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The Quality of Stored Rainwater for Washing Purposes

Joanna Struk-Sokołowska [1,*], Joanna Gwoździej-Mazur [2], Piotr Jadwiszczak [3], Andrzej Butarewicz [4], Piotr Ofman [1], Marcin Wdowikowski [5] and Bartosz Kaźmierczak [6]

1. Department of Environmental Engineering Technology, Faculty of Civil Engineering and Environmental Sciences, Bialystok University of Technology, 15-351 Bialystok, Poland; p.ofman@pb.edu.pl
2. Department of Water Supply and Sewerage Systems, Faculty of Civil Engineering and Environmental Sciences, Bialystok University of Technology, 15-351 Bialystok, Poland; j.mazur@pb.edu.pl
3. Department of Air Conditioning, Heating, Gas Engineering and Air Protection, Faculty of Environmental Engineering, Wroclaw University of Science and Technology, 50-370 Wroclaw, Poland; piotr.jadwiszczak@pwr.edu.pl
4. Department of Chemistry, Biology and Biotechnology, Faculty of Civil Engineering and Environmental Sciences, Bialystok University of Technology, 15-351 Bialystok, Poland; a.butarewicz@pb.edu.pl
5. Institute of Meteorology and Water Management-National Research Institute, 01-673 Warsaw, Poland; marcin.wdowikowski@imgw.pl
6. Department of Water Supply and Sewerage Systems, Faculty of Environmental Engineering, Wroclaw University of Science and Technology, 50-370 Wroclaw, Poland; bartosz.kazmierczak@pwr.edu.pl

* Correspondence: j.struk@pb.edu.pl

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Abstract: The use of rainwater for washing clothes is determined by its amount, composition and quality of washing. Raw rainwater is soft and free of pollution. The collected rainwater already contains pollution present in the atmosphere and washed away from roofs and other surfaces. It can also change its quality when stored in tanks. Washing clothes does not require drinking quality water but just clean, safe water that guarantees effective removal of dirt from fabrics. The study determined the physicochemical and microbiological changes of rainwater characteristics during retention. Rainwater was collected in a standard underground tank for 30 days and water analyses were conducted every 10 days. The possibility of tap water replacement in the household with collected rainwater for ecological clothes washing has been assessed.

Keywords: stored rainwater; RWH system; washing; retention; physicochemical and microbiological changes; Varimax

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1. Introduction

Drinking water resources are under increased pressure due to rising water demand, growing population, progressive urbanization, pollution and overexploitation of water bodies. To secure sufficient drinking water, new strategies of protection and prudent and rational use of water are promoted and developed, including sustainable rainwater harvesting (RWH) [1]. The RWH is an alternative, widely available, ecological and beneficial source of fresh water suitable for an entire range of uses and areas [2]. Rainwater harvesting increases water self-sufficiency and delays the need to build new centralized water infrastructure [3–5]. Globally implemented RWH systems could cover up to 90% of household water consumption [6] and the RWH plays a critical role in solving the world's problem of increased water stress [7,8]. Also, these systems can be useful in the reduction of flood risk in urban areas [9,10]. Many countries created legal and economic conditions to support or enforce the use of RWH as part of climate, environmental and social policies [11,12]. Next to the implementation project and design solutions, the support programs, grants and subsidies significantly and positively affect the system's economic profitability [13–15].

The prevalence of RWH systems and the use of rainwater in European countries is varied. In the UK, storage of rainwater for home use is popular and has a long tradition [16]. In Germany, one third of all new buildings use rainwater for household purposes through local government subsidies [17]. Similarly, Spain has launched a national program of subsidies for RWH in new buildings [18]. In France, a tax reduction has been implemented to encourage the use of rainwater [19]. To promote rainwater harvesting as complementary technology, Italy issued technical guidelines for RWH [20]. The high price of drinking water has increased the popularity of rainwater systems in Austria, Sweden, Switzerland, Belgium and Denmark [21–23].

A typical RWH system consists of the concentration, collection, and storage of rainwater for use on site and reduction of drinking water consumption from centrally supplied sources. In urban areas rainwater can be collected from impervious surfaces such as roofs, terraces or courtyards [24]. Harvested water is stored in above or underground tanks with capacities designed according to water demand [6,25]. Closed tanks minimize the risk of contamination from environment, people or animals, prevent growth of algae and reduce mosquito breeding. A system of gutters, downpipes, flush diverters, debris screens and filters supply the runoff to the tank during downpour. Separate pump and pipeline network supplies rainwater from the tank to devices and taps in the house [13,26].

In households, rainwater can be used for toilet flushing, washing, irrigation, cleaning, car washing and more. In the absence of rainwater, quality standards for household drinking and bathing water quality regulations apply in many countries [27–30]. Rainwater meeting the drinking water quality can fully replace tap water in households. Bathing water quality rainwater is suitable for laundry washing, toilet flushing, garden watering and car washing or other cleaning activities. The structure of water demand (Figure 1) indicates that up to 60% of domestic water can be replaced with bathing water quality rainwater without any inconvenience to inhabitants. Laundry consumes about 15% of total household water demand and replacement of hard tap water by soft rainwater is environmentally beneficial [15]. Rainwater has a very low hardness which prevents limescale in washing machines and reduces detergent consumption. This increases the life of washing machines and the energy consumption for heating remains constant for years. Less detergent means less pollution of both the wastewater treatment plant and the environment and less detergent residue in clothes which is particularly beneficial for allergy sufferers.

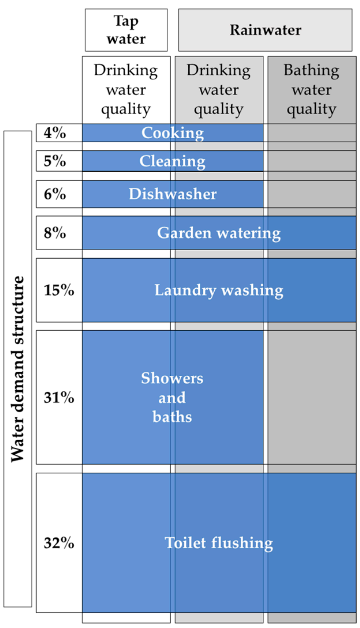

Figure 1. Matrix of water usage and allowed water quality in household needs [13,14,17,18,28–30].

It is very convenient to use rainwater in automatic washing machines as in one average cycle the washing machine consumes 30 to 90 L. Automatic washing does not require drinking water quality but physicochemical and microbiological standards of bathing water. The use of rainwater instead of tap water should provide users with a good quality effect. Unpleasant smell or color, and residues on cleaned and washed items would discourage users from using rainwater.

