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Changes in the Amount of Rainwater in the Roztocze National Park (Poland) in 2001–2020 and the Possibility of Using Rainwater in the Context of Ongoing Climate Variability

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Abstract: Data for the years 2001–2020 on changes in the amount of rainwater in the Roztocze National Park (RNP) in the catchment area of the Świerszcz River (Poland) were investigated to evaluate the possibility of using rainwater in the park for various purposes in the context of ongoing climate variability. An analysis of data from the RNP's Integrated Monitoring of the Natural Environment showed that the average annual air temperature increased by 2.1 °C over the 20-year period, while the amount of precipitation decreased, especially in the winter seasons. These changes periodically led to a negative hydrological balance. As an effect, the groundwater table was gradually lowering, the flow of the Świerszcz River was reduced, and there were periodic shortages of water feeding the Echo Ponds. Water shortages also negatively affected the flora and fauna of the RNP. In order to quantitatively protect the Park's water resources, a proposition was made to build a rainwater management system at the Animal Breeding Centre in Florianka to provide water for watering Polish Konik horses, flushing toilets, washing cars and agricultural equipment, and fire-prevention purposes. The excess water would be discharged to a nearby pond, which is an amphibian breeding site. It was estimated that the system was capable of meeting 100% of the demand for lower-quality water in the summer period. Moreover, it was determined that 9109 m^3 of rainwater could be obtained annually from the roofs of all public utility buildings located in the RNP.

Keywords: rainwater; precipitation; temperature; climate change; Roztocze National Park

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1. Introduction

Water is essential for human life and well-being, as well as the economy of all countries. Freshwater accounts for only 2.5% of the Earth's water resources, and the remainder (97.5%) is the salt water found in the world's oceans. On top of that, as much as 68.7% of the Earth's freshwater is frozen in mountain glaciers and ice sheets [1]. This means that the available water resources, mainly found as groundwater and surface waters, are small.

Freshwater is a renewable resource, but the world's reserves of clean and fresh water are constantly diminishing. In many parts of the globe, the demand for water exceeds the supply, and, as the human population continues to grow, numerous countries face increasing water shortages. Today, more than 2.1 billion people worldwide do not have easy access to water at home, and another 2.3 billion have poor sanitation [2].

The awareness of the global importance of water conservation did not develop until the 20th century, when more than half of the world's wetlands had been lost. Freshwater ecosystems, which are rich in biodiversity, are disappearing faster than marine aquatic ecosystems [3]. Therefore, it is necessary to rationally manage water resources and seek solutions that will permit us to protect the Earth's freshwater reserves and obtain water from various sources.

In recent years, there has been more and more talk worldwide of wastewater reuse and the use of closed-loop systems [4–8]. In countries which experience the greatest water shortages, attempts are being made at using the desalination technology to convert sea and ocean water into freshwater [9–12]. However, the costs of applying wastewater treatment and desalination technologies are quite high [13–15]. Therefore, it seems that a more advantageous solution is to employ, where possible, systems for the collection and use of rainwater [16–18], the treatment of which does not require expensive technologies.

The collection and use of rainwater is one of the measures that can improve water security and access to freshwater in the face of climate change [17]. Research conducted by numerous authors around the world shows that rainwater harvesting systems (RWHS) can provide from 12 to 100% of potable water for a household, depending on environmental and social conditions [16,19–23]. Eroksuz and Rahman [24] investigated the water-saving potential of rainwater tanks installed in multistory residential buildings in three cities of Eastern Australia. They found that a rainwater tank of an appropriate size installed in a multistory building could deliver considerable water savings even in dry years.

When designing RWHS, attention should also be paid to the selection of the right size of tanks and the comparison of the assumed and actual performance of the system. The return on investment costs can be significantly extended in the case of over-sized tanks in relation to optimized-sized tanks [25]. Attention is also drawn to the need for a more multi-criteria approach when modeling urban RWHS, not only to collect water, while taking into account economic constraints, but also considering other benefits to nature [26]. Additionally, the use of different optimization algorithms and ranking methods can help to reach the optimal solution while designing RWHS. Moreover, numerical optimization can provide an additional tool to increase efficiency of systems and reduce project cost [27]. The significance of RWHS is also shown in aspects of reduction of electricity consumption and greenhouse gas emissions compared to public centralized supply systems [28]. RWHS is of particular importance in countries with tropical climates, where RWHS can reduce water scarcity in dry season and may help urban drainage system in the rainy season [29]. In counties such as Ethiopia, RWHS from large institutions will enable a significant volume of potable water to be transferred to localities critically suffering from water shortage [30]. It should also be kept in mind that the efficiency of rainwater management is usually judged on the basis of long-term averages. However, such a long-term assessment is poorly suited to the goal of mitigating the effects of short-term high-intensity rainfall [31]. With the development of IoT (Internet of Things) technology, the possibility of real-time monitoring has also opened up; it can help in the construction of systems preventing urban flooding and sewers overflows [32].

The literature review presented above shows that, so far, rainwater management installations have been usually used in urbanized areas in cities. However, the proper management of rainwater should be a key concern for protected areas, such as national parks, landscape parks, nature reserves, or Natura 2000 sites, as it may contribute to sustainable protection of waters and biodiversity in those areas [33,34]. The existing and planned protected areas require adequate water resources to ensure the functioning of river valleys and other areas with aquatic and water-dependent ecosystems, as well as the proper protection of ecological corridors. This applies to all watercourses and their valleys, both within and outside protected areas [33].

The forecast climate changes, and especially their effects, may lead to a transformation of the water cycle and alterations in the structure of the water balance (water budget) of catchment areas, and above all, to an increase in the frequency and extent of droughts and a reduction in water resources [35]. Action is therefore needed to mitigate the future effects of climate change. Negative changes in the quantity of water resources mean that the demand of the human population and nature for water is not met in full; they also lead to an increased occurrence of contamination of water for public supply, periodic local deficits of water for public supply, and periodic water shortages for irrigation in agriculture and forestry. An acceleration of the hydrological cycle can lead to more and more frequent extreme water-related events—both droughts and floods. In order to reduce the risk of flooding, it is necessary to extend the existing retention systems by building dams and dry polders and developing solutions for the so-called "small retention" of rainwater [35]. Local measures also need to be taken to retain and use rainwater flowing from the roofs of single-family houses or public buildings.

The goal of this paper is to present data on changes in the amount of rainwater in the Roztocze National Park (RNP) in Poland in the years 2001–2020 and discuss the possibilities of using the rainwater for various purposes in the context of the climate change taking place in this protected area.

2. Materials and Methods

2.1. Characteristics of the Study Area

RNP is located in Roztocze, which is a region situated on the border between Poland and the Ukraine, in Southeastern Poland (Figure 1). It is a region that forms a natural borderline visible as a narrow belt of limestone hills connecting the Lublin Upland with Podolia. It differs from the neighboring lands in its geological structure, topography, climate, hydrological regime, soils, and vegetation. The region has many peculiar features, including a well-preserved, distinctive landscape, which is unique in Europe [36,37]. About 95% of the RNP is covered with various types of forests [38].

