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Article

Environmental Risks of Water Resources in the Belarusian Polesie

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Abstract: The article is devoted to the problems of water resources in Belarusian Polesie. Surface water resources analysis was carried out for the different types of runoffs. There was a significant decrease in maximum spring runoff and a decrease in the average annual runoff. A statistically significant increase in the minimum winter runoff is observed for the rivers of the Pripyat River basin. For the minimum summer–autumn runoff, there was no unambiguous trend in the runoff change. Quality of natural waters analysis included investigation of the annual concentrations of priority substances in the water of some rivers in Polesie for dissolved oxygen, phosphates, nitrogen, petroleum products, copper, zinc, etc. In general, there have been trends toward a pollution decrease in the Polesie Rivers. The possible consequences of changes in river runoff due to climate change are considered. The priority tasks of research on solving the Polesie water problems are outlined.

Keywords: runoff; water pollution; air temperature; Belarusian Polesie

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1. Introduction

Currently among the problems facing humanity the problem of water is increasingly being put forward in the first place since the state and development of the biosphere and human society are closely dependent on the state of water resources [1–4]. Water problems arise when there is no or insufficient water; it has unsatisfactory quality; the water regime does not correspond to the optimal functioning of ecosystems and host facilities; there is excessive moisture and floods. In the global aspect, the first three problems were generated by the XX century, and the fourth has been accompanying humanity since ancient times. All these problems are more or less inherent in the Belarusian Polesie.

Runoff distribution in a year is affected by a number of interrelated factors, the quantitative accounting of which is almost impossible to fully account for. First of all, the distribution of runoff depends on changes in the intra-annual course of air temperature and precipitation distribution. In addition to climatic factors, the runoff distribution is influenced by other physical and geographical parameters that express the natural runoff regulation in the basin. In general, water users and consumers are interested in a constant stable runoff without interruptions and sharp rises. This means that the river runoff with a high degree of natural regulation is most favorable for them. A low degree of natural regulation is a danger in the form of floods that lead to economic damage and even loss of life [5].

This problem is particularly relevant for the Belarusian Polesie whose main river is the Pripyat River and it is characterized by frequent flooding. Floods rank first among natural disasters in terms of the number of victims and damage caused [6,7]. At the same time, paradoxically, to this day, there are no reliable long-term forecasts of their appearance, reliable, and generally accepted methods of calculating the damages caused by them and a generally accepted concept of protection. As a result of changes in factors and conditions for the formation of runoff within the Pripyat River basin due to hydraulic reclamation, as well as the impact of modern climate change, the water regime of rivers has been significantly transformed.

Since the middle of the XX century, increased attention has been paid to the deterioration of the quality of natural waters due to the increase in point and area pollution caused by industry and agriculture. This is due to insufficient provision of treatment facilities, widespread lack of storm water treatment, unregulated use of mineral and organic fertilizers, as well as radionuclide contamination of the territory after the Chernobyl Nuclear Power Plant accident [8].

The purpose of the research is to analyze the current state of runoff in the Pripyat River basin, to investigate the quality of natural waters analysis, and to find out the main parameters of the current runoff transformations which can be used to forecast the water resources of the Belarusian Polesie in the future.

2. Materials and Methods

Belarusian Polesie is the largest region in Central and Eastern Europe where natural wetland ecosystems are concentrated, covering a total area of more than 680,000 ha. It constitutes almost 32% of the territory of the Republic of Belarus. The map of Belarusian Polesie is presented in Figure 1 [9].

Figure 1. The hydrographic map of Belarusian Polesie.

The river network of the Polesie region belongs to the Black Sea and Baltic basins. Rivers belong to the plain type with the predominance of elements of snow nutrition. The Pripyat River is the main river of Polesie and it is an average river of the Black Sea basin on a European scale. The length of the Pripyat River is 761 km; the catchment area is 173.7 thousand km^2. The general direction of the river flow is latitudinal from west to east which is not typical for the rivers of Eastern Europe. Most of the tributaries are fully or partially channeled. The largest tributaries of the Pripyat River are the Yaselda, Lan, Sluch, Ptich, Pina, Bobrik, Tsna, Ippa, Stokhod, Goryn, Stviga, and Ubort Rivers. The transborder

Western Bug River is a left tributary of the Narev River and it belongs to the Baltic Sea basin. The length of the river is 772 km with a catchment area of 39.4 thousand km^2. The main tributaries are the Kopayuvka, Mukhavets, Lesnaya, and Pulva Rivers. The right tributaries of the Western Bug River have almost all become channelized as a result of large-scale land reclamation. The Mukhavets River has been transformed into one of the sections of the Dnieper–Bug Canal. The regime of the rivers of the Western Bug basin has its own characteristics, mainly due to unstable weather conditions of winter and spring, due to which a flood regime is formed on the rivers in some years.

