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Article

Impact of Climate Change on the Runoff of the Sula River (Ukraine)

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Abstract: The article is devoted to the study of climate change in the Sula River basin and its impact on the river's water availability. To analyze changes in the runoff of the Sula River, the water balance method was applied; evaporation was calculated using Konstantinov's method, and aridity and runoff coefficients of the Sula River, as well as Pearson correlation coefficients, were determined. It is established that the Sula River has been characterized by a low-water phase lasting since 1989, and a persistent downward trend is observed for all quantitative characteristics of river runoff. Mean annual air temperatures during the period 1979–2020 show a stable upward trend, as do indicators of total evaporation; in contrast, a weak downward trend is observed for annual precipitation totals. An analysis of the components of the water balance equations of the Sula River basin for the periods 1979–1999 and 2000–2020 showed that annual atmospheric precipitation remained almost unchanged (a decrease of 1.8%), evaporation increased by 7.1%, and the runoff layer significantly decreased by 43.3%. The calculated correlation coefficients between the mean annual discharge of the Sula River and mean annual air temperature, as well as between minimum water discharge and sunshine duration, indicate an inverse correlation (correlation coefficients of −0.61 and −0.63, respectively). The relationship between the mean annual discharge of the Sula River and annual precipitation indicates a direct dependence (correlation coefficient of 0.38). A decrease in the runoff coefficient during the second observation period compared to the first period by more than one third is accompanied by a regular increase in the aridity coefficient of 7.3%.

Keywords: Sula river; runoff; water discharge; runoff layer; mean annual air temperature; precipitation; evaporation.

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1. Introduction

A pressing issue of the present day is the reduction in river water availability. Rivers of Ukraine in general, and those of Sumy Region in particular, are becoming shallower, silting up, overgrowing, and transforming into low-flow water bodies. The causes of reduced water availability include both natural factors, particularly climatic ones, which are manifested in changes in the components of the river water balance, and anthropogenic factors (significant regulation of runoff, deforestation in catchment areas, extensive land reclamation measures, etc.), which are also important and, in some cases, dominant. The problem of declining water availability is extremely acute for the Sula River, a left-bank tributary of the Dnipro River, which originates in Sumy Region and flows through the region for about 152 km (42% of the river's total length) (Fedchenko, 2006). Until recently, this river was more water-abundant, as indicated by its name, which in translation from Turkic means "much water". Therefore, the study of changes in the water availability of the Sula River and the identification of the causes of these changes are of particular relevance.

Global climate change consists of an increase in the mean global temperature. Each of the last four decades has been successively warmer than any preceding decade since 1850: the global temperature during the period 2001–2020 was 0.99 °C higher compared to the period 1850–1900 and 1.09 °C higher in 2011–2020 than in 1850–1900 (IPCC, 2021). Climate changes in the future will be even greater; global warming will lead to changes in the water balance, which will affect water availability issues, and these changes will bring society to a state in which climate change will become one of the major political issues (Schleussner et al., 2016; Donnelly et al., 2017; IPCC, 2021).

Publications addressing the problem of river water availability and changes in their hydrological regime under the influence of climate change appeared in the 1980s (Nemec and Schake, 1982; Peterson and Keller, 1990). The issue of the impact of climate change on river water balance, river runoff variability, and runoff of individual river basins has been considered in studies by American scientists (Najjar, 1999; Stone et al., 2003; Barnett et al., 2004) and European researchers (Ludwig, 2000; Middelkoop, 2001).

Changes in climatic indicators such as temperature and precipitation, as well as subsequent changes in river runoff over recent decades, have been confirmed by numerous studies in different regions of the world. The dependence of river water availability on climate change, as well as a shift in the peaks of spring runoff, was identified in 12 river basins of Central Asia (Didovets et al., 2024). A study of 230 catchment basins in British Columbia, Canada, found that abnormally low river water levels in the previous century were caused by precipitation deficits, whereas the current decline in river water availability is driven by increasing summer temperatures, despite near-normal precipitation (Ruzzante and Gleeson, 2025). The dependence of minimum water discharge on climate change was established in a study of 63 catchment basins in the mountainous regions of western North America (Dierauer et al., 2018), the results of which indicate that precipitation is the dominant factor of annual runoff variability; however, the sensitivity of low-flow conditions to air temperature may be twice as high as that of annual runoff.

The source (Smith et al., 2024) indicates that climate warming will lead to a decrease in mean river runoff and will be most pronounced in the south and east of the United Kingdom; at the same time, droughts are becoming more severe, and the frequency of extreme events and floods will increase in the future, especially in the north and west of the country. Some studies record an increase in floods associated with climate change, with the most consistent increases projected for tropical and subtropical regions, particularly South and Southeast Asia (Xu and Luo, 2015; Eccles et al., 2019). The results of studies (Avazpour, 2025) indicate a significant future increase in minimum and maximum temperatures; precipitation projections are characterized by variability, with decreases observed in some months and increases in others, while river runoff will noticeably decline by 2040 compared to historical data.

