

## Article

# The Use of Precipitation in the Cities of the Future—Problems, Barriers and Challenges

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**Abstract:** Due to climate change and its effects, it becomes indispensable to maximise the use of rainwater in cities. In order to effectively carry out this process in cities, it is essential to organise information and knowledge, and plan an appropriate action strategy. It is necessary to identify not only the strengths and opportunities for introducing solutions to collect and use rainwater in cities, but also the weaknesses and threats. The article presents a SWOT analysis (Strengths—Weaknesses—Opportunities—Threats) for the use of rainwater in the city, compiling comprehensive information and knowledge on this topic. Environmental, social and economic aspects have been taken into account. On its basis, the possibilities, as well as problems, barriers and limitations in the field of introducing the use of rainwater into the fabric of the cities of the future were discussed. The greatest challenges in this area were also identified, providing a basis for further planning of activities.

**Keywords:** rainwater management; water circular economy; stormwater; alternative source of water; water demand; water consumption; sustainable development; SDG; rainwater harvesting; rainwater use



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## 1. Introduction

In times of changing climate when, on the one hand, cities are threatened by drought and lack of water supply and, on the other hand, there are heavy rainfalls causing urban flooding, it is extremely important to pay special attention to the possibilities of using precipitation in the cities of the future. The issue is not new, and rainwater has been a source of water supply since ancient times [1]. Rainwater and stormwater are an important element in the city's water management system. If there is no decentralised intake of them, then in the case of combined sewage systems in cities, they will go to the municipal wastewater treatment plant, affecting its functioning by periodically changing both the quantity and quality of sewage supplied. It should also be added that sanitary sewage will be mixed with stormwater earlier with a significant difference in their quality before mixing. In turn, the intensification of activities related to the maximisation of the use of rainwater as an alternative source of water in the city may lead to easier management of municipal wastewater treatment plants and a more predictable amount and quality of urban wastewater during wet weather. Ultimately, this may also mean reducing the multiplicity of action of storm overflows in the case of combined sewage systems.

In the era of transformation of cities towards a circular economy, it is essential to look for innovative solutions. For example, the use of high-efficiency rainwater treatment plants scattered in the city aimed at supplying aquaponic systems in order to cover water losses occurring in their circulation may turn out to be such a solution. This is a way not only to manage rainwater and not to discharge it to the municipal wastewater treatment plant, but also to increase the food security of cities. Aquaponics is an example of a closed-loop food production system combining recirculating aquaculture systems (RAS) and hydroponics, in which plants use the waste produced by the fish, thereby continuously purifying the water [2,3].

What is needed is a new look at precipitation as a source of water supply for cities in times of climate change and a comprehensive arrangement of information and knowledge that takes into account not only the positive aspects of the issue, but also the potentially negative ones. It is also indispensable to take into consideration not only environmental but also social and economic aspects. An appropriate strategy is needed for the development of services for the cities of the future while ensuring safety for residents in various dimensions. For these reasons, a holistic approach was used in the work, and the SWOT (Strengths, Weaknesses, Opportunities, and Threats) method was chosen as the analysis tool. It should be added that SWOT analyses related to rainwater management are available in the literature, but the existing work mainly concerns a specific location [4–7], the choice of the type of rainwater collection, storage and distribution system [8], or where the type of stormwater management is found [9,10] and their number is insufficient.

In [8], the SWOT method was used to analyse which type of rainwater collection, storage and distribution system (individual, semi-distributed, centralised) would be most beneficial for allotment sites. The authors of [4] used a SWOT analysis to identify the problem arising from a small-scale conventional domestic Rainwater Harvesting (RWH) system, with particular emphasis placed on the design aspect; the work concerns Batu Pahat, Malaysia. The SWOT analyses conducted in [5] are characterised by a comprehensive approach to the issue of introducing Sponge City construction, but they concern the current conditions in specific cities (Guangzhou, Kunming City, China) and important factors in this regard. A comprehensive analysis of the RWH system can be found in [6], but it covers conditions in only one country—Bangladesh. In turn, in the works [9] and [10], SWOT analyses were carried out for the use of various variants of stormwater management. These included a conventional stormwater management system and sustainable systems with underground infiltration, surface infiltration, surface infiltration and retention, and retention. Some of the mentioned directions of stormwater management contribute to recharging and expanding groundwater resources and/or have high landscape values [9,10], which can also be considered a way of using stormwater in the city.

These works do not take into account the wide range of possibilities of using rainwater now and in the future or an approach covering situations that are possible in different regions of the world. For example, what may be a threat in one location may turn out to be an opportunity in another location.

For the above-mentioned reasons, the article adopts a comprehensive approach taking into account environmental, economic and social aspects, and at the same time covering both the positive and negative sides of the use of rainwater in the city in general terms, i.e., taking into account their various uses in both known ways of using water and the latest trends in this area.

The aim of the article was to produce a holistic analysis of information and knowledge regarding both the current and future use of rainwater in cities, and to determine the prospects and suggested courses of action in this area.

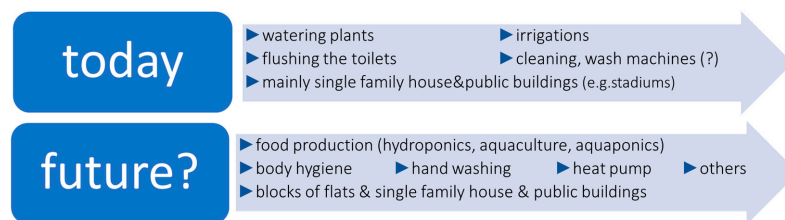
### *1.1. Characteristics of the Use of Precipitation in the Cities Today and in the Future*

Due to the quality and quantity of rainwater collected in cities, the current spectrum of its use is somewhat limited. It can be used for watering greenery, flushing toilets, and the literature also mentions its use for washing clothes, cleaning and washing cars [11,12]. In the case of using it for washing vehicles, there is the need for a properly prepared place for washing (due to wastewater collection).

In the future, rainwater with highly effective treatment could be used for food production in aquaponic and hydroponic systems (due to the small amount of water needed to replenish losses in the system). Applications for heat pumps [12,13] are also being considered. These are just examples, and every effort should be made to increase the range of rainwater applications in the city.

Currently, rainwater is collected primarily at single-family houses, or in public and commercial buildings, where its use was planned from the moment of design and con-

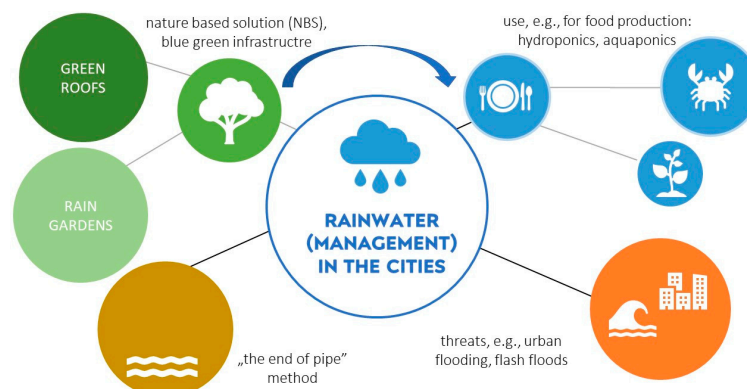
struction. In the future, the share of multi-family houses in this group should increase significantly, although today, of course, there are also such buildings [14]. Figure 1 shows the possibilities of using rainwater in cities today and in the future.



**Figure 1.** The use of rainwater in cities: today and in the future.

### 1.2. Rainwater (Management) in the Cities

In the context of collecting and using rainwater in cities, it is necessary to point out that currently—as part of rainwater management—there is still the ‘end of the pipe’ principle, i.e., the fastest possible drainage of water from the city [15]. At the same time, extreme precipitation phenomena, which are becoming more and more frequent in various parts of the world, pose a real threat to property, but also to the health and life of city dwellers. Therefore, in the process of transforming cities, it is necessary to strive to manage precipitation at the place of its generation through blue-green infrastructure and the collection and use of rainwater. One can also consider combining these two directions and try to use rainwater after passing through selected forms of blue and green infrastructure. Figure 2 shows the transformation of rainwater management in cities.



**Figure 2.** Rainwater (management) in the cities—currently and in the future (transformation).

## 2. Material and Research Methodology

The analysis was carried out globally, using examples from various parts of the world available in the literature, but with particular emphasis on the conditions of the city of Wrocław in terms of rainfall data. The analysis was conducted in the context of preliminary research work as part of the USAGE project [16], the aim of which is to use rainwater in the city for aquaponics, carried out in one of the largest cities in Poland—Wrocław.