The requirements for collected rainwater for washing purposes can be defined using three groups of factors: proper tank size, quality and safety of accumulated rainwater and washing quality based on outcome, results and users' satisfaction (Figure 2).

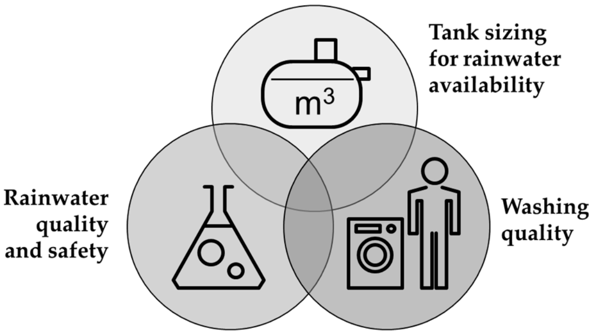

Figure 2. Three factors of stored rainwater suitability for washing purposes.

The quality and pollution of harvested rainwater depends on the environment, location, collection surface and the RWH system [31–35]. For the purposes of this analysis three areas of rainwater contamination have been identified (Figure 3). In the first one rainwater gets contaminated by assimilating air pollutants ("1" on Figure 3), in the second one it washes dirt away from the roof ("2" on Figure 3) and in the third changes occur during storage of rainwater in the tank ("3" on Figure 3). Combination of changes in the quality of rainwater in these three areas impact the quality of water at the point of use ("4" on Figure 3).

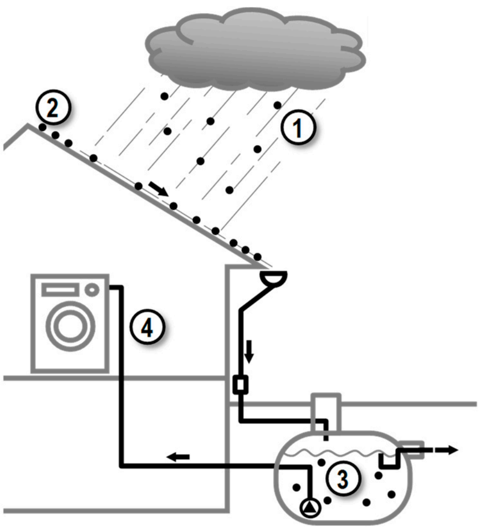

Figure 3. Schematic representation of rainwater harvesting for washing.

The level of water pollution in the first area is affected by local air pollution and time of year. It is an area independent of RWH solutions and should be treated as a characteristic of a given location [33]. In the second area, the runoff assimilates all pollution present on the roof, including precipitation (i.e., wet deposition), atmospheric deposition (i.e., dry deposition) and materials used in the roof construction. [13,26]. In urban areas, roofs are contaminated with wind-blown dirt including heavy metals and nutrias, lichens and mosses, fungus, fecal droppings from birds and other animals, insects and litter, or fallen organic matter from the surroundings trees pollute the water [36]. Metal roofs are suitable for high quality of harvested rainwater—high temperature and ultraviolet light effectively and naturally disinfect the rooftop surface. To maintain a high quality of collected rainwater a regular cleaning of catchment areas and storage tanks is required [33]. Literature review reveals that rainwater is highly variable in the quality and quantity of contaminants and microorganisms [33,37].

2. Materials and Methods

The aim of the study is to evaluate the possibility of using rainwater for washing in areas considered as being particularly clean in Europe, like north-west Poland. The analyses were conducted in 2017 (August–November) using standard RWH in single family house located in the suburbs of Bialystok, a city with a population of 300,000, elevated 160 m above the sea level. This new housing estate is surrounded by arable fields and forests, connected to the city by a national road. There is no heavy industry and noxious emitters of air pollution in the area. Only light industry plants are located in Bialystok city such as electromechanical, electrotechnical, food and textile.

Investigated rainwater was collected from 110 m^2 tiled cement rooftop by the standard rainwater harvesting system for residential purposes. The RWH system is built of PVC gutters, underground PE tank with a volume of 1.7 m^3 and automatic pump with a floating extractor. Gutter top screens, sloped debris screen and first flush diverter were used to supply the clean runoff to the tank. Tightly closed underground PE tank, covered with 50 cm of soil, protects water against secondary contamination, eliminates sunlight operation and stabilizes the storage temperature.

The study determined the physicochemical and microbiological changes of rainwater quality during retention in a tank for 30 days. The analyses were conducted every 10 days (4 times in the research cycle). To assess the quality of stored rainwater for washing purposes the characteristics were benchmarked against Polish drinking water standards (DWS) [38], World Health Organisation (WHO) Guidelines [39], EU Drinking Water Directive (DWD) [29] and EU Bathing Water Directive (BWD) [30].

An analysis of meteorological conditions was performed as the background for the conducted research. For this purpose, measurement data of the Polish hydrological and meteorological service conducted by Institute of Meteorology and Water Management-National Research Institute (IMWM-NRI) at the 1st order synoptic station, Bialystok was used. Basic meteorological elements such as precipitation (daily precipitation h_d (mm) and intensity h_t (mm·min^{-1})), air temperature (hourly t_h and daily values: average $\bar{t}_d$ (°C), minimum $t_{\min}$ (°C) and maximum $t_{\max}$ (°C)), air relative humidity R_h (%), atmospheric pressure reduced to the sea level p_r (hPa) as well as wind speed v_s (m/s) and direction v_d (°) were analyzed. Assessment of the meteorological situation describing considerate period will indicate potential conditions for the microorganisms' development in the proposed network of supplying rainwater to the household. Meteorological data was derived from IMWM-NRI website open access database (https:dane.imgw.pl).

On the basis of carried out laboratory studies, a complex database was obtained, which made it possible to identify factors influencing the quality of considered rainwater. The identification of the factors involved reduction analyses, the aim of which is to reduce the number of variables in the input data set. One such method is the principal components analysis. The effect of the data reduction is the separation of factors consisting of selected variables included in the analysis. The degree of connection of individual variables with a separate factor is determined by factor correlations. These factor correlation values can be interpreted in a similar way as the values of the Pearson or Spearmen correlation coefficients.

The crucial element of the analysis of the principal components is to determine the number of identified factors determining changes in the data matrix. The most frequently used criterion determining the number of identified factors is the Kaiser criterion, according to which the specific value of a given factor should be greater than 1. This means that if a single factor does not reveal more information than 1 variable, then it shall be rejected. According to the mentioned criterion, 3 factors influencing the quality of the studied rainwater were selected from the input data set. The number of factors and the value of the isolated variance are given in Figure 4. The first isolated factor was characterized by the value of the isolated variance at the level of 13.11, the second one at the level of 11.34 and the third factor at the level of 7.55.