A number of studies examine the impact of climate change on the components of the water balance using the SWAT (Soil and Water Assessment Tool) model, and the calculation results reveal a decrease in annual runoff, an increase in mean annual precipitation, and a rise in temperature (Reshmidevi et al., 2018; Abesh et al., 2022; Chawanda et al., 2024; Harraki and Zemzami, 2025). Oliver Moses and Wame L. Hambira found that climate change is likely to lead to a further increase in total evaporation (Moses and Hambira, 2018).

Changes in the climate of Ukraine indicate that since the late 1990s the mean annual air temperature has become higher than during the period 1961–1990, and the last decade has been the warmest in the entire history of observations in Ukraine; in some years, the mean annual temperature increase exceeded 2.0 °C. This factor affects changes in the hydrological regime of rivers, as well as the seasonality and duration of floods (Snizhko et al., 2024). The impact of climate change on river runoff in the territory of Ukraine is highlighted in the work of Vyshnevskyi (2001). Loboda, Korobchynska, and Rudnyk assessed the impact of possible climate changes on the water availability of the Dnipro River (Loboda, 2008; Loboda, 2010). An assessment of possible changes in water resources under conditions of global warming was carried out in the study by Gopchenko and Loboda (2000). The problem of assessing the impact of climate change on river regime is presented in detail in the monograph by Grebin (2010), who notes that 1989 was a turning point in climate change in Ukraine, namely that changes in climatic factors (precipitation and evaporation) determine the current changes in the intra-annual distribution of river runoff.

Projections of the impact of climate change on the water resources of Ukraine are presented in the study by Loboda and Kozlov (2020), which states that by 2050 water resource losses will reach 50–60% in the south and 10–40% in the north. A synthesis of assessments of expected changes in the quantitative characteristics of Ukraine's water resources under the influence of climate change was analyzed by Snizhko, Shevchenko, and Didovets (Didovets et al., 2020; Snizhko et al., 2021), and the results of their projections indicate a decrease in mean annual runoff for most basins in the mid-century period (2041–2070) and at the end of the twenty-first century (2071–2100). The main cause of the reduction in water resources will be an increase in heat resources against the background of predominantly minor changes in moisture resources.

According to the results of a study by Bibik, Vynarchuk, Lukianets, and Khilchevskyi on the spatio-temporal characteristics of river runoff in the basins of the Sula, Psel, and Vorskla rivers, it was established that a turning point in water availability phases begins in 1988: from 1960 to 1988 a high-water phase persisted, while from 1989 to 2009 a low-water phase was observed (Bibik et al., 2011). Low-water conditions manifest themselves in a reduction of all quantitative runoff indicators. At the same time, a decrease in the share of spring flood runoff (by 15–16%) and an increase in the share of runoff during the summer–autumn and winter periods (by 25% and 2–6%, respectively), compared to the period before 1989, are observed, which indicates an intra-annual redistribution of runoff. This trend is confirmed by studies of quantitative runoff indicators of other rivers in Ukraine presented in the works (Grebin, 2004; Danylchenko, 2019).

The fact that a low-water phase has been ongoing on the Sula River from the 1980s to the present day is evidenced by the research of Smyrnova, who established an overall decrease in mean annual runoff during the period 1981–2017 of almost 10 m^3/s and recorded that in recent years, very low water levels and a significant reduction in water discharge have been observed during the low-flow period (Restoration of the Sula River…, 2024). In certain summer months of 2018, river discharge was less than 20% of the long-term mean minimum values and approached the historical minimum observed in 1939, while in shallow sections a pronounced shallowing of the river was observed, up to complete drying. A persistent decrease in the monthly runoff of the Sula River since the late 1990s, with a global minimum in the decade 2010–2020, is documented in studies by Graf and Vyshnevskyi (2022).

According to information from the Ukrainian Hydrometeorological Center, as of 3 October 2019 low-water conditions had formed on the Sula River (19% of the norm) (The Sula River…, 2019). During the period from 2014 to 2019, the mean monthly water availability of the Sula River from May to September was close to low-water criteria, and in certain periods (the low-flow seasons of 2016–2017) low-water conditions were observed on the river. According to the study by Sarnavskyi (2023), the runoff layer of the Sula River basin decreased by 41.5% in 1991–2020 compared to the observation period 1961–1990. Analysis of changes in the seasonal distribution of river runoff revealed a persistent trend toward a decrease in spring runoff, which averaged 73% during 1931–1960 and declined to 44% in 1991–2020 (Sarnavskyi et al., 2024). However, the results presented in the publication by Graf and Vyshnevskyi (2022) project an increase in runoff for the Sula River (by 16–23%) by 2030, with a slight increase in precipitation and a rise in air temperature.

The Sula River is an important component of the hydrographic network of Left-Bank Ukraine and performs a significant ecological function in maintaining biodiversity, hydrological regime, and the natural balance of floodplain ecosystems. It also has considerable economic importance, as its water resources are used for agricultural needs, fisheries, recreation, and domestic water supply. In this regard, the decrease in river discharge and the intensification of low-water conditions may lead to substantial environmental and socio-economic consequences for the region.

The novelty of the study lies in the identification and scientific substantiation of current trends in river runoff reduction and increasing aridization within the Sula River basin under conditions of climate change.