A SWOT analysis was conducted out to identify possibilities, problems, barriers and limitations, and challenges. The SWOT technique is a planning tool used to identify strengths, weaknesses, opportunities, and threats related to a given project or organisation [17]. This is a universal method that is the first step necessary when implementing a new strategy [18]. The choice of the SWOT method is justified by the fact that it has already been used in the context of various environmental engineering issues (the raw materials recovery sector [19] or implementing circular water economy in a smart city [20]), and in particular also in the field of rainwater management—in the field of types of rainwater collection/storage/distribution systems [8], for specific locations—Guangzhou and Kunming City, China [5], Batu Pahat, Malaysia [4] and Bangladesh [6,7]—or in terms of retention

and/or infiltration [9,10]. SWOT analysis is one of the basic analyses regarding the current and future situation of the project [21] (in this case, the use of rainwater in cities). This heuristic technique is aimed at the correct ordering of information in the research area [22], and the created SWOT matrix is a way to collect information [23]. The choice of SWOT analysis as a tool allowed to provide material for selecting the most appropriate strategy for implementing the use of rainwater in cities. After its completion, the prospects for the use of rainwater in the cities of the future were determined.

In the adopted interpretation of the factors constituting the SWOT analysis, according to [24,25], strengths and weaknesses are features of the current state, while opportunities and threats are expected future phenomena. In short, it can be assumed that strengths and weaknesses describe the current state, opportunities and threats, and the future one [18]. For this reason, selected issues are repeated in the SWOT matrix. They appear, for example, in the context of both weaknesses and threats.

The research material in the work was the precipitation data of the Institute of Meteorology and Water Management—National Research Institute (short name in polish: IMGW—PIB) from the years 2018–2022 for the synoptic station Wrocław Strachowice [26]. Data analysis was carried out using the MS Excel and Grapher programs. The available polish and international scientific and technical literature was also analysed.

The topic covers a very large number of issues and, therefore, only selected examples were cited to confirm individual strengths and weaknesses, opportunities and threats, which presents a limitation.

### 3. SWOT Analysis of the Use Precipitation in the Cities of the Future

The results of the SWOT analysis carried out are summarised in Table 1. On their basis, the prospects for the use of rainwater in the cities of the future were defined, i.e., possibilities, main problems, limitations and barriers as well as challenges in this regard.

**Table 1.** SWOT analysis matrix of the use of precipitation in the cities of the future.

Elements of SWOT Analysis	Description
Strengths	<ul style="list-style-type: none"> <li>• low investment costs for simple installation</li> <li>• diversification of water supply source</li> <li>• realisation of water smart circular economy [27]</li> <li>• beneficial effect on reaching 17 SGDs (Sustainable Development Goals) [28]</li> <li>• securing the inhabitants in case of war and attacks on critical infrastructure</li> <li>• the amount of precipitation</li> <li>• reduction of tap water consumption</li> <li>• mitigation of pluvial floods [28]</li> <li>• reducing the risk of flooding [7] and resulting losses</li> <li>• reduction of hydraulic overloading of sewage networks during peak flows</li> <li>• benefits of water in the urban landscape [1]</li> <li>• adaptation to the effects of climate change</li> <li>• increasing the inhabitants' resilience to climate change (drought, water shortages)</li> <li>• water resources protection (i.e., directing less stormwater to the receiver [10])</li> <li>• different possibilities of use</li> <li>• management of rainwater in the place of its occurring</li> <li>• numerous facilitations and support base</li> <li>• financial support for investment</li> <li>• economic benefits for the investor</li> <li>• possibility of using it in PR (Public Relations) activities</li> </ul>

Table 1. Cont.

Elements of SWOT Analysis	Description
Weaknesses	<ul style="list-style-type: none"> <li>• high investment costs for more complex installations</li> <li>• operating costs (e.g., energy consumption)</li> <li>• dependence on energy supply</li> <li>• uneven occurrence of precipitation</li> <li>• quantitative inequality of water supply</li> <li>• limiting deliveries due to weather conditions</li> <li>• limiting the effects by roof parameters</li> <li>• the impact of materials in contact with rainwater on its quality</li> <li>• pollution of rainwater</li> <li>• variability of rainwater quality (e.g., depending on the season [29])</li> <li>• difficulties and limitations in introducing to existing buildings [30]</li> <li>• currently a narrow range of housing and municipal applications</li> <li>• the need for specialised skills and appropriate equipment to operate the supporting software [28]</li> </ul>
Opportunities	<ul style="list-style-type: none"> <li>• effects possible when used on a large scale in the city</li> <li>• less raw materials and energy used in the water treatment plant and for transport</li> <li>• reducing the multiplicity of action of storm overflows of combined sewage systems</li> <li>• occurrence an urgent need for an alternative source of water</li> <li>• climate change</li> <li>• increase in tap water prices</li> <li>• scientific research (scientific projects and research and development works, e.g., expanding the scope of rainwater applications, e.g., for food production through hydroponics and aquaponics)</li> <li>• technical and technological progress</li> <li>• development of RES (Renewable Energy Sources) allowing for the transformation of the water energy nexus</li> <li>• education of the society (addressed in various ways to different social and age groups), the aim of which is to increase social awareness in the field of adaptation to the effects of climate change and the possibility of obtaining water from alternative water sources</li> <li>• expansion of training programs, transfer of good practices in the field of education</li> <li>• multi-criteria assessment systems for buildings (e.g., BREEAM—Building Research Establishment Environmental Assessment Method or LEED—Leadership in Energy and Environmental Design)</li> <li>• environmental management systems (e.g., according to the ISO 14,000 series (International Organization for Standardization), EMAS—Eco-Management and Audit Scheme)</li> <li>• further maintenance and development of programs co-financing investments related to the collection and use of rainwater</li> <li>• building legal and formal support programs</li> <li>• use of other forms of precipitation (e.g., snow)</li> <li>• policies and strategies (e.g., European Green Deal)</li> <li>• new legal regulations, modification of existing ones</li> <li>• new incentives in the form of reliefs and discounts</li> <li>• searching for further savings by property owners and managers</li> <li>• development of guidelines</li> <li>• newly developed facilitations for design and construction</li> <li>• co-design together with society</li> </ul>

Table 1. Cont.

Elements of SWOT Analysis	Description
Threats	<ul style="list-style-type: none"> <li>• climate change (lack of precipitation or a significant reduction in its amount)</li> <li>• dangers of Legionella bacteria in some ways of using rainwater</li> <li>• increasing the unevenness of precipitation (the need to store water for a longer period of time and/or a larger volume of the reservoir and/or lowering the economic efficiency of the system)</li> <li>• increased pollution of rainwater and/or the appearance of new pollutants</li> <li>• lack of space for tanks outside the building in the city and inside newly built buildings</li> <li>• deterioration of the quality of rainwater, preventing or significantly hindering their treatment and use</li> <li>• insufficient education of society</li> <li>• lack of social acceptance</li> <li>• change of geopolitical situation, war</li> <li>• lack of financial support</li> <li>• increase in energy prices (resulting in an increase in operating costs and material costs)</li> <li>• in some countries, there are no regulations or they are not sufficiently specified</li> </ul>

### 3.1. Strengths of Collecting and Using Precipitation in Cities

There are many strengths of rainwater harvesting and use in the city, and most of them are interconnected, one resulting from the other. One of the main strengths of the use of rainwater in the city is the diversification of water supply sources. This is also the implementation of the basic assumptions of the water—smart circular economy [27]. In turn, the authors of work [28] argue that the beneficial effects (and, therefore, the strengths) of using rainwater collection/use systems are significant and can affect a large number of Sustainable Development Goals (SDGs). Examples of the beneficial impact of rainwater harvesting (RWH) on the achievement of all 17 SDGs indicate as confirmation. It should be added that the advantages of rainwater harvesting, which have a positive impact on the achievement of the SDGs, are also related to the pillars of sustainable development (economic, environmental or social) [28].

