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Rainwater Quality Analysis for Its Potential Recovery: A Case Study on Its Usage for Swimming Pools in Poland

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Abstract: This paper describes the possibility of using rainwater for filling artificial swimming pools in Poland. The overall purpose of this study is to understand whether the quality of rainwater collected from roofs would be suitable for use in the swimming pools without any additional treatment. The rainwater samples were collected from five areas in the Silesian region and analysed for a number of physico-chemical parameters. The results show that the content of nitrates met Polish standards, whereas the standards set for pH and turbidity would only be met after the water had undergone the treatment process which takes place in every swimming pool installation. The paper further compares rainwater data from this study with the corresponding data for drinking water and groundwater. It shows that the content of ammonia, some metals (Ni, Cr and Mn) and a semimetal are in line with the parameters used for drinking water and are a lot lower compared to those set for groundwater. However, the results indicated some possible consequences which might be harmful for swimming pool users. These include the adverse effects of zinc and other organic micropollutants which are classified as contaminants of emerging concern (CECs). These may form dangerous byproducts in the presence of the chlorine, the use of which is required by the standards to be applied for swimming pool disinfection purposes.

Keywords: rainwater harvesting; water pollutants; swimming pools

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1. Introduction

The situation in which there is not enough water of sufficient quality to meet the demands of people and the environment is already a reality in many parts of Europe. Even though water stress issues are being felt more and more acutely all over the world, there are still a huge number of cases and examples in modern society where rainwater is wasted by its immediate discharge when it could be successfully used for many different purposes. For example, in Poland the total volume of rainwater stored in existing harvesting systems is only 6.5% of the volume of the average annual river discharge, which clearly points to the untapped potential of this water stream as a possible source of water. Climate change is intensifying the problem, as rising temperatures lead to more unpredictable weather and extreme weather events, including floods and droughts. Governments are urged to find more innovative, collaborative ways to address the issue of water stress. The current European Union (EU) regulations recommend that water management should be carried out in accordance with the principle of sustainable development [1]. In accordance with the recommendations in the Communication of the European Commission of 11 December 2019 European Green Deal [2], all 27 EU Member States are committed to turning the EU into the first climate-neutral continent by 2050. Thus, The European Commission has adopted a set of proposals to make the EU's climate, energy, transport and taxation policies fit for reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels.

The basis for sustainable water management in cities is the management of rainwater by retaining it in the place where precipitation occurs. One of the ways of dealing with the amount of precipitation is to store the rainwater and then to find further uses for it. This approach will allow us both to prevent water shortages and to avoid the floods that may result from its excess. This way forward is especially important in our current society, as water resources have been heavily exploited and polluted, and the degree of water shortage will only increase in the next few years.

With regard to Poland, the problems related to Polish water resources and the deficiencies in water management may constitute a serious obstacle to the socio-economic development of the country. Moreover, the need to adapt urban areas to climate change, taking into account the construction of sustainable systems for the management of rain and snowmelt water, seems to be one of the greatest challenges for the community in the coming years. According to the 2022 report of the Central Statistical Office "Poland on the way to sustainable development" [3], Polish water resources are among the lowest in Europe and this can be seen in Figure 1. Their size is influenced by the amount of precipitation in river basins, the distribution of rainfall over time, and the natural and artificial retention capacity, especially the ability to manage rainwater. The indicator of per capita water resource availability in Poland is only about 1600 m^3/person/year, although in a dry year it can drop to as low as 1000 m^3/person/year. The amount of renewable freshwater resources per capita in Poland therefore indicates the potential risk of water stress. According to United Nations data, the threshold below which a country is considered to be at risk of water shortage is 1700 m^3/person·year [3]. Among the countries of the European Union, only three countries (Malta, Cyprus and the Czech Republic), see Figure 1, have a lower indicator of access to water resources per capita than Poland. For this reason, the recommended way to achieve the rational management of water resources, given their considerable temporal and spatial variability in Poland, is to increase retention (i.e., collecting water in case of surplus and returning it to users and the environment in times of shortage).

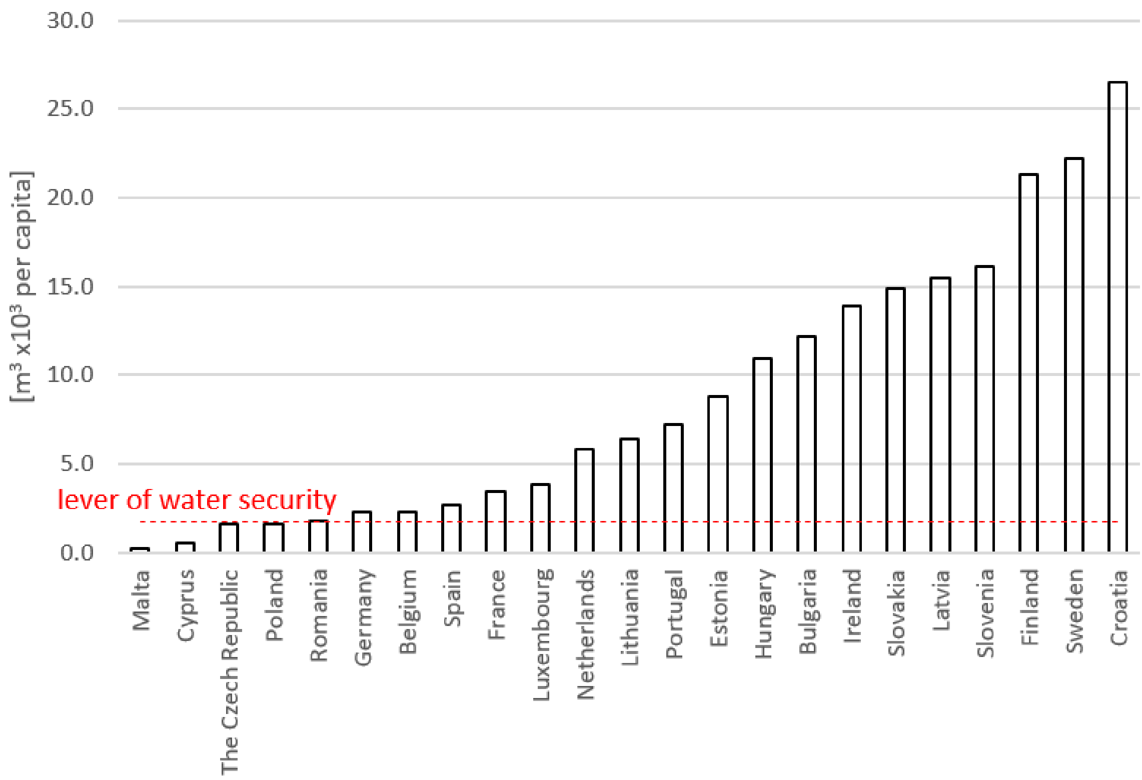

Figure 1. Renewable freshwater resources per capita (annual multi-year averages) in Europe [3].

One of the solutions to ongoing water shortages and a potentially successful way of using rainwater is to fill public swimming pools with it and, to the best of the authors' knowledge, this is a novel and innovative topic which requires further investigation and research. It is important to note that while rainwater is generally considered safe for nonpotable uses, it may not meet quality standards for swimming pools without proper treatment and testing. Apart from the possibility of using rainwater in swimming pool facilities, it may also be recycled for watering greenery or used to flush toilets, as has already been done, for example, on a single-family housing estate in Rzeszów, Poland [4] or for a dormitory located in the city of Košice, Slovakia [5]. The first attempts are being made to use rainwater from roofs for the purpose of backwashing swimming pool filter beds [6]. A hitherto completely unexplored approach, however, is the use of rainwater as a source for filling the pool basins of public artificial swimming pools.