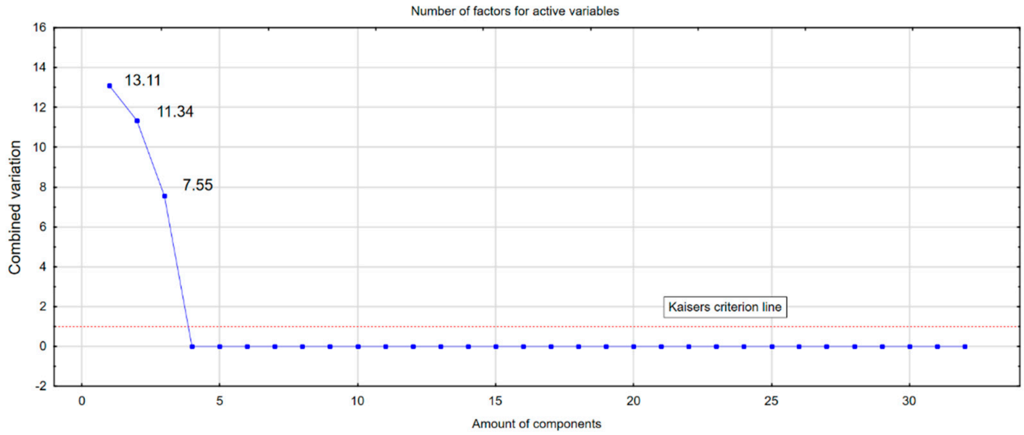

Figure 4. Settlement diagram.

The data was standardized before the analysis, which resulted in averaging the variance of all variables accepted for analysis. Additionally, the variables were rotated using the Varimax method in order to enable the interpretation of the separated factors.

Rainwater for analysis was sampled from the tank to sterile bottles and transported to the laboratory of Department of Chemistry, Biology and Biochemistry at Bialystok University of Technology. Microbiological analyses were carried out in the autumn of 2017. The total viable count of heterotrophic psychrophilic bacteria incubated in 22 °C (TVC 22 °C) and total viable count of heterotrophic mesophilic bacteria incubated in 37 °C (TVC 37 °C) were carried out in accordance with Polish Standards PN-EN ISO 6222:2004P. The presence of *Escherichia coli* (EC) and total coliforms (TC) was determined using the membrane filtration technique according to Polish Standard PN-EN ISO 9308-1: 2014-12 A 1:2017-4. After filtration, 100 mL of rainwater the filters were placed onto Chromocult Coliform Agar (CCA-Merck Ltd) and incubated at 37 °C for 24 h. All deep blue colonies were counted as EC and all red or pink-red colonies were counted as TC. For assaying the Enterococci membrane filtration method was used according with Polish Standard PN-EN ISO 7899-2:2004P. Detection of *Salmonella spp.* were carried out in accordance with Polish Standards PN-EN ISO 19250:2013-07E.

3. Results

3.1. Weather Conditions

For more than the first decade of October (1–13 October), Poland was under the dominant influence of Low-pressure area moving from the Atlantic through Scandinavia to western Russia. These Low centers were accompanied by systems of atmospheric fronts. During October 6 to 7, Poland temporarily found itself in the range of High-pressure area moving from Scandinavia. At that time, polar-sea air was flowing into the country, which was temporarily warmer. At the same time, arctic air was temporarily present, resulting in mostly large cloud cover, but with greater clear weather. During the High-pressure area there were also sunny weather. From 14 to 21 October, Poland was under the influence of the Low-pressure area of Western Europe, only initially succumbing to the High-pressure area from the Balkans. At that time, tropical air and temporarily warm polar-sea flowed in. The cloudiness was small and moderate, in the northwestern half of the country it increased to large periods causing rain. Until the end of October, northern and western Poland was under the influence of Low-pressure area with systems of atmospheric fronts, which moved on the Baltic Sea and the North Sea. The south and east parts of the country were reaching a High-pressure area wedge from the Atlantic Sea. Initially there was advection of tropical and then polar sea, temporarily warm. In the south of the country, the cloud cover was small, and in the rest of the area it was large, with more rain and local weather. It rained or drizzled in the north of Poland (Figure 5).

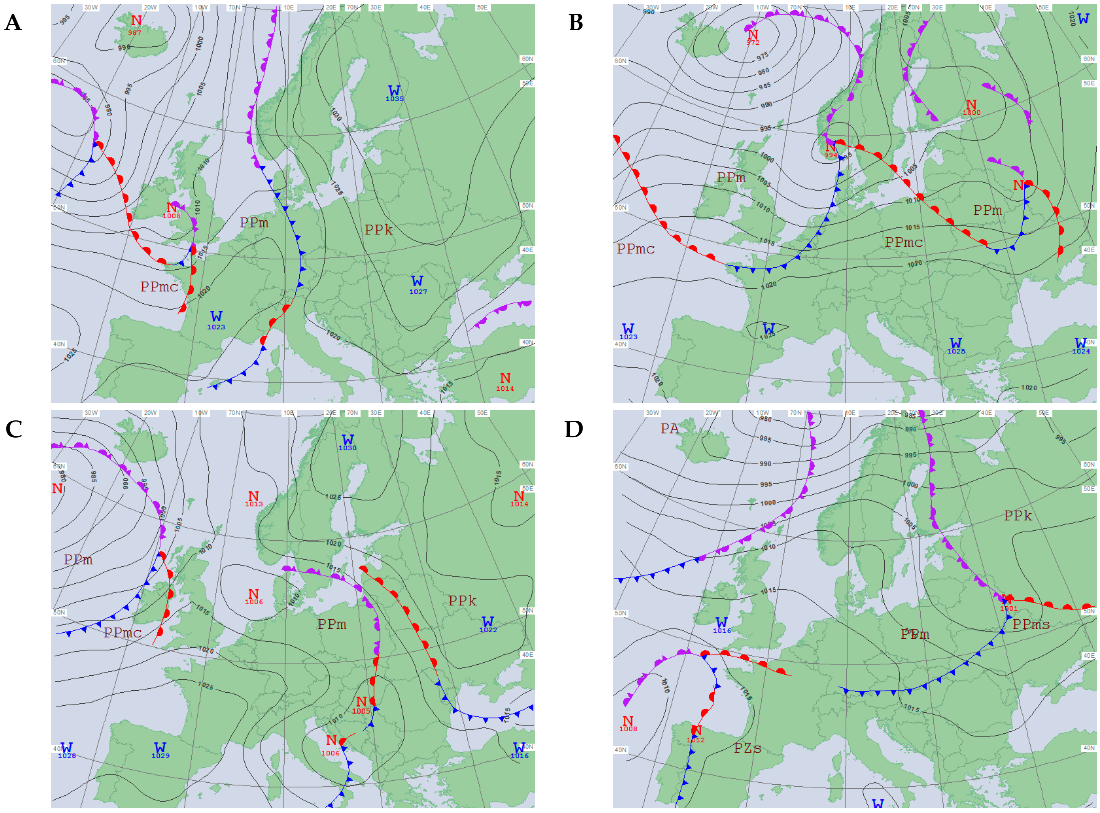

Figure 5. Weather charts respectively (W—High pressure area, N—Low pressure area): (**A**) 1 X, (**B**) 12 X, (**C**) 23 X, (**D**) 3 XI.