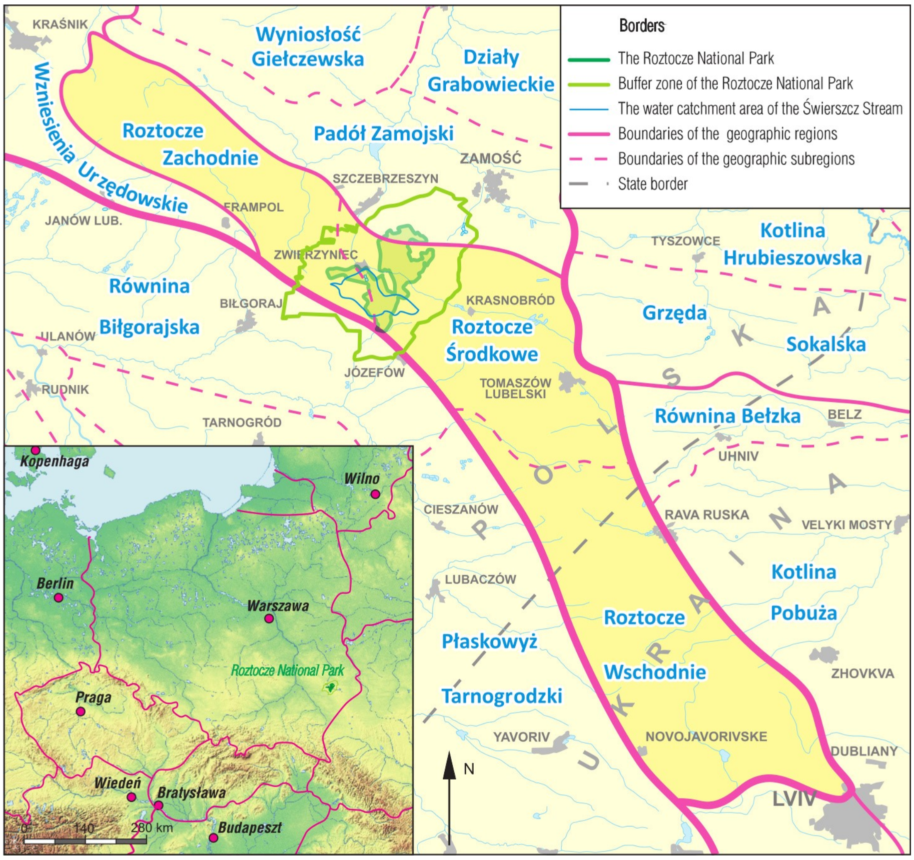

Figure 1. Physico-geographic regionalization and location of the Roztocze National Park in Roztocze [39].

The RNP covers an area of 8482.83 ha and is one of Poland's 23 national parks. It was established in 1974 to preserve the natural and cultural heritage of the Roztocze region and provide access to it for scientists, tourists, and recreation visitors in a way that would not adversely affect the protected object. According to the Nature Conservation Act, it is also one of the Park's tasks to provide nature education experiences [40].

In Romer's division of Poland into climatic regions [41], the climate of Roztocze was classified as a Central Uplands climate of the region of the Lublin–Lviv Uplands and Ridges (D4). The climate of the RNP is a temperate, transitional climate, which has slightly more continental features compared to other areas of Poland [42]. The area of the RNP is one of the coolest in the region. The average annual air temperature varies from 7.4 to 7.5 °C and is about 1–2 °C lower on the hills. Annual precipitation is usually 600–650 mm. The RNP has a moderately high insolation, with average annual sunlight hours ranging from 1550 to 1600. The park displays a considerable topoclimatic diversity related to its varied topography (which leads to variability of exposure), large elevation differences, and a plant species composition which determines the height and density of the vegetation cover [42].

The area of the RNP has a very sparse network of surface waters. This is mainly due to the high permeability and water capacity of the bedrock, which retains water from precipitation. Surface waters cover only 52.6 ha, which is 0.62% of the total area of the RNP. Groundwater is found in porous-fissure rocks of the Upper Cretaceous, occurring as marls, opokas, and gaizes, and in sandy sediments and Quaternary gravels filling buried river valleys. In the river valley zones, the waters of the Cretaceous layers merge with the waters contained in alluvia, creating a common circulation-and-drainage system, the so-called Roztocze Water Level, which is characterized by large resources of groundwater [43].

In the central part of the RNP is located the catchment of the Świerszcz River, along with the complex of Echo Ponds (Figure 2), which covers an area of 4651 ha, 40% of which lies within the park. The RNP is a Natura 2000 habitat area coded Central Roztocze PLH060017 and part of a Natura 2000 bird sanctuary coded Roztocze PLB060012. The remainder of the bird sanctuary is located within the RNP's buffer zone [44,45].

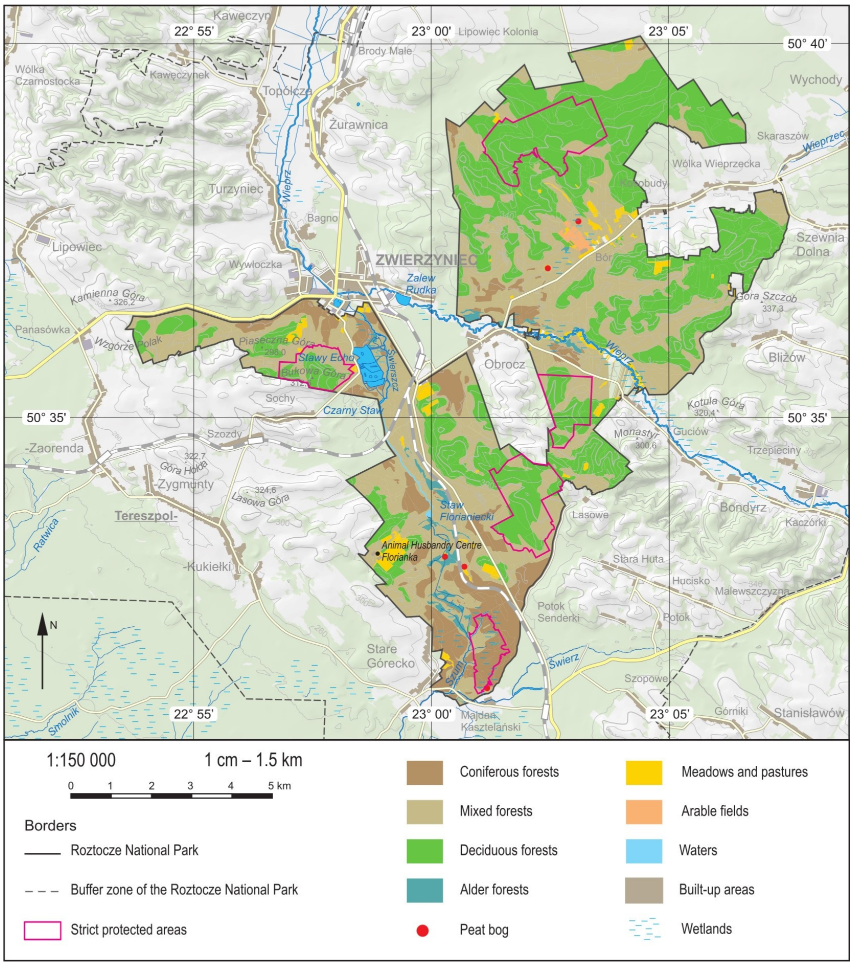

Figure 2. Land-use structure in the Roztocze National Park.

The map shows the coverage of the territory of the RPN in which the Animal Breeding Center is located. A total of 93.81% of the park is covered with various types of forests. The predicted climate changes will also affect the structure of forests in the Roztocze area. As it is known, the main factor influencing the diversification of species growth is the availability of water, which is conditioned by the level of rainfall and losses caused by evapotranspiration [46]. The land-cover map shows the natural context of the changes taking place.