The aim of the study is to analyze current changes in the water discharge of the Sula River and to determine the impact of climate change factors (mean annual air temperature, total evaporation, precipitation amount, and duration of sunshine) on the river's water discharge.

2. Materials and Methods

The Sula River is a typical left-bank tributary of the Middle Dnipro sub-basin, with a total basin area of 19,600 km², of which 4,440 km² are located within Sumy Region, and a total length of 363 km (Fedchenko, 2006). Previous studies have identified characteristic manifestations of low-water conditions, particularly a decrease in runoff indicators, which are more pronounced compared to other rivers of the sub-basin, namely the Psel and Vorskla rivers (Danylchenko, 2025). The Sula River basin is characterized by high climatic sensitivity, as the hydrological regime of the river strongly responds to contemporary changes in air temperature and atmospheric precipitation (Sarnavskyi, 2023; Sarnavskyi et al., 2024).

Within the Sula River basin, a high level of anthropogenic pressure is observed, caused by intensive agricultural land use, extensive plowing of land, reduction of forested areas, land reclamation measures, flow regulation, river channel transformation, and oil and gas extraction activities within the basin (Danylchenko, 2019). Such land-use characteristics contribute to increased surface runoff, deterioration of the water-retention capacity of the catchment area, and the inflow of significant amounts of pollutants into the river network (Bonchkovskyi and Osypov, 2024). Large-scale land reclamation activities carried out within the catchment have also affected runoff formation processes and the functioning of aquatic ecosystems (Sarnavskyi et al., 2024). The combined influence of climatic and anthropogenic factors has led to the deterioration of the river's ecological condition, which is currently assessed as "moderate" and "poor" (Danylchenko, 2025).

The Sula River basin is a representative hydrological system of the forest-steppe zone of Left-Bank Ukraine, where significant changes in runoff formation processes are observed under conditions of contemporary climate change and anthropogenic pressure. The selection of the river as the object of study is due to the availability of long-term hydrological observation records, as well as the increasing manifestations of low-water conditions, which make the basin suitable for assessing regional hydrological responses to climate change.

For the analysis of changes in the water availability of the Sula River, we used data from the hydrological station in the city of Romny regarding water discharge (mean annual, maximum, and minimum) for the period 1979–2020, as well as other quantitative runoff characteristics calculated based on water discharge: runoff layer and runoff coefficient. The last five years (2021–2025) were not included in the analysis due to the lack of open access to updated datasets. Meteorological indicators from the Romny weather station were also analyzed, including mean annual air temperature, precipitation, and humidity.

To explain the aforementioned hydrological processes, the water balance method was applied. This method is based on the law of mass conservation in a closed system, where atmospheric precipitation represents the inflow, and total evaporation, river runoff, and changes in soil and substrate moisture storage represent the outflow (Khilychevskyi, 2024; Kozintseva et al., 1987). Elements of the water balance were analyzed for two periods: 1979–1999 and 2000–2020. Based on the differences in water balance components between these two periods, aridity and runoff coefficients were calculated.

Using Konstantinov's method (Kozintseva et al., 1987), which is based on the theory of turbulent diffusion and the analysis of heat and water vapor exchange processes in the atmosphere, evaporation was calculated from the results of standard observations at the Romny meteorological station. Using air temperature, humidity, and precipitation, this method allowed the determination of monthly and annual total evaporation values for each multi-year period.

To establish the relationships between mean annual water discharge and mean annual air temperature, between minimum water discharge and sunshine duration, and between mean annual water discharge and atmospheric precipitation, the Pearson correlation coefficient was applied.

Statistical processing of climatic and hydrological data, as well as the preparation of graphical materials, was carried out using Microsoft Excel software. The analysis of precipitation extremes was performed based on the modal component using three-dimensional diagrams, which made it possible to identify the spatial and temporal distribution patterns of precipitation. The *SURFER* software package was used for the spatial interpolation, approximation, and visualization of sunshine duration fields, providing effective mapping and analysis of spatially distributed environmental data.

3. Results and Discussion

The analysis of the water availability of the Sula River for the period 1979–2020, based on the quantitative characteristic of runoff – water discharge, revealed that mean annual water discharge of the Sula River exhibits a stable downward trend. Low-water years prevail over high-water years, and a low-water phase has persisted since 1989 (Figure 1).