The analyzed period was relatively rainy (Figure 6). The occurred rainfall was moderately intensive, with intensities between 0.1–2.5 mm per 10 min, which is a characteristic domain of the Polish climate in October and November. During 40 analyzed days, there were 32 rainy days, with 3 days as a dust of precipitation which means h_d = 0.01 mm. The daily rainfall totals ranged from 0.1 mm to 14.7 mm, and the 40 days total was only 134.8 mm. Consecutive 10-day totals were 56.3, 12.7, 43.8 mm and 21.5 mm, respectively. In the analyzed period, the average air temperature was 7.1 °C, which was 2.7 °C deviation from the long-term period 1971–2000. The maximum temperature was 19.8 °C and the minimum temperature was −2.1 °C. There was no day with average temperature below 0 °C (Figure 7). Relative humidity ranged from 50 to 87% while atmospheric pressure varied between 953.9 and 1010.2 hPa. West and south-west wind directions dominated, 32 and 21% respectively, with the average wind speed 2.8 m s^{-1} (Figure 8).

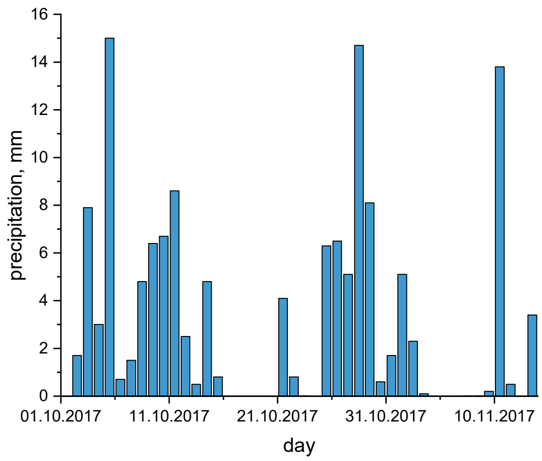

Figure 6. Precipitation for Bialystok station.

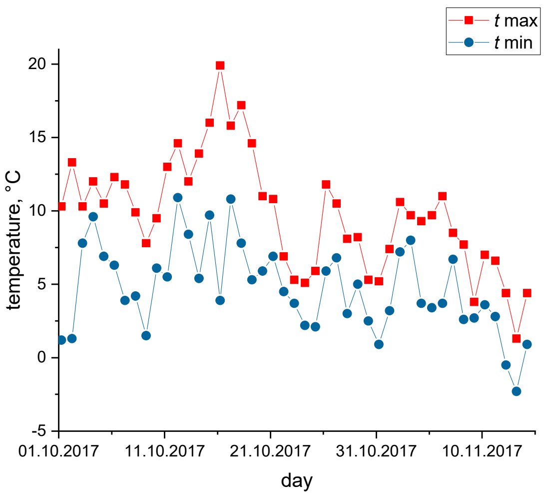

Figure 7. Air temperature for Bialystok station.

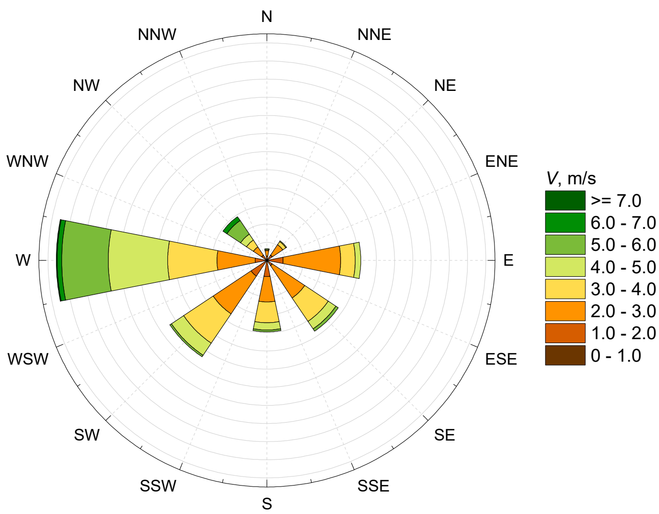

Figure 8. Wind direction for Bialystok station.

3.2. Rainwater

The aim of the study was to analyze changes in physicochemical characteristics of RWH rainwater for washing collected from tiled, ceramic roofs. The experiment was carried out with increased water retention time (immediately after rainfall and 10, 20, 30 days after rainfall). The results of physicochemical analysis of rainwater are presented in Table 1. According to the available literature [40–44] and standards [29,30,38,39], the pH of rainwater can range from weakly acidic (pH 3.1) to weakly alkaline (pH 11.4). In conducted studies, the pH of rainwater range of 6.6–8.26. Figures 4 and 5 show changes in the concentration of organic and nutrient compounds in harvesting rainwater during the experiment. It should be noted that that the concentration of all analyzed parameters was lower than that specified in the Polish standards [38] and global regulations [29,30,39]. The only exception was water turbidity which was slightly higher than required for drinking water (1 NTU). The water turbidity determined during the experiment was acceptable for washing purposes. Figure 6 shows changes in the concentration of heavy metals in rainwater. The concentration of all analyzed heavy metals was low and did not exceed the acceptable standards. Test results available in literature indicate that out of all heavy metals it is lead (Pb) which most frequently exceeds the DWS limit (10 μg·dm^{-3}) in raw rainwater. For instance, in a Malaysian study [40] Pb concentrations exceeded 10 mg/L in all rainwater samples. Simmons, et al. [41] indicated 14.4% of total samples had Pb concentrations exceeding New Zealand's water standards [41]. Similar results were reported by Huston, et al. [42] who concluded that 14.2% rainwater samples in Australia exceeded DWS [42]. Over 30% of rainwater samples in which lead concentration was exceeded was presented in Australian studies conducted by Magyar, et al. [43] and Huston, et al. [44]. The above-mentioned authors attribute the presence of lead in rainwater to chemical treatment of tanks or paint (as much as 58%), deposition in the atmosphere (21%) and hydraulics (16%). These authors have found that the most important element in a rainwater harvesting system is correct design. It is very probable that the RWH system that was built for the Polish experiment was designed and built correctly resulting in rainwater not exceeding requirements after 30 days storage. Additional positive influence on water quality is the location of the system in one of the cleanest regions in Europe, specifically Podlaskie, Poland. Al-Batsh, et al. [33] notice that after a stabilization period the stored rainwater becomes significantly cleaner [33], and this reflected many of the results in Table 1.