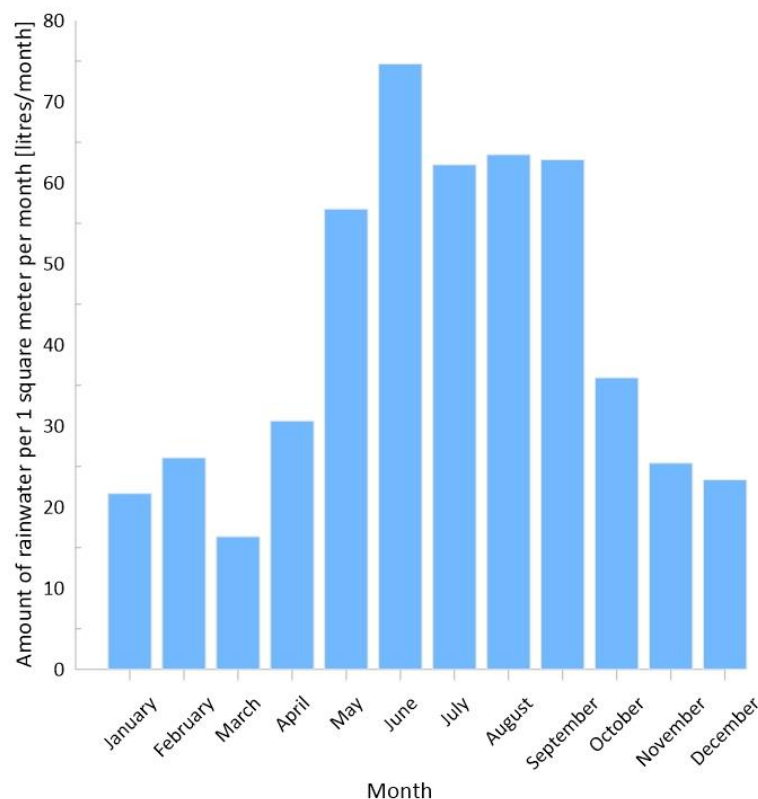
The low investment cost needed to start using this type of water, assuming, for example, the construction of the system performed independently by the investor, may also be considered a strength of the use of rainwater in the city. However, such solutions should not be promoted in cities, as it may affect unfavourably both aesthetics and further functioning.

Both water and water infrastructure facilities are attractive targets for acts of terrorism, which can be confirmed by examples of terrorist activities from the 19th, 20th and 21st centuries [31]. Water supply systems, next to food supply systems, are considered to be critical infrastructure, as they are crucial for the security of the state and its citizens [32]. On the other hand, the increase in terrorist actions indicates that facilities related to water management may become their target in the future, while forecasts of further attacks indicate a high probability of a bacteriological attack [31]. The use of rainwater in cities, in addition to tap water as the basic source of supply, is an additional security for residents in the event of war or attacks (including terrorist attacks) on critical infrastructure, i.e., the water supply system. This allows for partial independence from the supply of water from the water supply system.

The strong point of the use of precipitation is the sheer amount of precipitation as a free source of water (without taking into account the costs of enabling its use). For example, Figure 3 presents the average monthly volumes of rainwater that can be collected from 1 m<sup>2</sup> of surface in one of the largest cities in Poland—Wrocław—for the last five



years, i.e., 2018–2022, based on the IMGW–PIB data [26]. The calculations did not take into account the runoff coefficient reducing the runoff volume. The largest volumes of precipitation are possible to collect there in the period June–September. Assuming a roof with an area of 100 m<sup>2</sup>, this is a volume in the range of 6.2–7.5 m<sup>3</sup> per month. When corrected using the runoff coefficient depending on the type of roof/surface, this range will be slightly lower.



**Figure 3.** The average volume of rainwater that can be collected from 1 m<sup>2</sup> of surface in Wrocław during individual months of the calendar year, according to data for the Wrocław Strachowice synoptic station for the years 2018–2022, without taking into account the runoff coefficient—own elaboration based on the IMGW–PIB data [26].

When citizens use rainwater, the consumption of high-quality tap water is also reduced. By using rainwater instead of tap water, city dwellers can also count on reducing their tap water bills.

In the era of climate change, on the one hand, cities are threatened with drought and lack of water and, on the other hand, there is a risk of flooding due to extreme rainfall events. In such conditions, carrying out the process of adaptation to climate change and its effects and increasing the inhabitants' resistance to these changes are key activities. From this point of view, the strengths of collecting and using rainwater in cities are very important.

On the one hand, by building infrastructure for the gathering and use of rainwater in cities, residents are better prepared for a situation of shortages of tap water or drought. As a result, they become partially independent of the supply of water from the water supply network, which has already been mentioned. In addition, by incorporating water into the urban landscape, a number of benefits can be realised. Water moisturises dry air, calms extreme temperatures, and prevents dust formation and, during extremely hot weather without wind, as a result of water evaporation, a noticeable cooling is created, causing air circulation [1]. On the other hand, rainwater harvesting systems have the ability to mitigate pluvial floods [28]. This action can be qualified as an adaptation to the effects of climate change, such as excessive rains, causing widespread destruction in cities, although the increase in the frequency of overflows from the sewage system is mainly due to the

rapid sealing of the urban catchments surfaces [15]. The use of rainwater at the place of its generation in the city allows to reduce the hydraulic overload of sewage systems at the time of peak flows. The perspective of introducing rainwater use in the city on a large scale shows even more benefits. However, due to the current level of this type of water use in cities, the potential effects of large-scale use of rainwater have been classified as ‘possibilities’.

Another important advantage of the use of rainwater in cities is the possibility of using it for various purposes, which results, among others, in the fact that it is relatively little polluted (e.g., compared to sanitary sewage). The modes of rainwater use are different and depend mainly on the place where their use is planned [12]. Rainwater can be used in households for watering greenery, flushing sanitary equipment, washing or cleaning [11,28,29]. In turn, in cities, rainwater can be used to irrigate urban greenery or flush streets [11]. In Krakow, Poland, there is a washing facility for trams equipped with a rainwater harvesting system [33]. Rainwater can also be used in technological processes in services and industry, as well as for flushing the sewage systems [12]. In exceptional circumstances, rainwater can be treated to a level of water quality that meets the requirements for water intended for consumption, which may be of interest in areas with water deficit [11]. In countries such as Bangladesh, rainwater is treated as a reliable source of drinking water [7]. The recipient of urban rainwater treated with highly effective methods can also be hydroponics or aquaponics. In addition to the methods of rainwater management mentioned above, one can also mention its use for shaping and supplying elements of the local landscape [12], and at the same time supplying groundwater. Rainwater can be used in water playgrounds [34,35], interactive water playgrounds [1,12,36] or educational water parks [37].

The use of rainwater in cities allows for the management of rainwater in the place of its creation. This is particularly important due to the new phenomena that are characteristic of urbanised areas, such as urban floods and flooding, occurring during heavy rainfall, the intensity of which exceeds the capacity of urban sewage systems [15]. Among the environmental benefits resulting from the use of rainwater collection and utilisation systems in the urban environment is the already mentioned ability to mitigate pluvial floods [28], and thus flooding [7] and related losses. According to the authors of [38], the management of water from precipitation in urbanised areas is the most important task in the field of water management in cities as part of the adaptation to the effects of climate change.

The introduction of specific solutions and their subsequent operation is much more convenient, if different facilities (e.g., specialised software) and support bases including various types of educational materials are prepared. In the case of an action such as rainwater harvesting in the city, there is a rich information base, as exemplified by websites [39] or entire web services devoted to this issue [40,41]. Numerous guides have been prepared—both paid [42–44] and free [45]. In turn, as support in the design, you can mention, among others, software developed by the United States Environmental Protection Agency (U.S. EPA) for planning, analysis and design related to stormwater runoff [46], for which a detailed manual is available [47].

The advantage of harvesting and using rainwater is the existence of tools that encourage their implementation by providing financial support. The programmes available in Poland can be mentioned only as examples: the government programme ‘My Water’ [48], or the municipal programme ‘Catch the rain’ available to the inhabitants of Wroclaw [49]. In the United States, an example of this type of initiative is the offer of rebates for creating a rain garden [50].

A strength of the use of rainwater in some countries are also the economic benefits in the form of exemptions from the tax paid for the sealed surface of the property in the case that the owner undertakes to collect rainwater [35] or reductions in fees.

An additional strength of the use of rainwater in the case of public or commercial buildings is the possibility of using this action to promote the organisation as part of ecological Public Relations (eco PR).



### 3.2. Weaknesses of Collecting and Using Precipitation in Cities

The weaknesses of the use of precipitation in the city include the high investment costs appearing in the case of introducing a more complicated installation, e.g., supplying water for flushing toilets. An example of the total purchase cost of this type of installation for the use of rainwater for a tourist in a Slovakia facility was EUR 10,535 (euros), and the return on investment in this case was 15 years [51]. In turn, the application of the methodology proposed in [52] for assessing the benefits of large-scale installation of domestic RWH systems in multi-storey buildings for the old town of Lipari (Aeolian Islands) showed that about a quarter of the installed RWH systems could potentially pay for themselves in less than 10 years [52]. It should be remembered that these are just examples of installation costs and may vary in individual countries. The price also depends on the complexity of the installation. However, if the installation performed by the property owner using a DIY (do-it-yourself) method, the costs will be much lower, but its aesthetics and further operation may generate many issues.

It should also be remembered that the operation of rainwater utilisation systems may involve maintenance and operating costs. This applies, for example, energy consumption for pump operation or filter replacement costs. The system should also be periodically inspected. The annual cost of maintaining the installation for the use of rainwater for the aforementioned tourist facility in Slovakia was approximately EUR 49 [51]. Energy consumption should be particularly taken into account when highly efficient methods, such as reverse osmosis, are used for rainwater treatment.