There is a general zonal decrease in its direction from north to south and southwest in the annual runoff distribution of rivers in Polesie which is linked to the distribution of annual precipitation and water reserves in the snow cover. The annual course of the levels is characterized by a relatively low and flattened spring flood, a low summer low water, disturbed almost annually by rain floods, and a more elevated autumn and winter low water due to rains and thaws, the consequence of which is winter floods, exceeding the spring floods in some years.

To predict the change in water regime of Belarus' rivers, the method of hydrological and climate calculations based on the simultaneous solution of equations of heat, power, and water balance were used [10]. The equation of the water balance of the river basin for a certain period of time is as follows:

$$YK(I) = H(I) - Z(I),$$

where: $YK(I)$—the total climatic runoff [mm]; $H(I)$—the total resources humidification [mm]; $Z(I)$—evaporation [mm]; I—averaging interval.

Total evaporation is as follows:

$$Z(I) = Z_m(I)\left[1 + \left(\frac{\frac{Z_m(I)}{W_{HB}} + V(I)^{1-r(I)}}{\frac{X(I)+g(I)}{W_{HB}} + V(I)}\right)^{n(I)}\right]^{-\frac{1}{n(I)}},$$

where: $Zm(I)$—the maximum evaporation [mm]; W_{HB}—the smallest moisture content of the soil [mm]; $V(I) = W(I)/W_{HB}$—relative humidity of soil at the beginning of the billing period; $X(I)$—the amount of precipitation [mm]; $g(I)$—groundwater component of the water balance [mm]; $r(I)$—parameter that depends on the water-physical properties and mechanical composition of soil; $n(I)$—parameter that takes into account physical and geographical conditions of runoff.

The modeling of the river runoff is implemented in a computer program and carried out in two stages. The first step is setting the model of the river-equivalent, with the similarities of the formation of the water regime of rivers. The second stage is a direct calculation of the water balance of the river study [11].

3. Results

3.1. Surface Water Resources Current State

The average annual runoff of the Pripyat River is 450 m^3 s^{-1}. The intra-annual distribution of runoff is characterized by unevenness. The runoff of the spring period is on average of about 61%, summer–autumn—23%, and winter—16% of the annual runoff. The average annual runoff of the Western Bug River is 127 m^3 s^{-1}. The spring flood period accounts for 30–35%, summer–autumn—40–50% of the annual runoff, and the rise of water in comparison with the inter-level is 2–4.5 m. The quantitative characteristics of the flow modules of the Polesie Rivers for various probabilities are presented in Table 1. The calculations were performed over a series of observations over a 120-year period using a three-parameter Gamma distribution.

Table 1. Water flow modules (μ; $dm^3\ s^{-1}\ km^2$) of the Polesie Rivers for various probabilities.

Runoff Type	Variability Coefficients	μ_p = 1%	μ_p = 5%	μ_p = 50%	μ_p = 95%	μ_p = 99%
Annual	0.32	7.17	5.97	3.85	2.22	1.77
Maximum	0.89	73.4	44.3	18.12	5.06	3.40
Minimum summer-autumn	0.51	4.23	2.98	1.53	0.68	0.52
Minimum winter	0.76	5.37	3.31	1.48	0.52	0.39
Annual	0.32	7.17	5.97	3.85	2.22	1.77

The most valuable component of the Pripyat floodplain is the ancient lakes which play an important role in the runoff formation, in the processes of accumulation of substances, and self-purification of waters. There are more than 1100 lakes in the Pripyat valley which are places of growth of aquatic and coastal vegetation and habitats of aquatic and near-aquatic fauna, including bird feeding sites.

In addition to natural lakes, 363 ponds and 66 reservoirs have been created in the Belarusian Polesie territory with a total water mirror area of 224.5 km^2 and the Western Bug River—41.1 km^2 with a total volume of 650.7 and 66.4 million m^3, respectively.

The spring flood usually begins in the first half of March at the Polesie Rivers, but in some years it may shift to February or April. The average long-term duration of flooding of the floodplain is 80–110 days and sometimes up to 150–180 days. The width of the spring flood varies from 5 to 15 km; the largest in the area of Pinsk reaches 30 km. The depth of flooding is mainly 0.3–0.8 m, sometimes 2–2.5 m [12]. Flooding of the Pripyat River from floods of various probabilities is shown in Figure 2 [13].