Table 1. Physicochemical characteristics of rainwater (cement tile roof) in comparison with Polish drinking water standards (DWS) [38], World Health Organization guidelines for drinking water quality (WHO) [39], EU Drinking Water Directive (DWD) [29] and EU Bathing Water Directive (BWD) [30].

Parameter	Unit	After … Days				DWS [38]	WHO [39]	DWD [29]	BWD [30]
		0	10	20	30				
Water temperature each time it was sampled	°C	13.0	13.5	12.3	11.8	–	–	–	–
pH	-	6.60	7.58	8.26	7.61	6.5–9.5	6.5–8.5	6.5–9.5	–
Alkalinity	mg·dm^{-3}	0.50	0.70	0.80	0.30	–	–	–	–
Hardness	mg·dm^{-3}	28.02	22.16	20.02	21.60	60.0–500.0	–	–	–
Conductivity at 25 °C	μS·cm^{-1}	72.40	50.00	34.40	35.16	2500.0	2000.0	2500.0 at 20 °C	–
Turbidity	NTU	2.40	3.00	2.25	2.10	1.0	5.0	acceptable	–
Colour	Pt-Co	30.00	36.00	25.00	27.00	acceptable	–	acceptable	–
Total dissolved solids (TDS)	mg·dm^{-3}	31.00	56.00	61.00	45.00	–	500.0	–	–
Total suspended solids (TSS)	mg·dm^{-3}	10.00	10.00	10.00	21.00	–	–	–	–
Dissolved oxygen (DO)	mg·dm^{-3}	3.10	4.96	3.60	4.41	–	–	–	–
Biological Oxygen Demand (BOD_5)	mg·dm^{-3}	5.00	4.00	5.00	6.00	–	–	–	–
Chemical Oxygen Demand (COD)	mg·dm^{-3}	29.00	38.00	36.00	22.00	–	–	–	–
Oxidizable ($KMnO_4$)	mg·dm^{-3}	2.50	2.40	2.80	2.10	5.0	–	5.0	–
Sulfate (SO_4^{2-})	mg·dm^{-3}	3.00	5.00	2.00	4.40	250.0	–	250.0	–
Total Kiedjahl nitrogen (TKN)	mg·dm^{-3}	1.31	1.28	2.23	1.19	–	–	–	–
Total phosphorous (P)	mg·dm^{-3}	2.10	2.80	2.60	1.90	–	–	–	–
Phosphates (PO_4-P)	mg·dm^{-3}	1.41	1.54	2.24	0.90	–	–	–	–
Ammoniacal-nitrogen (NH_3^-N)	mg·dm^{-3}	0.41	0.42	0.26	0.38	–	–	–	–
Nitrate-nitrogen (NO_3^-N)	mg·dm^{-3}	1.71	2.40	2.00	1.90	50.0	–	50.0	–

Table 1. *Cont.*

Parameter	Unit	After … Days				DWS [38]	WHO [39]	DWD [29]	BWD [30]
		0	10	20	30				
Nitrite-nitrogen (NO_2^-N)	mg·dm^{-3}	0.00	0.01	0.02	0.01	0.5	–	0.5	–
Chloride (Cl^-)	mg·dm^{-3}	2.00	1.00	1.00	1.00	250.0	250.0	250.0	–
Cadmium (Cd)	µg·dm^{-3}	0.00	0.02	0.02	0.01	5.0	–	5.0	–
Calcium (Ca)	mg·dm^{-3}	4.2442	4.2810	3.5006	3.6801	–	–	–	–
Chromium (Cr)	µg·dm^{-3}	0.0198	0.0221	0.0290	0.0271	50.0	–	50.0	–
Copper (Cu)	mg·dm^{-3}	0.0126	0.0063	0.0151	0.0583	2.0	–	2.0	–
Iron (Fe)	µg·dm^{-3}	0.1405	0.1215	0.1488	0.1533	200.0	–	200.0	–
Lead (Pb)	µg·dm^{-3}	0.0306	0.0295	0.0281	0.0297	10.0	–	10.0	–
Magnesium (Mg)	mg·dm^{-3}	0.0925	0.1311	0.0802	0.1103	30.0–125.0	–	–	–
Manganese (Mn)	µg·dm^{-3}	0.0023	0.0002	0.0006	0.0017	50.0	–	50.0	–
Nickel (Ni)	µg·dm^{-3}	0.0415	0.0341	0.0414	0.0366	20.0	–	20.0	–
Potassium (K)	µg·dm^{-3}	1.8386	2.0873	1.2937	1.8953	–	–	–	–
Zinc (Zn)	µg·dm^{-3}	0.0557	0.0138	0.0306	0.0432	–	–	–	–

Table 1 shows the results of physicochemical characteristic of the rainwater samples: immediately after rainfall and 10, 20, 30 days later. The pH values of the rainwater ranged from 6.6 to 8.26 with an average value of 7.51 and was similar to that given by Al-Khatib, et al. (2019) [35]. In addition, the average value of conductivity for the analyzed rainwater (47.99 µS·cm^{-1}) was eight times lower than the average value (389 µS·cm^{-1}) noted in rainwater from Yatta [35]. This confirms the good quality of rainwater in one of the cleaner regions of Europe. Another parameter confirming this statement is the concentration of total dissolved solids (TDS). The highest value of total dissolved solids measured in the analyzed rainwater was 61 mg·dm^{-3} while the literature data [35] give values more than five times higher. A similar accuracy was noted for the other examined parameters such as: chlorine, ammonia, etc., which were many times lower in the examined rainwater than the literature reports [35].

Rainwater flowing down from the roof is cleaned on mechanical filters. Suspensions (mainly heavier than water) sediment and settle on the bottom of the tank, and some (lighter than water) float on the surface. However, the stable temperature in the ground (about 8–10 °C) and the lack of access to sunlight significantly inhibit biological processes, causing the rainwater in the tank to remain odorless, colorless and turbid for a long time. Overflowing of the tank causes the suspensions to be carried away from the tank, at the same time oxygenating the water and ensuring its high clarity.