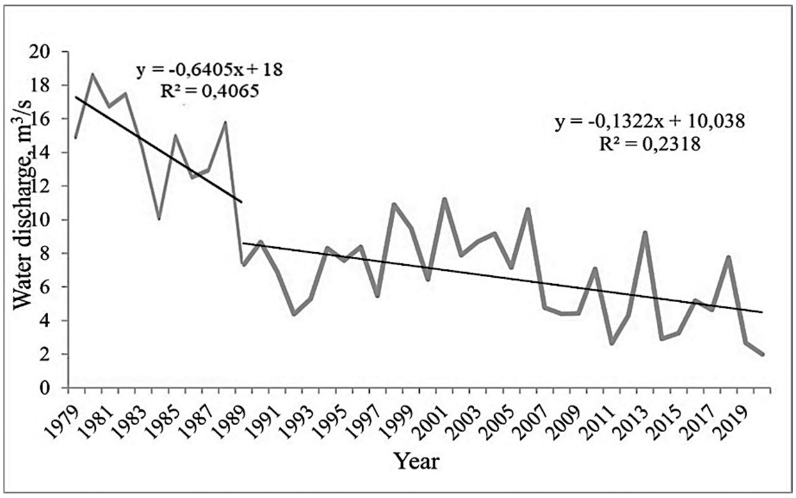
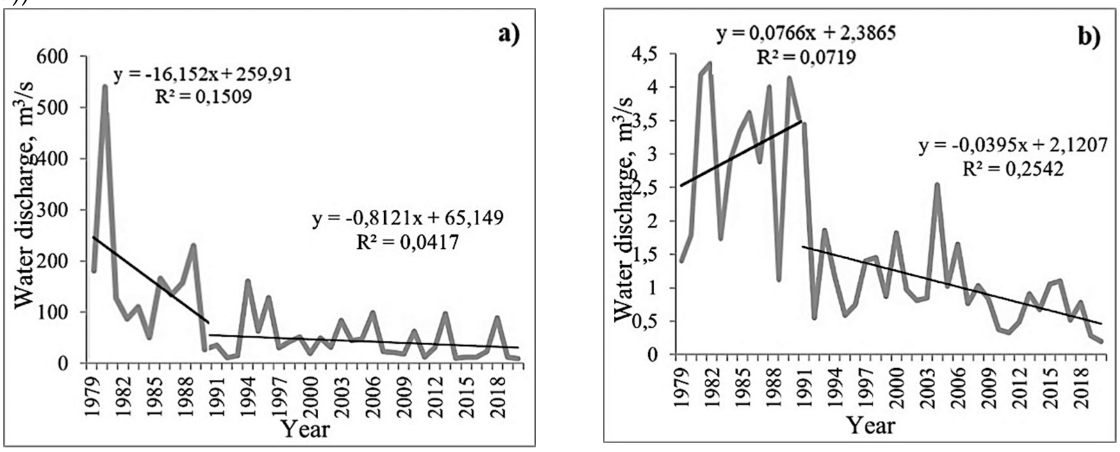


Figure 1. Dynamics of mean annual water discharge of the Sula River (Romny) for the period 1979–2020.

The breakpoint observed in 1989 is consistent with the results of studies on climatic and hydrological changes in Ukraine, according to which the late 1980s marked a significant disruption in the intra-annual distribution of river runoff under the influence of climatic factors, primarily changes in atmospheric precipitation and evaporation (Grebin, 2010). According to Bibik et al. (2011), the high-water phase for the rivers of the Sula, Psel, and Vorskla basins lasted until 1988, whereas from 1989 onward a transition to a stable low-water phase has been observed. These changes were accompanied by a decrease in the share of spring flood runoff and a redistribution of runoff among the seasons of the year. Before 1989, mean annual water discharge of the Sula River decreased sharply, whereas afterwards a downward wave-like dynamics of this indicator is observed. The mean value of mean annual water discharge for the period 1979–1999 was 11 m³/s, while for the period

2000–2020 it was 6.2 m^3/s, representing a 44% decrease. This indicates an intensification of low-water processes in the Sula River basin under contemporary climate change conditions.

The values of maximum annual water discharge also decrease sharply: 65.9% of the sample data are below 75.1 m^3/s, and only in 1980 an abnormally high value of 540 m^3/s was recorded (Figure 2(a)). Regarding the rate of decrease of this indicator, a pattern similar to the dynamics of mean annual water discharge is observed. Minimum water discharge of the Sula River also shows a decreasing trend, but with certain differences: before 1991, this indicator increased while maximum discharge values decreased, resulting in a redistribution of runoff. After 1991, minimum water discharge began to decline sharply, and its mean value for the period 2010–2020 was 0.7 m^3/s (Figure 2(b)).



(**a**) (**b**)

Figure 2. Chronological graph of water discharge of the Sula River (Romny) for the period 1979–2020: **(a)** maximum; **(b)** minimum.

Based on the analysis of difference-integral curves of mean annual, maximum, and minimum water discharge, it was established that the turning point in the water availability phases of the Sula River begins in 1989, which confirms the findings of Grebin (2010). This trend is particularly pronounced for maximum water discharge of the Sula River (Figure 3).

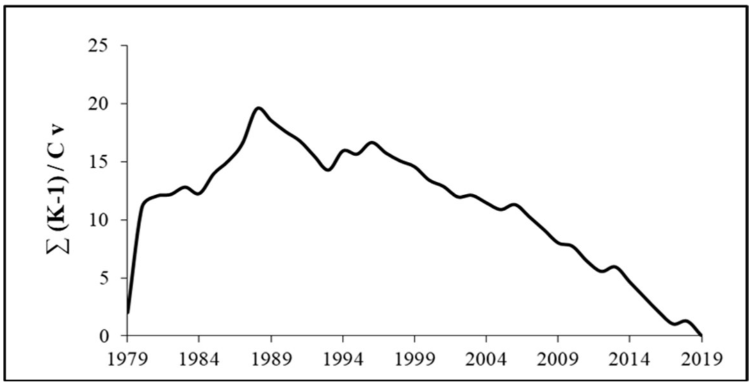


Figure 3. Difference-integral curve of maximum water discharge of the Sula River.