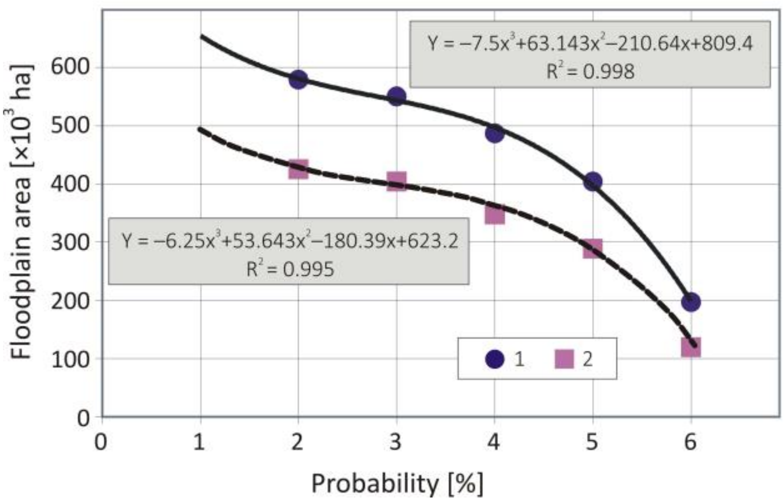

Figure 2. Floodplain areas of the Pripyat River depending on various probabilities: 1—all over the floodplain; 2—within Belarus.

The maximum spring flood in the Pripyat River was noted in 1845 and was so catastrophic that it can probably be attributed to the group of extremely possible events in our climatic epoch. It is a unique hydrological phenomenon of very rare occurrence. The maximum level exceeded zero in the schedules of the modern gauging station near the city of Mozyr by 6.75 m, and the water flow is estimated at 11,000 $m^3\ s^{-1}$ and can be approximately considered to be repeated no more than once every 800 years [14]. The last significant flood was in 1999. Table 2 shows the water runoff of the 10 most significant floods in the Pripyat River and their probability.

Table 2. Maximum water runoff (Q) of the spring flood and probability (P) of the Pripyat River at the city of Mozyr.

Year	1845	1877	1895	1888	1889	1940	1979	1932	1970	1958
Q [$m^3\ s^{-1}$]	11,000	7500	5670	5100	4700	4520	4310	4220	4140	4010
P [%]	0.8	1.6	2.3	3.1	3.9	4.7	5.4	6.2	7.0	7.6

Rain floods occur irregularly, and in terms of the maximum runoff rates, they are significantly less than the spring flood maxima. However, the rain floods of 1952, 1960, 1974, 1993, and 1998 in the Pripyat River exceeded the flood and caused significant damage to the national economy. Even local floods on tributaries can cause significant level rises in the lower reaches of the Pripyat, due to the downward movement of the flood wave. The height of floods in the middle and lower reaches of the Pripyat is 2–3.5 m above the pre-lifting level.

The high water is replaced by the summer–autumn low water which is characterized by significant variability. The summer low is usually lower than the winter low and is interrupted almost annually by rain floods. Winter snowfall is often interrupted by thaws, the consequence of which is winter floods which exceed the spring flood in some years.

The formation conditions of the inter-soil flow of rivers can be considered favorable in general because the territory of Polesie is in a zone of excessive moisture, and the outflow of groundwater into the river network is more or less long and constant. Minimum water levels and runoff in summer are observed at high average daily air temperatures and during prolonged periods of absence of precipitation; in addition, in winter—at low temperatures. During the dry years (1939, 1951, 1952, etc.) in Polesie, the drying of watercourses with catchment areas over 1000 km^2 was observed. Freezing is observed only on small rivers and for a short time.

The summer–autumn low-water period is mainly observed in July and August, less often in September. Its duration for small and medium-sized watercourses is up to 130 days, and for Pripyat—85–90 days. Winter low water is usually set at the end of December. The earliest dates of the onset of autumn low-water are at the end of October–beginning of November, and the latest—in the end of January with the beginning of the spring flood.

Within Polesie, zero runoff was recorded on 17 watercourses with catchment areas of 11–1280 km^2. The average duration of one case of zero runoff can reach 195 days in summer and 75–100 days in winter.

The lowest average monthly summer runoff values naturally decrease across the territory of Polesie from the northwest and north to the south and southeast, obeying geographical zoning on large and medium-sized rivers. However, on small rivers, the intra-zonal nature of changes is detected depending on local hydrogeological features—the presence and thickness of groundwater horizons, the nature of their opening by river valleys and the conditions of their discharge.