The energy demand for the functioning of the rainwater utilisation system is related to its dependence on the supply of this energy, which should also be treated as a weakness of these solutions.

An additional weakness of the use of rainwater in the city is also the uncertainty as to the occurrence and volume of their supplies, uncertainty of which may increase due to the ongoing climate change (threat). According to [12], the problem with rainwater is that its quantity cannot be predicted; however, at the same time, one should take into account the possibility of long-term, intense rainfall. It can, therefore, be concluded that rainwater supplies are limited by weather conditions.

In respect to rainwater supplies, there is unevenness in terms of rainfall occurrence. For example, analysing the precipitation data from [26] for Wrocław, one of the largest cities in Poland, in terms of the number of rainy days and rainless days in the last five years (2018–2022), it can be observed that the number of days with rain during the year, i.e., days with rainwater supply, accounts for only between 35% and 44% of all days, as shown in Figure 4. Figure 5 shows daily volume of rainwater in litres in relation to 1 m<sup>2</sup> of surface in Wrocław in 2022, according to the data from [26].

Assuming the formula for the coefficient of daily inequality  $N_d$  characterising water consumption fluctuations from [53]:

$$N_d = \frac{Q_{dmax}}{Q_{daverage}} \quad (1)$$

as a basis for calculating by analogy the coefficient of unevenness of rainwater supply during the year, the coefficient of unevenness of rainwater supply  $N_{d \text{ rainwater supply}}$  was calculated by:

$$N_{d \text{ rainwater supply}} = \frac{Q_{\text{max rainwater supply}}}{Q_{\text{average rainwater supply}}} \quad (2)$$

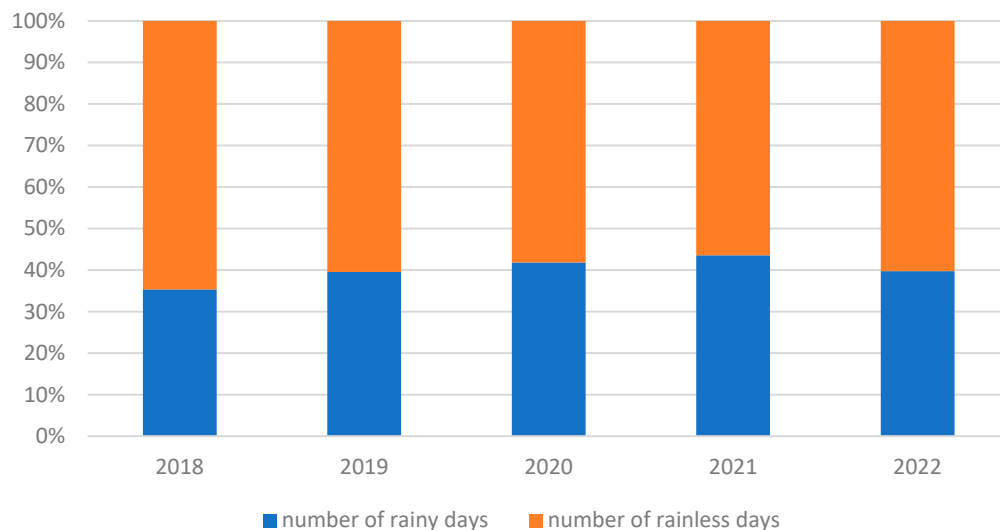
where:

$Q_{\text{max rainwater supply}}$ —maximum rainwater supply from 1 m<sup>2</sup> of surface per day, dm<sup>3</sup>/d

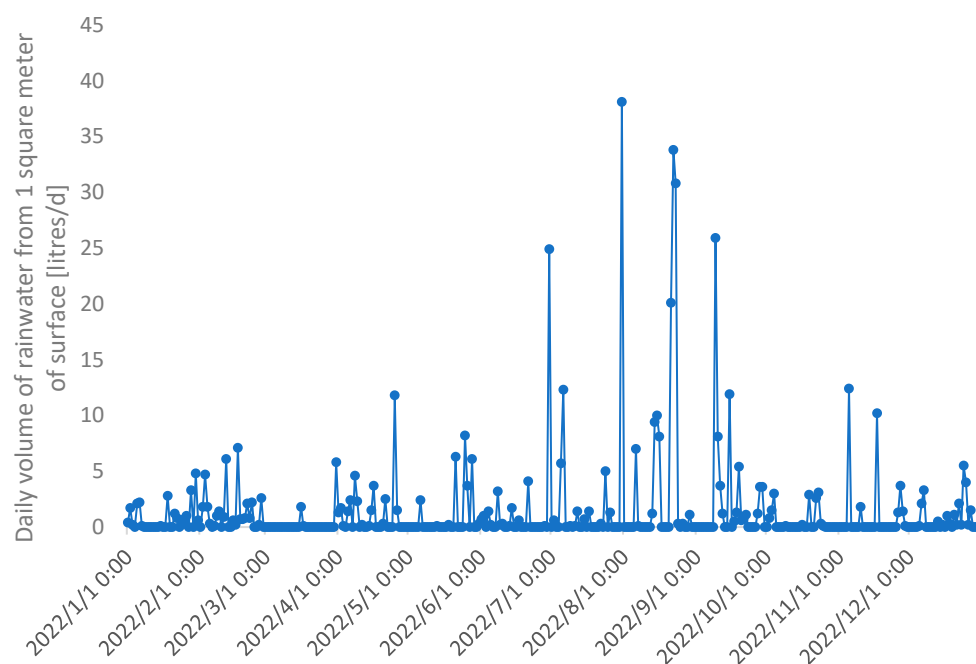
$Q_{\text{average rainwater supply}}$ —average rainwater supply from 1 m<sup>2</sup> of surface per day, dm<sup>3</sup>/d,

where in the average rainwater supply is an averaged value for the whole year, taking into account rainless days in the calculations. The values of  $Q_{\text{max rainwater supply}}$  and  $Q_{\text{average rainwater supply}}$  were calculated on the basis of daily precipitation amounts (in mm)

per 1 m<sup>2</sup> of the area, and converted into the volume of precipitation during the day. The runoff coefficient was not included due to the fact that its value has no influence on the calculation result (in the formula it would appear in the same value both in the numerator and in the denominator).



**Figure 4.** Number of rainy and rainless days in Wrocław in 2018–2022, own elaboration based on IMGW—PIB data for the Wrocław Strachowice synoptic station [26], for 2019—no data for 1 day a year.



**Figure 5.** Daily volume of rainwater in litres in relation to 1 m<sup>2</sup> of surface in Wrocław according to data for the Wrocław Strachowice synoptic station for 2022, without taking into account the runoff coefficient—own elaboration based on IMGW—PIB data [26].

For the year 2022, for Wrocław, Poland, based on data from IMGW—PIB [26], the value of the coefficient *N* of rainwater supplies was 28.2, which confirms the aforementioned significant unevenness of rainwater supplies during the year. Table 2 summarises the unevenness coefficients of rainwater supply in the years 2018–2022. Due to the ongoing climate change, only data from the last five years are included. The largest coefficient of unevenness rainwater supply occurred in 2021 and amounted to 44.5.

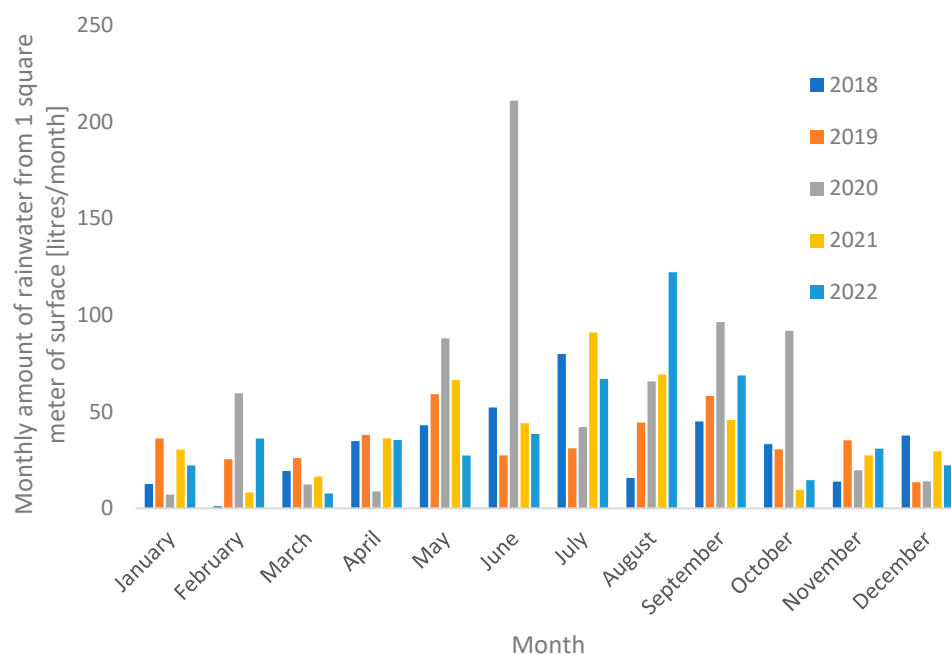
**Table 2.** Coefficient of unevenness of rainwater supply in the years 2018–2022, calculated on the basis of data on daily precipitation for the Wrocław Strachowice synoptic station, own elaboration based on IMGW—PIB data [26].