2.2. Scope and Statistical Analysis

The literature data regarding climate change in the RNP were gleaned from monographs on the RNP and the Roztocze region [42,47]. Changes in the precipitation levels in the area of the RNP in the years 2001–2020 were determined on the basis of data coming from the Reports of the "Roztocze" Base Station of the Integrated Monitoring of Natural Environment (BS IMNE), which belongs to the RNP, and from the Chief Inspectorate for Environmental Protection (CIEP), which operates under the Integrated Monitoring of Natural Environment (IMNE). The missing data were obtained from the Roztocze Scientific Station in Guciów, affiliated with Maria Curie Skłodowska University (MCSU) in Lublin. The IMNE measurement data meet the relevant standards and norms and are based on proven and comparable field research and laboratory analysis methods. The methodological assumptions of the IMNE, a compilation of data on the measurement system, methods of laboratory analysis, and the principles of collecting and processing measurement results are presented in a study from the series Biblioteka Monitoringu Środowiska (Environmental Monitoring Library) [48]. The study also presents a conception of a system for the harvesting and utilization of rainwater designed for the RNP's Animal Breeding Centre (Ośrodek Hodowli Zwierząt) in Florianka and discusses the possibility of using rainwater in all public utility facilities in the RNP. The aspects covered by the research and methodology adopted in the analysis are presented in Figure 3.

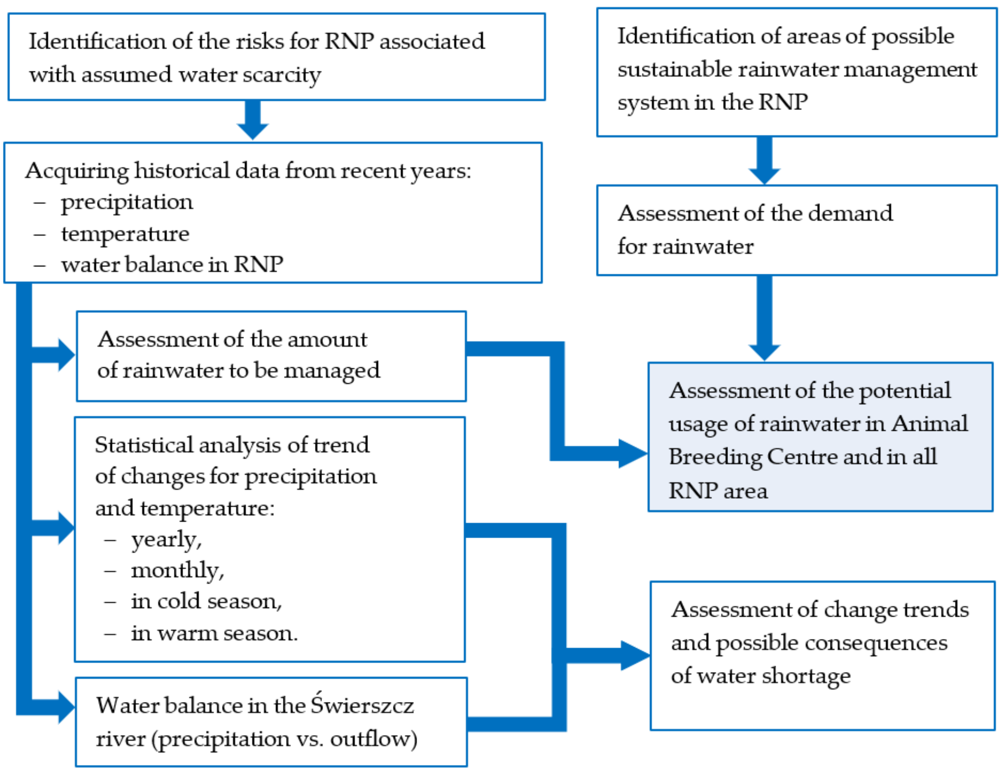

Figure 3. The aspects and order of procedures in the research methodology.

Two statistical analyses were performed to assess changes in the value of the sum of precipitation and air temperature. In the first one, mean precipitation and air temperature values for the RNP were compared between two decades (2001–2010 and 2011–2020), using one-way analysis of variance (ANOVA). Comparisons of mean values for precipitation and air temperature were made for various periods, namely all-year-round, cold season, warm season, and for each month separately, in order to get a more accurate overview of the observed changes. The second analysis was aimed at determining the trends of changes in air temperature and precipitation in relation to the subsequent years of the studied period. The precipitation and air temperature trends over the study period were determined by using linear regression. Pearson's correlation coefficients, *r*, between the study year and precipitation and between the study year and air temperature were calculated. As in the case of ANOVA, these trends were analyzed whole years, warm and cold seasons, and for each of the months. Statistical calculations were performed by using Tibco Statistica v. 14 software [49]. Statistical differences were determined at the significance level of $\alpha = 0.05$.

3. Results

3.1. Changes in the Precipitation Level and the Water Balance in the RNP in 2011–2020

Studies conducted by the RNP as part of the IMNE program of CIEP's State Environmental Monitoring show the unfavorable changes in the hydrological regime of the RNP that had occurred over the past ten years (2011–2020) [50]. In May 2020, the level of Cretaceous groundwater recorded in the Roztocze National Park was the lowest in the entire history of measurements which had been conducted since 1986—the water table was 17.5 m below ground level (b.g.l). It was 3.50 m lower than the highest level recorded in mid-June 2013 (13.92 m b.g.l). This situation was caused by a decrease in the precipitation levels, a distribution of precipitation that was unfavorable from the point of view of nature (especially a lack of a snow cover in winter), and an increase of approx. 2.0 °C in the average annual temperature. All of this gave rise to a periodically negative hydrological balance in the territory of the RNP, especially in the catchment of the Świerszcz River [50,51], resulting in a number of biotic changes. The simplified water balance of the catchment area of the Świerszcz River presented in Figure 4, which compares precipitation and outflow in the years 2012–2020, does not show a significant statistical change. Still, the decrease in the precipitation levels and the unfavorable distribution of precipitation across the year (no winter precipitation), as well as the increase in temperature in the years 2017–2019, led to a lack of water in Echo Ponds and resulted in the upper section of the Świerszcz River drying up.

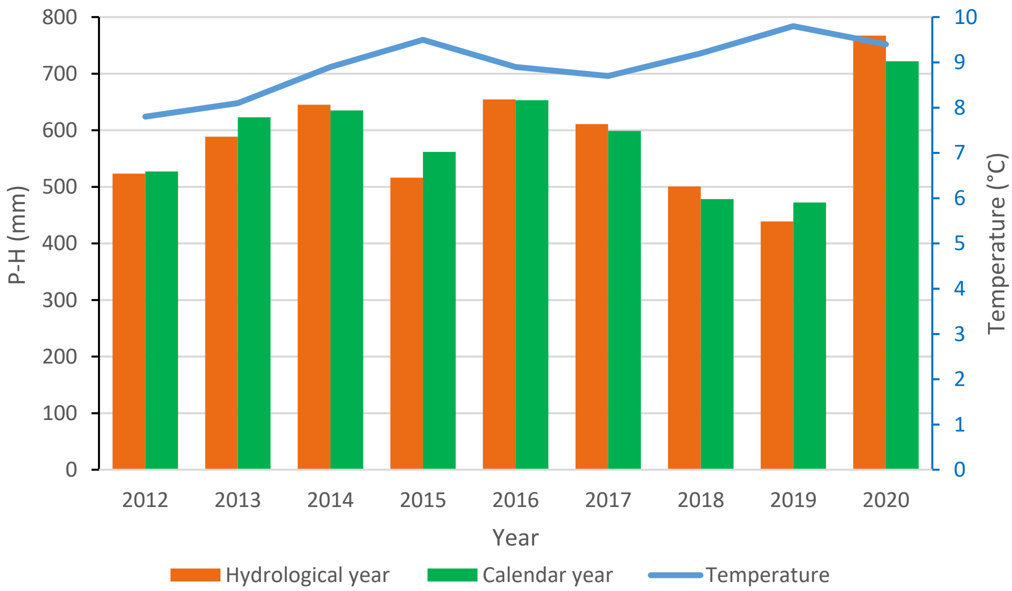

Figure 4. Simplified water balance of the Świerszcz River catchment area in 2012–2020 (P—rainfall, H—outflow).