The runoff layer of the Sula River, calculated from data of the Romny hydrological station, was 86.3 mm for the period 1979–1999 and 48.9 mm for the period 2000–2020, corresponding to a decrease of 37.4 mm (43.3%), which represents a significant change and may be catastrophic in low-water years. The obtained values are comparable with results reported by other researchers (Sarnavsky, 2023).

River water availability directly depends on climatic conditions. Therefore, the dynamics of air temperature and precipitation were analyzed using observations from the Romny meteorological station for the period 1979–2020.

Mean annual air temperatures at the Romny station during 1979–2020 show a stable upward trend (Figure 4). The minimum value was recorded in 1987 at +4.5 °C, and the maximum in 2020 at +9.9 °C. The mean value of mean annual air temperature for the period 1979–1999 was +7 °C, and for 2000–2020 it was +8.4 °C, corresponding to an increase of 1.4 °C.

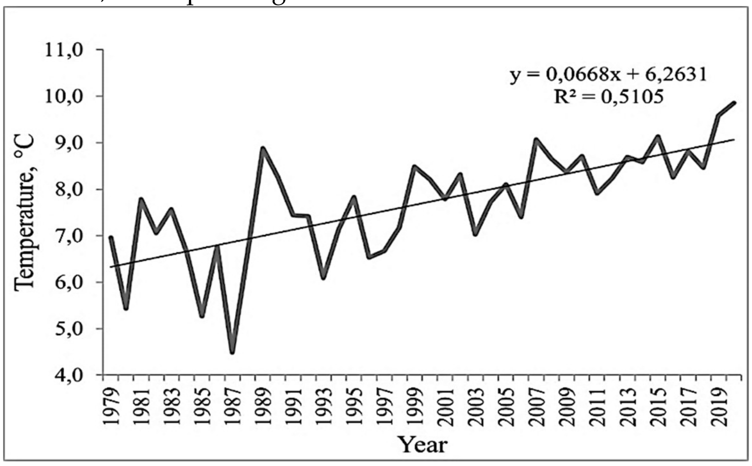


Figure 4. Dynamics of mean annual air temperature (Romny) for the period 1979–2020.

Analysis of the annual course of air temperature over different observation periods demonstrates an increase, especially during the spring–summer period (Figure 5). Considering individual months, the greatest temperature increase was recorded in February, as well as in June, July, and August.

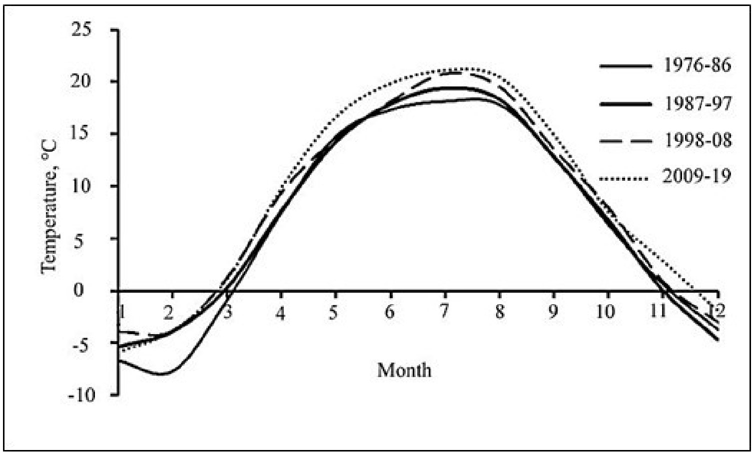


Figure 5. Mean annual air temperature at the Romny meteorological station for different observation periods.

It should be noted that warming occurs against the background of an increase in sunshine duration (Figures 6 and 7(a)), while the number of sunny days does not increase (Figure 7(b)), indicating a reduction in cloudiness.