The annual volume of water commonly used in swimming pools in Poland can vary widely depending on the size and type of the pool. Residential or private swimming pools typically have much smaller volumes compared to public or commercial pools. However, to provide a rough estimate, requirements for replenishing swimming pool water according to the German Standard DIN19643 [7] and the Polish sanitary and hygienic requirements that refer to the DIN19643 Standard [7] stipulate that a minimum of 30 L of water should be supplied for each person using the swimming pool in one day. The above-mentioned figures could vary from country to country in accordance with the local standards. The average unit consumption of supplementary water for Polish indoor pools analysed in 2012 by Piechurski et al. was much greater than the above-mentioned Standard and was approx. 64 L/person. The number of swimming pool users differs depending on the type of swimming pool and the month of year. For the indoor pools analysed in 2012 by Piechurski at al., the average number of swimmers was 574 users/day, which gives an average water consumption equal to 36,736 L/day.

The use of harvested rainwater can be important in supplying the required amount of water for swimming pools. Considering the sustainability, harvesting rainwater for pool filling and maintenance can be a sustainable practice. It reduces the demand for treated municipal water. In terms of cost savings, rainwater is typically free and requires less treatment compared to tap water. Using rainwater reduces the expenses associated with water bills. Reducing the consumption of municipal water for pool use can have a positive environmental impact by conserving water resources.

The discussion of this issue touches on some legal inconsistencies in this matter. A wide range of Standards are applied across Europe to the pool and spa industry. The overview of European norms for the main standards applicable to the swimming pool and spa industry EN 15288 includes Swimming pools for public use—Part 1: Safety requirements for design [8] and Part 2: Safety requirements for operation [9]. These documents do not specify the limit values for the concentrations of pollutants with respect to swimming pools. Unfortunately, the legislation on the quality of swimming pool water is not consistent across Europe; it varies from country to country. There are no clearly defined limit values for the pollutant concentrations, which could specify whether the water is safe for swimming and bathing purposes or not. For example, only in Poland are a swimming pool, a bathing area and a spa pool considered to be three completely different types of facility, in accordance with Polish law and its definitions of them, so they are subject to quite distinct sets of regulations. It should also be emphasized that these standards and regulations do not apply to pools used for domestic purposes (and in some cases in Poland the pools in hotels are not considered, surprisingly, to be public swimming pools!).

The Act of 18 August 2011 on the safety of persons staying in water areas (Polish Journal of Laws of 2020, item 350, as amended), defines a swimming pool as an indoor or outdoor facility with circulating water that is intended for swimming or bathing. It should be equipped with at least one artificial swimming pool basin (an artificial tank of water intended for swimming or bathing) with a durable edge and bottom and it should be accompanied by sanitary facilities, changing rooms and showers (Article 2 point 8). The

Regulation of the Polish Minister of Health of 9 November 2015 on the requirements to be met by water in swimming pools (Polish Journal of Laws of 2015, item 2016, as amended) specifies the requirements that should be met by water in swimming pools; the frequency of water sampling at swimming pools; the reference methodologies for its analysis and the method of assessing whether the water in swimming pools meets the required conditions; and the way of informing the population about the quality of water in swimming pools. The above-mentioned requirements for public artificial swimming pool water in Poland are divided into microbiological requirements (Annex No. 1) and physical and chemical requirements (Annex No. 2). Annex No. 1 defines the highest permissible number of microorganisms [CFU or NPL] of Escherichia coli, Pseudomonas aeruginosa and the total number of microorganisms present at 36 ± 2 °C after 48 h, which may include Coagulase-positive staphylococci and Legionella sp. depending on the water stream type in the swimming pool facility (The possible types are: water introduced into the swimming pool basin from the circulation system; water in the swimming pool basin; water in swimming pool basins equipped with devices that generate a water–air aerosol water in swimming pool basins that are made available for swimming lessons for infants and small children under 3 years of age; or water in showers). Annex No. 2 is divided into part A (Physical and chemical requirements) and part B (Additional physical and chemical requirements). Part A defines the minimum and maximum values of redox potential at the Ag/AgCl electrode 3.5 m KCl, pH values and chlorine concentration depending on the water stream type in the swimming pool facility (as listed above, the possible types are: water introduced into the swimming pool basin from the circulation system; water in the swimming pool basin; water in swimming pool basins equipped with devices that generate a water–air aerosol; water in swimming pool basins that are made available for swimming lessons for infants and small children under 3 years of age; or water in showers). Additional physical and chemical requirements relate to turbidity, nitrates, combined chlorine, chloroform, Σ THM and other parameters determined for certain specific situations. For example, in the case of water ozonation, after sorption filtration, this part defines the permissible concentration of ozone in water introduced into the swimming pool basin from the circulation system. In the case of di- and trichloroisocyanurate usage, the maximum isocyanuric acid concentration is defined for water in the swimming pool basin and water in the swimming pool basins equipped with devices generating a water–air aerosol.

Natural water courses such as rivers, lakes and the sea are called bathing areas, which are defined according to European Bathing Water Directive in Polish Art. 16 Act of 20 July 2017 Water Law (Polish Journal of Laws of 2021, item 1641) as consisting of a separated and marked fragment of surface waters, designated by the commune council, which may be used by a large number of bathers, provided that no permanent bathing ban has been issued in relation to this bathing area. The Regulation of the Polish Ministry of Health of 17 January 2019 on the supervision of water quality in bathing areas and places occasionally used for bathing (Journal of Laws, item 255) specifies the requirements that should be met by water in bathing areas and places occasionally used for bathing Water quality assessment in bathing areas includes the application of microbiological requirements (Enterococcus ≤ 400 CFU/100 mL measured in accordance with PN-EN ISO 7899-1 [10] or PN-EN ISO 7899-2 [11] and Escherichia coli ≤ 1000 CFU/100 measured in accordance with PN-EN ISO 9308-3 [12] or PN-EN ISO 9308-1 [13]), as well as other stated requirements including the following: there should be no cyanobacterial bloom (streaks, scum, foam); no evidence of macroalgae or marine phytoplankton proliferation; and no presence of contaminants in the water such as tarry materials from refining, distillation or any pyrolytic treatment, in particular distillation residues, glass, plastics, rubber or other waste (in quantities that cannot be deleted immediately). The Act of 14 March 1985 on the State Sanitary Inspection (Journal of Laws of 2021, item 195) stipulates that the supervision of the quality of bathing areas and places occasionally used for bathing must be carried out by the bodies of the State Sanitary Inspection under the terms set out in the regulations of the State Sanitary Inspection.

In light of the above, in Poland the artificial public swimming pools can be located indoors or outdoors and the water must be disinfected by chlorine, as required by Polish law. The water treatment itself for the artificial public swimming pools will normally include mechanical and physico-chemical treatment according to European Standards EN 15288 and Polish recommendations (see Figure 2) [14].

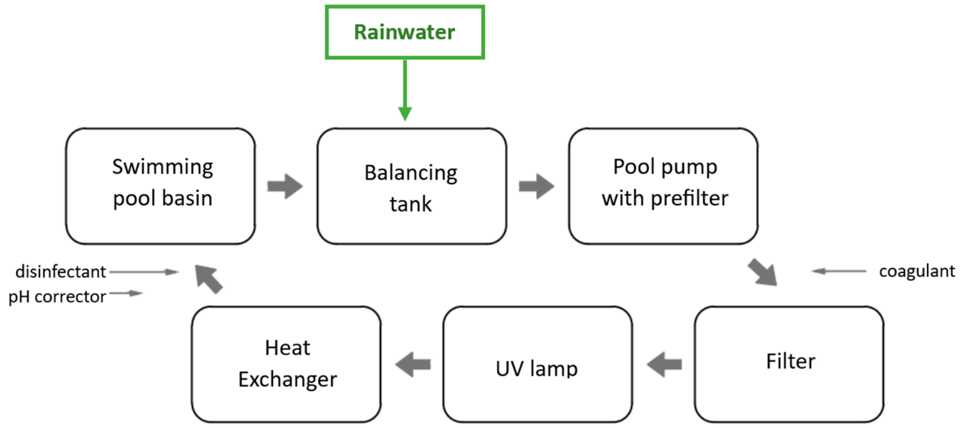

Figure 2. A typical artificial public swimming pool installation for swimming or bathing purposes with a marked potential point for the introduction of rainwater.