Year	Coefficient of Unevenness of Rainwater Supply, Nd Supply of Rainwater
2018	27.7
2019	26.2
2020	35.3
2021	44.5
2022	28.2

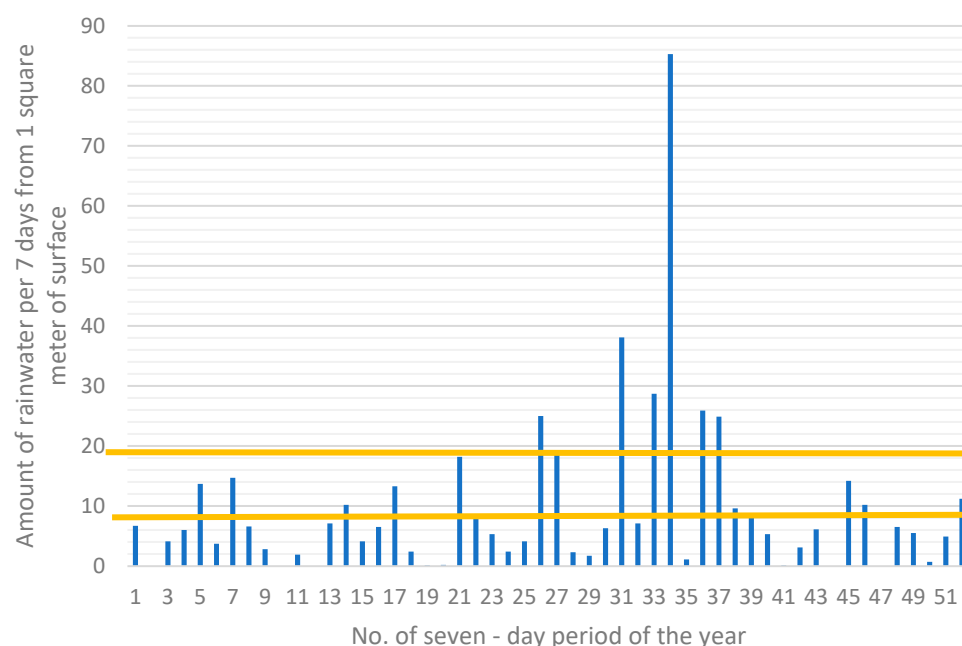
In addition to the annual variability in the amount of water supply, changes occurring during the individual months of the year should also be taken into account. For this purpose, data from the last 5 years for the city of Wrocław regarding the amount of precipitation (i.e., the volume of rainwater that can be obtained from 1 m<sup>2</sup> of surface per month) in individual months of each year were analysed. Data for each month are presented in the chart (Figure 6). It can be observed that also in terms of monthly rainfall sums (i.e., the amount of rainwater collected during a month) there are significant differences both during each calendar year and in one year in relation to the following year.

Assuming that rainwater can be stored in tanks, for the rainfall data [26] from the last calendar year (i.e., 2022) for Wrocław, it was calculated what amount of rainwater from 1 m<sup>2</sup> of surface can be obtained in subsequent seven day periods in a calendar year. The seven day period resulted from the assumed water storage period. The calculations did not take into account the runoff coefficient, which, depending on the type of surface from which water would be collected, will reduce the value of the supply volume. The calculations are shown in the graph (Figure 7).

It can be observed that using this approach to the analysis, a slightly lower unevenness of rainwater supply is obtained, but supplementation with water from the water supply network or treated grey sewage will still be required. In 37 seven day periods, no more than 10 litres per square meter was reached, and in 46 out of all 52 periods, the amount of water did not exceed 20 litres per square meter.



**Figure 6.** Monthly volume of rainwater in litres in relation to 1 m<sup>2</sup> of surface in Wrocław according to data for the Wrocław Strachowice synoptic station for the years 2018–2022, without taking into account the runoff coefficient—own elaboration based on IMGW—PIB data [26].



**Figure 7.** The volume of rainwater that can be collected over the consecutive seven day periods from the area of 1 m<sup>2</sup> of surface in Wrocław according to data for the Wrocław Strachowice synoptic station for the years 2018–2022, without taking into account the runoff coefficient—own elaboration based on IMGW—PIB data [26].

It should be noted that the presented data and analyses for Wrocław are only illustrative, confirming the occurrence of the discussed inequality both in terms of the occurrence and amount of precipitation. At the same time, they constitute preparation for the use of rainwater in a research project [16] to replenish water losses in an aquaponic farm in the city. However, it should be remembered that this variability depends on many factors, including location, and will be different in different regions of the world. As such, it should be taken into account that it will occur, and its nature should be checked and assessed each time. The presented example of an approach to analysing the unevenness of rainwater supplies carried out for Wrocław can serve as a template for developing a procedure for analysing the unevenness of rainwater supplies in other locations for different purposes. In turn, to confirm the unevenness in other locations, another example could be small settlements of the Mediterranean Sea characterised by sharp fluctuations in precipitation between winter and summer periods [52]. The monthly precipitation distribution typical of the Mediterranean islands is characterised by a wet period in October–March and a long period of dry summer with minimum precipitation in July and August [52]. The work [15] presents the results from [54] showing the average monthly rainfall in selected European cities representing different types of climate, which also confirms the occurrence of different types of rainfall unevenness.

The unevenness of rainfall was also mentioned in [5] as a weakness of the current conditions in Kunming City for the introduction of Sponge City construction. In turn, for Bangladesh, the extension of dry periods (i.e., increased changes of rainfall throughout the year) was indicated as a threat to RWH systems [7].

For the period 1900–2005, as part of the analyses conducted by the Intergovernmental Panel on Climate Change (IPCC) for the world, estimation of long-term trends in the amount of precipitation was made [15]. A high variability of the area distribution and time distribution of precipitation was found [15]. This represents an additional weakness of the use of rainwater in global terms. In some areas, a significant increase in the amount of precipitation was observed (e.g., in the northern part of Europe), and in some areas—a significant decrease in the amount of precipitation (i.e., in the southern part of Asia) [15]. This means that solutions for the use of rainwater must be adapted to a specific location

(region, country) due to the amount of precipitation, but it should also be borne in mind that during the use of the installation it may be necessary to modify it due to changes in the amount of precipitation.

The weakness of the use of rainwater in the city is also due to the fact that the type of roof, its slope and the size of the surface determine the amount of rainwater that can be collected. This is expressed by the previously mentioned runoff coefficient. The typical value of runoff coefficient can be taken from the technical literature, for instance, for green roofs depending on the thickness of the green roof layers [55], for different types of surfaces and different types of development [56] and for different types of surfaces and different types of development depending on the slope [57]. The roofing material and the material of the gutter system are among the factors determining the quality of rainwater flowing from the roof and collected in the tank. Both rainwater and roof runoff contain pollutants. This is confirmed in numerous studies and publications, as exemplified by the works: Ref. [11]—in the field of rainwater quality and runoff from roofs in Gdansk, Poland, Ref. [58]—in terms of the quality of rainwater flowing from roofs for the Tri-City, Poland, Ref. [59]—in terms of concentration levels for principal pollutants in stormwater (Polish and foreign research), Ref. [60]—in the field of variability of selected pollution indicators determined in rainwater (in different countries), and works on urban runoff pollution in Paris, France [61], Haifa, Israel [62] and Genoa, Italy [63]. For this reason, they usually require treatment, which is also one of the weaknesses of the use of rainwater in the city. One should also be aware that in ecologically clean regions, runoff from the roof is of better quality than in cities or industrialised regions [52,64]. The variability of rainwater quality should be treated as their basic feature [12]. The location of the rainwater collection system is also important for the quality of runoff because rainwater is also polluted by assimilation of pollutants from the air, so the level of pollution is influenced by, among others, local air pollution [29]. The season of the year is also important for the quality of rainwater [29].