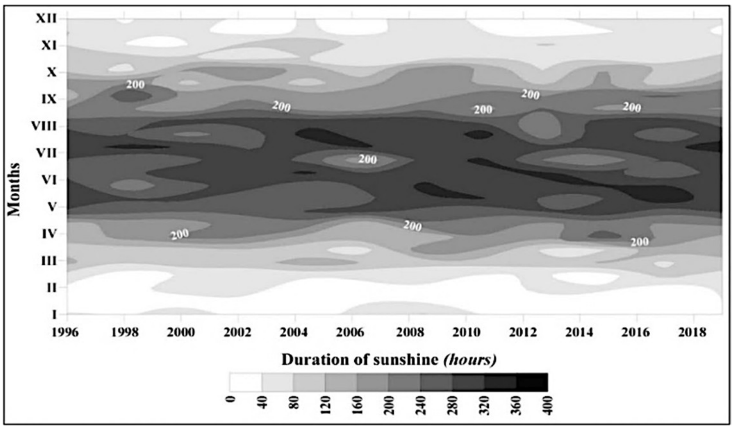
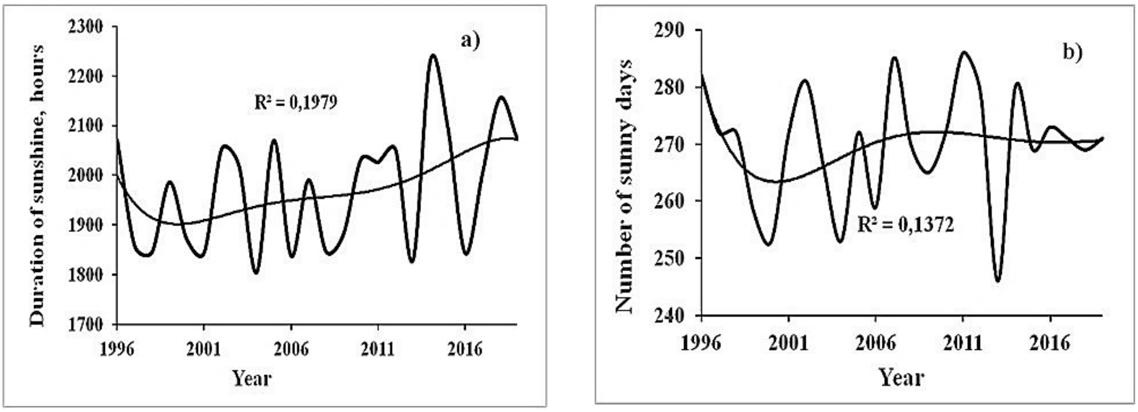


Figure 6. Sunshine duration at the Romny meteorological station for the period 1996–2020.



(**a**) (**b**)

Figure 7. Sunshine duration **(a)** and number of sunny days **(b)** at the Romny meteorological station for the period 1996–2020.

The dynamics of atmospheric precipitation at the Romny meteorological station for the period 1979–2020 are wave-like, although the overall trend is slightly downward (Figure 8). The maximum precipitation was recorded in 2016 at 896.8 mm, and the minimum in 2019 at 452.6 mm. The mean precipitation for the entire period of observation was 613.9 mm, for 1979–1999 it was 619 mm, and for 2000–2020 it was 608.0 mm. A weak decreasing trend in total annual precipitation of 1.8% is observed over the specified observation periods.

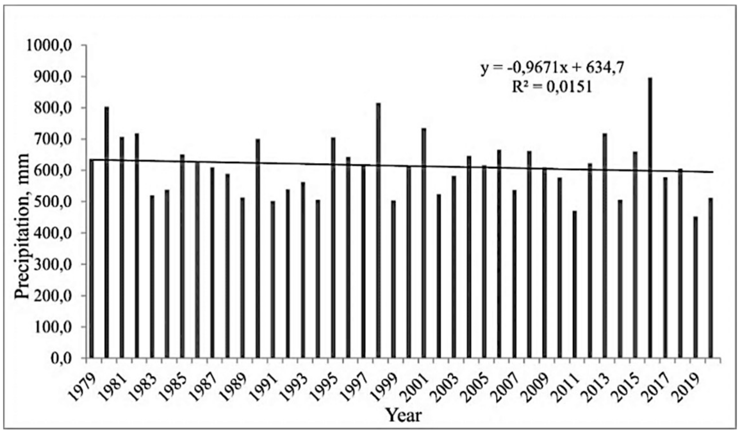


Figure 8. Dynamics of annual precipitation at the Romny meteorological station for the period 1979–2020.

At the same time, the modal values of precipitation in absolute terms are increasing. In addition, the maximum monthly precipitation values in recent decades are observed exclusively during the warm period of the year, whereas until the mid-1990s they occurred in all months. In recent years, monthly precipitation maxima have shifted to late spring and early summer and have increased in absolute values (Figure 9).

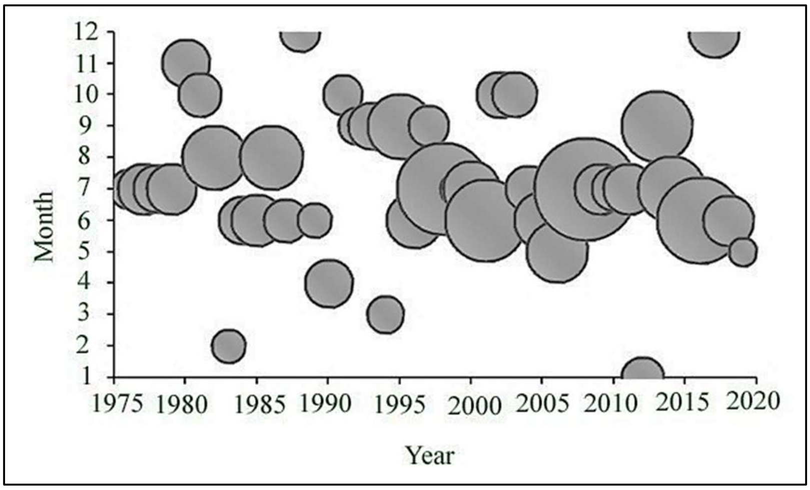


Figure 9. Distribution of the modal component of precipitation at the Romny meteorological station for the period 1979–2020.

