Journal of Cleaner Production 209 (2019) 1119–1125

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Environmental and economic assessment of rainwater application in households

Henrieta Pavolová, Tomáš Bakalár*, Dušan Kudelas, Petra Puškárová

Technical University of Košice, Faculty of Mining, Ecology, Process Control and Geotechnologies, Letná 9, 042 00 Košice, Slovak Republic

ARTICLE INFO

Article history:
Received 2 March 2018
Received in revised form
25 October 2018
Accepted 28 October 2018
Available online 29 October 2018

Keywords:
Rainwater
Slovakia
Household
Expenditures

ABSTRACT

Drinking water management is becoming more and more important these days as water consumption and sewage production are constantly increasing in Slovak households. Although Slovakia is not considered a water-poor country, rainwater utilisation in households is becoming widespread. One of the possibilities of reducing the costs in household budgets is the use of rainwater in meeting the daily needs wherever the water quality parameters for potable water are not required for example flushing toilets, washing machines, watering of gardens, and so on. Other positive economic and environmental aspects of the use of rainwater can be considered the protection of water resources, which determines the global status of water management in the Slovak Republic, hence the environment. Based on the results of the study significant reduction of charges for drinking water can be achieved by the use of rainwater i.e. roundly 225 Eur per year in total budget can be saved compared to an average household.

1. Introduction

A continuing growth of population with a reduction in surface and ground water resources over the past years encourages demand for secure water supplies and for long term sustainable management of water resources. The world's population is expected to grow by 2–3 billion people by 2050, suggesting increased freshwater demand. Further, by 2050 the urban population is expected to be about 2.9 billion more than in 2009 (3.4 billion) and the urban population is expected to grow the same rate as the world population plus transfers from the rural population (UNESCO, 2012).

The substantial part of highly urbanized agglomerations surface is made of concrete, asphalt and stone with very good thermal conductivity. "Green areas" as natural thermoregulatory valves largely absent; therefore, an effort is made to get rid of rainwater into sewerage as quickly as possible.

The use of rainwater in these areas can be addressed by environmental devices that reduce the load of the wastewater treatment plants. They allow accumulation and/or processing of atmospheric precipitation in the place where they fall thus preventing their running off without further use. Rainwater accumulation in the areas with a high degree of urbanization has an effect on protection, reduction of the cost of sewerage, water supply, e.g. by replacing potable water used for flushing toilets, watering the garden, heating, etc. By a comparison of two households in Slovakia, Pavolová and Bakalár (2012) showed a 60% saving of potable water by introducing rainwater for non-potable use. Dixon et al. (1999) studied the reuse of domestic greywater and rainwater and proved that this combination can increase the water saving efficiency using up to a 100 L storage tank and also reported that greywater has higher efficiency than rainwater. Morales-Pinzón et al. (2015) introduced a rainwater harvesting system which environmental analysis showed that tanks with less than 5 m^3 of storage capacity are suitable. Campisano et al. (2017) also found that there is a strong impact of economic limits and local regulations on rainwater harvesting systems implementation and the technology selection. It also contributes to the protection of drinking water sources, counterbalancing the difference between surplus and shortage of rain water. The consequent increase in evaporation improves the microclimate, vegetation flourishing, and biodiversity (Kahinda et al., 2010). This layout also meets the criteria for sustainable water management (Ding and Ghosh, 2017).

Published studies proved significant positive effects on the environment as well as economic advantages. Angrill et al. (2012) studied a diffuse and a compact urban areas as a density contrast and reported that the environmental impact on a compact urban

* Corresponding author.
E-mail addresses: henrieta.pavolova@tuke.sk (H. Pavolová), tomas.bakalar@tuke.sk, bakalar.tomas@gmail.com (T. Bakalár), dusan.kudelas@tuke.sk (D. Kudelas), puskarovap@gmail.com (P. Puškárová).

https://doi.org/10.1016/j.jclepro.2018.10.308
0959-6526/

area was lower than that on a compact urban area. Muthukurmaran et al. (2011) demonstrated that 77% of potable water can be saved by combined use of rainwater and water efficient appliances of which up to 40% is represented by use of rainwater in regional Victoria in Australia. The studies were done in different parts of the world reflecting not only the amount of rainwater but also local environmental conditions, infrastructure, laws, individual needs, etc., but little attention was paid on the particular savings in expenses for water and the household. In some studies the efficiency of whole rainwater harvesting systems (Sample and Liu, 2014; and recently Ghimire et al., 2017) or of a whole residential complex (García-Montoya et al., 2016) or even of a part of a country (Lee et al., 2016) was studied, also not paying attention to the household as such and the savings. The rainwater quality in these studies is neglected probably assuming suitable quality of rainwater for particular purposes. Physicochemical and microbiological contamination of rainwater in urban areas was studied based on 172 previous scientific and technical works by Sánchez et al. (2015) resulting in acceptable values of physicochemical parameters.