Figures 9–11 present the characteristic of rainwater immediately after rainfall and 10, 20, 30 days later.

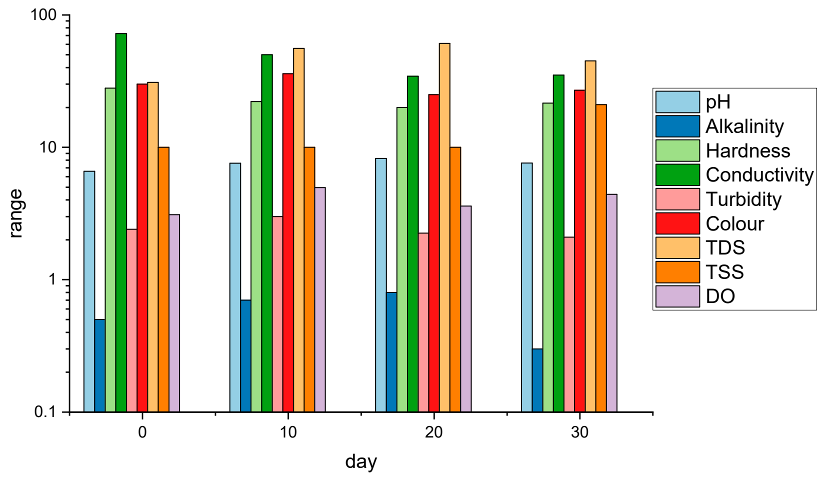

Figure 9. Physicochemical indicators of rainwater (immediately after rainfall and 10, 20, 30 days later) used in the study.

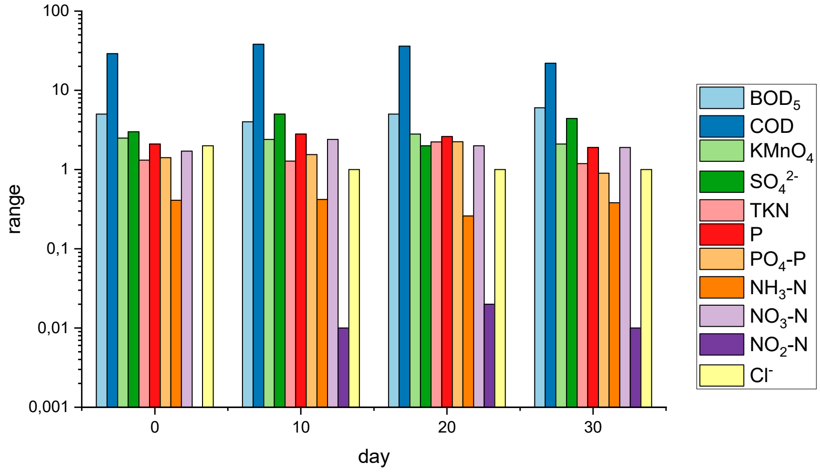

Figure 10. Changes in quantities of organic and nutrient compounds in rainwater (immediately after rainfall and 10, 20, 30 days later) used in the study.

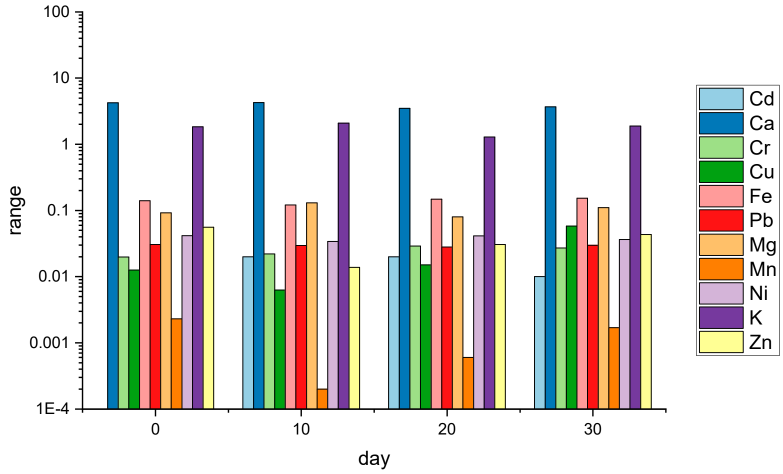

Figure 11. Concentration of heavy metals in rainwater (immediately after rainfall and 10, 20, 30 days after rainfall) used in the study.

The pH of the analyzed rainwater ranged from 6.6 to 8.26 and increased after falling on roofs and during storage in tanks. It indicates that the rainfall is not acidic in the study area and thus eliminates the possibility of any undesirable chemical reaction. Similar observations are given in the literature [35]. The increase in pH of the stored rainwater could be due to the alkaline nature of roof materials (cement tile roof) [35,45]. The increase in pH could not be caused by the material from which the storage tank was made, as the literature states [35,46], as a PE tank was used in the study.

The physical characteristics of the rainwater in all analyzed samples as color and temperature were acceptable. However, the turbidity was found to be two to three times higher than recommended in the DWS [38]. This pollution may have been caused by dust settling on the roof during the traffic of the estate's residents. The roads in the surveyed housing estate were not yet paved. Between the rainfall in the surveyed area, the roofs were covered with characteristic dust. Additionally, this dust is generated as a result of numerous construction and finishing works on the housing estate.

In the analyzed rainwater samples the concentration of chlorides was very low from 1 to 2 mg/L. None of the samples contained chlorides exceeding the DWS [38] or WHO [39] standards. According to the literature, concentrations of chlorides exceeding 250 mg·dm^{-3} cause salty taste of water and may lead to physiological damage [35,47]. The results of the studies exclude the possibility of the above-mentioned problems.

The alkalinity values ranged from 15 to 40 mg/L $CaCO_3$ with an average value of 28.8 mg/L $CaCO_3$, and all values were very low and acceptable. According to the literature [35] alkalinity is a very important parameter for safe drinking water as it buffers against rapid pH changes. Values of total dissolved solids (TDS) in the rainwater samples ranged between 31 to 61 mg/L with an average value of 48.3 mg/L and all values were within the DWS [38] and WHO [39] standards. The average TDS value in analyzed rainwater was four times lower than value noted by Al-Khatib, et al. [35]. Therefore, the water will not have a bitter or salty taste, as the TDS concentration does not exceed 500 mg/L. In addition, the purpose of the water is not to consume it, but to use it for laundry purposes.