Aquifers in fractured and calcareous carbonate-sulfate rocks of the Upper Cretaceous and Neogene are the most abundant. Cretaceous water outlets are observed within the Polesie lowland in the form of ascending sources with a flow rate of up to 200 m^3 per hour. These waters feed a number of lakes, numerous marsh massifs, and partially right-bank tributaries of the Pripyat—the Turya, Stokhod, Goryn, Styr Rivers, etc. The modulus of the minimum average daily runoff of these rivers of 97% probability varies from 0.07 to 0.18 $dm^3\ s^{-1}\ km^2$. Those rivers that are fed from aquifers of alluvial and fluvioglacial deposits have low minimum flow modules, and in dry years their flow completely stops for a period from 15 to 120 days. Stopping the flow on these rivers is also possible during cold thaw-free winters.

3.2. Quality of Natural Waters Analysis

The formation of the composition of Polesie river waters occur with the complex interaction of a number of natural and anthropogenic factors. The main natural factors determining the chemical quality of surface waters and the characteristic features of their hydrochemical regime include climatic conditions, the geomorphological and geological structure of the territory, and the nature of soils and vegetation cover. The dominant factor is the climatic conditions that determine the main features of the water regime of the Polesie Rivers and the direction of the soil-forming process. The soil layer of sod-podzolic soils is everywhere well washed from easily soluble inorganic compounds (sulfates and chlorides) which contributes to the formation of bicarbonate waters here, mainly of small and medium mineralization. The influence of peat–bog soils has two effects. It is generally recognized that the most widespread in the territory of the non-dried lowland and upland swamps enrich the waters with a large amount of organic compounds, as a result of which waters with low mineralization, high oxidability, and color are formed in the swampy catchments.

In addition, low-lying peat bogs in a natural state play the role of a kind of buffer in the formation of the chemical composition of surface waters. Thus, hard ground waters feeding lowland swamps reduce their hardness from 5–7 to 3–4 mg-eq dm^{-3}, and low-mineralized flood waters entering peat bogs increase their hardness to 2–4 mg-eq dm^{-3}. The change of phases of the water regime during the year, as well as differences in the water content of individual years, cause seasonal and long-term changes in the mineralization and chemical composition of surface waters. The presence of forests affects the overall mineralization of water and some other hydrochemical characteristics, in particular, because the podzol-forming process proceeds most intensively in forests. In forested catchments, surface–slope waters during high water and high summer floods flow over the surface of well-washed forest soil and their mineralization remains close to the mineralization of snow waters. At the same time, they leach the decomposition products of plant and animal residues from the forest floor and the upper soil horizon and are enriched with organic substances of humus origin, in particular organic acids. This is manifested in an increase in the color of water, a decrease in the pH value and a weakening of the severity of the bicarbonate character of water, which is associated with a relative increase in the content of SO_4^{2+} ions. During the inter-war period, the influence of afforestation is noticeably weakened [15].

Table 3 shows the chemical composition of the Polesie Rivers' water during the summer low water before significant anthropogenic impact which can be taken as the natural hydrochemical background of the Polesie Rivers waters.

Table 3. Background chemical composition of the Polesie Rivers waters [mg dm^{-3}].

River	Ca^{2+}	Mg^{2+}	$Na^+ + K^+$	HCO_{3-}	SO_4^{2-}	Cl^-	NO_{3-}	NO_{2-}	Fe	Total Dissolved Salts
Shchara	50.1	7.8	1.0	186.0	5.9	0.3	0.08	0.006	0.71	251.2
Grivda	53.5	7.4	2.2	190.4	8.5	2.4	0.05	–	0.5	264.4
Vedrich	63.8	10.1	1.5	226.3	4.4	3.2	2.00	0.058	1.12	311.4
Ryta	40.5	2.3	–	115.9	4.0	1.9	0.35	0.006	1.62	165.0
Lesnaya	53.0	4.6	–	171.4	3.4	0.8	–	0.002	0.71	233.2
Pripyat	73.7	3.0	0.5	233.7	3.7	1.4	0.07	0.001	0.48	316.1
Yaselda	44.5	5.7	–	139.1	2.1	0.9	–	0.005	2.12	192.3
Goryn	70	9.9	5	243.4	15.7	6.5	–	0.002	0.38	350.5
Oressa	42.7	7.4	2.2	148.2	10.7	6.0	0.50	0.105	3.50	217.8

Currently, most of the rivers of Polesie belong to the category of "clean and moderately polluted". The hydrochemical regime of rivers is greatly influenced by the large swampiness of basins as well as industrial enterprises and housing and communal services of cities. The greatest load from wastewater discharge in recent years was experienced by Sluch River below Soligorsk city, Western Bug River below the Brest city, Pripyat River below Mozyr city, and Yaselda River below Bereza city. The most characteristic pollutants of water in the rivers of Polesie are petroleum products, ammonium nitrogen, nitrite nitrogen, and iron compounds.