In addition, there are also facilities called public swimming ponds [15]. These are artificial ecosystems for swimming or bathing in which the conditions of natural waters are imitated. They are distinct from official bathing areas in surface water and from conventional public swimming pools. The justification for using them is the fact that the water has been treated biologically by planting certain species which have special properties to treat water and by applying plant filters. These measures are occasionally supported by other treatment processes such as phosphate/nitrate treatment. In this particular case, water will be disinfected by means of UV or ozone instead of chlorine, as the latter could kill all the bacteria and plants responsible for the biological treatment. The whole idea of swimming ponds is to mimic constructed wetlands or lagoons which are part of SuDS and consequently part of the rural and urban landscapes, where they play a crucial rule [16].

Swimming or bathing in natural water (understood as not being disinfected by chlorine) may pose health risks to users when the water quality is microbiologically poor. Microbiological contamination of surface water in bathing areas or water in swimming ponds may occur, for example, through direct faecal input from humans or animals, sewage overflow, discharge from wastewater treatment plants and surface runoff. The water quality may also deteriorate because of the growth of microorganisms that are part of the natural aquatic flora [15,17]. Since the water in artificial public swimming pools (which are the subject of the analysis presented in this article) must be disinfected by the use of chlorine [18], the risk of microbial contamination is relatively lower there. However, in cases where both organic and inorganic micropollutants occur in the water, these might react with free chlorine, and this reaction will lead to the production of disinfection byproducts (DBP) that are dangerous for human health, including trihalomethanes (THMs) [19–21].

Thus, the purpose of this study is to investigate rainwater with reference to various types of physico-chemical pollution that may affect it in order to comment on its suitability for usage in public artificial swimming pools as a source for filling the pool basins, particularly in the context of water quality and the formation of disinfection byproducts. A comprehensive analysis has been conducted of various water quality parameters, including nutrients, metals, semimetals and a range of organic micropollutants have been identified. The latter have been a great cause of concern for human health.

Nowadays, as a result of the development of analytical tools, it is possible to separate compounds with very low concentrations (μg/L, ng/L) from environmental samples, together with their selective analysis using chromatographic techniques. These compounds, called micropollutants, are therefore increasingly the subject of research by scientists from around the world. The growing awareness that they can cause a real threat to the environment and to future generations makes micropollutants a leading problem confronting specialists in engineering and environmental protection. Research on the presence of organic micropollutants in the human environment, including the determination of their concentration levels, the search for their emission sources and the development of effective methods for their elimination, indicates that this is one of the most important challenges to be met as a part of protecting and improving the quality of the environment. Please see the Section 3 for a more elaborated description of the micropollutants.

This study is focused on the physico-chemical parameters only and not on the microbiological parameters, as the former are precursors of disinfection byproducts (DBP). The authors do not underestimate the significance of microbiological pollutants but, in this particular case, they will not compromise the usage of rainwater for swimming pools, as the water will be heavily disinfected to counter that risk.

The literature review described above helped to test the key hypothesis of this research, namely that rainwater would be an appropriate source of water for public artificial swimming pools for swimming or bathing purposes. Hence the research questions will be as follows: (1). Is the rainwater quality appropriate for public artificial swimming pools without any treatment? (2). What kind of pollutants can be found in rainwater, if any, and which of them are crucial in terms of that water's suitability for use in public artificial swimming pools?

The importance of the subject of the research presented in this paper becomes obvious when one sees how it takes account of the advantages to be gained from using rainwater for public swimming pool purposes in Poland, thanks to the simplicity and low-cost efficiency of that procedure. Water stress resulting from various causes (including population growth, high water demand and climate change) currently represents a problem on a different scale at global, regional and local levels from environmental, social and economic points of view.

A general schematic diagram of the artificial public swimming pool system is shown in Figure 2, indicating the place of rainwater introduction in the installation of public artificial swimming pools, as proposed by the authors of this paper. A typical artificial public swimming pool installation is a complex and carefully designed facility that provides a safe and enjoyable environment for people to swim and engage in aquatic activities. The primary feature is the pool basin itself, which can come in various sizes and shapes, including rectangular, oval or freeform. The basin is typically constructed from materials such as concrete, fiberglass or vinyl, and it is designed to hold the water. Public swimming pools are equipped with sophisticated water filtration and circulation systems. This includes pumps, filters and chemical treatment systems to keep the water clean, clear and safe for swimming. The heart of the circulation system is a pool pump. It draws water from the pool through the main drain and skimmers using suction. The pump then pushes the water through the filtration system, which can be one of several types. In addition to physical filtration, chemical treatment is essential to disinfect the water and maintain water balance. Chlorine, bromine or other sanitizers are added to kill bacteria, viruses and algae. pH levels are also controlled to ensure swimmer comfort and water clarity. Ultraviolet (UV) lamps or ozone disinfection systems are sometimes used in swimming pools as an additional method to improve water quality and reduce the presence of harmful microorganisms. UV-C technology is effective at inactivating bacteria, viruses, algae and other pathogens by disrupting their DNA, preventing them from reproducing. Ozone (O3) is a powerful oxidizing agent use to disinfect and purify swimming pool water. It is generated on-site at the pool facility using specialized ozone generators. It is injected directly into the pool water using ozone contact chambers or injection points in the pool circulation system. Both UV-C and ozonation are considered a supplementary water treatment method to traditional disinfection by the use of chlorine.

From an economic point of view, the use of rainwater for swimming pools could permit a reduction in the operating costs of swimming pool facilities, because rainwater can provide a free source of water for public swimming pools, to be used for swimming or bathing purposes. A general schematic diagram of the public artificial swimming pool system that is shown in Figure 2, indicates the place, proposed by the authors of this paper, of rainwater introduction in the installation of such a pool system. As can be seen in Figure 2, the authors do not envisage the introduction of any additional devices other than those already used in public artificial swimming pool circulation systems. Thanks to this, the authors do not anticipate an increase in investment costs, while the operating costs could be reduced.

2. Materials and Methods

2.1. Subject of Study

The research was carried out from April to June 2023 in the Upper Silesia Region, located in Central Europe in the southern part of Poland (see Figure 3).

Figure 3. Location of Silesia Region (highlighted in dark blue) in the context of Poland.

This period of sampling was chosen as the most favourable in terms of its potential to provide rainfall which would produce substantial runoff. The peak amount of precipitation will fall from approximately April to June in the Silesian region [22]. Another reason is that the Silesia region in Poland has historically been known for its air pollution, primarily due to heavy industry and coal mining. Air quality can vary throughout the year, but the worst months for air pollution in the Silesia region tend to be during the colder months of winter and a substantial proportion of the pollution in the roof runoff of our study would therefore be airborne [23]. Finally, April is a month with high fluctuations in the ambient daytime and night-time temperatures and these fluctuations could have an impact of the roofing material (releasing some elements) and hence on the water quality.

Upper Silesia has a Central European climate that is influenced by oceanic and continental air masses. The climate of this area is characterized by its high variability and irregularity of cycles, with a predominance of oceanic influences, which determines small temperature fluctuations. The climatic conditions are transient and are affected by both oceanic air masses from the west and continental air masses from the east. The average annual rainfall is high (700–800 mm), due to the prevailing upland nature of the area, and the average annual temperature ranges from 7 °C to 8 °C. Westerly winds of low speed predominate. The annual number of days with frost can reach 40, and there may be up to about 50 snowy days. The greatest frosts rarely exceed −30 °C, while the maximum temperature is 38 °C. The thickness of the snow cover varies from 50 cm in the Silesian Lowland to 150 cm in the Beskids.

Natural processes are also overlapped by anthropogenic factors, which results in the creation of separate local climatic conditions within urbanized areas, which are distinct from those in the surrounding areas. In the areas of economic agglomeration, a local climate has developed which is characterized by an increased number of foggy and rainy days. In GOP (the Upper Silesian industrial district), the air pollution indicators are higher than in other industrial agglomerations.