Numerous difficulties in introducing installations using rainwater into existing buildings should also be reckoned with, and the following should be mentioned here: lack of space in installation shafts for additional risers or lack of space for a rainwater tank. Depending on the quality of the collected rainwater and its intended use, the need to provide space for the water treatment system should also be taken into account. Similar difficulties (weaknesses) occur when using greywater in buildings. In older buildings, it is necessary to take into account the possibility of lack of complete documentation or lack of its sufficient readability. The downside in this regard in the case of introducing this type of installation to existing multi-family buildings is the need to obtain consent from the residents. This topic was discussed extensively in [30].

Weaknesses also include a small range of current uses of rainwater in housing; it can be used in households mainly for flushing the toilet and laundry [11,52], as well as for irrigation of household greenery [51]. However, it is possible to extend this scope in the future.

The existence of specialised software for the design and modelling of rainwater utilisation systems can be both a strength—as already mentioned—but selected authors [28] indicate that the preparation of models requires specialised skills, and the calculations require a medium or high specification computer, which may be beyond the reach of some. For this reason, highly specialised software can also be qualified as a weakness.

### *3.3. Opportunities of Collectiong and Using Precipitaion in Cities*

The introduction of rainwater utilisation systems in buildings may be accelerated in the future due to the occurrence of the urgent need for alternative sources of water. The reasons for this need may vary, from the effects of climate change to the price of tap water, and such a situation can be qualified as an opportunity for the development of rainwater utilisation systems. In view of such a situation, the priorities of city dwellers may change significantly. An analogy can also be found here to the current situation with electricity.

The prospect of introducing the use of rainwater in future cities on a large scale shows the potential additional effects of such action. The reduction in tap water consumption achieved together with the use of rainwater is also associated with less chemicals and energy used to prepare it in water treatment plants, as well as less energy used for transfer. However, it should be remembered that the preparation and transport of rainwater to the place of final use also requires energy and consumables. If large-scale collection and use of rainwater is introduced, municipal water treatment plants will produce less tap water. As such, they will be able to devote even more attention to activities aimed at further improving the quality of tap water. Another potential environmental benefit is water protection by reducing surface waters pollution as a result of limiting the activation of combined sewer overflows [28].

Regardless of whether it is promoting the minimisation of water consumption, introducing blue-green infrastructure into the urban fabric, or collecting and using rainwater in urban areas, the opportunities for their conduction and the introduction and development of these activities are usually similar, as they involve environmental benefits and adapting cities to the effects of climate change. The methods of encouraging and supporting these investments follow similar principles.

In the case of collecting and using rainwater, the main development opportunities should be sought primarily in scientific projects and research and development works, as well as in technical and technological progress. As a result, new ways of using rainwater or more effective solutions for collecting or treating rainwater can be expected. An example here is the USAGE project (Urban Stormwater Aquaponics Garden Environment), one of the goals of which is to try to use rainwater for urban aquaponic cultivation in order to create a food supply system that is as independent as possible [16]. In the current situation of cities, it is extremely important to look for alternative sources of water supply. In the discussed scope, the development of RES (renewable energy sources) due to potential changes in the water-energy nexus deserves special attention. Renewable energy sources are being introduced in cities to increase the resilience of urban water systems [65]. The literature emphasises both the current and future need to search for ways to obtain the largest amount of water with the lowest possible energy consumption [66]. Innovative solutions are needed to ensure the possibility of water purification and its transport, while generating a minimal carbon footprint. New possibilities can be opened by developing new roof coverings or surfaces with special properties that are conducive to the reduction of the pollution of rainwater flowing from them, or by using the Internet of Things (IoT) and other techniques to collect rainwater, omitting the most polluted volume, i.e., the so-called the first flush of rain (perfect diverters).

An opportunity to disseminate the use of rainwater is also education and raising awareness of the society, which supports the acquisition of social acceptance. Such education should be addressed to different age, professional and social groups and should be conducted using different methods. Its overarching goal should be to increase social awareness in the field of adaptation to the effects of climate change in cities and the possibility of obtaining water from alternative water sources. The role of education in the programming of alternative methods of rainwater management, including its use, is discussed in detail in [67]. Opportunities for the development of rainwater use can be created by expanding training programmes or transferring good practices through education from other fields. An example here may be training activities conducted in the field of geothermal energy in Poland, combined with technical visits conducted as part of the project [68], and crowned with a manual [69]. A significant opportunity could be a programme created by pattern of projects [70] aimed at identifying knowledge gaps in the use of rainwater in the city and building the capacity of key stakeholders in cities to use this source of water.

Multi-criteria assessment systems for buildings can also contribute to the use of rainwater, as they promote the management of rainwater at the place of its generation. Rainwater management appears in such certification standards as BREEAM (Building Research Establishment Environmental Assessment Method) and LEED (Leadership in



Energy and Environmental Design) [71]. Within the American LEED rating system, there is a category called Sustainable Sites, and within it—the possibility of gaining points under the Rainwater management credit, e.g., for collecting and reusing rainwater using LID (Low Impact Development) or GI (Green Infrastructure) practices [72]. In another category of this system—Water Efficiency—under the credit Outdoor Water Use Reduction, points can be also earned for the use of alternative sources of water (e.g., rainwater). In another popular multi-criteria building assessment system (BREEAM), the issues of rainwater management appear in the category Water (Water efficient equipment) [73] and the category Pollution (Surface water run-off) [70].

Similar opportunities can be expected for the use of rainwater in the case of introducing or maintaining environmental management systems (e.g., according to the ISO 14,000 series (International Organization for Standardization) [74–76] or EMAS (Eco-Management and Audit Scheme) systems [77]) in enterprises.

The possibility of further development and dissemination of the use of rainwater in cities is the subsequent maintenance and development of programmes subsidising investments related to the management of rainfall in the place of its generation (such as the previously mentioned programs operating in Poland: ‘My water’ [48] and ‘Catch the rain’ [49]), that is, among others, increasing the scope of co-financed investments. An opportunity will also be the creation of complementary support programmes that are not only financial, but also legal and formal.

The discussed programmes may allow for quick and easy implementation of solutions for harvesting and using rainwater. This will facilitate the construction of a large number of scattered rainwater acquisition and utilisation systems in cities. Their individual yield will not be large; however, an abundant number of installations and their total efficiency will show the effect of the scale of the venture.

An opportunity to increase the efficiency of precipitation harvesting and use systems is also to consider the use of other forms of precipitation, such as snow, although this will require solutions to many problems (e.g., functioning of the reservoir at low air temperatures or removing impurities in the snow). Runoff of water from snowmelt generates quality problems due to heavy pollution, e.g., atmospheric dusts, after a long period of being on the ground surface [57].

The development and introduction of policies and strategies with appropriate provisions on the use of rainwater in cities, together with documents operationalising the objectives contained in these strategic documents, also provides an opportunity to disseminate the use of rainwater in cities as an alternative source of water. The role of policies and incentives is confirmed by the situation with green roofs in Europe, which can also be adopted as a way of using rainwater. Most cities with a high density of green roofs are located in Austria, Germany and Switzerland, as these countries were among the first to adopt policies and incentives for green roofs [78]. Opportunities will also be provided by the implementation of the European Union strategy—the European Green Deal. Among the assumptions of the main elements of the European Green Deal, one can mention, among others, adaptation to climate change [79].

Opportunities to enlarge the use of rainwater in cities can be found in the adoption of new laws or modifications to existing ones. This may apply to both national and city-specific regulations. These provisions may concern, among others: the introduction of additional fees related to rainwater, the obligation to apply specific solutions in the field of rainwater management or the use of reliefs and discounts in the form of incentives for specific actions. An example of a tax may be the fee for reducing natural retention introduced in Poland by [80]. In Basel, Switzerland, the Building and Construction Law requires a green roof on all buildings with flat roofs [78]. In the city of Linz, Austria, the municipal building regulations have included an obligation for new buildings to have green roofs [78]. Another incentive was the municipal regulations established in Wroclaw [81], enabling exemption from real estate tax in the case of construction of a green roof or a

vertical garden. The financial motivation introduced in this way may turn out to be one of the most effective ways to increase the number of rainwater gathering and use installations.

Guidelines for the introduction of rainwater utilisation systems in new buildings, co-created with industry specialists and key stakeholders, may also be a solution favouring the dissemination of the use of rainwater in the cities of the future, as well as expanding the scope and updating existing standards, i.e., in [82,83].

An increase in prices for tap water or a high price for water due to, among others, accessibility problems (e.g., due to the small size of river basins and/or the need to replenish the water supply through tankers and desalination, as is the case in several Mediterranean archipelagos [52]) can also contribute to the intensification of activities leading to the use of alternative source of water, which is rainwater.