Back in the XX century, petroleum products were the main pollutant of the water of the rivers of Polesie. So, in 1985, the content of petroleum products in water was very high and varied from 11 to 76 of the maximum allowable concentration (MAC). MAC_{drink} (the MAC ratio for water objects of economic and drinking purposes for petroleum products) is 0.3 mg $dm^{-3,}$ and $MAC_{fishery}$ (the MAC ratio for water objects of fishery purpose) is 0.053 mg dm^{-3}. In recent years, due to the reduction of cargo transportation by river transport, the anthropogenic influence has noticeably decreased which has led to a decrease in the load on river waters for petroleum products. Currently, their concentration does not exceed the MAC ratios, so today the average annual concentration of oil pollution in the Mukhavets River is 0.03 mg dm^{-3}, and in the water of the Pripyat River—0.03–0.04 mg dm^{-3}.

The maximum pollution of the Pripyat River with ammonium nitrogen was in 1987, then there was a tendency to decrease, and today its maximum concentration is observed in Pripyat River—1.32 mg dm^{-3}; Goryn River—0.64 mg dm^{-3}; Yaselda River—0.60 mg dm^{-3}; Mukhavets River—0.38 mg dm^{-3} (MAC_{drink} = 1.0 mg dm^{-3}; $MAC_{fishery}$ = 0.39 mg dm^{-3}). Thus, although there is a tendency to decrease this indicator, but in some cases, there is still an excess of the MAC ratios.

Pollution associated with the presence of increased nitrogen in the waters is typical for the rivers of the region. The maximum pollution of the Mukhavets River was observed in 1994 and it was 2.5 times MAC (MAC_{drink} = 0.99 mg dm^{-3}; $MAC_{fishery}$ = 0.02 mg dm^{-3}). Nowadays, the maximum concentration in the Pripyat River reached 0.051 mg dm^{-3}; the Yaselda and Mukhavets Rivers—0.018 mg dm^{-3}; the Sozh and Goryn Rivers—0.024 mg dm^{-3}.

Traditionally, there is increased iron content in the surface natural waters of Polesie. In 2020, the maximum concentrations of iron in water were observed in Pripyat River—1.08 mg dm^{-3}; in Goryn River—0.82 mg dm^{-3} (MAC_{drink} = 0.3 mg dm^{-3}; $MAC_{fishery}$ = 0.5 mg dm^{-3}) [16].

Before the Chernobyl Nuclear Power Plant acci-dent the concentrations of ^{90}Sr and ^{137}Cs in the water of the Pripyat Rivers were 0.0033–0.00185 and 0.00185–0.0066 Bq dm^{-3}, respectively. In the first days after the accident the total beta activity of the Pripyat River water exceeded 3000 Bq dm^{-3} and only by the end of May 1986 decreased to 150–200 Bq dm^{-3}. The maximum concentrations of Plutonium-239 in the water of the Pripyat River were 0.37 Bq dm^{-3}. Currently, the highest content of Strontium-90 from 1.59 to 2.70 Bq dm^{-3} is observed in the waters of the Braginka, Zhelon, Rotovka, and Nesvich Rivers, as well as in the old Pripyat in the territory of the settlement zone. Concentrations of ^{137}Cs in water are significantly lower than allowable concentrations according to radiation safety standards and do not exceed the allowable level for its content in drinking water. However, it is still higher than the pre-accident values.

Thus, although there are ecologically unfavorable areas in Pripyat, it remains a fairly clean river by European standards.

The abiotic and biotic components of water systems have undergone significant changes under the influence of anthropogenic factors. The first significant changes in the hydrological and hydrochemical regimes of aquatic ecosystems were noticed in the 1960s–early 1970s. An increase in the concentrations of a number of components in the water of rivers and lakes has been established almost everywhere, significantly exceeding their background values: chlorides (2–9 times), sulfates (1.5–2 times), and alkali metals (1.3–3 times).

Figure 3 shows the gradients of changes in the average annual concentrations of priority substances in the water of some rivers of Polesie over the past 15 years.