Samples of rainwater collected from five different locations were subjected to (i) broad-spectrum quality analysis, including basic water pollution indicators; (ii) an extended analysis taking into account, inter alia, the presence of metals; and (iii) nontarget chromatographic analysis (NTCA), the aim of which was to identify as many compounds as possible by comparing the obtained mass spectra with reference spectra collected in the commercial NIST v.17 database. These specific Silesian locations were chosen in order to determine the impact of roofing material on water quality. Different areas have been taken into account, such as urban, rural and industrial ones, to check whether the type of area might contribute to the rainwater quality. Rainwater quality tests were carried out for samples taken from the outlet pipes of roofs. The sampling points were located in a city centre, a rural area, an allotment garden area and an industrial zone, as can be seen in Table 1. All the rainwater samples collected came into contact with different surfaces (steel tile, corrugated sheet, bitumen). Water samples were collected in dark glass bottles, secured for transport in accordance with the procedures of PN-EN ISO 5667-3: 2018-08; Water Quality–Sampling–Part 3: Fixation and Handling of Water Samples [24]. Samples were collected during selected rainfall episodes according to the rainfall intensity and after rejecting the first flush.

Table 1. Characteristics of the sampling locations.

No.	Surface	Location
R1	steel tile roof	city centre
R2	corrugated sheet roof	rural area
R3	corrugated sheet roof	allotment garden area
R4	corrugated sheet roof	industrial zone
R5	bitumen roof	city centre

The rainfall intensity is a parameter which measures the amount of precipitation over a period of time and, it will normally be measured in mm/min. It is a very changeable parameter. It can vary over a wide range within one rainfall event, regardless of its duration. For example, with the maximum intensity maintained for 20 min, under a heavy rainfall, almost half of the monthly amount of precipitation can fall.

In accordance with the morphological features, i.e., with the set of external signs, rainfall types can be classified as drizzle, cloudy rainfalls and storm rainfalls. Drizzle refers to rains with an intensity of 0.1 mm/min; rains with an intensity from 0.01 mm/min to 0.02 mm/min can be categorised as cloudy rainfalls; and rains with an intensity of more than 0.5 mm/min (30 mm/h) can be classified as storm rainfalls. Thus, in the case of our study, moderate and intense rains have been chosen with the intensity exceeding 0.02 mm/min.

The first flush time was established for intensive and moderate rainfalls and for heavy or moderate torrential rain. Based on the changes in the quality of rainwater during precipitation in southeastern Poland, as described by Zdeb at al. [25], and the time necessary for the first flush off roof surfaces, the moment for sampling during rainfall was set as 10 min after the onset of rain.

During the observed period from April to June 2023 in the area that was the subject of this study, there were 40 rainy days in total [26]. However, six water samples were collected from each location in accordance with the assumptions made regarding the intensity and the duration of the rainfall, which relates to the rejection of sampling from the first flush.

The area-average sum of precipitation in April 2023 in Poland amounted to 39.8 mm and it was 3.4 mm higher than the norm for this month as determined on the basis of measurements made in 1991–2020. According to these numbers and to Kaczorowska's classification, April 2023 should be classified as a normal month (109% of the norm) [26].

The area-average sum of precipitation in May in Poland was only 36.0 mm and this figure was as much as 27.6 mm lower than the norm for this month, as determined on the basis of measurements made in the years 1991–2020. According to these numbers and to Kaczorowska's classification, May 2023 should be classified as a very dry month (since the precipitation amounted to 56.6% of the norm for this month) [26].

The area-average sum of precipitation in June in Poland amounted to 52.4 mm and in this case the total was as much as 16.6 mm lower than the norm for this month, as determined on the basis of measurements made in the years 1991–2020. According to these numbers and to Kaczorowska's classification, last June should be classified as a dry month (as the precipitation amounted to 75.9% of the norm for this month) [26].

For each location, six water samples were collected and the mean values have been included. Standard deviation (SD) and coefficient of variation (CV) have been calculated.

2.2. Scope and Methodology for the Determination of Properties of the Examined Rainwater

Table 2 summarizes some water quality parameters which are presented in this study, including the method of analysis and the equipment used.

Table 2. Method and equipment used for analysing the water quality parameters.

Parameter	Unit	Method Description	Instruments Used
pH	[-]	electrochemical method using electrodes and a millivoltmeter; according to the procedure described in PN-EN ISO 10523:2012 [27]	SensIONmeter+ MM150DL (Hach®, Ames, IA, USA)
Turbidity	[NTU]	nephelometry, a method of measuring scattered radiation according to the procedure described in PN-EN ISO 7027-1:2016-09 [28]	Turbidmeter TN-100 (Eutech Instruments, Singapore)
EC	[mS/cm]	Electrochemical resistance measurement; measured with a probe and a meter. Voltage is applied between two electrodes in a probe immersed in the sample water. The drop in voltage caused by the resistance of the water is used to calculate the conductivity per centimetre. The meter converts the probe measurement to micromhos per centimetre	CPC-505 conductivity meter (Elmetron, Zabrze, Poland)
TOC	[mg/L]	High-temperature catalytic oxidation at 680 °C in an oxygen-rich environment inside tubes filled with a platinum catalyst followed by NDIR	TOC-L carbon analyser (Schimadzu, Kyoto, Japan)
PO_4^{3-}	[mg/L]	Phosphate cuvette test 0.05–25.0 mg/L no. 114546	UV VIS spectrophotometer Spectroquant®Pharo 300 (Merck, Darmstadt, Germany)
N	[mg/L]	Nitrogen cuvette test 10.0–150.0 mg/L no. 114763	
NO^{3-}	[mg/L]	Nitrates cuvette test 0.10–25.0 mg/L no. 109713	
NO^{2-}	[mg/L]	Nitrites cuvette test 0.002–1.00 mg/L no. 114776	
NH^{4+}	[mg/L]	Ammonia cuvette test 0.2–8.00 mg/L no. 114558	
Copper	[mg/L]	Copper cuvette test 0.02–6.00 mg/L no. 114767	
Zinc	[mg/L]	Zinc cuvette test 0.025–1.00 mg/L no. 100861	
Nickel	[mg/L]	Nickel cuvette test 0.1–6.00 mg/L no. 114554	
Manganese	[mg/L]	Manganese cuvette test 0.10–5.00 mg/L no. 100816	
Chrome	[mg/L]	Chrome cuvette test 0.05–2.00 mg/L no. 114552	
Arsenic	[mg/L]	Arsenic cuvette test 0.001–0.1 mg/L no. 101747	

The collected rainwater samples were also subjected to chromatographic analysis for a number of micropollutants coupled with mass detection (GC-MS), which was preceded by solid phase extraction (SPE) according to the authors' own procedure [29] that allows for the extraction of the maximum number of analytes present in the sample. Chromatographic analyses were carried out using a Gas Chromatograph with a Mass Spectrometry detector (GC-MS) by Agilent Technologies (Santa Clara, CA, USA) equipped with capillary columns by Sigma-Aldrich (Poznań, Poland). For Solid Phase Extraction (SPE) use was made of disposable Superclean^{TM} extraction tubes by Merck KGaA (Darmstadt, Germany) and organic solvents with a purity of over 99% from Avantor Performance Materials Poland S.A. (Gliwice, Poland). The deionized water was obtained from a laboratory water distillation station Arium Comfort II UV by Sartorius AG (Göttingen, Germany). The mass spectra obtained were compared with the United States National Institute of Standards and Technology NIST v17 Mass Spectral Library using MassHunter software (version B07.00).

3. Results and Discussion

The results of this study have been summarized as follows. Table 3 summarizes some water quality parameters, including the nutrients, metals and semimetals that it contains. Figure 4 represents the values of total Zn concentration found in the five areas where sampling took place.

Table 3. Water quality parameters found in roof runoff.