In some countries with seasonal availability of surface water and rainwater, e.g. Ghana, Kenya and Zambia, which are Lower-Middle-Income Economies according to the World Bank, rainwater is also collected in simple water systems during rainy seasons and used in households. This collection becomes difficult in dry seasons (Kelly et al., 2018). In some counties (Liberia, Ghana, Bangladesh, etc., i.e. especially in some of the Low-Income Economies and Lower-Middle-Income Economies) rainwater is even used in hospitals (Chawla et al., 2016).

Rainwater concerning its composition has much better performance for many purposes in households and is more appropriate than the hard potable water meeting all requirements of the Slovak legislation (Sklenárová, 2011):

- effective dissolution effects - making it perfect for laundry, washing floors and cleaning,
- containing no minerals - after drying leaves no white patches, so it is suitable for window cleaning or car body washing,
- containing no aggressive chlorine,
- warmer - suitable for watering household plants, gardens,
- soft - does not form lime scale, which is advantageous in many respects,
- distilled water - washed linen is soft and free of all grease and detergent residue, there is no need to use fabric softener, and
- does not cause osmosis.

Rainwater, in accordance with the Slovak legislation (Act no. 442/2002 Coll. on public water supply and public sewerage and on amendment to Act no. 250/2011 Coll. on the regulation of network industries as amended), can be considered as precipitation water from the surface runoff which does not filter into the soil but is discharged by means of public sewage system from the reinforced areas and, with the other wastewater, is cleaned in the wastewater treatment plant, i.e. the precipitation water from the surface runoff is charged. The amount of the precipitation water from the surface runoff is determined according to the Decree of the Ministry of Environment of the Slovak Republic no. 397/2003 Coll. which provides for the measurement of the quantity of water supplied by the public water supply system and the amount of discharged water, for the method of calculation of the quantity of discharged waste water and surface water runoff and for the reference water consumption figures for each real estate from which the precipitation water is discharged.

Based on these facts the objective of this article is an evaluation of potential savings from use of rainwater in households for purposes other than potable use e.g. drinking, cooking, dishwashing, etc. with respect of local conditions, applicable laws and rainwater quality. The use of rainwater in households in Slovakia can contribute not only to the conservation and sustainable use of water resources but also to the rationalisation of household expenditure with a consequent reduction in overall expenses.

2. Method

In Slovakia, supply of drinking water is provided by individual water companies which are also responsible for setting up the price of water and sewage in accordance with applicable Slovak regulations. For comparison of funds savings in the budgets of individual households, three specific households from Košice (household A), Banská Bystrica (household B) and Žilina (household C) regions have been chosen. Water consumption was monitored in each household during a year in ordinary daily activities, with the same number of persons per household. In Slovakia, supply of drinking water is provided by individual water companies which are also responsible for setting up the price of water and sewage in accordance with applicable Slovak regulations. For comparison of funds savings in the budgets of individual households, three specific households from Košice (household A), Banská Bystrica (household B) and Žilina (household C) regions have been selected. Water consumption was monitored in each household during a year in ordinary daily activities, with the same number of persons per household (Fig. 1).

The amount of water diverted from surface runoff into the public sewer system shall be calculated using the equation (Sklenárová, 2011)

$$Q = Hz \bullet S \bullet \psi \tag{1}$$

where

Hz - annual average of total precipitation for the site,
S - size of the area from which surface runoff water flows out into the public sewer system,
Ψ - runoff coefficient determined depending on the nature of the surface area.

2.1. Rainwater sampling

The samples were collected from roof runoff. All samples for the physicochemical parameters were taken as 24 h mixed samples, stored at 4 °C and processed within 24 h. Only selected physicochemical parameters were tested as microbiological parameters are not substantial for irrigation, maintenance, WC flushing, and

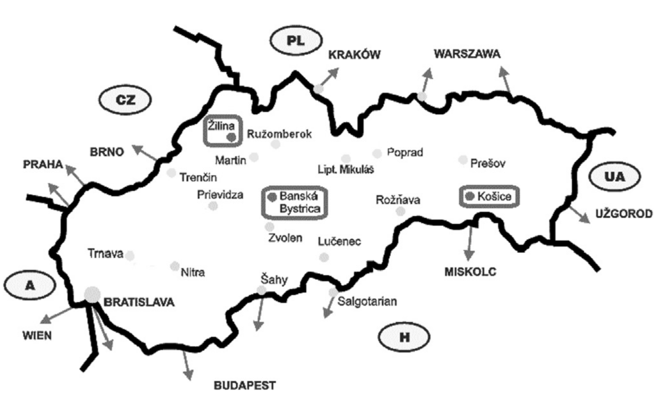

Fig. 1. A simplified map of cities selected for the study.

laundering, as follows:

