	Life Cycle Cost, €		
		3 Occupants	4 Occupants	5 Occupants
2	0	18,526	21,242	23,957
	1	18,672	20,941	23,291
	2	18,015	20,284	22,698
	3	16,928	19,439	22,103
	4	16,714	19,310	21,946
3	0	18,526	21,242	23,957
	1	18,853	21,070	23,598
	2	18,111	20,292	22,654
	3	16,806	19,312	21,959
	4	16,579	19,152	21,784
4	0	18,526	21,242	23,957
	1	18,983	21,159	23,413
	2	18,179	20,313	22,634
	3	16,729	19,235	21,874
	4	16,496	19,065	21,697
5	0	18,526	21,242	23,957
	1	19,363	21,510	23,741
	2	18,520	20,604	22,898
	3	16,973	19,478	22,104
	4	16,726	19,290	21,943

In the case of the location of the RWHS system in Warsaw, its financial effectiveness is primarily influenced by the amount of precipitation whose average annual amount in this area is 578 mm. Such low value limits the economical use of precipitation water and consequently reduces the cost-effectiveness of RWHS in the building is being analyzed. The obtained results show that differences in LCC values between Variant 0 and Variant 4 are insignificant and vary from 8 to 9%, respectively (Table 3.6). It also turned out that only if the installation was used by three people, then the variant in which rainwater was used only to toilet flush (Variant 1) was less profitable than the traditional installation solution. In all other cases, Variant 0 had the highest LCC costs.

In the research, the impact of RWHS tank capacity on tap water savings was also analyzed. Their size is affected primarily by the demand for non-potable water resulting from the number of inhabitants and the amount of daily precipitation that depends on the location of the rainwater harvesting system. The results of this study are shown in Figs. 3.8, 3.9, and 3.10.

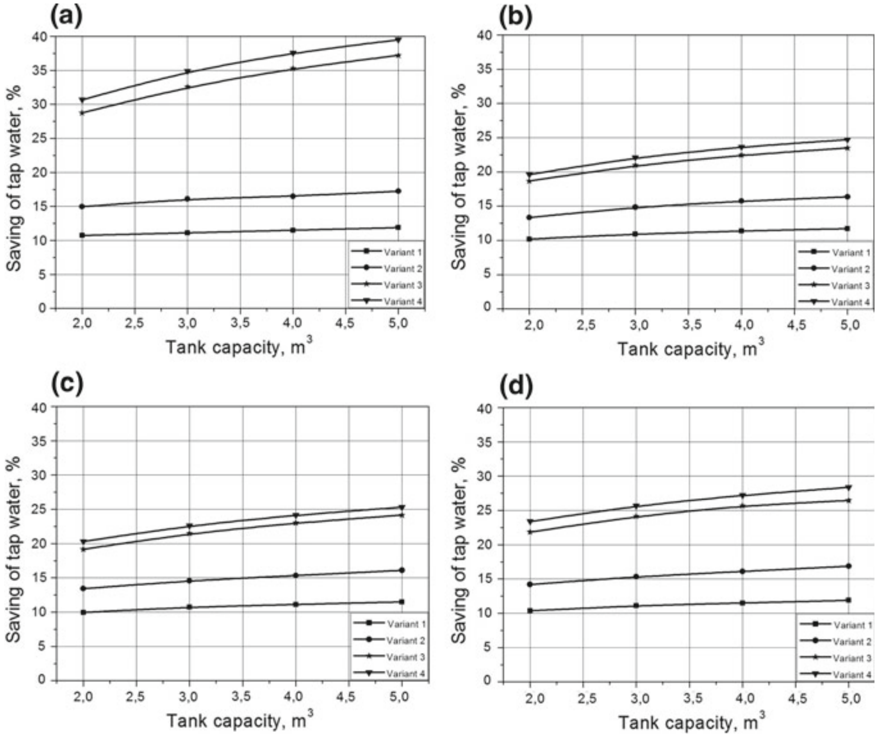

Fig. 3.8 Savings of tap water depending on the capacity of the tank used in the rainwater harvesting system for the case where the plant is used by three people **a** Zakopane, **b** Katowice, **c** Warsaw, **d** Koszalin (*Source* Authors)