Parameter	R1			R2			R3			R4			R5		
	Mean	SD	CV [%]	Mean	SD	CV [%]	Mean	SD	CV [%]	Mean	SD	CV [%]	Mean	SD	CV [%]
pH [-]	6.8	±0.30	4	6.2	±0.5	8	6.1	±0.2	3	6.4	±0.1	2	6.3	±0.3	5
Turbidity [NTU]	4.3	±0.20	5	5	±0.3	6	1.5	±0.5	33	1.2	±0.2	17	2.6	±0.6	23
EC [mS/cm]	267.3	±11.5	4	369.1	±20.1	5	112.7	±12.6	11	125.4	±4.8	4	168.9	±10.1	6
PO_4^{3-} [mg/L]	0.12	±0.02	17	<0.05	-	-	<0.05	-	-	<0.05	-	-	<0.05	-	-
N [mg/L]	8.6	±0.44	5	8.47	±1.69	20	2.32	±0.7	30	2.57	±1.2	47	4.85	±0.86	18
NO_3^- [mg/L]	5.5	±0.2	4	6.2	±0.3	5	1.6	±0.2	13	1.7	±0.7	41	3.4	±1.2	35
NO_2^- [mg/L]	0.05	±0.02	40	0.07	±0.02	29	0.01	±0.01	100	0.01	±0.01	100	0.03	±0.01	33
NH_4^+ [mg/L]	0.24	±0.08	33	0.3	±0.04	13	0.21	±0.03	14	0.26	±0.06	23	0.22	±0.08	36
Cu [mg/L]	0.02	±0.01	50	0.05	±0.02	40	<0.02	-	-	<0.02	-	-	<0.02	-	-
Ni [mg/L]	<0.02	-	-	0.02	±0.01	50	<0.02	-	-	<0.02	-	-	<0.02	-	-
Mn [mg/L]	<0.005	-	-	<0.005			<0.005	-	-	<0.005	-	-	<0.005	-	-
Cr [mg/L]	0.023	±0.011	48	0.012	±0.004	33	<0.01	-	-	<0.01	-	-	<0.01	-	-
As [mg/L]	<0.02	-	-	<0.02	-	-	<0.02	-	-	<0.02	-	-	<0.02	-	-

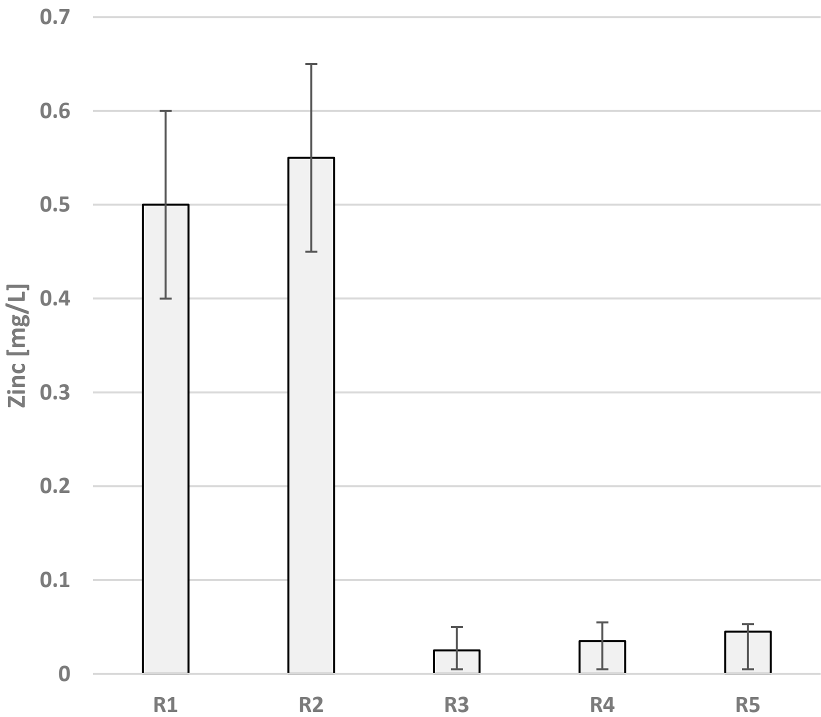

Figure 4. Total zinc concentration that occurred in roof runoff.

From Table 3 one can see that nitrogen is present in the form of nitrates, nitrites and ammonia as well as phosphates. However, the values for all areas are much lower in comparison with those reported in some other literature [30] on the presence of nutrients and this can be explained as confirmation of the fact that nutrients are the main and crucial parameters for agricultural runoff.

In relation to the suitability of water for use in swimming pools, three parameters (pH, NO_3 and turbidity) have been included in the Polish Standards [31] and they have been summarized in Table 4.

Table 4. Some water quality standards for swimming pools, according to Polish requirements [31].

Parameter	Min	Max
pH [-]	6.5	7.6
Turbidity [NTU]	-	0.5
EC [mS/cm]	not standardized for Polish swimming pools	
PO_4^{3-} [mg/L]	not standardized for Polish swimming pools	
N [mg/L]	not standardized for Polish swimming pools	
NO_3^- [mg/L]	-	20.0
NO_2^- [mg/L]	not standardized for Polish swimming pools	
NH_4^+ [mg/L]	not standardized for Polish swimming pools	
Cu [mg/L]	not standardized for Polish swimming pools	
Ni [mg/L]	not standardized for Polish swimming pools	
Mn [mg/L]	not standardized for Polish swimming pools	
Cr [mg/L]	not standardized for Polish swimming pools	
As [mg/L]	not standardized for Polish swimming pools	

Comparing the values obtained for NO_3 in this study with the Polish Standards [31], it can be seen that these parameters are in line with them. It is extremely important, since nutrient pollutants such as phosphates and nitrates can promote algae growth in the pool. Algae can provide a protective shield for harmful microorganisms, making them more resistant to disinfection by chlorine.

The water pH values in R2, R3, R4 and R5 are slightly lower than the minimum recommended pH values according to the standards for swimming pools. The negative effects of a too low pH value in swimming pools are, amongst others, the irritation of the mucous membranes, an unpleasant smell in the water due to the formation of chloramines (combined chlorine) and the corrosion of metal parts as well as damage to some of the joints between the tiles. The pH of swimming pool water impacts the effectiveness of chlorine in the disinfection process. In accordance with the standard practice in Europe and in Poland, in particular, as a minimum, a three-stage water treatment must take place before the water goes into the pool itself. The steps of coagulation, filtration and disinfection (see Figure 2) are preceded by an automatic pH adjustment system [32]. This treatment will be sufficient for meeting the standards for both turbidity and pH.

As to turbidity, it can be seen that the values are higher in comparison with the Standards [31]. The Pool Water Treatment Advisory Group (PWTAG), 2014 recommends that pool water should be no more than 0.5 NTU and this figure has been adopted by the Polish Standards. This gives a good overall indicator of its clarity and cleanliness [33]. This point does require some clarification, however, and it may be explained as follows. In accordance with the standard practice in Europe and in Poland, in particular, a minimum of three-stage water treatment must take place before the water goes to the pool itself (see Figure 2), that is coagulation, filtration and disinfection preceded by an automatic pH adjustment system [32]. This treatment will be sufficient for meeting the standards for both turbidity and pH. Another important point can be noted from the analysis of the diagram below (see Figure 5). The diagram represents the turbidity scale measured in NTU from 10 to 4000. The implemented standard of 0.5 NTU equates to an extremely low level—the scale demonstrating the standard calibration (see Figure 5) only begins at 10 NTU, while the Polish Standard set for turbidity in drinking water is 1 NTU [34].

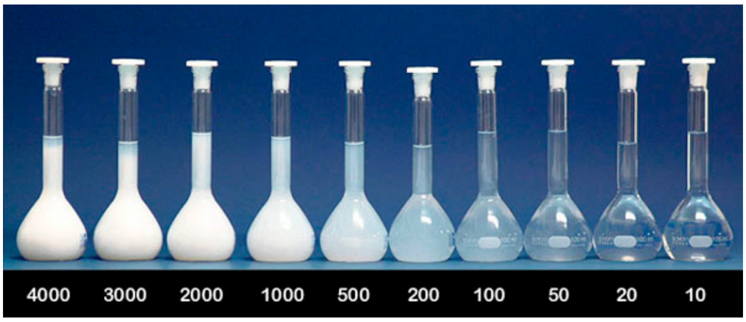

Figure 5. The turbidity scale in NTU [24].