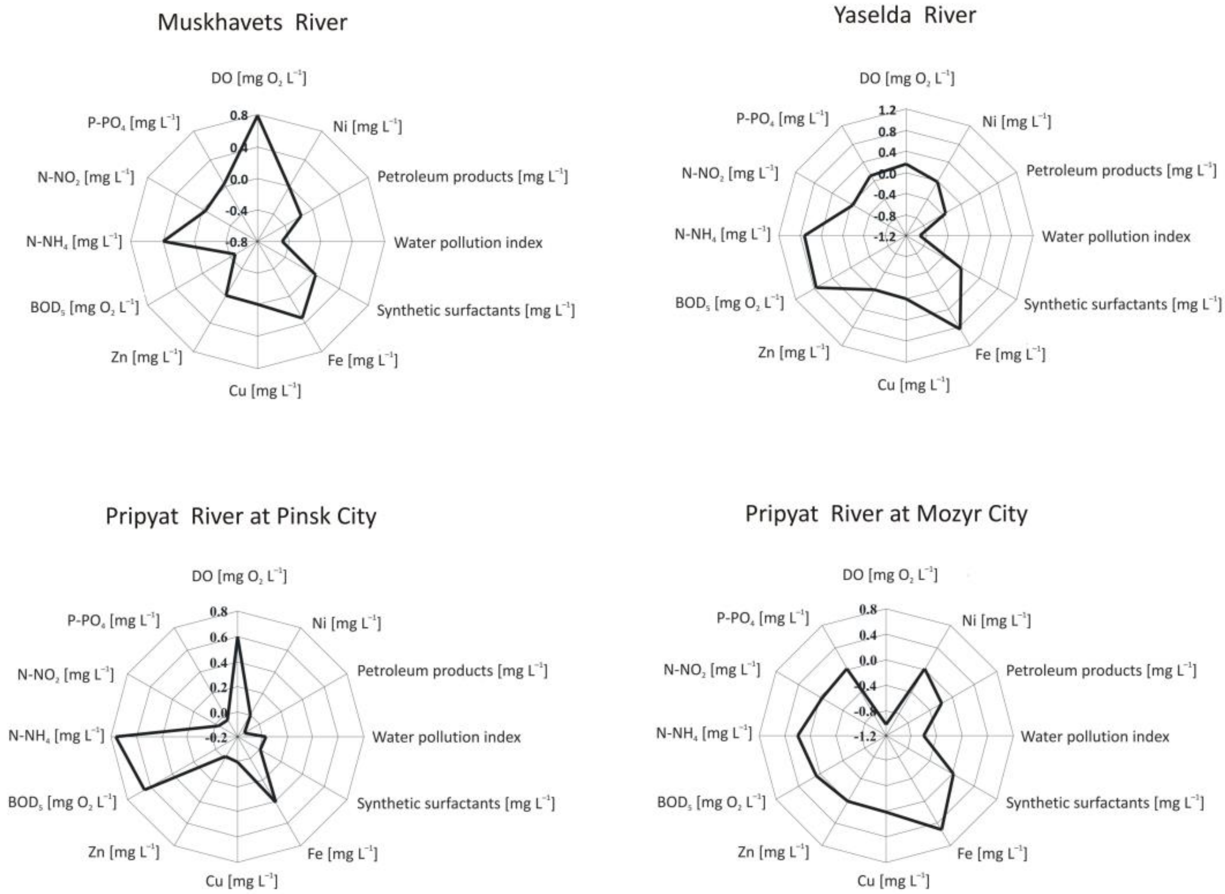

Figure 3. Gradients of changes in the average annual concentrations of priority substances in the water of the Polesie Rivers.

In general, we can say that there have been trends toward a pollution decrease in the Polesie Rivers; however, the quality of surface waters in the Yaselda, Berezina, and Western Bug Rivers is still not satisfactory.

The process of water pollution has stopped and there have been positive trends toward improving the ecological condition of individual river basins. However, despite the decrease in the discharge of contaminated wastewater, no significant improvement in the quality of surface water is currently observed.

The main direction of improving the quality of natural waters remains the reduction of anthropogenic load and restoration of the ecological well being of waters, namely, the intensification of the work of municipal wastewater treatment plants, the construction of municipal wastewater treatment plants at agricultural enterprises, rain runoff treatment, etc.

4. Discussion

Since the middle of the XX century, there has been a discussion about the impact of land reclamation on river flow. The main impact on the water regime of the Pripyat River was exerted during the period of large-scale hydraulic reclamation of the Polesie lowland. At the same time, the water resources of Polesie were more strongly affected by anthropogenic impacts than other regions. A total of 23% of the territory was drained, the total length of the open reclamation network exceeded 65,000 km, and the hydrographic network was significantly transformed, especially if we take into account the straightening and deepening of the Pripyat itself and its large tributaries. In addition, the collapse of individual sections of Pripyat and the construction of polder reclamation systems that exclude flooding of the collapsed floodplain areas led to the fact that groundwater dropped by 1.0–1.5 m, followed by a decrease in water levels in rivers. All this resulted in a change in the hydrological regime of rivers. The runoff changes the analysis of the Pripyat River showed an increase in the average runoff during the period of active land reclamation in all months of the year, except April and May. The growth of the average annual runoff is 12% compared to previous years and compared to the previous 20 years is already about 30%. The maximum losses from irretrievable water consumption and during the regulation of river flow over the past years in the basin of the Pripyat River within the Belarusian Polesie amounted to 190 million m^3 per year, in the basin of the Western Bug River—27 million m^3 per year. So far, the degree of influence of these losses is small and is within the measurement error [16].