- The chemical oxygen demand (COD) measurements were carried out using titration laboratory method using potassium permanganate as oxidant.
- Biochemical oxygen demand (BOD) was determined in the fresh sedimented sample. The oxygen concentration was measured with the WTW Oximeter OXI 538 and the oxygen probe Oxi-Cal®-SL (WTW, Germany).
- Dissolved oxides (DO) measurements were carried out using titration laboratory method.
- pH, the electrical conductivity (EC) and the total dissolved solids (TDS) were measured with the combined pH meter Combo pH & EC, model: HI 98129 (Sigma-Aldrich, Germany).
- The cations of calcium (Ca^{2+}) and magnesium (Mg^{2+}) measurements were carried out using titration laboratory methods.
- The cations of copper (Cu), manganese (Mn), nickel (Ni), zinc (Zn), mercury (Hg), iron (Fe), aluminium (Al), lead (Pb), and chromium (Cr) measurements were carried out using the atomic absorption spectrometry performed using iCE 3300 (Thermo Scientific, USA). AAS is an optical method based on absorption of electromagnetic radiation in the range of wavelengths 190–850 nm and is ranked among the most common methods for the determination of heavy metals in environmental samples.
- The anions of chloride and sulphate measurements were carried out using titration laboratory methods. The anions of nitrate and phosphate were measured with the Palintest 7500 Photometer (Palintest, UK).

2.2. Characteristics of selected cities

A simplified map of Slovakia with largest cities and the selected cities for the study are shown in Fig. 1. All the cities are characterised by their location, area, population, industry, supply of drinking water, especially the sources and the yield of each source in order to show the need for search of alternative water source for non-potable purposes to decrease the consumption of drinking water.

City of Žilina is the fourth largest city in Slovakia. It is the seat of Žilina region with an area of 6788 km2 Žilina region is one of the Slovak territories which has the largest area of high quality environment (5913 km^2) and there is no strongly disturbed environment at all. Žilina covers an area of 80.03 square kilometres and its population was 83,600 on December, 31 2015. Its gross domestic product (GDP) per capita is one of the highest in Slovakia. It is also the capital of the automotive and engineering industry, building industry, power industry, electronics, textile, chemical industries, and services. It is a major transportation hub which combines roads of international importance.

City of Žilina is supplied with drinking water from various water sources. The decisive source is Nová Bystrica water reservoir with a capacity of 1030 L per second. The water is treated at Nová Bystrica water treatment plant with a capacity of 680 L per second. Other water sources supplying drinking water to the city of Žilina are Teplička nad Váhom with permitted withdrawal of 160 L per second, Lietava with permitted withdrawal of 100 L per second, springs in Turie with the average yield of 47.67 L per second in 2006, Lietavská Svinná with a capacity of 20 L per second, Kamenná Poruba with yield of 2 springs of 31.50 L per second, Fačkov with a yield of 84.30 L per second, and Stráňavy with a yield of 25 L per second. In the city of Žilina 100% of its population is connected to public water supply (Žilina, 2016).

Currently, the city of Banská Bystrica is a complex multifunctional city which is the centre of Banská Bystrica region ranked among highly urbanized areas with industrial agglomerations and agricultural activities. Industrial production consists mainly of metallurgy, mechanical engineering, wood processing, chemical, pharmaceutical, food, paper, glass, ceramic and textile industries. The southern part of the region is more focused on agricultural production. Banská Bystrica region comprises the area of two environmentally polluted areas: Pohronský environmentally loaded area, and Jelšava-Lubenica environmentally loaded area.

The supplying of the city of Banská Bystrica with drinking water ensures Water Operating Company of Central Slovakia. The water sources of public water supply are sources in karst area of the Low Tatras and the Great Fatra. Drinking water supply is provided from three major water systems (Laskomerský water line, Pohronský group water supply, and water from the well in the Slovenská Ľupča), accompanied by smaller local water sources. 99.81% of the total population is supplied from the public water supply of Banská Bystrica (Banská Bystrica, 2015).

Košice region plays an important role mainly due to the importance of the city of Košice, which is the second largest city in Slovakia with a developed economic base with focus on industry. In terms of industrial structure the most important industries include metallurgy, machinery, mining, food industries and production of building materials. Southern part of the region is characterised by agricultural production. The region is involved in the performance of the economy by 18.4%. Despite the fact that it is an industrially developed and urban region of Slovakia with great development potential, the Košice region is one of the regions with strong environmental load including three polluted areas: Rudňany-Gelnica, Košice-Prešov and Zemplín environmentally loaded areas. In the surroundings of the city there is the largest metallurgical complex U.S.Steel Košice, Ltd., which produces a wide variety of steel and other metal products.

The city of Košice is currently supplied with potable water from group supply systems of water sources Bukovec, Starina, and Drienovec with about 99.63% of the population being connected to the public water supply system (Košice, 2016). The supplying of the population of the city of Košice with drinking water is provided by Water Company of Eastern Slovakia.