On the basis of the collected data, it was found that the annual precipitation levels in the RNP in 2011–2020 were, on average, 41.75 mm lower than in 2001–2010, with the largest drop in the precipitation level occurring in the winter season (41.02 mm) and only a slight decrease observed in the warm period (by 0.73 mm).

The mean annual precipitation values for the two decades did not differ significantly statistically (ANOVA, *p*-values: 0.283, 0.067, and 0.362, respectively). No significant statistical differences were found either when each month was analyzed individually. The air-temperature data showed that, in the second decade (2011–2020) the annual air temperature was 1.03 °C higher than in the first one. In the cold season, the average temperature in the second decade was higher by 1.18 °C, and in the warm season, it was higher by 0.87 °C. These differences were statistically significant (ANOVA, *p*-values: 0.002, 0.026, and <0.001, respectively). When changes in average temperatures in the individual months were analyzed, significant increases were observed in the second decade in June (the mean higher by 1.51 °C, $p = 0.022$), August (1.28 °C, $p = 0.005$), September (1.69 °C, $p = 0.002$), and, the highest, in December (2.66 °C, $p = 0.036$). In the remaining months, the changes were not statistically significant, and a decrease was recorded only in July (by 0.23 °C).

Analogous results were obtained when the trends were analyzed by using linear regression: there was a decrease in the precipitation level and an increase in air temperature (Figure 5). As the regression line coefficients show, the average annual decrease in the precipitation level was 1.53 mm, which represents a total decrease of 30.6 mm between 2001 and 2020 ($r = -0.11$, $p = 0.654$). In turn, the average air temperature increased by 0.11 °C annually, giving a total increase of 2.1 °C ($r = 0.77$, $p < 0.001$) over the twenty-year period.

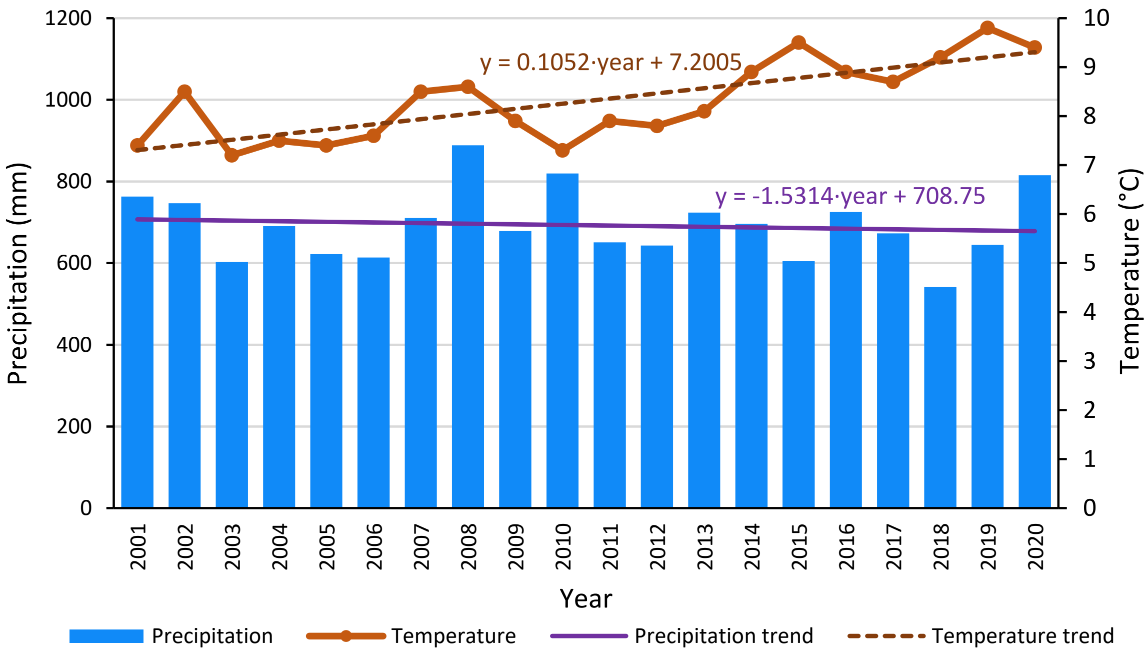

Figure 5. Changes in precipitation and air temperature in years 2001–2020.

Regression lines obtained in the analysis of the trend in the amount of precipitation in the cold period (Figure 6a) indicate that precipitation fell annually by 2.62 mm, which corresponds to a decrease of 52.5 mm between the beginning and end of the study period (the years 2001 and 2020) ($r = -0.32$, $p = 0.174$). In the warm period (Figure 6b), a slight upward trend was recorded, with precipitation increasing by 1.09 mm annually (21.9 mm over the 20-year period, $r = 0.08$, $p = 0.752$).