The analysis of the Polesie rivers runoff has showed that since the middle of the XX century there was a significant decrease in maximum spring runoff and a decrease in average annual runoff (insignificant for the half of the rivers). A statistically significant increase in the minimum winter runoff is observed for the rivers of the Pripyat River basin. For the minimum summer–autumn runoff, there was no unambiguous trend in the runoff change.

A significant decrease in the maximum spring runoff and an increase in the minimum winter runoff allow us to conclude that the main feature of modern changes in the water regime of the Polesie Rivers is the redistribution of runoff within the year, occurring with a relative constancy of average annual runoff. From the point of view of water use, reducing the maximum spring flood runoff entails ambiguous consequences. A positive aspect is the reduction of hydro-ecological risks, damage from floods, and flooding of territories. A negative reaction is the possible formation of tension in water use in the summer.

A search for the relationship of the river runoff with the main flow-forming factors in the study area was made to identify the causes of the patterns of long-term and intra-annual runoff changes. A study of the series of air temperature and precipitation for weather stations located in the territory of Polesie for the period 1946–2018 was carried out. The temporal variability of the average annual air temperature is characterized by a positive linear trend of 0.28 °C per 10 years with a positive increment (according to the trend) of 2.04 °C over the interval 1946–2018 (Figure 4).

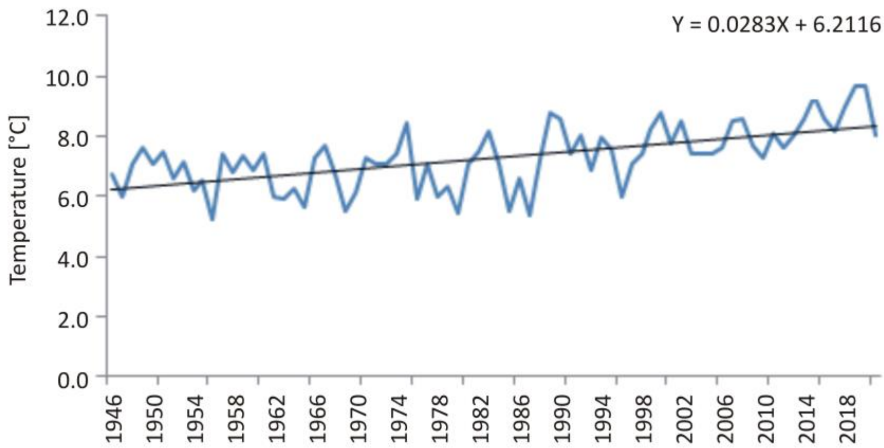

Figure 4. The long-term course of the average annual air temperature in the territory of Polesie (1946–2018).

Table 4 shows the data obtained from the analysis of atmospheric air temperatures in the territory of Polesie according to the following indicators: I—intensity of growth for the period 1946–1987 (°C per 10 years); II—intensity of growth for the period 1988–2018 (°C per 10 years); III—average temperature for the period 1946–1987 (°C); IV—average temperature for the period 1988–2018 (°C). Analysis of the results shows that the last 30 years period is warmer than the first in all months of the year.

Table 4. Changes in air temperature in the study area.

Month	1	2	3	4	5	6	7	8	9	10	11	12	Year
I	−0.03	0.00	0.04	−0.02	0.01	−0.03	−0.03	−0.01	−0.03	0.03	0.02	0.00	−0.01
II	−0.06	−0.03	0.03	0.03	0.01	0.08	0.06	0.06	0.06	0.04	0.12	0.09	0.04
III	−5.22	−4.76	−0.30	7.00	12.99	16.40	17.63	16.90	12.68	7.11	2.09	−1.99	6.71
IV	−2.69	−1.76	2.06	8.26	13.68	17.15	19.11	18.22	13.13	7.77	2.69	−1.37	8.03

As a result of the analysis of the precipitation data series for the meteorological stations of the studied territory, it was concluded that there were no significant changes in the amount of precipitation for the period 1946–2018 (Figure 5).

