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ECONOMIC AND ECOLOGICAL ASPECTS OF RAINWATER RECLAMATION IN CITIES

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ABSTRACT: The aim of this paper was to investigate the economic and ecological benefits of rainwater utilization in urban areas. The case of Toruń. Conducted analysis has shown that in case of individual households which roof surface ranges from 100 to 150 m2 there is no economic justification for rainwater reclamation. With the exception of one variant, with the roof surface equal to 150 m2 and annual sum of precipitation significantly higher than the mean observed in Toruń. However, from the perspective of the whole city such projects may lead to significant financial and ecological benefits. It therefore seems essential for municipalities and environmental protection organizations to establish special programs, financially supporting such projects.

KEYWORDS: rainwater, urban areas, sustainable development

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Introduction

Water is a fundamental commodity which determines the human existence and the condition of environment. It is also one of the main factors which has impact on the economic development. Poland possesses very scarce water resources, especially when it comes to surface waters. It is estimated that natural water resources in Poland, determined as the mean surface water drainage in the multiannual period, amount to 62.4 km^3 – which translate into roughly 1 600 m^3 per capita. In Europe this indicator is almost three times greater, whereas in other countries over four times (Hotloś, 2004, p. 262) It is important to note that this volume is only theoretically available. Meaning that the useful resources for human population and economy (considering the minimum acceptable flow) amount to 250 m^3 per capita (Slota, 1997, p. 257).

Water resources in Poland are additionally characterized by significant temporal and spatial variability. Those result mainly from varying meteorological conditions, terrain and various retaining capabilities of individual regions (Pływaczyk et al. 2008, p. 172). Considering only the annual sums of precipitation, the lowest values are being observed in the Greater Poland – Kuyavian lake area and are lower than 500mm (whereas the mean for Poland amounts to 612 mm.

Till the end of 80s the water consumption in Poland exhibited an increasing tendency. This was directly related to the industry and housing market development, increasing number of people using waterworks, low water price, huge loses in waterworks system and general wastage (Piasecki, 2016, p. 1412). The socioeconomic changes in Poland which occurred at the break of 80's and 90's of the 20th century lead to an increase in water prices and changes in counting the amount of water used (water meters have been installed). In consequence the amount of water used by households significantly dropped (Piasecki, 2014, p. 198).

Cities are supplied with water by means of more and more developed system of waterworks. Over the recent years in Poland, this trend was mostly supported by the European Union founds. Water provided by waterworks must have a suitable quality and meet the criteria of potable water. However, water is also used for purposes where its high quality is not required e.g. watering trees or grass; cleaning streets and sidewalks or flushing toilets. In many countries rainwater is used for those purposes. Already in 90s Germans have installed over 100 000 tanks for storing water, which total volume exceeded 600 000 m^3 (Herrmann and Schmid, 2000, p. 313). Usage of rainwater is also popular in Japan, Austria, Spain or Brazil (Zaizen et al. 2000, 355; Rozis and Rahman, 2002, p. 1; Domènech and Saurí, 2011, p. 598; Ghisi and Oliveira, 2007, p. 1731). Also in Poland, especially on areas with high population density the popularity of rainwater application for various purposes is gaining on significance (Preisner, 2015, p. 90).

Goals and methods

The aim of this research was to indicate the economic and ecological benefits resulting from using rainwater on the urbanized areas in Poland – base on case study of Toruń. An economic effectiveness analysis has been conducted for one of the possible solutions which is an installation of a specialized equipment in individual households. A detailed analysis was conducted for a single household in case of which the rainwater is gathered only from the roof. Three variants of roof surface were considered, namely 100, 125 and 150 m^2. Additionally the variability of annual precipitation sums has been taken into the account – it means that the precipitation with various probability of occurrence 25, 50 and 75% where used in calculations. Further analysis will be conducted for a theoretical three-person household with a 100 m^2 garden.

To assess the economic effectiveness the index of mean annual unitary cost (W) and net present value (NPV), which have been presented inter alia by (Rogowski, 2004, p. 261), were used.

The mean annual unitary cost W [PLN/m^3] has been calculated based on formula:

$$W = \frac{I(r+s)+K}{E} \tag{1}$$

where:
I – investment expenditure [PLN],
r – interest rate,
s – rate of depreciation,
K – mean annual cost of operation [PLN],
E – result (in terms of acquired water m^3).