The concentration of total Zn in this study ranged from 0.025 to 0.55 mg/L, which coincides very well with some results obtained elsewhere for this metal from roof runoff [35,36]. Thus, one of the studies from Christchurch, New Zealand [37] reported that the Zn concentration in the roof runoff ranged from 0.098 to 0.64 mg/L with a pH of 6.87. However, another investigation of roof runoff with a Zn concentration (Paris, France) [38] found that the concentration of Zn was 7.8 mg/L. The authors also helpfully reported a pH which was less than 5.6, i.e., much lower than that reported in our study (6.1–6.8) and in the study from New Zealand reporting on roof runoff (pH = 6.7) [37]. In this case, the pH value taken together with the several climatic factors that provoked the corrosion process played a crucial role in creating the enormously high Zn concentration. The level of Zn pollution in roof runoff depends on many factors such as the properties of the roofing material as well as the building characteristics. Galster and Helmreich [36] have pointed out in their study related to Zn used as roofing material that Zn will mainly be present as dissolved ions (Zn^{2+}).

The discussion on the ability of Zn to become freely available in an aqueous environment requires special attention, as it is known that metals in their dissolved form are persistent and toxic [39,40]. For example, Zakharova et al. [41] reported the release of Zn into the water environment in the presence of a high concentration of sodium (around 700 mg/L), due to the use of a de-icing salt. This salt has a strong impact on the behaviour of Zn, with evidence from study showing that the dissolved concentration of this metal reached 98% of its total value.

Zn value is not a parameter that is included in recommendations for swimming pools in Poland. However, for the purpose of this study and specifically for the assessment of rainwater's suitability for use in swimming pools, we must be aware of the potential of zinc chloride ($ZnCl_2$) to form toxic volatile compounds of hydrogen chloride (HCl) and zinc oxide (ZnO) and there is a slight possibility for it to occur in this instance [42]. It is particularly important, as the swimmers may inhale the volatile products while in the swimming pool [43].

Figure 6 represents TOC for all five areas. The presence of the organic compounds can potentially act as a trigger for THMs formation. Although TOC has not been standardized for swimming pools, it is a very important parameter as it indicates that there is a possibility of chemical reactions occurring between organic matter and free chlorine. It is known that this parameter indicates the presence of organic micropollutants, which are precursors of very dangerous disinfection byproducts (DBPs). Sixteen micropollutants have been detected in this study and they are summarized in Table 5. The compounds identified belong to the toxic group of human environment pollutants. Some of them may be genotoxic or carcinogenic. For example, hexadecane causes skin irritation, and 5-tert-butylpyrogallol is known to be toxic if ingested or inhaled. Consequences of inhalation exposure to dibutyl phthalate may include irritation of the eyes, nose and throat. It may cause nausea, tearing of the eyes, vomiting, dizziness and headache. Long-term exposures may cause liver and kidney damage.

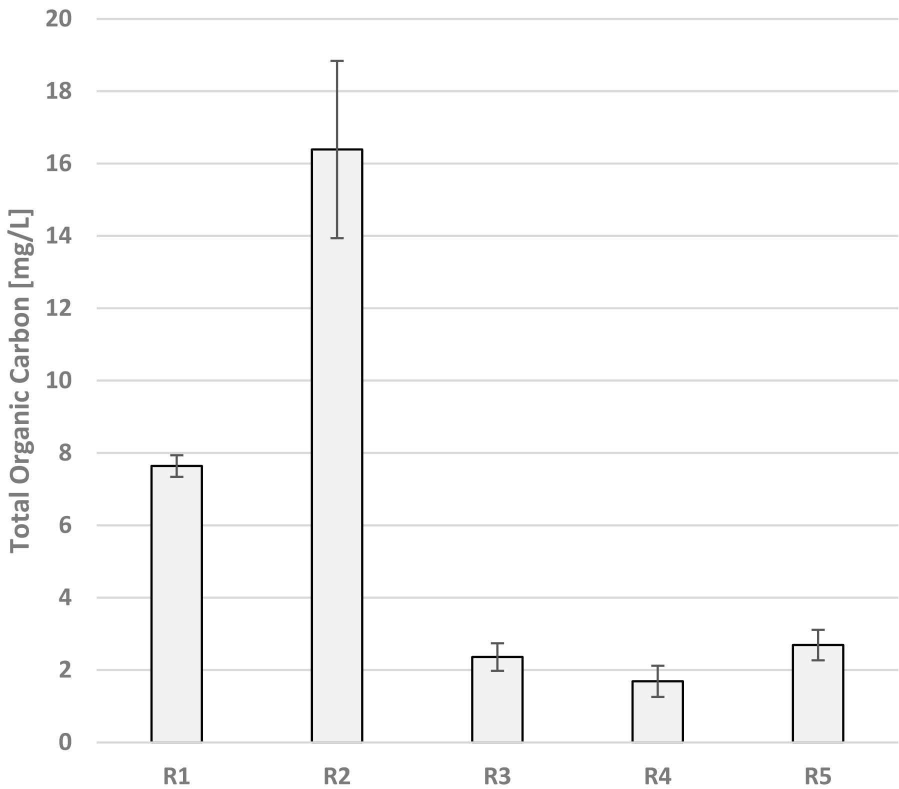

Figure 6. Total Organic Carbon found in roof runoff from five areas.

Table 5. Organic micropollutants identified in the collected samples.

No.	Compound Name	Structural Formula	CAS-RN	Molecular Weight	Top Peaks [m/z]
1	Pentanoic acid	$C_5H_{10}O_2$	109-52-4	102.13	60, 73, 102
2	Butanoic acid	$C_4H_8O_2$	107-92-6	88.11	60, 73, 88
3	Neodecanoic acid	$C_{10}H_{20}O_2$	26896-20-8	172.26	87, 102, 116, 130
4	5-tert-butylpyrogallol	$C_{10}H_{14}O_3$	20481-17-8	182.22	115, 139, 167, 182
5	2,6-dimethoxy-phenol	$C_8H_{10}O_3$	91-10-1	154.16	93, 96, 111, 139, 154
6	Diisobutylphthalate	$C_{16}H_{22}O_4$	84-69-5	278.34	104, 149, 205, 223, 278
7	Dibutyl phthalate	$C_{16}H_{22}O_4$	84-74-2	278.34	149, 205, 223, 278
8	Hexadecane	$C_{16}H_{34}$	544-76-3	226.44	71, 85, 99, 226
9	Nonadecane	$C_{19}H_{40}$	629-92-5	268.52	71, 85, 99, 113, 228
10	Octadecane	$C_{18}H_{38}$	593-45-3	254.50	71, 85, 99, 254
11	Tetradecane	$C_{14}H_{30}$	629-59-4	198.39	71, 85, 99, 113, 127, 198
12	Galaxolide	$C_{18}H_{26}O$	1222-05-5	258.40	171, 187, 213, 243, 258
13	Versalide	$C_{18}H_{26}O$	88-29-9	258.40	159, 187, 201, 243, 258
14	Benzo(a)pyrene	$C_{20}H_{12}$	50-32-8	252.31	113, 126, 224, 252
15	Naphthalene	$C_{10}H_8$	91-20-3	128.17	77, 102, 113, 128
16	Anthracene	$C_{14}H_{10}$	120-12-7	178.23	89, 152, 176, 178

Micropollutants, which are typically trace levels of synthetic or naturally occurring chemicals, can indeed undergo degradation or transformation in pool water, potentially contributing to the formation of new disinfection byproducts (DBPs). The interaction between micropollutants and pool disinfectants can lead to chemical reactions that produce DBPs, which may have health implications for swimmers. This process can occur by:

Direct Reaction with Disinfectants: Micropollutants can react directly with pool disinfectants such as chlorine or ozone. This can lead to the formation of new chemical compounds, including DBPs. For example, some micropollutants contain functional groups (such as amines or organic matter) that can react with chlorine to form chlorinated compounds. These chlorinated compounds may be less effective at disinfection and could be harmful to swimmers.