3. Results

Supplies of potable water in the world continue to shrink. UNESCO experts expect the next twenty years that water availability per capita will be reduced by a third (UNESCO, 2012). Healthy clean potable water is a limiting factor for survival of the human population, which determines further socio-economic development. From this perspective, potable water is becoming a strategic commodity with increasing price. In the past, the price of drinking water (water, sewage) was very low; hence its consumption was many times higher.

3.1. Development of potable water consumption and its impact on household budgets

Consumption of potable water in Slovak households is showing a negative trend, in spite of the fact that the number of households supplied by public water ducts has opposite tendency, i.e. growing (Fig. 2). Specific water consumption in households is in fact the amount of water actually delivered to households (i.e. water invoiced to households) per capita per unit of time, the value of which fell by approximately 38% in 2010 and by approximately 42% in 2015 compared to 2000.

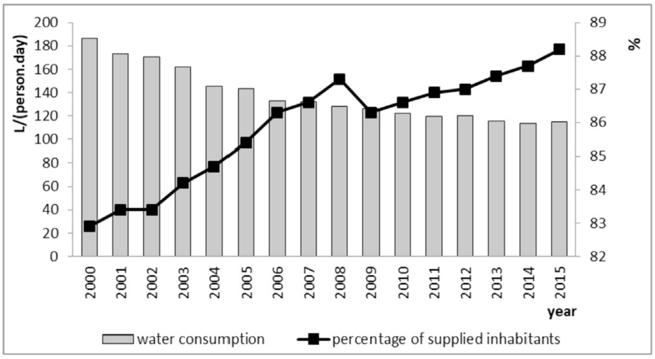

Fig. 2. Trend of percentage of potable water supplied inhabitants from public water supply systems and specific water consumption in households of Slovakia (SOSR, 2000-2015).

Since 1990, the price of potable water has increased approximately 40-times; nevertheless it is still below the EU level, where the price of potable water is 5-times higher on average. Water and sewage tariffs are higher for households in their budgets from year to year, leading to savings and thus to reduction in consumption of potable water (Fig. 2) supplied by water companies. Thus its partial replacement by rain water, the use of which is an essential aspect of economic budgets of individual households in Slovakia, is vital.

In Slovak households the most water is consumed for bathing and showering (approx. 55 L per inhabitant per day) along with flush toilet (about 48 L per inhabitant per day) while for direct use the smallest amount is consumed – just about 4 L per inhabitant per day (Table 1). These data show that in households almost 54% of potable water can be replaced by rainwater (Fig. 3), which represents a significant reduction in the household budgets.

3.2. Alternative use of rainwater in Slovak households

Rainwater does not meet the requirements for potable water in terms of Slovak legislation establishing the requirements for water intended for human consumption and quality control of water intended for human consumption. Due to its nature and character, it can be used for many activities (Fig. 3), for example: laundering (saving 15% of potable water), cleaning (saving 4% of potable water), flushing the toilet (saving 29% of potable water), watering plants and washing cars (saving 5% of potable water), or even committing of heating systems. The use of rainwater is determined by its composition (Sklenárová, 2011), which shall in no case cause:

- health hazard for users,
- a threat to potable water quality,
- a threat to comfort of the use of water,
- contamination of the environment (especially soil and ground water).

Table 1
Potable water consumption in Slovak households (Sklenárová, 2011).

Purpose of consumption	Consumption in litres per inhabitant per day
cooking and drinking	4
washing-up	8
personal hygiene	46
laundering	16
flushing toilet	40
cleaning	4
other (car, garden)	7

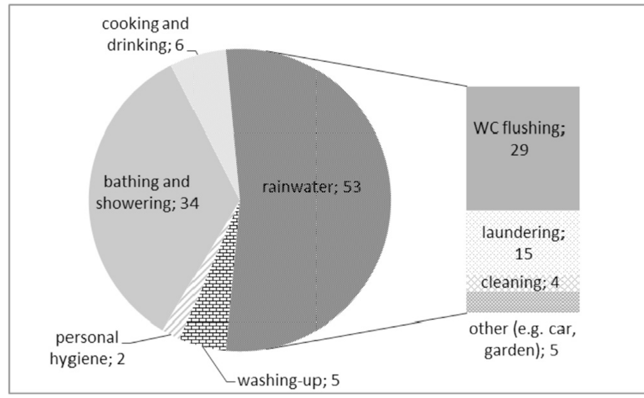

Fig. 3. Alternative use of rainwater in Slovak households – activities for use of and savings of potable water (Sklenárová, 2011).

3.3. Rainwater quality in particular regions

Generally the quality of collected rainwater has depended on local atmospheric and weather conditions as well as other local amenities and industrial production. The rainwater samples were collected from June 2014 to October 2015 and analysed for water quality parameters, presented in Table 2.