The net present value NPV [PLN] has been calculated based on formula:

$$NPV = \sum_{t=0}^{n} \frac{CF_t}{(1+r)^t} - N \tag{2}$$

where:
N – investment expenditure [PLN],
CFt – cash flow, not considering the initial investment expenditures [PLN],
r – discount rate,
t – considered operation period.

The market analysis has shown that the average investment expenditure should amount to about 10 000 PLN (valid for the year 2015). The cost of operation and maintenance is estimated to be around 150 PLN per year. The main component of those costs is electricity which price is constantly increasing. It has been calculated the over recent years the electricity price grew by 2.5% per year. Therefore it has been assumed that operation cost will follow the exact tendency.

What is more, the initial investment expenditure will be covered from household own founds. The interests and discount rate will amount to 3% whereas the rate of deprecation will be equal to 3.3% for a 30 years long operation period. The yearly profits from the above described investment will originate from:

- The amount of water used for watering garden (lawns) multiplied by the unit cost of water (3.56 PLN/m^3 – in the year 2016). It is important to note that the annual increase in water prices has been considered and in case of Toruń it amounted to 10% over the last 10 years. In line with the regulation issued by the Minister for Infrastructure[1] it has been assumed that the water usage for watering lawns amounts to 200 liters per square meter.
- The volume of water used for flushing toilets multiplied by unitary cost of water. Accordingly to the above mentioned regulation issued by the Minister for Infrastructure the mean daily water usage per person amounts to 50 liters.

Results

Toruń is located in area which is characterized by relatively low sums of precipitation which amount to 524 mm per year. However over individual years significant variations are observed. Over the last 55 years, the year 1980 was the most humid one and the year 1989 was the driest one. The observed precipitation in those years was respectively 843 mm and 310 mm (Figure 1).

Table 1 summarizes the volume of rainwater available to be collected for nine variants of various roof surfaces and probabilities of precipitation occurrence. Naturally along with the increasing likelihood of the rainfall the quantity of water for individual roof surfaces also builds up. For roofs with a surface equal to 100 m^2 this increase amounts to 7.4 m^3 whereas for those with surface by half greater the volume of water stored can be by 11.1 m^3 greater.

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[1] Rozporządzenie Ministra Infrastruktury z dnia 14 stycznia 2002 r. w sprawie określenia przeciętnych norm zużycia wody (Dz. U. 2002 nr 8 poz. 70).

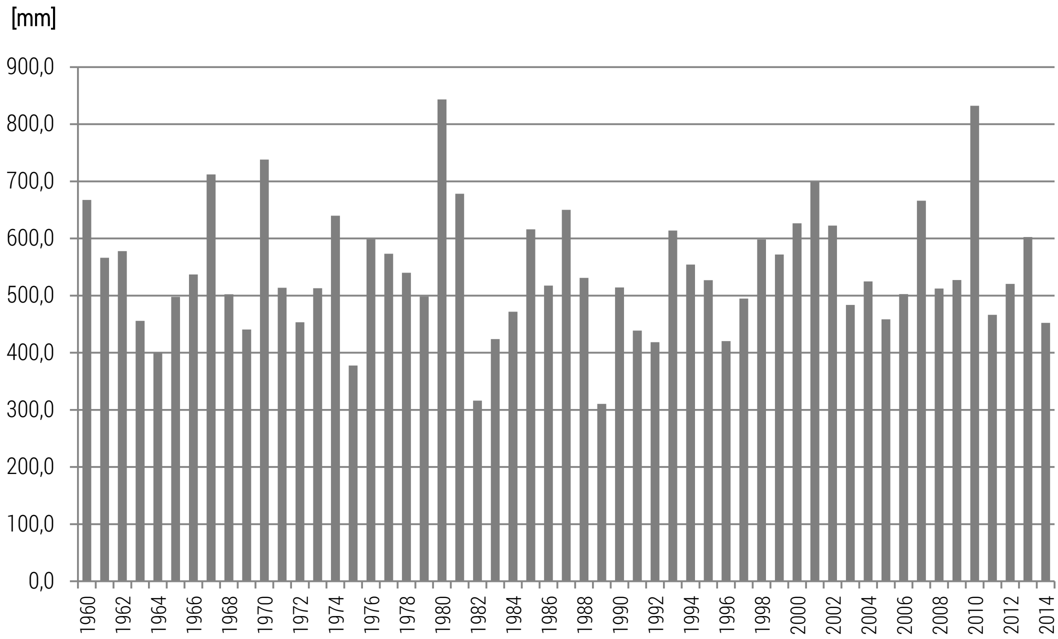

Figure 1. Annual sums of precipitation in Toruń over the years 1960–2014

Table 1. The volume of water which can be acquired from roofs with varying surfaces and in case of three different probabilities of rainfall occurrence