It was noted that with an increase in the number of users of the system, the efficiency of using rainwater in the analyzed building for Variant 3 and Variant 4 was decreasing, irrespective of its location in Poland. This is due to the high demand for non-potable water in those variants that rainwater cannot cover, even in the case of the RWHS system located in Zakopane, where the highest precipitation occurs. In the case of Variant 1 and Variant 2, tap water savings increased slightly as the number of inhabitants increased. The highest tap water savings were obtained for the RWHS system located in Zakopane and ranged 25 to almost 40% for Variant 4, 23 to 37% for Variant 3, 15 to 19% for Variant 2, and 11 to 14% for Variant 1. Due to the comparable precipitation rates for Katowice and Warsaw, the savings on tap water were very similar in the range of 15–25% for Variant 4, 15–23% for Variant 3, 13–16% for Variant 2, and 10–13% for Variant 1. The average annual rainfall of about 760 mm in Koszalin area resulted in savings of 19–28% for Variant 4, 17–26% for Variant 3, 14–17% for Variant 2, and 10–14% for Variant 1.

The study also showed that with the increase in the capacity of the retention tank, the tap water savings increases. This tendency was especially noticeable for the

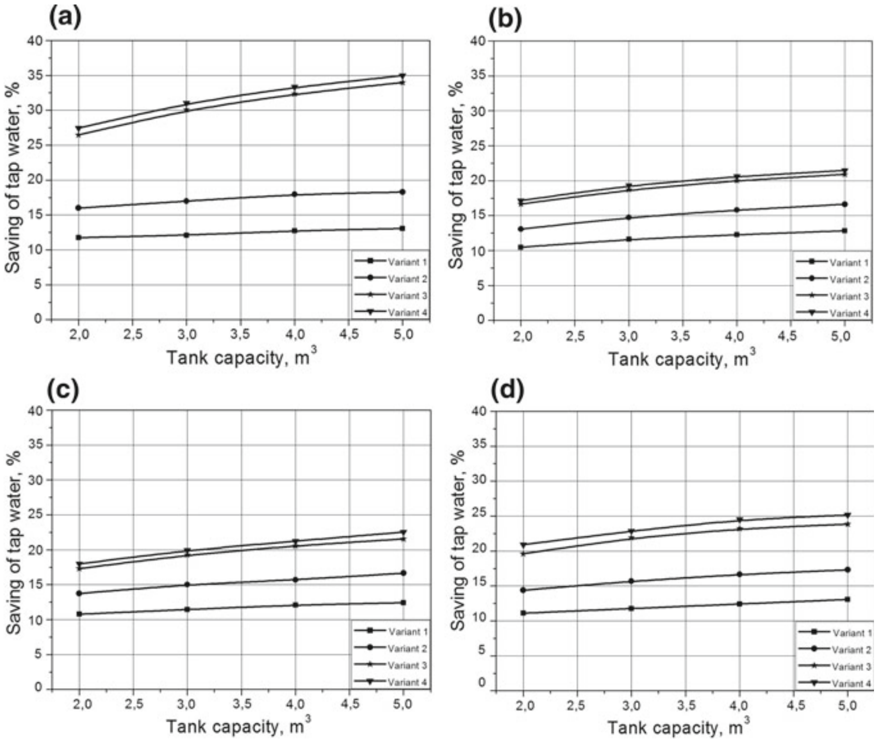

Fig. 3.9 Savings of tap water depending on the capacity of the tank used in the rainwater harvesting system for the case where the plant is used by four people **a** Zakopane, **b** Katowice, **c** Warsaw, **d** Koszalin (*Source* Authors)

location of the RWHS in high rainfall areas and for the variants where the demand for rainwater was significant (Variant 3 and Variant 4). For example, for Zakopane, Variant 4 and the case where the installation was used by three people (Fig. 3.8a), the increase in the tank capacity from 2 to 5 m^3 determined the increase in water savings by almost 10%. For the same case of calculation but localization of the RWHS system in Katowice or Warsaw this increase was about 5% (Fig. 3.8b and c). Taking into account the same cities and the situation when the installation is used by four people (Fig. 3.9) and five people, an increase of the capacity of the tank resulted in an increase in tap water savings of about 7% for Zakopane (Fig. 3.10a) and 4.5% for Katowice and Warsaw (Fig. 3.10b and c). These results have shown that the impact of increased RWHS users on tank capacity and associated tap water savings is noticeable in areas with high rainfall, while in other cities the impact was almost imperceptible.