The pH of all samples varied in the range of 6.5–8.4 which stands for values typically found in nature. COD was less than 5.94 mg/L, BOD was less than 2.98 mg/L, DO was less than 2.98 mg/L and TDS wasless than 118 mg/L, EC was less than 129 mS/cm, the content of Ca^{2+} was less than 8.90 mg/L and Mg^{2+} was less than 2.30 mg/L, which assumes that its use for drinking purposes is not suitable. Though, the contents of anions Cl^- was less than 4.90 mg/L, SO_4^{2-} was less than 0.04 mg/L, NO_3^- was less than 0.80 mg/L and PO_4^- was less than 0.60 mg/L, and elements Ni, Zn, Hg, Fe, Al, Pb and Cr were not detected, only non-potable use of tested rainwater is possible.

4. Discussion

Differences in water consumption of households A, B, and C were caused by housing amenities, as well as the frequency of normal activities in the conditions of the household (Table 3).

Household A from Košice region disposes the latest technology - a dishwasher so called smart washing machine (energy class washing performance, water consumption - class A), a two-flush toilet, shower bath with saving shower heads and a stop valve, and thus its consumption was the lowest – 125.85 cubic metres per year. Household B from Banská Bystrica region showed the highest consumption since it does not have a dishwasher or a two-flush toilet or saving shower heads. In addition, the household members prefer bathing to showering, which is also reflected in the total consumption, which reached 166.59 cubic metres per year. In the event that individual households would have fully alternated consumption of potable water for laundering, flushing toilets, cleaning by rainwater, their budgets could significantly decrease as they could replace more than 60% of the total annual consumption. This option would enable individual households to reduce charges for supply of drinking water as well as fees for rainwater drainage.

The water quality significantly differed in the selected regions. Though the microbiological parameters were not tested, the analysed physicochemical parameters do not fulfil the requirements of rainwater for drinking water use according to the Slovak legislation; nevertheless, the rainwater is suitable for use in household for aforementioned activities based on the requirements mentioned in

Table 2
Comparison of water quality parameters between the regions.

	Košice				Banská Bystrica				Žilina			
	city		surroundings		city		surroundings		city		surroundings	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
pH	7.46	0.8424	8.00	0.4460	7.50	0.6442	7.43	0.5451	7.63	0.4955	7.54	0.6442
COD, mg/L	2.09	0.0991	4.62	1.2338	0.67	0.6095	0.88	0.6293	1.56	0.4014	1.48	0.3617
BOD, mg/L	1.15	0.1387	2.26	0.8126	1.95	0.4608	2.05	0.1982	2.31	0.2775	2.26	0.2676
DO, mg/L	113.00	45.5865	243.14	102.0740	17.57	18.3337	17.57	17.3427	122.86	40.6314	115.43	16.3517
TDS, mg/L	58.00	27.2528	98.43	30.2258	55.71	31.7123	49.57	11.3966	57.57	12.8831	57.86	9.9101
EC, mS/cm	67.14	28.2438	107.57	19.3247	55.71	10.9011	54.00	6.4416	66.00	15.8562	55.57	6.4416
Ca2+, mg/L	4.57	0.3171	6.76	2.4775	6.34	1.1843	4.86	2.9978	3.34	0.4212	2.20	0.5401
Mg2+, mg/L	1.53	0.3667	1.08	0.6739	1.09	0.7829	0.92	0.3419	1.21	0.2329	1.42	0.2378
Cl-, mg/L	0.01	0.0099	0.00	0.0000	4.32	0.4955	0.00	0.0050	0.00	0.0000	0.00	0.0000
SO_4^{2-}, mg/L	0.01	0.0198	0.00	0.0000	0.01	0.0198	0.00	0.0099	0.00	0.0000	0.00	0.0000
NO_3^-, mg/L	0.20	0.3964	0.19	0.2478	0.09	0.1982	0.36	0.2973	0.13	0.1487	0.11	0.0991
PO_4^{3-}, mg/L	0.14	0.1982	0.36	0.2478	0.14	0.1982	0.21	0.2478	0.13	0.1487	0.10	0.0989
Cu, mg/L	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000
Mn, mg/L	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000
Ni, mg/L	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000
Zn, mg/L	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000
Hg, mg/L	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000
Fe, mg/L	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000
Al, mg/L	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000
Pb, mg/L	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000
Cr, mg/L	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000

Note: SD – standard deviation.

Table 3
Consumption of potable water in individual households.