Roof surface [m²]	Probability of rainfall p (%)		
	25	50	75
100	45,7	53,1	60,4
125	57,1	66,3	75,6
150	68,6	79,6	90,7

Considering the results from Table 1 and 2: only the roof surface which is 125 and 150 m² gives an opportunity to cover the water demand of the investigated households. Additionally in case of the roof with 125 m² surface the annual sum of precipitation must be significantly higher than multiannual mean. In case of the household with the smallest roof area the water demand can be covered only partially. In that regard important is also the part of the year during which the highest sums of precipitation occur. In case of Toruń, those are observed in spring/summer period, what means that they perfectly correlate with the highest water demand (watering lawns).

Table 2. Unit cost and annual water consumption

Demand	Water demand according to standards	Annual demand [m³]
watering garden (including lwans) – 100 m²	200 liters/m²	20
use in household (toilets) – 3 people	50 liter/person/day	54,7

The mean annual cost of obtaining one cubic meter of rainwater in all investigated variants is significantly higher than the current cost of water from the waterworks in Toruń (figure 2). According to the assumed price increase in coming years it is expected that in 15 to 20 years those cost will be comparable. Additional analysis based on the NPV methods pointed to the fact that this investment will be cost-effective in only one case: namely when the household will have a relatively large roof (150 m²) and the precipitation will by 14% greater than the observed mean in that area. In practice in means that without additional financial incentives (e.g. governmental organizations or local authorities) such investments are not justified from the economic point of view.

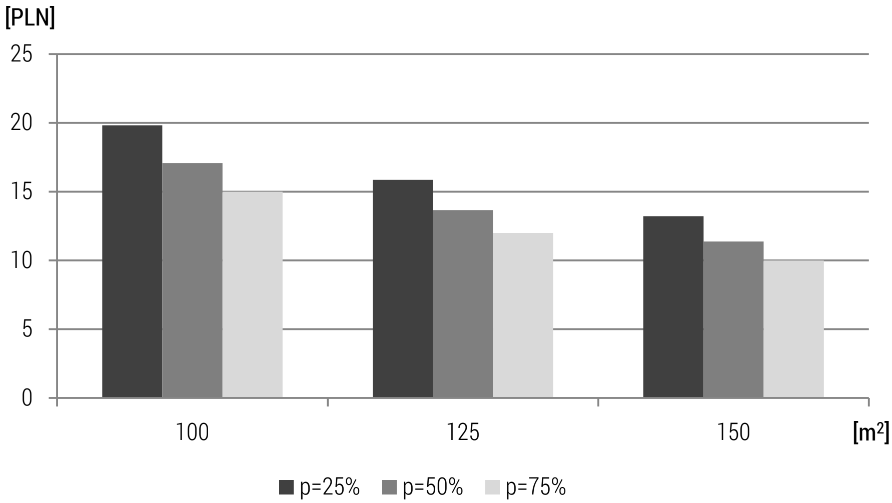

Figure 2. Mean annual unit cost for various roof surfaces and precipitation probabilities

Presented results are valid only in case of Toruń and its local climate and policy. Therefore it is impossible to transfer them to other cities in Poland. This inability to draw wider conclusions is supported by the analysis conducted for other cities in Poland which support the cost-effectiveness of such investments (Rogasik, Piasny, 2014, p. 32; Kujawiak et al. 2014, p. 91). The