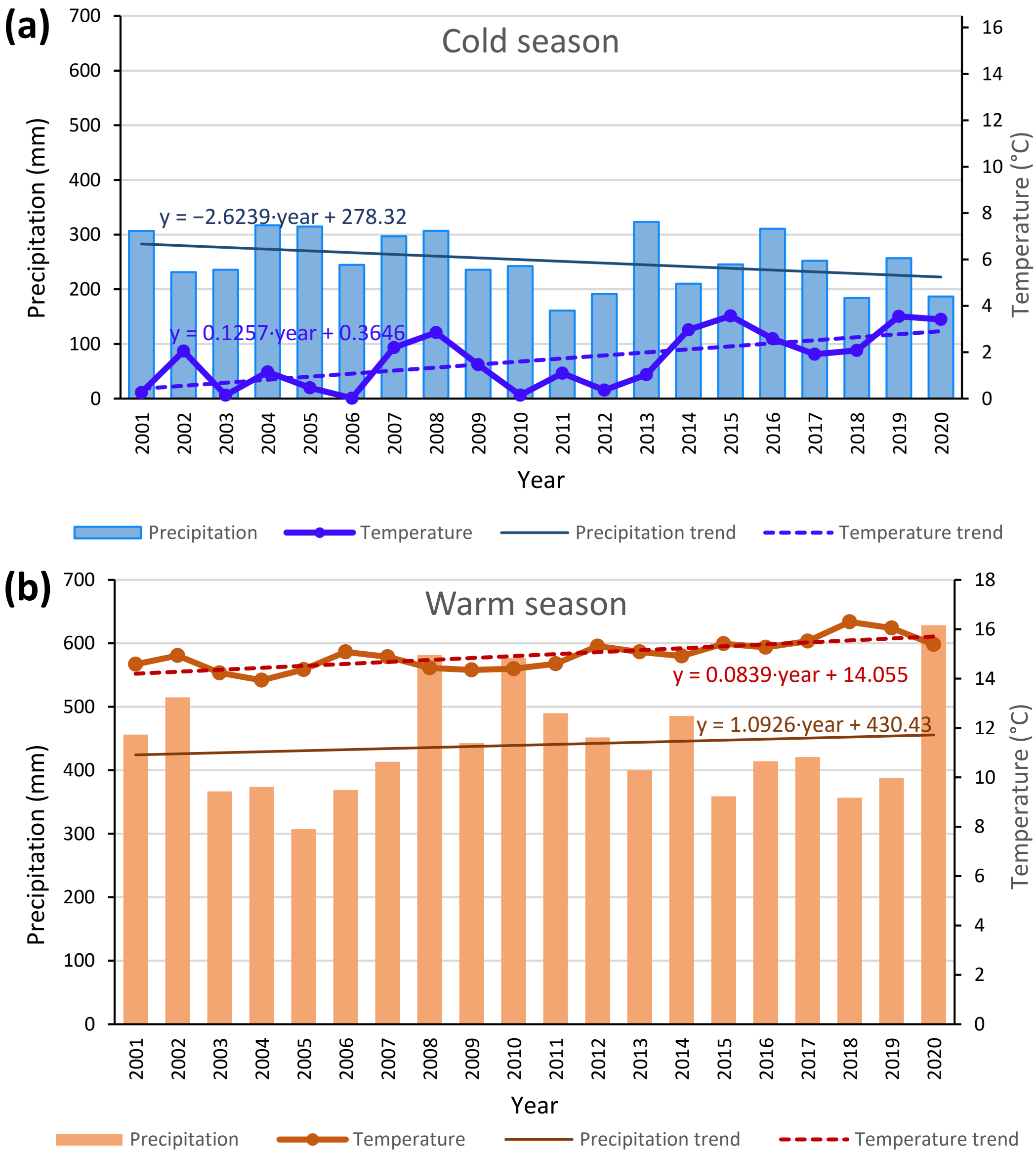

Figure 6. Changes in average total precipitation and temperature in the (**a**) cold and (**b**) warm season.

The *p*-values show that these correlations are not statistically significant, and the upward trend in the warm half-year was influenced by a large amount of rainfall received in the last year of the study (2020). In the case of air temperature, statistically significant upward trends were recorded both in the cold and the warm season. The temperatures in the cold half-year increased by 0.13 °C annually (by 2.61 °C over the 20-year period, $r = 0.62$, $p = 0.004$), and in the warm half-year by 0.08 °C (1.58 °C over the 20 years, $r = 0.79$, $p < 0.001$). The research we conducted shows that changes in air temperature in the RNP are not uniform. Decadal periods can be discerned in precipitation in the warm season.

Table 1 shows the trend in the amount of average precipitation in the years 2001–2020. December was the only cold month in which an increase in precipitation (by 0.48 mm annually) was recorded; in the remaining cold months, precipitation decreased. In the case of the warm months, the greatest changes were recorded in May (average annual increase by 0.19 mm) and July (average annual decrease by 0.17 mm). The correlation coefficient was not statistically significant for any of the months.

Table 1. Average precipitation trend for the years 2001–2020. Data compiled by the authors from the Reports of the "Roztocze" Base Station of the Integrated Monitoring of Natural Environment.

Month	Average (mm)	Min (mm)	Max (mm)	SD (mm)	r	p-Value	Regression Slope	Change Over 20 Years (mm)
January	45.2	19.2	104.5	18.9	−0.33	0.152	−1.06	−21.3
February	34.6	3.6	66.9	16.3	−0.22	0.353	−0.60	−12.1
March	46.3	9.7	87.6	20.4	−0.12	0.602	−0.43	−8.6
April	42.5	8.4	75.9	18.2	−0.25	0.297	−0.75	−15.1
May	89.5	31.5	163.4	36.1	0.30	0.193	1.85	37.1
June	73.4	25.6	170.3	40.9	0.04	0.879	0.25	5.0
July	98.4	30.8	207	44.9	−0.32	0.169	−2.43	−48.6
August	65.8	6.6	144.2	37.4	−0.05	0.848	−0.29	−5.8
September	61.1	7.5	125.7	41.4	0.20	0.405	1.38	27.6
October	51.7	7.5	119.3	34.5	0.15	0.522	0.89	17.8
November	44.3	0.4	90	25.3	−0.19	0.420	−0.82	−16.3
December	39.9	14.8	85.6	16.8	0.17	0.478	0.48	9.6
Cold season	252.8	161.1	323.3	49.0	−0.32	0.174	−2.62	−52.5
Warm season	439.9	307.3	628.5	85.7	0.08	0.752	1.09	21.9
Year	692.7	541.1	888.6	84.8	−0.11	0.654	−1.53	−30.6

Cold season (January–April and November–December) and warm season (May–October).

In the case of air temperature, significant increases were recorded in the following months: June (by 0.17 °C annually and by 3.48 °C over the 20 years, r = 0.68, p = 0.001), August (0.13 °C and 2.65 °C, respectively; r = 0.71, p < 0.001), September (0.15 °C and 2.92 °C, respectively; r = 0.64, p = 0.002), and December (0.26 °C and 5.29 °C, respectively; r = 0.54, p = 0.014). In the remaining months, the regression slope was not significantly different from 0 (Table 2).

Table 2. Average air temperature trend for the years 2001–2020. Data compiled by the authors from the Reports of the "Roztocze" Base Station of the Integrated Monitoring of Natural Environment.

Month	Average (°C)	Min (°C)	Max (°C)	SD (°C)	r	p-Value	Regression Slope	Change Over 20 Years (°C)
January	−2.7	−9	2.6	2.8	0.14	0.568	0.07	1.33
February	−1.5	−8.6	3.6	3.2	0.32	0.167	0.18	3.58
March	2.3	−2.5	5.7	2.4	0.30	0.200	0.12	2.48
April	8.6	6	13.3	1.5	0.33	0.160	0.08	1.68
May	13.6	11	16.6	1.4	−0.11	0.632	−0.03	−0.55
June	17.4	14.3	21.5	1.5	0.68	0.001 *	0.17	3.48
July	19.3	17.8	20.7	0.9	−0.18	0.442	−0.03	−0.56
August	18.4	16.6	21.1	1.1	0.71	<0.001 *	0.13	2.65
September	13.1	10.9	15	1.3	0.64	0.002 *	0.15	2.92
October	8.0	4.4	10.4	1.7	0.27	0.256	0.08	1.56
November	3.9	0.4	6.1	1.5	0.24	0.302	0.06	1.30
December	−0.6	−7.2	2.9	2.8	0.54	0.014 *	0.26	5.29
Cold season	1.7	0.0	3.6	1.2	0.62	0.004 *	0.13	2.51
Warm season	15.0	13.9	16.3	0.6	0.79	<0.001 *	0.08	1.68
Year	8.3	7.2	9.8	0.8	0.77	<0.001 *	0.11	2.10

* A statistically significant correlation. Cold season (January–April and November–December) and warm season (May–October).

The air temperature in the RNP in the 20-year period from 2001 to 2020 increased by 2.1 °C, which was a greater increase than that recorded in Poland [52–54] and in the world [55,56] in the previous periods (decadal increases by 0.2–0.5 °C). A particularly large increase in temperature in the RNP in the period between 2001 and 2020 was recorded in December—by as much as 5.29 °C. Such a situation may lead to the occurrence of snowless winters in the future and more and more frequent dry periods in spring. Despite the lack of clear trends in annual precipitation totals in the RNP, large fluctuations in the amount of precipitation in the individual years caused an increase in the frequency of dry periods, which was also mentioned by Ziernicka-Wojtaszek and Kopciska [57]. This unfavorable situation is exacerbated by the downward trend observed in the share of winter precipitation in the annual total, as this contributes to changes in the natural environment in the RNP.

3.2. Natural Determinants and Consequences of the Climate Changes in the Roztocze National Park

Research conducted by the RNP as part of the IMNE program of CIEP's State Environmental Monitoring shows that the natural environment of the RNP had experienced unfavorable changes over the past decade (2011–2020), especially in the catchment area of the Świerszcz River [50]. The ongoing climate change has led to adverse changes in the natural environment and the human socio-economic environment.