Purpose of potable water consumption	Potable water consumption					
	Household A		Household B		Household C	
	Litres per person per day	m^3 per year	Litres per person per day	m^3 per year	Litres per person per day	m^3 per year
cooking and drinking	2.2	3.21	3.1	4.53	2.8	4.09
washing-up	2.4	3.50	4.5	6.57	3.3	4.82
personal hygiene	29.6	43.22	35.7	52.12	32.1	46.87
laundering	7	10.22	15.7	22.92	12.3	17.96
flushing toilet	31.1	45.41	36.8	53.73	35.2	51.39
cleaning	1.5	2.19	3.2	4.67	2.5	3.65
other (car, garden)	12.4	18.10	15.1	22.05	9.8	14.31
Total		**125.85**		**166.59**		**143.08**

chapter 2 by Sklenárová (2011). In the review by Sánchez et al. (2015) rainwater, in general, based on the analysis in the reviewed studies, has acceptable values of physicochemical parameters even for drinking purposes. The values of the microbiological parameters indicate contamination and a health risk. Common microbiological pollutants detected in rainwater are especially faecal bacteria (E. Coli and intestinal enterococci), Campylobacter, Salmonella from bird faeces, Cryptosporidium, Giardia, Norovirus, Enterovirus, Legionella (de Man-van der Vliet, 2014). For this reason rainwater needs to be treated for potable use but can be used for non-potable purposes without any treatment. Even in this case, if any rainwater storage tank is used, disinfection can be used to avoid pathogens and reproduction of mosquito larvae (Sánchez et al., 2015).

In some EU countries, for example in Germany, Switzerland or Austria rainwater has been used in houses intensively for more than 10 years (Fonhit, 2011). There are also areas where the use of rainwater is even supported by the government through various subsidies. The use of rainwater in houses is in several cases much more favourable than use of potable water supplied by water companies directly as, in the case that supply of potable water fails, it will not distort normal running of the household - flush toilets, machine washing, watering gardens, and even committing of heating systems will continue to operate. This way a household gains certain independence, security and quality of life (Fonhit, 2011).

If rainwater was not diverted into public sewer system, it would be possible to quantify the annual savings of wastewater costs (Table 4) under the existing Slovak legislation, in a way that it is the product of reduced roof area and the average amount of precipitation in the region over the past 5 years. In Table 4 the charges for rainwater (highlighted in bold), i.e. the payment of the household for rainwater collected from the rooftop and discharged into the public sewer system, were calculated based on the amount of rainfall and sewage fees. The amount of rainfall is calculated by the Slovak Hydrometeorological Institute and is calculated based on

Table 4
Quantification of the amount of rainwater fees in individual households.

	Household A	Household B	Household C
S, m^2	120	130	118
Ψ	0.9	0.9	0.9
Overall reduced surface – S	**108**	**117**	**106.2**
Hz, mm	820	840	819
rainfall, m^3	88.56	98.28	86.98
sewage fees, Eur.m^{-3}	0.8842	1.0909	1.0772
Charges for rainwater, Eur	**78.30**	**107.21**	**93.69**

equation (1), taking into account the overall reduced surface highlighted in bold. The sewage fees are given by the particular water companies in each region.

Total financial savings resulting into a reduction of the annual budgets of individual households can be quantified by calculating the water fees in case of potential alternation of particular activities by rainwater. Sewage fees would be saved by drainage of atmospheric precipitation (Table 5). The water and sewage charges are given by particular water companies. The fees for drinking water supplying and water drainage were calculated based on the charges and the annual consumption and are highlighted in bold. The savings were calculated based on the percentage of replacement of drinking water by rainwater. The final amount of savings (total savings highlighted in bold) is affected not only by the actual consumption and facilities of housing but also by price for supplying and draining of water from households per unit in different regions of Slovakia, which is set by individual water companies responsible for providing comprehensive services in this area.

Given the above detailed analysis of potable water consumption in selected households of Košice, Banská Bystrica and Žilina regions it can be concluded that the highest total savings achieved would have been in case of alternative use of rainwater in household A from the Košice region amounting to more than 64%, the lowest would have been in household B from Banská Bystrica region and household C from Žilina region that showed a saving of almost 61%.

Detailed partial analysis of individual savings by usage of rainwater in households points to the following facts:

1. Total water consumption in the analysed households is primarily influenced by the housing amenities,
2. Use of the potential volume of rainwater is determined by the total reduced area of water capturing and collection for its further use in the particular households,
3. Use of rainwater in the monitored households leads to a reduction of their annual fees for the water supply and drainage of more than 50%, and
4. Total savings are subject to geographical integration of individual households within the territorial management of water companies, in which the amount of water and sewage charges is different.

The study showed that the rainwater used in households has helped to save significant amounts of potable water. Savings from use of rainwater for different applications inside and outside a household were also proved in Australia where an introduction of simple water efficient appliances and use of rainwater tanks saved up to 77% of drinking water (Muthukumaran et al., 2011) and potable water conservation is more important than energy consumption (James, 2003). Studies in the Mediterranean areas (Angrill et al., 2012) and Colombia (Morales-Pinzón et al., 2011) indicated not only significant potable water savings by use of rainwater but also reduction in environmental impact of rainwater in urban areas. Significant environmental benefits were also proved by a German study (Nolde, 2007) documenting the efficiency of non-point source pollution reduction and minimisation of requirements for new water supply infrastructure. Ghimire et al. (2017) compared a commercial rainwater harvesting system with a municipal water supply system and concluded that the former was operating better or equivalent (45–55%) to the latter in acidification, energy demand, water extraction, human health criteria, evaporative water consumption and other, totally in 10 out of 11 parameters. In Malaysia a case study of rainwater harvesting was presented with rainwater being an alternative water resource in the country (Lee et al., 2016). Different problem may occur in areas with semiarid climate suffering from either flood by heavy rainfalls or drought from abnormally low rainfall. The use of rainwater in such an area of Brazil was studied by Santos and de Farias (2017).