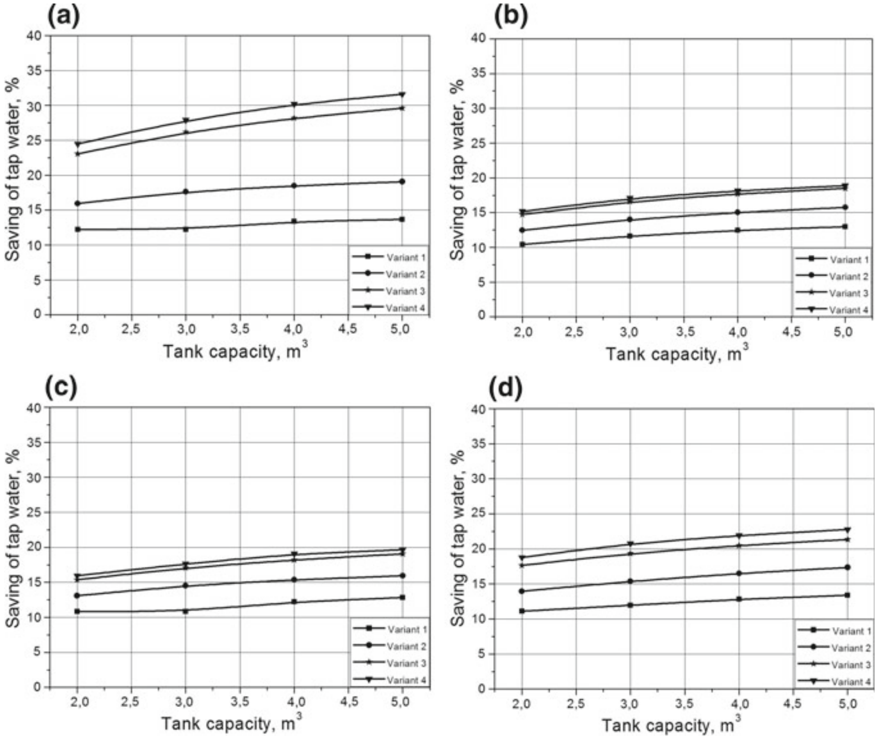

Fig. 3.10 Savings of tap water depending on the capacity of the tank used in the rainwater harvesting system for the case where the plant is used by five people **a** Zakopane, **b** Katowice, **c** Warsaw, **d** Koszalin (*Source* Authors)

3.6 Conclusion

In the chapter, the research was conducted to investigate the cost-effectiveness of the rainwater harvesting system, depending on local climatic conditions. Four cities were located in different parts of Poland. The analysis was performed using the Life Cycle Cost Methodology. The results of these studies showed that the RWHS performance under varying climatic conditions was very varied, but it was also found that the variant in which rainwater was used to flush toilets, wash, and water the garden (Variant 4) was characterized by the lowest LCC cost regardless of the volume of the tank, number of inhabitants, and location of RWHS system. This was due to the largest reduction in water consumption from the water supply and the resulting savings. It was also found that the traditional variant of the installation (Variant 0) in none of the analyzed cases was the most financially advantageous solution, even though its use was associated with the lowest initial expenditure. It confirms the validity of using the Life Cycle Cost methodology to evaluate different investment options, as selecting a solution based only on the initial investment outlay can result in wrong decision making and choosing a variant that will generate high operating costs in the long run.

The study also examines the impact of tank capacity, which is the main component of the RWHS system, on tap water savings. The capacity of 2, 3, 4, and 5 m^3 was taken into consideration. The magnitude of tap water savings was mainly influenced by the demand for non-potable water resulting from the number of inhabitants and the amount of daily precipitation that depends on the location of the rainwater harvesting system. It was noted that as tap water capacity increased, tap water savings for RWHS locations in high rainfall areas such as Zakopane and for variants where the demand for rainwater is high (Variant 3 and Variant 4) also went up. In cities with low annual precipitation, such as Warsaw and Katowice, the effect of increasing water tank capacity was low. Depending on the installation variant, these savings ranged from 11 to 40% for Zakopane, 10 to 25% for Warsaw and Katowice and 10 to 28% for Koszalin.

The research carried out and their results are not only of scientific but also practical importance and may provide guidance for potential investors in the investment decision-making process already at the stage of designing the buildings.

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