Water shortages, thermal and precipitation conditions which are unfavorable for trees, and the lowering of the groundwater level have affected the main forest-forming species of the RNP. As observed by Szwagrzyk and Bodziarczyk [58], climate change has an adverse effect on the most important tree species in the Park—the Baltic pine (*Pinus sylvestris*). In the last few years, events such as drought and the massive outbreaks of the sharp-dentated bark beetle (*Ips acuminatus*) have resulted in a decline in Baltic pine stands, especially where the pine grows in fertile sites. If summers continue to be hot and dry, the dieback of the pine may considerably accelerate [58].

Through the Roztocze National Park runs the eastern border of the continuous range of the beech (*Fagus sylvatica*), fir (*Abies alba*), larch (*Larix decidua*), and spruce (*Picea abies*). The presence of beech and fir forests in this area as borderland communities and the tracking of their dynamics may be helpful in interpreting climate change. It is all the more important that Holly Cross fir forests (91P0) (*Abietetum polonicum*) occur only in Poland [59]. The fir trees growing in the forests of the RNP show two opposite trends. On the one hand, the share of fir trees in fertile sites, especially in beech forests, decreases due to the gradual loss of older trees; in recent years, this phenomenon has been accelerated by droughts. On the other hand, in poorer soils, especially under the canopy of pine, fir regenerates much better. Its growth in less fertile sites, however, may be hampered over time by water scarcity.

In recent years, a significant decrease in the population of spruce (*Picea abies*) has been observed in Poland, compared to all other tree species. It has been caused by adverse climate changes [58]. The temperature and rainfall conditions in the recent years have been unfavorable for trees, inducing the development of pathogenic fungi and leading to a dynamic increase in the population of cambio-xylophage and foliophage insects, which damage trees, threatening their health and sometimes also causing their dieback and falling out of stands [60].

In the last decade, a decrease in the level of groundwater has been observed in both deep Cretaceous aquifers and in shallower Quaternary waters, e.g., those of the peat bog complex "Międzyrzeki". It should be emphasized that maintaining a high and stable level of the groundwater table in a peat bog ensures its longevity and proper functioning, as it prevents the destructive processes of peat rotting and encourages the development of vegetation appropriate for this extremely valuable ecosystem, which is endangered across Europe [50]. On a positive note, Szwagrzyk and Bodziarczyk [58] note that the coniferous swamps and swamp forests that grow in the peat bogs of the "Międzyrzeki" area are neither endangered nor subject to adverse changes. The current distribution and range of fragments of these forests confirm that this habitat has been stable over the last 30 years. Nevertheless, it should be borne in mind that the changes in the hydrological regime and the potential increase in eutrophication are the effects of the appearance of ecologically alien species.

3.3. Socio-Economic Determinants and Consequences of Climate Changes in the Roztocze National Park

It has been observed that climate changes in the RNP are manifested by a lack of water in the upper section of the Świerszcz River and in Echo Ponds. These changes were particularly acute in the years 2011–2020 and were found to have important social ramifications. Echo Ponds are open to bathers, and the operation of the bathing site constitutes a sort of social compromise included in the Plan for the Protection of the RNP [61]. The lack of water in Echo Ponds in the tourist season of 2020 caused the dissatisfaction of the local community and visitors to the park. Failure to understand the ongoing changes in climate resulted in numerous media "attacks" on the RNP in which the ponds are located. The scarcity of water caused social tensions and contributed to the negative perception of the RNP. Meanwhile, the employees of the Park, who continuously monitor the environment, noted the changes taking place and made good use of the low water level, performing repairs and maintenance on hydro-technical devices to ensure effective water retention. Small flows in the Świerszcz River led to an increased activity of the European beaver (*Castor fiber*), which built dams in the lower section of the river, thus increasing water retention.

The levels of surface waters and groundwater in the RNP also affect the rearing of Polish Konik horses (*Equus ferus caballus*), which are bred in a stud farm located in the catchment area of the Świerszcz River. This stream is a natural watering place for the herd, which lives in semi-natural conditions in the sanctuary. The stud farm where the Polish Konik horses are kept is supplied with water from a groundwater well located at the Animal Breeding Centre in Florianka. In the years 2011–2020, the groundwater level in the well in Florianka was observed to become lower and lower, and the efficiency of the well decreased. In the same period, a lack of water or a large drop in the water level was also found in the wells located in the northern part of the Roztocze National Park in the settlements of Krzywe, Stara Huta, and Sochy and in the catchment area of the Świerszcz River. Water shortages in the area of the Animal Breeding Centre in Florianka constitute a serious fire hazard, as the groundwater intake, due to its low efficiency, does not meet the legal requirements set out in the applicable regulations [62].

3.4. Conception of a Rainwater Management System for the RNP's Animal Breeding Centre in Florianka

In order to quantitatively protect the Park's decreasing water resources and limit the consumption of high-quality water, a decision was made to introduce rainwater retention and management solutions in the Park's public utility facilities. Figure 7 shows a diagram of a rainwater management system which is planned to be built at the RNP's Animal Breeding Centre in Florianka. The schematic of the installation was drawn on the basis of the Functional and Utility Program prepared by Grabowski et al. [63].

The Animal Breeding Centre runs a stud farm of the Polish Konik horse, and the Uhruska sheep and white-backed cattle, and maintains meadows and pastures to provide the animals with fodder. Aside from that, the Animal Breeding Centre is open to visitors. Annually, 2.5 thousand tourists visit Florianka, and 35 thousand pass through it in transit. The forest settlement Florianka is supplied with water from a 50 m–deep well located at an altitude of 264.2 m a.s.l. The average annual water usage in Florianka calculated from water-meter readings taken in the years 2018–2021 is 1137 m^3. The decreasing groundwater level and the reduced efficiency of the well call for the use of rainwater.

The rainwater harvested from the planned installation is planned to be used for various purposes at the RNP's Animal Breeding Centre. Treated by filtration and irradiation with a UV lamp, it will be used to water the Polish Konik horses and flush toilets. Untreated rainwater, on the other hand, will be used for fire prevention purposes and washing cars and agricultural equipment; excess water will be discharged into the nearby19th century ponds, which serve as a natural breeding site for amphibians. The design also assumes that the wastewater generated during the flushing of toilets and washing vehicles will be discharged, after appropriate pretreatment in a skimming tank, to the existing hybrid constructed wetland located in the neighboring settlement in Florianka, approximately 500 m away from the Animal Breeding Centre. The structure, efficiency, and reliability of the discussed treatment plant have been described in a study by Micek et al. [64].

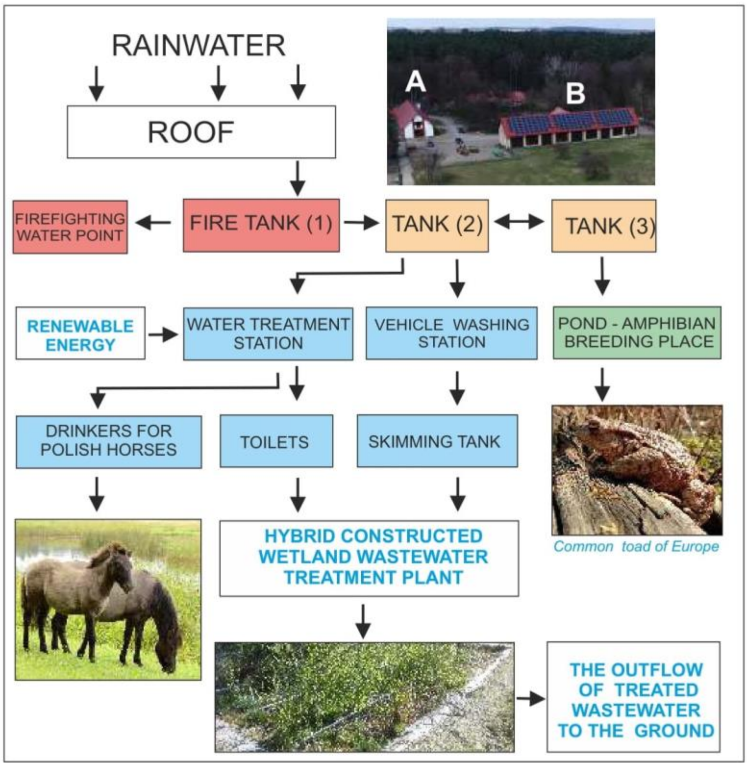

Figure 7. Diagram of a sustainable rainwater management system in the Animal Breeding Centre in Florianka in the Roztocze National Park. A—stable and B—barn.