Indirect Reactions: Micropollutants may also indirectly influence the formation of DBPs by altering water chemistry. For instance, they can affect the pH of the pool water, which can impact the effectiveness of chlorine and contribute to the formation of DBPs.

Competition for Disinfectants: Micropollutants can compete with microorganisms for disinfectants. If disinfectants are consumed by micropollutants, there may not be enough available to effectively kill harmful microorganisms. This can compromise the disinfection process and potentially lead to the formation of DBPs.

Enhanced Formation of DBPs: Some micropollutants can act as precursors for DBPs. When these micropollutants react with disinfectants, they can produce compounds that are more prone to form DBPs when further exposed to disinfection or environmental factors (e.g., sunlight or temperature changes).

Numerous studies conducted around the world have shown the presence of DBPs in sewage treatment plant effluents, surface waters, tap water and even bottled water. In this connection particular interest is aroused by rainwater due to the European Green Deal, the new circular economy action plan and especially the new EU strategy on adaptation to climate change. Other worldwide studies analysing the suitability of rainwater for different purposes also found some of the organic micropollutants in rainwater. For example, Villagour-Marquez et al. [44] and Guidotti et al. [45] reported on this group of compounds, which are classified as contaminants of emerging concern (CECs) [46], meaning that they might be candidates for future health regulations. In the studies mentioned above, it has been shown in particular that rainwater may contain organic pollutants, such as polycyclic aromatic hydrocarbons (PAHs), phthalate ester (PEs), pesticides and polychlorinated biphenyls (PCBs). Other compounds analysed were: atrazine, pentachlorophenol (PCP), chlorpyrifos, 2,4-dichlorophenoxyacetic acid (2,4-D), prometon, simazine, carbaryl, nonylphenol (NP), perfluorooctanoic acid (PFOA), perfluorooctane sulfonic acid (PFOS), perfluorobutane sulfonic acid (PFBS) and perfluorononanoic acid (PFNA). Studies of CECs' occurrence in Poland [47] reported that rainwater runoff was characterized by variable concentrations of polycyclic aromatic hydrocarbons (benzo(a)pyrene, benzo(b)fluoranthene, phenanthrene, fluoranthene and pyrene) and microplastics. Stuk-Sokolowska et al. [48] focused on low molecule benzotriazoles (BTRs) in urban road rainwater in Poland, showing that concentrations of BTRs in rainwater ranged from 4.5 µg/mL to 26.4 µg/mL.

With this in mind, these compounds are likely to create disinfection byproducts with free chlorine, which is why it is important to take them into account when considering the potential reuse of rainwater for swimming pools, despite the fact that they have not been standardized. This is especially alarming, as in swimming pools there is direct contact of humans with the water [49]. In swimming pool technology, there are three ways in which swimmers may be exposed to pollutants present in pool water:

Oral—by direct swallowing of water. Studies presented in [50] showed that during 45 min of swimming, an average adult swallows 16 mL of pool water, and an average child 37 m.

Inhalation—by inhalation of volatile or aerosolized dissolved substances. Among them, volatile disinfection byproducts are mentioned, e.g., trichloramine (NCl_3), chloroform ($CHCl_3$), dichloromethylamine (CH_3NCl_2), cyanogen chloride (CNCl) and dichloroacetonitrile ($CNCHCl_2$) [51,52]. Clinical studies have documented the occurrence of respiratory ailments (e.g., asthma) among swimmers, especially in relation to indoor swimming pools. Most studies have identified trichloramine as the causative agent of these conditions.

By skin contact and skin absorption—some contaminants can directly affect the skin, eyes and mucous membranes, and some can also penetrate the skin and be absorbed by the body. The extent of such absorption depends on a number of factors, including: the length of time of the swimmer's contact with water, the water temperature and the concentration of the absorbed chemical substance.

Appropriate water disinfection, i.e., the process of destroying pathogens by using chemical and physical methods, counteracts the presence of any pathogenic organisms in the swimming pools. In this range of disinfectants, chlorine compounds (sodium hypochlorite or calcium hypochlorite), chlorine gas, ozone and ultraviolet radiation are most often used [53]. Chlorination, the most popular and obligatory method of disinfection used in Polish swimming pools, can cause the formation of a wide range of disinfection byproducts (DBPs) through the reaction of the disinfectant with organic and inorganic matter. Nonetheless, the obligatory measurement of the concentration of combined chlorine, trihalomethanes and chloroform does not mean that the level of all compounds formed as a result of the reaction of disinfectants with impurities present in swimming pool water is controlled [54]. More than 600 different byproducts have already been identified in pool water [55]. In addition to the obligatory controlled THMs, which were detected in swimming pool water already in 1980 [55], these include: haloacetic acids (most often di- and trichloroacetic acids), haloacetonitriles (dichloroacetonitrile, dibromoacetonitrile, trichloroacetonitrile) [56], halobenzoquinones, halonitromethanes and N-nitrosamines, as well as chloral hydrate and bromine hydrate, cyanide halides and chloropicrin [56,57] In addition, when inorganic bromides are present in pool water (e.g., seawater pools or brines), they can be oxidized and may then participate in the reaction leading to the formation of brominated byproducts. The type of DBP formed depends primarily on the type of disinfectant used, as well as the pH and temperature of the water.

The presence of organic micropollutants in rainwater, as demonstrated in this study (see Table 5) may raise concerns in respect of the potential these compounds have in the context of DBP formation.

Removing micropollutants from harvested rainwater involves various treatment methods to ensure the water is safe and suitable for its intended use, including filling artificial public swimming pool basins. The recommended treatment methods for the removal of micropollutants from harvested rainwater include filtration (especially Granular Activated Carbon filters are known as effective at removing organic micropollutants, such as pesticides, pharmaceuticals and some volatile organic compounds), sediment filtration (which can remove particulate matter, suspended solids and some larger micropollutants), Advanced Oxidation Processes (AOPs) including ozonation which can oxidize and break down organic micropollutants or UV treatment combined with hydrogen peroxide can break down micropollutants through advanced oxidation. A wide range of micropollutants can be removed by the use of membrane filtration. Certain ions and metals can be removed from water by the use of Ion Exchange Resins. It is important to note that the effectiveness of these treatment methods can vary depending on the specific micropollutants present, their concentrations and the water's characteristics. Therefore, a combination of treatment methods or a tailored treatment approach may be necessary to achieve the desired water quality. Additionally, the treated rainwater should be regularly tested to ensure that it meets the quality standards and is safe for the intended use. Treatment system maintenance and monitoring are crucial to ensure the ongoing removal of micropollutants and the continued provision of safe water.

In order to assess the suitability of rainwater for filling artificial swimming pools, which is at variance with existing practice, Table 6 compares data resulting from this research which indicates the quality of rainwater with that of drinking water and that derived from raw water sources. The last two varieties are commonly used for filling swimming pools.

Table 6. The comparison of rainwater quality assessed in this study with that of drinking water and of raw source water.