Zinc, lead and nickel have the biggest share in rainwater. They account for about 60–80% of all metals, which is due to the widespread use of these elements in the automotive and fuel industries. In analyzed rainwater, a lead concentration of 0.0306 $\mu g \cdot dm^{-3}$ was found. The amount of lead decreased with the storage of rainwater in the tank. The main source of lead in urbanized areas is public transport. The majority of lead compounds are emitted together with exhaust gases and occur e.g., in the form of lead ammonium halide. All lead compounds are highly dispersible and are easily absorbed on the surface of atmospheric dust particles, which are deposited on hardened surfaces, from where they are further flushed to rainwater. Nickel atmospheric air pollution is closely related to emissions from the metallurgical industry and the burning of liquid fuels. The stored rainwater contained a small concentration of nickel (min. 0.0341 $\mu g \cdot dm^{-3}$, max. 0.0415 $\mu g \cdot dm^{-3}$) which, like lead, decreased with the storage of rainwater in the tank. The chromium found in the analyzed rainwater (min. 0.0198 $\mu g \cdot dm^{-3}$, max. 0.029 $\mu g \cdot dm^{-3}$) may be obtained from non-ferrous metallurgy and cement and lime materials production. Chromium compounds concentrations, and its increased amounts are caused mainly by industrial activities. Minor amounts of copper (min. 0.0063 $\mu g \cdot dm^{-3}$, max. 0.0583 $\mu g \cdot dm^{-3}$) in the rainwater under investigation may originate from coal combustion processes and industrial activities.

Figures 12 and 13 show the projection of the identified factors into the plane of variables. The variables that were considered to describe a given factor to the greatest extent were those characterized by the greatest cosine of the angle of inclination of the straight line routed from the center of the coordinate system and the resultant point of variance. Hence, component 1 consisted mainly of the pH value (component correlation value −0.92), hardness (0.84), TDS (−0.96), TKN (−0.80), NO_2-N (−0.94), Cd (−0.92), Pb (0.97), Mn (0.86). Taking into account the values and signs of component correlations of significantly influencing variables, this factor may be related to the inflow of fresh water into the retention tank. This is indicated by negative correlations with the reaction, TDS and forms of nitrogen and a positive correlation with water hardness. Component 1 explained 40.96% of the changes of variance in the arrangement of variables. The percentage of the explained variance can be interpreted as the amount of explained changes. Therefore, this factor was responsible for almost 41% of changes in the quality of rainwater. Component 2 consisted of water temperature (component correlation value 0.90), color (0.99), turbidity (0.98), Ca (0.81) and Fe (−0.99). This component explained 35.43% of the variance and could be related to the water retention time in the retention tank.

The third component was correlated only with TSS (0.84) and oxidizability (−0.80). It explained 23.60% of the changes in the variable system and could be responsible for precipitation processes under the influence of oxygen dissolved in precipitation water.

Despite the possibility of the occurrence of a large variety of pathogenic organisms in harvested rainwater there is no need to detect them all. Therefore, common indicator organisms as *Salmonella*, *Escherichia coli*, total coliforms, enterococci and total viable count of heterotrophic bacteria were chosen to assess the degree of microbiological contamination. The results of microbiological analysis of harvested rainwater samples from Bialystok area are presented in Table 2.

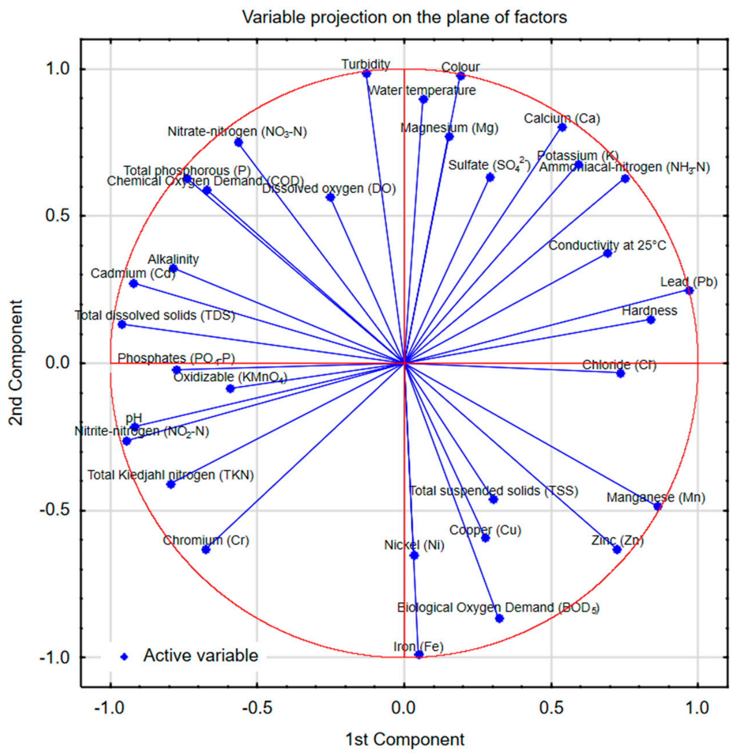

Figure 12. Projection of variables on component 1 and component 2 plane.

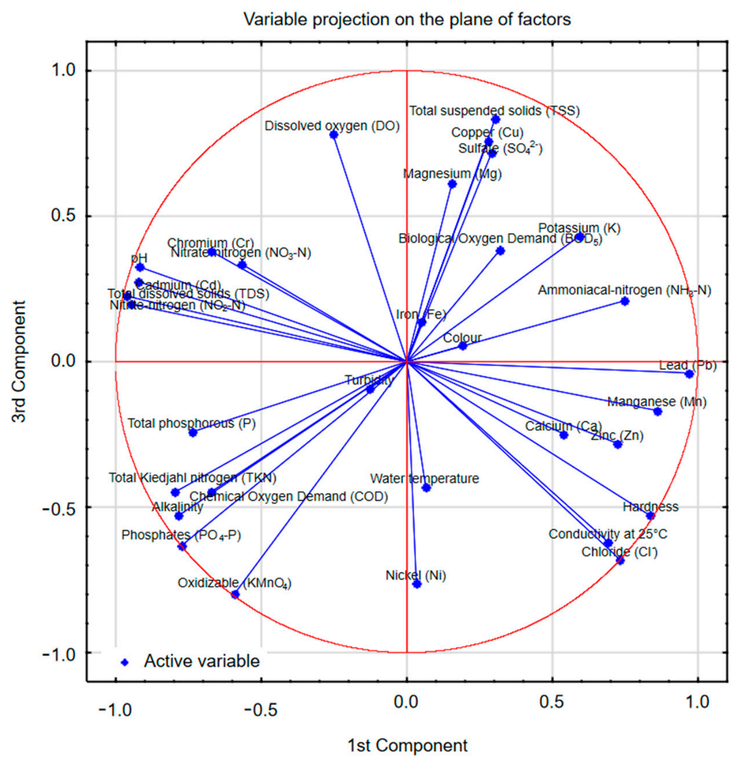

Figure 13. Projection of variables on component 1 and component 3 plane.