The subsections below contain calculations regarding the water demand in the RNP's Animal Breeding Centre and the amount of rainwater that can be harvested from the roofs of two farm buildings located at the Animal Breeding Centre.

3.4.1. Demand for Water for Different Usage in the RNP's Animal Breeding Centre

To calculate the demand for water in the Animal Breeding Centre, we used the water consumption standards set out in the Regulation of the Polish Minister of Infrastructure [65] and quarterly water usage readings taken from the Centre's deep water intake in 2018–2021. Table 3 shows the monthly demand for rainwater in the Animal Breeding Centre.

Table 3. Monthly demand for rainwater in the RNP's Animal Breeding Centre in Florianka.

Type of Rainwater Use	Demand for Rainwater by Month (m^3)												
	January	February	March	April	May	June	July	August	September	October	November	December	Total
Fire tank	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	19.2
Toilets	3.0	3.0	3.0	3.0	6.0	6.0	6.0	6.0	3.0	3.0	3.0	3.0	48.0
Vehicle washing	0.91	0.91	2.77	4.02	3.67	2.42	2.42	2.42	3.07	3.07	1.21	0.91	27.8
Animal watering	60.0	64.5	69.0	69.0	69.0	69.0	69.0	69.0	69.0	69.0	61.5	61.5	799.5
Total	65.51	70.01	76.37	77.62	80.27	79.02	79.02	79.02	76.67	76.67	67.31	67.01	894.5

The data provided in Table 3 show that the total annual demand for rainwater in the Animal Breeding Centre was 894.5 m^3. The greatest demand for water was for watering animals—almost 800 m^3, which represented over 89% of the total demand. The data show that the demand for water was the highest in the spring and summer, from May to August, i.e., in the period when the precipitation levels were also the highest.

3.4.2. Determination of the Amount of Rainwater Flowing from the Roofs of the Animal Breeding Centre Buildings in the RNP

Field measurements and calculations show that the total area of the roofs of the Animal Breeding Centre's two farm buildings (A—stable and B—barn) (Figure 7) from which rainwater will be harvested is 1191 m^2. The roof area of building A is 467 m^2, and that of building B is 724 m^2.

The amount of rainwater flowing from the surface of roofs A and B was calculated by using a modified formula, Formula (1), previously used by Aladenol and Adeboye [66], Adugna et al. [30], and Villar-Navascués et al. [67]:

$$V_{RW} = (TRA \cdot AAR \cdot SRC)/1000 \quad (1)$$

where: V_{RW}—volume of rainwater flowing from the roof surface during a year (m^3); TRA—total area of roofs A and B (m^2); AAR—average annual rainfall in the RNP in the years 2001–2020 (686 mm); and SRC—surface runoff coefficient—a dimensionless value (0.9) determined for smooth sheet metal roofs based on a study by Farrene et al. [68].

The calculations made using Formula (1) show that, on average, 735 m^3 of rainwater, which can be used for various purposes, flows annually from the roofs of the two buildings (A and B) located in the RNP's Animal Breeding Centre. There is a large variation in the amount of rainfall throughout the year, and Figure 8 shows the volume of water that is available for use in the different months. Monthly volume of roof rainwater was calculated from Formula (2):

$$V_{MRW} = (TRA \cdot AMR \cdot SRC)/1000, \quad (2)$$

where V_{MRW}—average rainfall volume in the RNP for a given month in the 20-year period from 2001 to 2020.

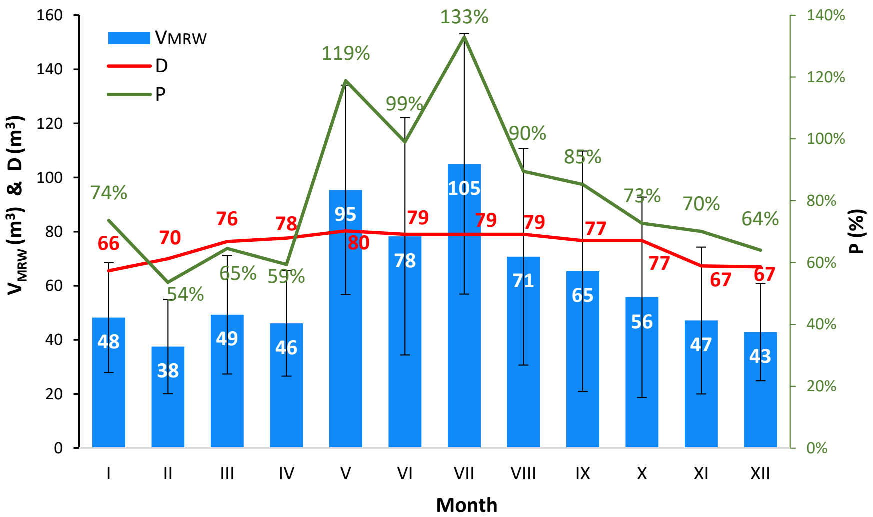

Figure 8. The amount of rainwater flowing from the roofs of the buildings in the Animal Breeding Centre in the RNP in different months of the year (V_{MRW}), demand for rainwater (D), and the potential to meet the Animal Breeding Centre's needs (P) in the period 2001–2020.

Figure 8 shows that the amount of rainwater was the largest in the spring and summer (from May to August), i.e., when the demand for water was the highest. During this period, rainwater could cover 100% of the demand for water to be used for various previously mentioned purposes. In the remaining months, rainwater could cover 54–90% of the Animal Breeding Centre's demand for water.

4. Discussion

Regional climate models (RCA3, HadRM3, HIRHAM5, CLM, and RegCM3) for Poland, including Roztocze and the RPN, forecast an increase in air temperature [69]. The forecasts of changes in thermal conditions for the years 2021–2050 in relation to the years 1961–1990 show that the greatest warming will occur in winter and the smallest in summer. The average temperature is predicted to increase by about 1 to 3 °C. It will be caused by a shorter duration of snow cover of ever smaller thickness. The HIRHAM3 model in Roztocze assumes that the average temperature will not change. The HADRM3 model predicts warming and an increase in temperature in Roztocze by 3.75 °C.

According to the research in the years 2001–2020, the air temperature increased by 2.51 °C in the cold season, and in the warm season, it increased by 1.68 °C. The average temperature increase is 2.10 °C, which corresponds to the projected changes. The temperature in December increased by 5.29 °C. In the warm season, the months of May and July were colder by 0.5 °C. The obtained results are consistent with the forecasts from the abovementioned models.

Total annual precipitation in the territory of the RPN does not show clear trends in comparison to the air temperature. The research carried out in 2001–2020, however, confirms some forecasts. Air-temperature changes in the RPN are not uniform. We can distinguish 10-year periods when, in the winter half of the year, a drop in air temperature is accompanied by an increase in precipitation, and in the warm half of the year, a decrease in air temperature is associated with an increase in rainfall. Annual amounts of precipitation in the territory of the RPN in 2011–2020 were, on average, 41.7 mm lower than in 2001–2010, with the largest decrease in the amount of precipitation in the cold season (41.02 mm), and only insignificant in the warm season (by 0.73 mm).