However it should be noted the fact that the above model solutions of household expenditure reduction do not reflect the potential savings for wastewater, as the discharge of domestic waste water is not measurable by water companies in the same way as in the case, the amount of drinking water supplied is precisely quantified through a meter. Water companies in Slovakia quantify the total amount of sewage on the basis of quantification of potable water consumption (the amount of water withdrawn from the water company corresponds to the discharged amount). An accurate determination of quantities of wastewater from individual households could approach to an explicit quantification of savings for charges of rainwater not drained directly into the public sewer system as such but in the form of sewage from households.

5. Conclusions

Expenditures of Slovak households, among other things, are increased by a constant growth of charges for drinking water. Water companies respond to decreasing consumption by raising the price because the costs of extraction, treatment and distribution of water are not decreasing; even, in some cases, they are increasing due to more demanding methods for its treatment and transport at large distances from high capacity water resources.

The study demonstrated that significant reduction of payments for drinking water can be achieved by use of rainwater in households where the purpose of its use does not require potable water in terms of Slovak Regulations. Eventually the findings of this study showed that up to 225 Eur per year of expenses in total budget can be saved compared to an average household. Based on quantification of savings, alternative utilisation of atmospheric precipitation in homes for not only economic benefits but also environmental positives can be recommended. It also contributes to rationalisation of water sources and thus protection of the environment. In addition, according to the chemical analysis rainwater is soft and does not create limescale. Other parameters do not fulfil the requirements for drinking water, as predicted, but also do not cause any problems in the intended way of use. Households can thus

Table 5
Quantification of savings in case of rainwater use in households.

Resources	Household A	Household B	Household C
water charges, Eur.m^{-3}	1.3667	1.147	0.952
sewage charges, Eur.m^{-3}	0.8842	1.0909	1.0772
fees for drinking water supplying, Eur	172.00	191.07	136.21
fees for water drainage, Eur	111.28	181.73	154.13
Total fees (supplying + drainage)	**283.28**	**372.80**	**290.34**
savings when using rainwater, Eur	103.76	118.56	83.12
savings on sewage fees, Eur	78.30	107.21	93.69
Total savings	**182.06**	**225.78**	**176.81**

eliminate the expenditure for fabric softeners, detergents, and various means for removing limescale. Even though, the individual facilities, location and other factors can influence the amount of savings.

In the future, further interdisciplinary research involving not only analysis of water consumption, household budget and rainwater quality but also social and technical analyses will be required to improve the efficiency of rainwater use and also community involvement to improve the awareness of the inhabitants. It also might be useful to study the microbiological composition of rainwater and a possibility to improve the quality for potable use which would require an implementation of some simple system for disinfection. Though it would be a non-stable source of potable water, in combination with drinking water from public supply system, it could save further expenses of a household.

Declarations of interest

None.

References

Angrill, S., Farreny, R., Gasol, M.C., Gabarrell, X., Vinolas, B., Josa, A., Rieradevall, J., 2012. Environmental analysis of rainwater harvesting infrastructures in diffuse and compact urbanmodels of Mediterranean climate. Int. J. Life Cycle Assess. 17 (1), 25–42.

Banská Bystrica, 2015. Investment Opportunities in the City of Banská Bystrica. City of Banská Bystrica. Retrieved on 26 March 2016 from. www.banskabystrica.sk/?id_menu=15996&module_data__144327__month_actual=5&module_data__144327__year_actual=2016.

Campisano, A., Butler, D., Ward, S., Burns, M.J., Friedler, E., DeBusk, K., Fisher-Jeffes, L.N., Ghisi, E., Rahman, A., Furumai, H., Han, M., 2017. Urban rainwater harvesting systems: research, implementation and future perspectives. Water Res. 115, 195–209.

Chawla, S.S., Gupta, S., Onchiri, F.M., Habermann, E.B., Kushner, A.L., Stewart, B.T., 2016. Water availability at hospitals in low- and middle-income countries: implications for improving access to safe surgical care. J. Surg. Res. 205 (1), 169–178.

de Man-van der Vliet, H., 2014. Best Urban Water Management Practices to Prevent Waterborne Infectious Diseases under Current and Future Scenarios. Utrecht University Repository, Utrecht. Retrieved on 30 March 2016 from dspace.library.uu.nl/handle/1874/294399.

Ding, G.K.C., Ghosh, S., 2017. Sustainable water management—a strategy for maintaining future water resources, reference module in earth systems and environmental sciences. Encyclopedia Sustain. Technol. 91–103.