Based on the results given in Table 2, it can be concluded that water stored in the RWH system for 30 days does not meet the requirements for water intended for human consumption due to Total Viable Count of heterotrophic bacteria incubated in 22 °C and 37 °C. The limit values of the first of the above-mentioned indicators were exceeded by 2.5 times to maximum 38 times. Exceedances of the limit values of Total Viable Count of heterotrophic bacteria incubated in 37 °C were significantly lower, i.e., with maximum 3.5-fold. The water stored in the RWH system, on the other hand, corresponded to the quality of bathing water and was of excellent quality. None of the harvested rainwater samples showed the presence of *Salmonella*. Only in one sample *E. coli* or *Enterococcus* were detected in very low numbers but on the other hand, total coliforms were detected in each investigated sample. The number of total coliforms ranged from 6 to 2300 (CFU/100 mL) with a downward trend during the study. There is a high probability that contamination of total coliforms, *E. coli* or *Enterococcus* was caused by bird or animal droppings. In the case of rainwater retention, it is worth considering introducing disinfection, e.g., by UV lamps to improve the water's sanitary safety.

Table 2. Microbiological contamination of harvested rainwater in Bialystok area in comparison with EU Drinking Water Directive (DWD) [29] and EU Bathing Water Directive (BWD) [30].

Indicator	Unit	After … Days				DWD [29]	BWD [30]
		0	10	20	30		
TVC 22 °C	CFU/mL	1.6×10^3	2.9×10^2	3.8×10^3	2.5×10^2	100	-
TVC 37 °C	CFU/mL	7.0×10^1	6.0×10^1	5.0×10^1	2.0×10^1	20	-
E. coli	CFU/100 mL	2.0×10^0	0	0	0	0	500 excellent quality *
Total coliform	CFU/100 mL	2.0×10^1	2.3×10^3	2.3×10^1	6.0×10^0	-	-
Enterococci	CFU/100 mL	0	0	3.0×10^0	0	0	200 excellent quality *
Salmonella	CFU/100 mL	0	0	0	0	-	-

* Based on the 95th percentile.

Figure 14 present the microbiological characteristic of rainwater immediately after rainfall and 10, 20, 30 days later.

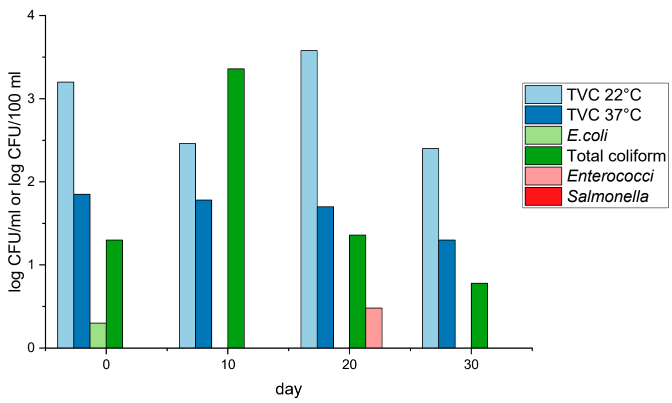

Figure 14. Microbiological indicators of rainwater (immediately after rainfall and 10, 20, 30 days after rainfall) used in the study.

Anticipating future changes is always difficult and uncertain. When analyzing two divergent scenarios, an improvement or deterioration of the environment can be expected. If climate policies and actions are successful, the environment will become stable and clean, without weather extremes. Rainwater will contain natural pollutants with little or no pollution of civilization (anthropogenic). Regular rainfall will counteract the accumulation of pollutants on the roofs, the water in the tank will be "overflowing" and overhead, which is conducive to maintaining its good quality. The collected water will not require any advanced treatment but only filtration. If climate change worsens, extreme climate events such as aridity, droughts, floods or storms rainfall are expected. A dry climate and rare rainfall will promote the accumulation of pollutants on the roof, including heavy metals from polluted air. Acid rainfall will drastically deteriorate the quality of rainwater flowing into the tank. The accumulated water may be completely unsuitable for domestic use. In a favorable scenario it can also be predicted that the water will have an appropriate chemical composition with low biological activity. It will be suitable to be kept in tanks for domestic use, including washing.

4. Conclusions

On the basis of the results of the research carried out the following conclusions were drawn:

- The stored rainwater contains pollutants flushed from roofing and atmosphere. This is in accordance with the research results available in literature. The detected contaminants have been classified as safe for the process and quality of washing clothes.
- The multi-day storage of rainwater process changes water parameters in a safe range. It remains of good quality and is suitable for washing clothes. Underground tanks which are closed in a safe way can store water and help to maintain its good quality.
- Storage of water in the RWH system for 30 days was observed: Conductivity has more than doubled with the biggest drop occurring between 10 and 20 days. An inverse regularity was observed in the case of TDS and TSS whose highest increase occurred in the first 10 days after rainfall and between 20 and 30 days of storage respectively. This indicates changes in the composition of water stored in the RWH system in the underground tank, but these changes do not cause a critical deterioration in water quality. The stored water still corresponds to the quality of water intended for human consumption except for the microbiological parameters TVC of heterotrophic bacteria incubated in 22 °C and 37 °C (CFU/mL) which do not disqualify the water as suitable for laundry use.
- During the entire test period the water met BWD requirements which confirms its suitability for washing.
- Throughout the entire test period the tested water met the general requirements of three factors of stored rainwater suitability for washing purposes (Figure 2) guaranteeing safety and good washing quality. The indicated parameters of water affecting the quality of washing such as hardness, pH, color, turbidity met the requirements and did not change adversely during the test period.
- The results indicated that harvested and stored rainwater can be directly used for washing purposes even after 30 days of storage. The experiment carried out and the results obtained prove that disinfection process is not necessary.
- The ecological and economic benefits of using rainwater for laundry should be highlighted in terms of reducing the use of tap water and washing detergents.
- Based on the experiment results the myth of a drastic decrease in rainwater quality during storage can finally be dispelled. Appropriate design and materials of RWH system guarantees the maintenance of its quality, prevents water bloom and mosquitoes from growing. The favorable factor is low temperature in the underground tank. We are convinced that that the results will dispel doubts and myths about inferior rainwater quality which will result in the growing popularity of such solutions in Poland.
- For the safe use of collected rainwater on a large scale a legal framework for water quality and RWH systems design is needed.

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