Previous studies have shown that rainwater is usually of fairly good quality [20,70,71]. Only some parameters of rainwater exceed the standards specified for water intended for human consumption [70]. A study of rainwater flowing from the roofs of two outbuildings located near the Roztocze National Park Directorate building also showed that the water was of a fairly good quality [72], although it contained increased levels of ammonia, coliform and fecal coliform bacteria, and meso- and psychrophilic bacteria, which were probably caused by contamination of the roof surface with bird droppings. The water also had a slightly alkaline pH, which may indicate that the air and the surfaces of the roofs were polluted with dust particles from local furnaces and with animal waste. Jóźwiakowski et al. [72] showed that, in terms of microbiological parameters and some chemical parameters, the rainwater tested was not suitable for drinking or hygienic purposes, but could be safely used for washing vehicles, watering green areas, or flushing toilets. On the other hand, rainwater can be easily treated to drinking-water standards; the sole shortcoming is the low level of minerals [73,74].

The installation for the harvesting and utilization of rainwater mentioned above, which collects water from the buildings of the Roztocze National Park Directorate, was constructed in 2014 on the basis of a conception developed by Jóźwiakowski et al. [75]. The authors of the conception determined that 323 m^3 of rainwater could be harvested per year from two garage roofs with a surface area of 185 and 302 m^2 and used for washing vehicles and irrigating green areas. They also calculated that this amount of water was sufficient to meet the annual water demand for these purposes. The rainwater-harvesting installation for the RNP Directorate building has an ecological effect, as it allows users to limit the consumption of high-quality groundwater from the Roztocze aquifer located in this legally protected area. At the same time, the installation improves the image of the RNP as a pro-ecological institution which implements modern technological solutions to protect and preserve the most valuable assets of the natural environment. In the future, other systems of this type are planned to be installed in the RNP.

Table 4 shows a list of all public utility buildings located in the Roztocze National Park that could be equipped with rainwater-harvesting and -utilization systems, as well as the average annual amount of water that could be collected from these facilities. The surface area of the roofs of the RNP's public utility facilities was determined on the basis of a register of the Roztocze National Park's structures and buildings and GPS measurements.

Table 4. Monthly demand for rainwater in the RNP's Animal Breeding Centre in Florianka.

Settlement Number	Settlement Name	Name of Facility/Property Number	Facility No.	Number of Objects	Total Roof Area TRA (m^2)	Surface Runoff Coefficient (SRC)	Type of Roof Covering *	The Amount of Rainwater to Be Used (m^3)
1	Florianka	Animal Breeding Centre	1	6	1863.7	0.9	1	1151
		Izba Leśna (Forest Chamber)	2	6	562.2	0.7	3	270
		Forester's Lodge "Komanówka"	3	3	664.7	0.9	1	410
		Forester's Lodge "Jawor"	4	3	245.7	0.9	1	152
2	Zwierzyniec	Rybakówka	5	7	722.3	0.9	1	446
		RNP Directorate building	6	5	907.3	0.9	1	560
		Office of the Protected Area Bukowa Góra	7	5	503.0	0.9	1	311
		Property 1D	8	2	130.2	0.9	1	80
		Property 2P	9	3	214.1	0.9	1	132
		Property 3B	10	1	109.7	0.9	1	68
		Museum and Centre for Education	11	3	1389.8	0.8	2	763
		Property 4T	12	2	378.7	0.9	1	234
		Property 5H	13	5	451.8	0.9	1	279
		Property 6B	14	2	79.1	0.9	1	49
		Property 7 B	15	5	505.1	0.9	1	312
		Office of the Protected Area Florianka	16	3	491.3	0.9	1	303
		Brickyard	17	4	241.2	0.9	1	149
		Roztocze Centre for Science and Education	18	6	1617.9	0.9	1	999
3	Górecko Stare Obrocz	Rain shelter	19	1	17.0	0.7	3	8
		Property 8F	20	3	296.3	0.9	1	183
		Property 9S	21	3	340.2	0.9	1	210
		Office of the Protected Area Słupy	22	4	300.9	0.9	1	186
4	Kosobudy	Forester's Lodge "Bezednia"	23	7	376.9	0.9	1	233
		Office of the Protected Area Horodzisko/Jarugi	24	6	864.3	0.9	1	534
		Property 10P	25	2	263.3	0.9	1	163
		Property 11P	26	2	309.0	0.9	1	191
		Property 12K	27	3	352.3	0.9	1	218
		Rain shelter	28	1	17.0	0.7	3	8
5	Wólka Wieprzecka	Property 13P	29	3	275.1	0.9	1	170
		Rain Shelter "Szewnia Dolna"	30	1	17.0	0.7	3	8
6	Krzywe	Forester's Lodge "Krzywe"	31	4	428.6	0.9	1	265
7	Wojda	Cellar	32	1	12.4	0.9	1	8
8	Czarny Wygon	Bat Tower	33	2	68.7	0.8	2	38
9	Guciów	Forester's Lodge	34	1	35.2	0.9	1	22
		Total	34	115	15,052.0			9109

* 1—sheet (SRC = 0.9); 2—ceramic tile (SRC = 0.8); 3—wood shingle (SRC = 0.7).

The calculations show that the construction of rainwater harvesting systems for the public utility facilities located in the RNP would allow for the collection and use of 9109 m^3 of rainwater per year.

5. Conclusions

The climate-change forecast based on regional climate models for 2021–2050 regarding changes in thermal conditions and precipitation in Poland and in Europe [69] and data from the literature on the Roztocze National Park [47] indicate that there is an upward trend in air temperature and a very high yearly variability in precipitation levels. This tendency was also confirmed in this present study, which additionally shows that there is a downward trend in the amount of precipitation, especially in the winter months. These changes have a negative impact on the natural environment, especially the Park's forest-forming species, and contribute to the lowering of the level of groundwater and the lack or scarcity of surface waters in water bodies, such as the upper section of the Świerszcz River and Echo Ponds. Particularly dramatic changes were recorded in 2017–2020, and they led to profound environmental and social consequences. The study focuses mainly on the impact of rainfall and temperature on the groundwater level balance, but, of course, not all aspects affecting it were considered in the study, such as infiltration, which also affects the lowering of the level of groundwater [73].

In the present study, we proposed that, in order to quantitatively protect the diminishing water resources in the area of the RNP and to limit the consumption of high-quality water, measures should be taken for the retention and management of rainwater in public utility facilities. We found that local solutions based on natural resources of rainwater could satisfy a considerable part of the water demand of the Roztocze National Park's public utility facilities. We determined that approximately 9109 m^3 of water could be retained and used in the park during a year. As an example of such a solution, we presented a sustainable rainwater management system to be installed at the Animal Breeding Centre in Florianka that would ensure the continuity of operation of the Polish Konik horse stud farm (the symbol of the RNP) and the proper maintenance of the Animal Breeding Centre in Florianka, which is visited by about 40 thousand people yearly. It was assumed that, in this system, rainwater, after treatment, would be used for watering the horses and for flushing toilets. Untreated rainwater, on the other hand, would be used for fire prevention purposes and for washing cars and agricultural equipment. The excess water would be discharged to a nearby pond, which is an amphibian breeding site. It was found that, in the spring and summer period (from May to August), rainwater could cover 100% of the Animal Breeding Centre's demand for water used for various purposes.

In the future, the use of rainwater harvesting and utilization systems will contribute to the broadly understood water protection and will help counteract the effects of drought in the face of the changing climate in Poland and around the world.

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