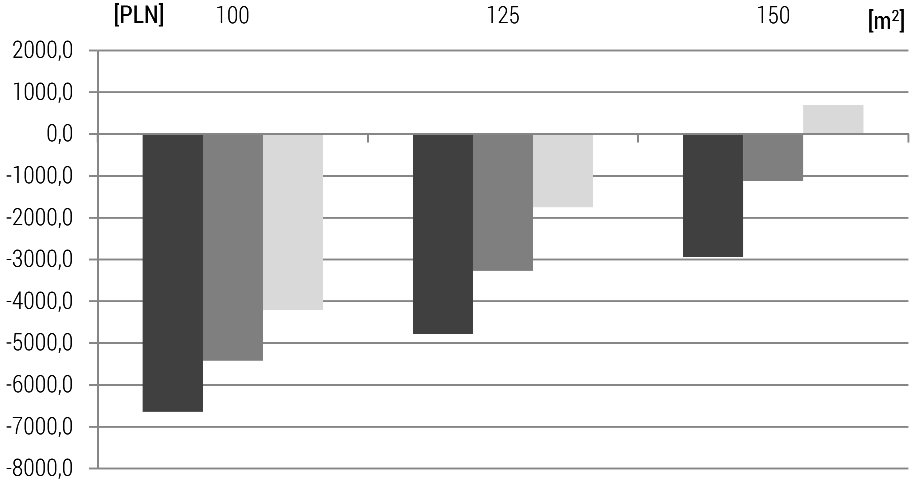

Figure 3. Values of NPV indice for various roof surfaces and precipitation probabilities

observed differences result from the local circumstances, such as water prices, precipitation, and charges for rainwater discharge to the sewage system. In Toruń, the observed precipitation is high below the country average and simultaneously the water prices are relatively low. So far the charges for rainwater to the sewage system have not been introduced.

It is important to underlie that the lack of economic cost-effectiveness has been shown only from the perspective of a single household. In a broader context which encompasses the operation of the whole sewage system in the city and related to it economic and ecological aspects, such investments are of great value. They are gaining on importance along with increasing volume of acquired and stored rain water.

One of the main threats in case of the sewage system in each city are heavy rains. They lead to a rapid increase of water volume in the general sewage and drain system. The consequence of the last one is an activation of storm overflows. In result untreated sewage along with rainwater are directly fed to the receiver which is usually a river or lake (Bruszta-Adamiak, 2012, p. 35; Królikowski and Królikowska, 2012). Rainwaters flowing through the sewage system lead also to an increase in effluents reaching the sewage treatment plants. In case of Toruń this increase amounts to about 10% (Marszelewski and Piasecki, 2012, p. 107). Additional and unsuspected increase in volume of water which must be processed leads to greater costs which result from energy consumption, operation of equipment, fuel and other components. Popularity of rainwater collection systems might significantly reduce the amount of water discharged to the sewage system and thereby curtail the negative consequences of heavy rains.

In Poland, over recent years we have observed believe that rainwaters should be as quickly as it is only possible removed from the urban areas. This trend led to several negative natural phenomena. Mainly, they concern the dwindling retention capabilities of urban catchments which in consequence exhibit greater surface runoff coefficient and an increase in flood waves intensity in natural watercourses (Przedwojski, 2002, p. 58). A process of over drying urban soils has been also observed. Distinguished effects bring significant disturbance to the natural water balance in the environment.

Relatively low popularity of rainwater collecting systems can be explained by old regulations which curtailed the usage of such water only to flushing toilets. Current laws enables using rainwater for purposes different that consumption purposes. This change has been issued in the Decree by the Minister of Health[2].

Research results

Rainwaters on the urban areas in Poland are still extremely rarely used. One of the reasons behind this situation may be the lack of economic effectiveness. Conducted analysis for the city of Toruń supported this hypothesis in case of households which have a roof surface ranging from 100 to 150 m^2. In case of the household with a roof surface exceeding 150 m^2 and the assumption that the sum of precipitation will significantly exceed (about 14%) the multiannual sum in the investigated area. An increase in the probability of the precipitation occurence decreased the mean annual unitary cost. This cost reduction was proportional to the roof surface. It is important that shown in this study lack of economical effectiveness resulted from a number of local factors such as: water price, non-existent charges for rainwater discharge to the sewage system, and relatively low precipitation. Simultaneously it has been pointed out that acquiring and using rainwater in case of the whole city is of great importance from the perspective of water and wastewater system. Therefore it is essential to undertake certain actions which will encourage citizens to invest in the rainwater harvesting systems which without financial support may not be economically cost effective but will play an important role in a city wastewater system. Authors suggest that organizing awareness-raising campaigns will potentially increase the society interest in those systems and to some extent lead to their greater market penetration.

2 Rozporządzenie Ministra Zdrowia z dnia 19 listopada 2002 r. w sprawie wymagań dotyczących jakości wody przeznaczonej do spożycia przez ludzi, Dz.U. 2002 nr 203 poz. 1718.

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