Attention should be paid to the intra-annual redistribution of precipitation. During the most recent observation period (2000–2020), precipitation significantly increases in May and July; however, this increase is offset by higher air temperatures during this time of year. In addition, precipitation increases in September and October and slightly in January, February, and March. Conversely, a significant decrease in precipitation is observed in April, June, August, as well as in November and December (Figure 10).

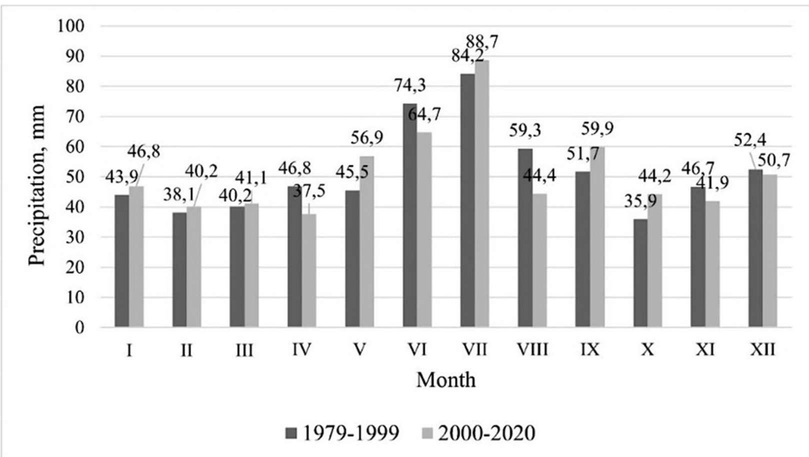


Figure 10. Monthly precipitation at the Romny meteorological station for the observation periods 1979–1999 and 2000–2020.

The level of total evaporation has increased. The mean value of total evaporation for the period 1979–1999 was 505.5 mm, and for 2000–2020 it was 541.5 mm, corresponding to an increase of 7.1%, which confirms the findings of Moses and Hambira (2018). Evaporation increased in all months except June, with the maximum increase observed in March and September, which is explained by higher heat availability during these months (Figure 11).

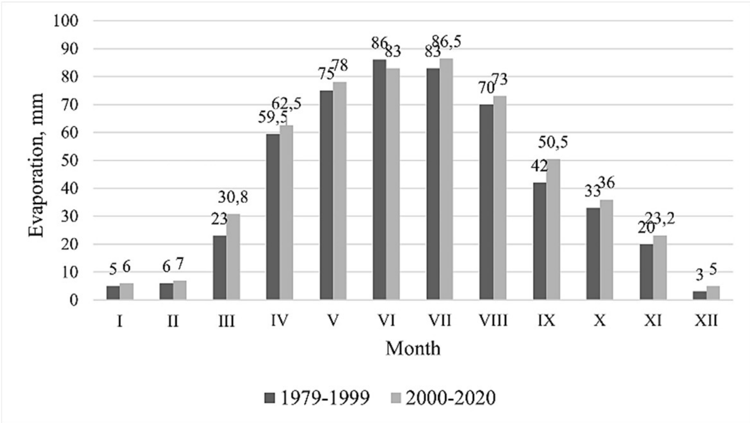


Figure 11. Monthly evaporation at the Romny meteorological station for the observation periods 1979–1999 and 2000–2020.

The conducted studies allowed the determination of quantitative values of the water balance components based on data from the hydrological station and the Romny meteorological station for two observation periods (1979–1999 and 2000–2020), presented in Table 1. The water balance equation does not close, i.e., the algebraic sum of its components does not equal zero. When determining water balance relationships within river basins, there is always a discrepancy (error) in the water balance calculation; the smaller the discrepancy, defined as the residual term of the water balance equation, the more accurate the water balance. Calculations with a discrepancy (error) up to 10% of the precipitation amount are considered acceptable.

Table 1. Components of the water balance of the Sula River basin for the periods 1979–1999 and 2000–2020

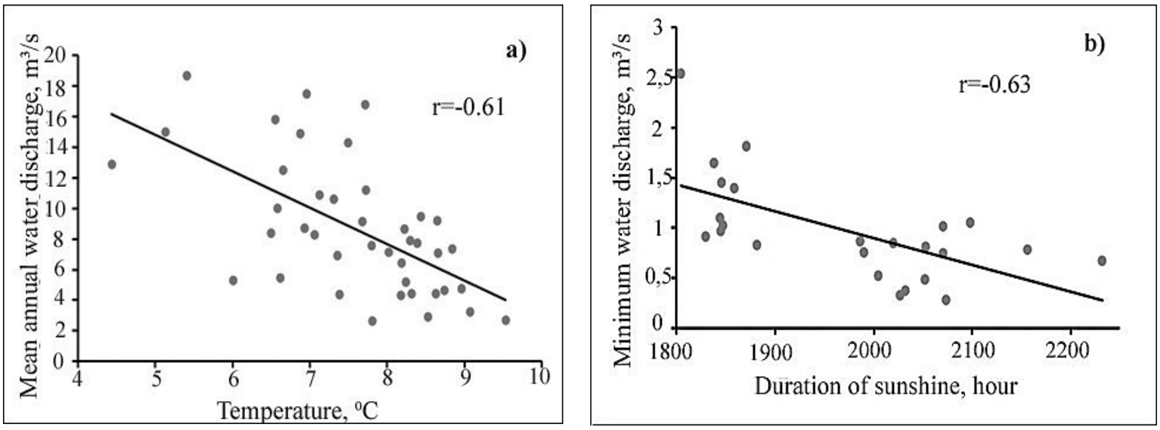
Period, years	**Elements of water balance**			**Discrepancy (error), mm**
	Precipitation, mm	**Evaporation, mm**	**Runoff layer, mm**	
1979-1999	619	505,5	86,3	27,2
2000-2020	608	541,5	48,9	17,6
Difference	-11	+36	-37,4	