Abilities for increasing the number of systems for harvesting and using rainwater in cities may also be created by the development of facilities of their design, selection of equipment and execution. At this point, it is possible to list, among others, programs facilitating the selection of devices and clear and evident (if possible) guidelines for the selection of devices and installation. It is also possible to include here facilitations in the use of modelling programs that currently require specialist skills, which is indicated by some [28] as a limitation.

Possibilities to increase the number of installations may also be provided by appropriate preparation of the investments consisting in cooperation and co-creation of projects (so-called co-design) together with the local community that will use these installations in the future. Guides on how to achieve community support and solve problems and possible conflicts can be used for this purpose. An example of this can be the guide [84] on the implementation of green infrastructure projects. An example here may also be the USAGE project [16], in which an aquaponic farm powered partly by rainwater was introduced to the urban tissue of Wroclaw through co-design workshops with the city's inhabitants.

### *3.4. Threats to the Harvesting and Use of Precipitation in Cities*

The main threat to the use of water in cities is the reduction or lack of rainfall. This phenomenon is associated with the effects of climate change. The author [15] noted that climate predictions indicate a decrease in precipitation in Central Europe in the summer. At the same time, in the same part of Europe, an increase in precipitation in winter should be expected [15]. Increasing the unevenness of precipitation will lead to problems with rainwater storage, although the results of research [29] indicate that the myth of a drastic drop in the quality of rainwater during its storage can be dispelled. It should be added, however, that in the aforementioned studies the process of water storage in the RWH system was observed for only 30 days, and the unevenness of precipitation in the future may force longer periods of rainwater storage.

At the same time, the same authors of [29] analysed the situation of worsening climate change and the occurrence of extreme climatic events as one of the possible scenarios. They predicted that the then rare rainfall will be conducive to the accumulation of pollutants (including heavy metals) from polluted air on roofs, and acid rain will significantly deteriorate the quality of rainwater directed to reservoirs in RWH systems [29].

In turn, the studies on the seasonality of extreme precipitation over the Mediterranean Sea in the future conducted by [85] indicate that there will be a seasonal shift of extreme events to colder months in most Mediterranean regions. This may also generate a threat if the infrastructure will not be properly secured for the winter period.

Another threat related to climate change consisting in an increase in air temperature and, therefore, an increase in the temperature of stored rainwater, which can result in the problem of multiplication of *Legionella* bacteria, especially since the occurrence of bacteria of this type has also been proven in rainwater. In Tokyo, Japan, the bacterium *Legionella pneumophila* was found abundantly in puddles, especially during warm weather [86]. In turn, research conducted by the authors of [87] found a risk associated with toilets supplied with water from RWH tanks infected with *Legionella*.

One should also take into account the possibility of the emergence of new pollutants of rainwater, which have not found to date. Thus, another threat to the use of rainwater can be mentioned, which may be the deterioration of the quality of rainwater, which prevents or significantly hinders its purification and use in the city.

In the event of a significant increase in unevenness of rainfall, a threat may also be the lack of space for rainwater tanks, which in such cases should be of larger dimensions. Then, the existing methods of dimensioning tanks, based on 5% of the average annual precipitation, or  $14 \div 30$  day water demand for flushing toilets that is described in, among others, ref. [12], may be unhelpful. The process of urbanisation in cities is also not conducive to locating rainwater tanks near buildings. If steps are not taken to establish guidelines for new buildings in cities, the problem will also concern the introduction of rainwater collection systems (including tanks) into the space of the building itself. With an increase in the unevenness of precipitation, one should also take into account a decrease in the economic efficiency of RWH systems. The main factor influencing the economic efficiency of the system is the uniformity of precipitation in a given area, as rainfall occurring evenly throughout the year is much more favourable [12].

A threat to the use of rainwater in cities may also arise from the social side. When 'social acceptance' is mentioned, this refers to the way people will accept the realisation of any important project in the area where they are living [88]. In the case of definitions related to the concept of 'social acceptance', one can refer to the literature related to the introduction of other solutions important for the environment, such as geothermal projects. According to [89], it is assumed that social acceptance is achieved, among others, when the sector affected by the project can see some advantages from the project. In turn, according to [90], public or social acceptance is defined as a combination of such categories as socio-political, market and community acceptance. In terms of RES innovation, the author of [90] lists the socio-political acceptance of technologies and policies by the public, key stakeholders and decision makers, and in terms of social acceptance, he lists procedural and distributional justice. The work [91] also addresses procedural and distributional justice. In this regard, one can look for analogies to the use of rainwater in the city. This may be the lack of acceptance for solutions for the use of rainwater resulting from, among others, lack of social awareness in this regard, as well as a lack of interest and motivation to introduce any changes. This may apply to both the potential main stakeholders of introducing the use of rainwater in the city, as well as decision makers.

The aforementioned lack of social acceptance, interest and motivation to introduce changes in cities may be related to insufficient education. The learning, in turn, may be carried out to an inadequate extent due to the lack of sufficient funding or the current geopolitical situation of the states and directing funds to other, more urgent goals.

A change in the geopolitical situation of individual countries or even a war, associated with a possible change of priorities, may result in a lack of financial support for both the implementation of RWH systems in cities and education in this area. Nevertheless, it should be remembered that in the event of war, rainwater may turn out to be an independent source of water supply, because then the critical infrastructure (i.e., water supply systems) is most at risk.

The mere lack of financial support for activities related to the dissemination of rainwater harvesting and use, possible for various reasons, can also be listed as a threat.

Other threats to the propagation of rainwater gathering and use systems may be an increase in energy prices (needed for water distribution and possible high-efficiency treatment) resulting in an increase in operating costs and material prices. This, in turn, can impact the RWH systems investment costs.

The lack of regulations in this area in some countries or their insufficient elaboration or clarification can also be mentioned as a threat. On the one hand, this may be associated with difficulties in introducing such installations to cities, although the opposite is also possible. The authors of the paper [28] are of a similar opinion, as they believe that legal regulations can both help and hinder the widespread implementation of rainwater harvesting systems.

In turn, according to the authors of the work [29], the legal framework for water quality and the design of rainwater harvesting systems (RWH) is needed for the safe use of collected rainwater on a large scale.

### 3.5. Discussion of the Results in Terms of SWOT Analysis

Some of the SWOT analyses available in the literature do not specifically concern the use of rainwater in the broad sense of the word, but only selected solutions [4,8], or processes [9,10] in the field of rainwater management. However, it should be taken into account that, for example, rainwater infiltration can also be treated as a way of using it, because in this way we can recharge groundwater and shape the local landscape. In turn, some SWOT analyses are also related to a specific place [4,5] or country [6,7,10], which to some extent narrows their scope, although it is possible that similar conditions may also occur in other cities and countries. Despite this, one can find many common points in terms of individual elements of the SWOT analyses between published SWOT analyses and the analysis carried out in this work.

The work [8] in the context of rainwater collection, storage and distribution systems indicates, similarly to the assumption in this work, low investment costs as a strength (for individual systems), and high costs as a weakness (for semi-distributed and centralised systems). Among the weaknesses, the need for specialised knowledge in the case of medium and high complexity of systems was also indicated [8], which results from the application area of the systems discussed. In the general approach adopted in the article, the need for the services of a designer or expert was not considered a weakness; only the need for specialised knowledge in modelling was indicated [32]. However, in this paper [8], attention was paid to the need for a site wide agreement set up, which is consistent with the need to obtain social acceptance. The SWOT analysis conducted in [4] concerns the RWH system in a specific location (Batu Pahat, Malaysia). The authors of [4] indicate among the possibilities that RWH systems may constitute a backup source of water in emergency situations. This is consistent with this work with a general approach, where the strengths of using rainwater include the diversification of water supply sources, as well as the preparation of city residents for situations of war or terrorist attacks. The paper [4] also highlighted the potential lack of aesthetics as well as problems in maintaining the system. The developed article did not discuss aesthetic issues, and particular attention was paid to problems with maintaining rainwater utilisation systems in the context of potential problems with *Legionella* bacteria, which may become more and more likely in the face of rising air temperatures. Lack of awareness of the benefits of RWH system among the residents of Batu Pahat was mentioned among the threats in the paper [4], which confirms the assumption of the lack of public awareness as a problem in the analysis conducted for the use of rainwater in current study. The threats to the quality of rainwater posed by rodents mentioned in [4] are consistent with the adopted threat of the appearance of new pollutants and deterioration of the quality of rainwater. The paper [4] also addresses problems with rainwater pressure, which was omitted in the current work due to the well-developed market offer of devices dedicated to solving this problem. Instead of this threat, problems with financing such investments and electricity consumption by them can be mentioned.