Parameter	Unit	Rainwater in This Study	Drinking Water (e.g., Tap Water)	Raw Source of Water (e.g., Well Water)
pH	[-]	6.1–6.8	6.5–9.5 [58,59]	6.0–8.5 [60]
Turbidity	[NTU]	1.2–5	≤1.0 [58] ≤4.0 [59]	vary widely
Conductivity	[µS/cm]	112.7–369.1	≤400 [61] *	vary widely from 100 up to 1000 or higher
TOC	[mg/L]	1.69–16.39	<2.2 [59]	vary widely from 1 up to 10 or higher
PO_4^{3-}	[mg/L]	<0.05–0.12	<6.5 [59]	0.01 to 0.1 in areas with minimal human activity, 0.1 to 1.0 or higher in developed, urban or agricultural areas
N	[mg/L]	2.32–8.6	not specifically regulated	0.1 to 1 in areas with minimal human activity, 1 to 10 or higher in developed, urban or agricultural areas
NO^{3-}	[mg/L]	1.6–6.2	<50 [58,59] <10 [62]	<0.1 or lower in areas with minimal human activity, 1 to 10 or higher in developed, urban or agricultural areas
NO^{2-}	[mg/L]	0.01–0.07	<0.1 [58,62] <0.5 [59]	
NH^{4+}	[mg/L]	0.21–0.3	<0.5 [58]	<0.1 or lower in areas with minimal human activity, 0.1 to 1.0 or higher in developed, urban or agricultural areas

Table 6. *Cont.*

Parameter	Unit	Rainwater in This Study	Drinking Water (e.g., Tap Water)	Raw Source of Water (e.g., Well Water)
Zinc	[mg/L]	0.025–0.55	<5 [62]	<0.01 or lower in areas with minimal human activity, up to hundreds or even thousands of mg/L in areas with heavy industrial or mining activities
Nickel	[mg/L]	<0.02–0.02	<0.02 [58]	
Manganese	[mg/L]	<0.005	<0.05 [58]	
Chrome	[mg/L]	<0.01–0.023	<0.05 [58]	
Arsenic	[mg/L]	<0.02	<0.01 [58]	

* The electrical conductivity (EC) of drinking water is not typically regulated as a standalone parameter in most countries, including those following World Health Organization (WHO) guidelines. Instead, EC is often used as an indicator of the water's mineral content and can indirectly reflect the presence of dissolved ions, including salts and minerals. The specific EC levels that are considered acceptable for drinking water can vary depending on regional factors, water sources and local regulations. In practice, the acceptable range for EC in drinking water is generally quite broad.

The pH of the samples tested is slightly lower than the pH of drinking water, but it is still in line with the typical pH of raw source water (e.g., groundwater). The European Union's Drinking Water Directive (Council Directive 98/83/EC) sets a maximum allowable turbidity value for drinking water as 4 NTU at any time in the water distribution system. The World Health Organization stipulates that the turbidity of drinking water should not exceed 5 NTU, and should ideally be below 1 NTU, while the turbidity of rainwater determined in this study ranged from 1.2 up to 5 NTU.

Measuring the conductivity (EC) of the water allows to estimate the amount of salt or solid material dissolved in it. The electrical conductivity of fresh groundwater varies widely from 100 µS/cm up to 1000 µS/cm or higher. Pure water is a poor conductor of electricity, but as more salts become dissolved in it, the conductivity increases. Under the EU Drinking Water Directive, there are no specific maximum or minimum EC values mandated for drinking water. However, EC is considered an important parameter in the evaluation of water quality, and it is used as an indicator of the mineral content and the general composition of the water. According to some standards [61], the EC value of drinking water should not exceed 400 µS/cm. The current investigation indicated that the EC value of the rainwater was 112.7–369.1 µS/cm, which is in line with the recommendation for drinking water quality [61]. Total Organic Carbon (TOC) is a key parameter used to assess the quality of drinking water. While there are no universal TOC limits for drinking water that apply globally, regulatory agencies in different countries and regions establish their own guidelines and standards based on local conditions and considerations. The European Union sets guidelines for TOC in drinking water as part of its Drinking Water Directive (Council Directive 98/83/EC) which states that TOC levels should not exceed 2.2 mg/L as a parameter indicative of organic pollution. Determinations of this parameter provide valuable diagnostic evidence of the extent of water contamination by organic compounds. TOC concentrations in surface waters are generally less than 10 mg/L, and in groundwater less than 2 mg /L, unless the water receives discharges of municipal or industrial wastes or is highly coloured due to the presence of natural organic material, as is the case, for example, in swamps. The TOC values in the study presented in this work vary from 1.69 mg/L (which is in line with the standard for drinking water) up to 16.39 mg/L. The latter should be considered as a high value and as a sign of the contamination of the rainwater samples by organic compounds which pose a huge risk of DBP formation if the rainwater were used as a source for filling pool basins.

Regarding the nutrient content, the tested rainwater samples are in line with the recommendations for the quality of drinking water as well as with typical values obtained for the quality of raw source water. It should also be mentioned that although natural ammonia levels in groundwater and surface water are usually below 0.2 mg/L, many regions throughout the world have high levels of naturally occurring ammonia as a result of the degradation of naturally occurring organic matter or of inputs from manmade sources.

Metals and semimetals concentrations in groundwater depend on the soil use, pH and depth of sampling. For example, the 60 average concentration of nickel in groundwater ranges from 7.9 μg/L (in urban areas) to 16.6 μg/L (in rural areas) and nickel concentrations as high as 980 mg/L have been measured in groundwater with a pH below 6.2. The levels of manganese in groundwater from natural leaching processes can vary widely depending upon the types of rock and minerals present in the water table. Typically, manganese concentrations arising from natural processes are low, but they can otherwise range up to 1.5 mg/L or higher. Among the potentially toxic trace elements, chromium is the most common pollutant in groundwaters. The USEPA regulates total chromium in drinking water, and it has set a Maximum Contaminant Level (MCL) of 0.1 mg/L. The World Health Organization (WHO) guideline is 0.05 mg/L for total chromium. Groundwater concentrations of arsenic (semimetal) have been documented in the literature which reveals a very wide range from less than 0.5 to 5000 ppb, covering natural arsenic contamination found in more than 70 countries. As regards metal pollution, rainwater seems to be a better source than raw water (e.g., well water). At this point, it should be emphasized that the metal contamination of the rainwater samples in this study did not exceed the values recommended for drinking water.

4. Conclusions

1. The rainwater from roofs appears to be a cost-free, valuable source of water for swimming pools, and this is especially important in light of the current European policy pertaining to Green Deal Strategies. From the environmental viewpoint, its use entails no impact or stress on water resources. The use of harvested rainwater can be an important and sustainable strategy for supplying water to swimming pools in Poland and other regions. It offers potential cost savings, reduces the environmental impact, and it can contribute to water conservation efforts. From the economic point of view, no additional energy consumption is involved when pumping water from the source to the swimming pools by utilising existing systems used in the swimming pools. However, careful planning, water quality management and compliance with local regulations are essential when implementing rainwater harvesting for pool use. All the above-mentioned points (measures) are at the initial stage of discussion and development in Poland.

2. In this study rainwater from roofs was analysed for the presence of a number of groups of pollutants and it was shown that it contains a variety of pollutants, such as metals, nutrients and organic pollutants, including CECs. The parameter set for NO^{3-} was shown to be in line with the Polish Standards for swimming pools. Turbidity and pH, by contrast, exceeded the permissible level of 0.5 NTU and pH was slightly lower than the minimum recommended pH values according to the standards for swimming pools. Nevertheless, the water treatment facilities utilised in swimming pools are sufficient in themselves to enable rainwater to meet the turbidity and pH requirements.

3. This study showed that metal and semimetal contamination of rainwater samples did not exceed the values recommended for drinking water. On the other hand, this study showed that groundwater quality will normally exceed that of rainwater in relation to the parameters set for metals and semimetals.

4. The presence of metals in rainwater might have an adverse effect on the suitability of rainwater in terms of its direct usage as a source for swimming pools. In the case of Zn, it was shown that some toxic byproducts could be formed in the presence of chlorine compounds.

5. A number of micropollutants were detected in the rainwater sampled for this study and it would need to be treated against these in order to render it suitable for use in swimming pools. Not only are those micropollutants dangerous on their own but there is also the risk that they could give rise to the creation of DBPs, including THMs and chloroform, which have been standardised.

6. The limits and standards for swimming waters and natural swimming areas are typically established by regulatory authorities to ensure the safety and health of swimmers.

These standards may vary by region and country, but they generally encompass parameters related to water quality, sanitation and safety. These standards and limits are enforced by local health departments, environmental agencies or other regulatory bodies responsible for overseeing swimming facilities and natural swimming areas.

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