Dixon, A., Butler, D., Fewkes, A., 1999. Water saving potential of domestic water reuse systems using greywater and rainwater in combination. Water Sci. Technol. 39 (5), 25–32.

Fonhit, 2011. Utilisation of rainwater in houses. In: [Využívanie Dažďovej Vody V Rodinných domoch.] Center of Water Technologies [Centrum Vodohospodárskych Technológií], Košice. Retrieved on 26 March 2016 from. www.fonhit.sk/prospekty/Vyuz.dazd.vod.RD1.pdf.

García-Montoya, M., Sengupta, D., Nápoles-Rivera, F., Ponce-Ortega, J.M., El-Halwagi, M.M., 2016. J. Clean. Prod. 130, 82–91.

Ghimire, S.R., Johnston, J.M., Ingwersen, W.W., Sojka, S., 2017. Life cycle assessment of a commercial rainwater harvesting system compared with a municipal water supply system. J. Clean. Prod. 151, 74–86.

James, K., 2003. Water issues in Australia-an LCA perspective. Int. J. Life Cycle Assess. 8 (4), 242.

Kahinda, J., Taigbenu, A., Boroto, R., 2010. Domestic rainwater harvesting as an adaptation measure to climate change in South Africa. Phys. Chem. Earth 35, 742–751.

Kelly, E., Shields, K.F., Cronk, R., Lee, K., Behnke, N., Klug, T., Bartram, J., 2018. Seasonality, water use and community management of water systems in rural settings: qualitative evidence from Ghana, Kenya, and Zambia. Sci. Total Environ. 628 (629), 715–721.

Košice, 2016. City of Košice. Retrieved on 24 March 2016 from. www.kosice.sk/index.php.

Lee, K.E., Mokhtar, M., Hanafiah, M.M., Halim, A.A., Badusah, J., 2016. Rainwater harvesting as an alternative water resource in Malaysia: potential, policies and development. J. Clean. Prod. 126, 218–222.

Morales-Pinzón, T., Angrill, S., Rieradevall, J., Gabarrell, X., Gasol, C.M., Josa, A., 2011. LCM of rainwater harvesting systems in emerging neighborhoods in Colombia. In: Finkbeiner, M., Finkbeiner, M. (Eds.), Towards Life Cycle Sustainability Management. Springer, Berlin, pp. 277–288.

Morales-Pinzón, T., Rieradevall, J., Gasol, C.M., Gabarrell, X., 2015. Modelling for economic cost and environmental analysis of rainwater harvesting systems. J. Clean. Prod. 87, 613–626.

Muthukumaran, S., Baskaran, K., Sexton, N., 2011. Quantification of potable water savings by residential water conservation and reuse – a case study. Resour. Conserv. Recycl. 55, 945–952.

Nolde, E., 2007. Possibilities of rainwater utilisation in densely populated areas including precipitation runoffs from traffic surfaces. Desalination 215, 1–11.

Pavolová, H., Bakalár, T., 2012. Potential household savings from rainwater use - a Slovakian study. Water 21 (2/2012), 20-20.

Sample, D.J., Liu, J., 2014. Optimizing rainwater harvesting systems for the dual purposes of water supply and runoff capture. J. Clean. Prod. 75, 174–194.

Sánchez, A.S., Cohim, E., Kalid, R.A., 2015. A review on physicochemical and microbiological contamination of roof-harvested rainwater in urban areas. Sustain. Water Qual. Ecol. 6, 119–137.

Santos, S.M., de Farias, M.M.M.W.E.C., 2017. Potential for rainwater harvesting in a dry climate: assessments in a semiarid region in northeast Brazil. J. Clean. Prod. 164, 1007–1015.

Sklenárová, T., 2011. Decentralised Wastewater Treatment (I). A Comparison of Systems, Desar Concept./Water, Sewer System. [Decentralizovaný Spôsob Nakladania S Odpadovými Vodami (I). Porovnanie Systémov, Desar Koncept./Voda, Kanalizace] Tzb-info, Prague. Retrieved on 20 March 2016 from voda.tzb-info.cz/likvidace-odpadnich-vod/5663-decentralizovany-sposob-nakladania-s-odpadovymi-vodami-i.

SOSR, 2000-2015. Statistical Office of the Slovak Republic. Retrieved on 26 March 2016 from. www.statistics.sk/pls/elisw/vbd.

UNESCO, 2012. The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. UNESCO, Paris.

Žilina, 2016. Program of Management and Social Development of the City of Žilina in 2014-2020 with a View to 2023. [Program Hospodárskeho a Sociálneho Rozvoja Mesta Žilina Na Roky 2014 – 2020, S Výhľadom Do Roku 2023.] City of Žilina, Žilina. Retrieved on 20 March 2016 from. www.zilina.sk/userfiles/2017/PHSR_Zilina_2-0.pdf.