Many common points in the individual elements of the SWOT analysis can be found in the work [6] analysing the RWH system for Bangladesh. It is characterised by a similar approach, taking into account both economic, environmental and economic aspects. Here, low public awareness is listed among the weaknesses, and huge annual rainfall is considered as an opportunity. Similar to the work of [8], the threats include the possibility of rainwater quality affection by, among others, animal and bird droppings [6]. The research closest paper to the current work is the SWOT analysis from [7] on the adoption of RWH systems to ensure water security in the coastal region of Bangladesh. Although it refers to a region in one country, it is not as comprehensive as in this work, which especially concerns the opportunities of increasing the scope of the implementation of rainwater use in the

future. Moreover, the work [7] does not directly refer to the lack of public awareness in this area, but only indicates the lack of training in the operation and maintenance of this type of systems.

The works [9] and [10] do not refer directly to the use of rainwater, but to the methods of its management, which is an even broader issue. In these works, SWOT analyses were carried out for various stormwater management systems (conventional and sustainable). Here, several common elements can also be found or related to the analysis carried out. For conventional stormwater management systems, it lists factors among the threats that constitute opportunities for the use of rainwater, or only their lack may constitute a threat; these include co-financing of sustainable stormwater management technologies, improved ecological awareness of the society or introduction of legal regulations targeting sustainable stormwater management [10]. In turn, among the SWOT analyses for sustainable stormwater management systems in [10], one can find such factors as: reduction of the amount of stormwater directed to surface receiving reservoirs, co-financing of sustainable stormwater management technologies, development of sustainable stormwater management techniques or absence of unified standards and guidelines and data for design and introduction of suitable legal regulations, which are consistent with the factors taken into account in the analysis carried out in the article. At the same time, the SWOT analyses conducted in [5] are aimed at specific conditions in the cities of Kunming City and Guangzhou, China. They refer to, among others: to urban drainage system, water pollution treatment system, ecology, economy and environment. Climate change appears in many SWOT analyses [5–7,9,10], but almost always in the context of threats. In work [6], huge annual rainfall in Bangladesh was indicated among the opportunities. In the current work, climate change was treated as both a threat (lack of sufficient rainfall) and an opportunity that may motivate acceleration of the introduction of large-scale RWH systems.

#### **4. Prospects for the Use of Precipitation in the Cities of the Future**

The perspectives for the use of rainwater, i.e., opportunities on the one hand, and the main challenges on the other hand, are discussed through the prism of existing problems, limitations and barriers.

##### *4.1. Problems*

Significant unevenness of precipitation during the calendar year was indicated as one of the great problems in the use of rainwater in cities and it is important that it may still change in the future. Related to this problem is the volume of rainwater tanks. The need to adjust to the unevenness of precipitation with the simultaneous desire to use as much of it as possible forces a large volume of reservoirs. In turn, the large volume of rainwater reservoirs is associated with two further problems—finding a place to locate the tanks (both in buildings and outside) and maintaining the quality of rainwater during a long storage period.

##### *4.2. Barriers and Limitations*

In existing buildings in cities, it is often impossible to introduce rainwater gathering and distribution systems (barrier) or their implementation may encounter significant difficulties (limitation). The reasons for such barriers and limitations are described in detail in [47]. It is also necessary to mention the lack of space for the location of the water treatment system in buildings, which together with the intake and distribution installation make up the entire RWH system.

In some regions of the world and/or in some cases, a barrier or a significant limitation to the implementation of rainwater utilisation systems in cities may be the lack of or insufficiently clear and complete regulations on the use of rainwater. However, it should be remembered that, as mentioned earlier, legal regulations can both help and hinder the widespread introduction of rainwater harvesting systems [28].



#### 4.3. Possibilities

There is significant potential in cities for the harvesting and use of rainwater. This is mainly determined by the degree of sealing of cities and the demand for water in the same area. Particular attention should be paid to the possibilities that are associated with buildings with large-area roofs, e.g., shopping centres, factories, churches, schools or sports arenas. This should apply to both public and commercial buildings. The potential can be demonstrated by the statement [15] that, in the period after 1945, the share of rainwater discharged through rainwater drainage systems in cities increased from little to over 20%. However, the introduction of rainwater collection and use requires multi-directional activities preceding it.

#### 4.4. Challenges

An undoubted challenge for the cities of the future is the dissemination and promotion of the use of rainwater. In order to use the existing opportunities in cities, it is necessary to undertake multi-directional actions in many areas. And coordinating these activities and consciously managing them in such a way that they complement and not duplicate each other is one of the greatest challenges for decision makers of cities in the era of transformation. A difficult task that needs to be solved is also to ensure the possibility of introducing RWH systems to new buildings, due to the difficulties and limitations encountered when introducing these systems to existing buildings. The challenge for the world of science is to minimise the pollution of collected rainwater. In turn, the legal framework for the use of rainwater should be adapted and updated in line with the expanding range of rainwater applications and technological progress.

#### 4.5. Suggested Courses of Action

The challenge of popularising the use of rainwater in cities can be implemented through education leading, among others, to a revolution in the approach to designing installations that supply buildings with water. The right direction of action is the continuation of the current education, as well as adapting it to the current needs, but also to specific professional, social and age groups. As a result, there should be a revolution in the approach to design and the development of building regulations and guidelines for the construction industry, ensuring the possibility of implementing an additional source of water, which is rainwater. For newly constructed buildings, guidelines are needed to secure the possibility of introducing installations for collecting, storing and using rainwater in the future (unless they are not designed in the building from the beginning of the design process). This mainly applies to securing space in installation shafts and for tanks and water treatment systems. Such solutions will provide wider opportunities for the use of rainwater in the cities of the future.

Minimising the pollution of the harvested rainwater can be achieved by developing an appropriate method of collecting water from a given area, omitting the most polluted volume, the so-called first wave of rain, or by developing an inert roofing material. Perhaps, following the example of roof surfaces purifying the air [92,93], roofs treating rainwater collected from them will also be built.

Great opportunities for increasing the use of rainwater in cities can be seen in solutions dedicated to buildings with large roof surfaces. This applies both to technical solutions and to activating the owners or managers of these facilities to follow such solutions. An opportunity for the use of rainwater in cities is to encourage or oblige managers of facilities with large roofs to collect rainwater. The implementation of this goal may consist in the introduction of appropriate legal regulations or subsidy programmes. These can be legal solutions applicable throughout the country, such as a tax paid for reducing the natural retention of land, often called a rain tax, combined with discounts for rainwater management on a plot. The management of rainwater from large-area roofs should be one of the priority directions of action.



The work does not introduce weights and ratings for individual factors of the SWOT analysis due to the difficulty of introducing them for a global analysis. Taking into account the number of all factors assigned to individual categories, one can observe the predominance of strengths and opportunities over weaknesses and threats. This suggests the possibility of use of an aggressive strategy for the implementation of rainwater use in the cities of the future. It will be a development strategy that uses both strengths and opportunities, also known as maxi—maxi [94].

## 5. Summary and Conclusions

Preparing for the use of rainwater in the cities of the future is an important element of transforming cities in the era of climate change. It is necessary to strive to minimise limitations, overcome barriers, and make maximum use of the existing potential in this regard. A detailed SWOT analysis for the use of rainwater in the cities of the future was carried out in the work. On its basis, challenges in the use of rainwater were identified and further directions of action were indicated. The most important challenges include:

- multiplication of the use of rainwater in cities
- developing new ways to use rainwater (e.g., for hydroponics and aquaponics)
- coordination of multi-directional activities aimed at dissemination the use of rainwater in cities
- ensuring the possibility of introducing RWH systems to newly constructed buildings in cities
- minimising the pollution of collected rainwater
- ensuring the safe use of rainwater (especially with regard to the increasing threat of Legionella bacteria due to climate change)
- searching for solutions to reduce the carbon footprint associated with RWH systems
- providing a properly adapted legal framework for the implementation of RWH systems in the cities of the future.

The implementation of these difficult tasks should be carried out by undertaking multidirectional activities, of which the suggested courses of action include:

- the further education of society
- a revolution in the approach to designing water supply systems for buildings in the cities of the future
- guidelines for newly built/newly designed buildings
- a method of rainwater intake that omit the most polluted first wave of rain, and the development of an inert roofing material
- management of rainwater from buildings with large roofs.

The SWOT analysis carried out allows the following conclusions to be formulated:

- introducing rainwater use into cities has both strengths and many opportunities, but there are also weaknesses and threats to this activity
- from a global perspective, taking into account the number of factors in individual categories, there is an advantage of strengths over weaknesses and opportunities over threats
- it is suggested to consider a globally aggressive strategy for implementing rainwater use, although every effort should also be made to eliminate or minimise weaknesses and threats
- the importance and strength of selected factors may take on different values depending on, among others, location
- some effects resulting from the introduction of rainwater use in the city may only be observed when this measure is used on a large scale (e.g., reducing the multiplicity of combined sewer overflows)
- some factors may be assigned to different categories (such as investment costs or climate change).

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