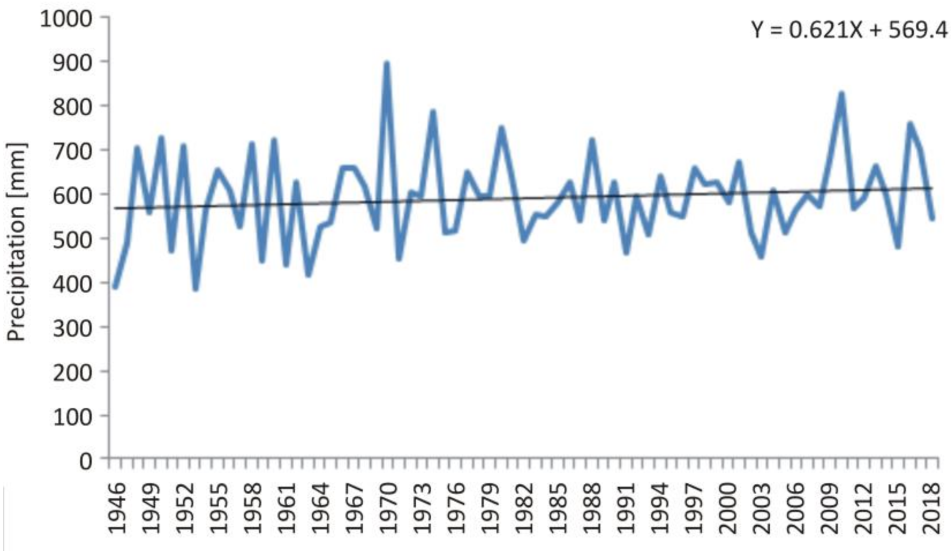

Figure 5. Long-term changes in total annual precipitation in the territory of Polesie.

The changes in precipitation are characterized by ambiguity by month. The greatest positive dynamics in precipitation changes is observed in February, March, and summer months. Table 5 shows the data obtained from the analysis of the amount of precipitation in the territory of Polesie according to the following indicators: I—intensity of growth for the period 1946–1987 (mm per10 years); II—intensity of growth for the period 1988–2018 (mm per 10 years); III—average precipitation for the period 1946–1987; (mm), IV—average precipitation for the period 1988–2018 (mm); V—increment of precipitation for the second period (mm).

Table 5. Changes in precipitation over the study area.

Month	1	2	3	4	5	6	7	8	9	10	11	12	Year
I	0.54	−0.15	0.10	0.05	0.31	−0.36	0.43	−0.36	0.20	0.07	−0.09	0.35	1.09
II	0.80	−0.08	−0.21	0.15	0.45	−0.04	0.89	−0.51	−0.50	0.45	−0.12	0.36	1.65
III	34.86	30.63	28.17	37.82	55.25	75.31	72.24	74.05	49.54	42.85	43.57	42.11	586.38
IV	36.65	35.44	35.44	39.50	58.68	65.55	86.44	60.74	57.48	41.77	41.44	41.61	600.73
V	1.79	4.81	7.27	1.68	3.43	−9.76	14.20	−13.31	7.95	−1.07	−2.14	−0.49	14.35

The results obtained allow us to identify patterns of the formation of various types of river runoff in the Polesie region. The main climatic factors determining the spring flood runoff are precipitation during the winter and spring periods and the air temperature of the winter period. Autumn precipitation has a significant impact on winter runoff, as it is a source of groundwater formation, which acts as the main source of river nutrition during the winter and autumn. The result of an increase in air temperature in winter is an increase in the proportion of precipitation falling in liquid form and an increase in the number of thaws and their intensity; a change in groundwater supply; an increase in groundwater supply. All these factors contribute to an increase in the minimum winter runoff.

A numerical experiment of runoff prediction in the future was carried out on several variants based on the analysis of currently existing estimates of possible climate changes. The most unfavorable forecast of the development of changes in river runoff for the Belarusian Polesie is the hypothesis, in which a decrease in flow is predicted to be 45%. It is equivalent to a change in probability from 50 to 85%, and the coefficient of variation is from 0.47 to 0.54. When the anthropogenic component is applied to the runoff, the decrease in the average annual runoff can reach 50–70% of the current state.

5. Conclusions

The main task in the study of the Polesie water resources is their comprehensive assessment of the current state, taking into account spatial and temporal fluctuations and changes in the main components of the water balance of river catchments. At the same time, it is necessary to take into account the influence of various natural and anthropogenic factors on them, and the forecast of changes in water resources under various scenarios of climate development. One of the main questions is to develop measures to minimize possible negative consequences in the event of a change in the regime of water resources.

Further research should be focused on the following main tasks:

- prevention and reduction of negative consequences from floods;
- improving the quality of natural waters;
- protection water resources during the design, construction, and operation of public facilities;
- management the regime of natural waters that ensures the biospheric functioning of natural ecological systems;
- creation the basin schemes for water resources management in Polesie.

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