The water balance of the Sula River basin (Romny) for the period 1979–1999, calculated based on multi-year data, is: 619 = 505.5 + 86.3 (mm). The discrepancy (residual) in the water balance calculation for 1979–1999 is 27.2 mm, which corresponds to 4.4% of the total precipitation.

The water balance of the Sula River basin (Romny) for the period 2000–2020, calculated based on multi-year data, is: 608 = 541.5 + 48.9 (mm). The discrepancy (residual) in the water balance calculation for 2000–2020 is 17.6 mm, corresponding to 2.9% of the total precipitation.

Analysis of the water balance equations for the two twenty-year periods of the Sula River basin, based on data from the hydrological and meteorological stations in Romny, showed that the amount of atmospheric precipitation has hardly changed, with a slight decreasing trend in the second period (2000–2020) by 1.8% compared to 1979–1999. In contrast, evaporation increased by 7.1% during 2000–2020 compared to the previous period, while the runoff layer in the Sula River basin decreased by 43.3% – from 86.3 mm in 1979–1999 to 48.9 mm in 2000–2020. Analyzing the interrelationships between the runoff layer, precipitation, and total evaporation, it can be noted that rising air temperatures lead to increased evaporation, which, against the background of a slight decrease in annual precipitation, results in a reduction of river runoff. The results of our study confirm the trend that the current decline in river water availability is driven by increasing temperatures, despite minor fluctuations in precipitation (Ruzzante and Gleeson, 2025).

The Pearson correlation coefficient between mean annual water discharge of the Sula River, according to the Romny hydrological station, and mean annual air temperature at the Romny meteorological station for the period 1979–2020 is –0.61 (Figure 12(a)), while the correlation coefficient between minimum water discharge and sunshine duration is –0.63 (Figure 12(b)).



(**a**) (**b**)

Figure 12. Correlation between: (a) mean annual discharge of the Sula River and mean annual air temperature; (b) minimum water discharge and sunshine duration (Romny).

The Pearson correlation coefficient between mean annual water discharge of the Sula River and annual precipitation in the study area is 0.38 (Figure 13).

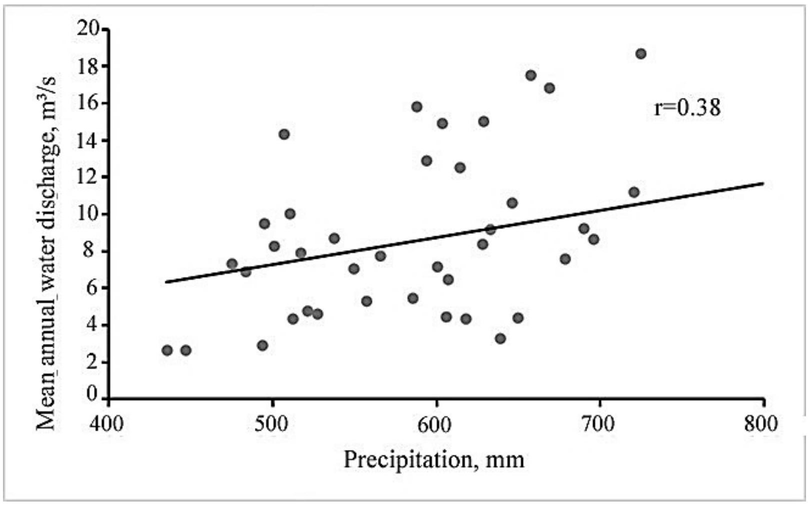


Figure 13. Correlation between mean annual water discharge of the Sula River and annual precipitation (Romny).

The runoff coefficient calculated for the period 2000–2020 is 8% (only 8% of total precipitation contributes to river runoff), which explains the low correlation coefficient. For the period 1979–1999, the runoff coefficient was 13.9%, indicating a significant decrease in this indicator in the current period.

The aridity coefficient (percentage ratio of total evaporation to precipitation) was 81.7% for 1979–1999 and 89% for 2000–2020, corresponding to an increase of 7.3%.

The obtained values of the runoff coefficient and aridity coefficient for different observation periods indicate significant climate-driven changes in the water discharge of the Sula River. The decrease in the runoff coefficient from 13.9% to 8%, together with an increase in the aridity coefficient to 89%, indicates an intensification of climate aridization, increased water losses due to evaporation, and a corresponding reduction in the proportion of atmospheric precipitation transformed into river runoff. This confirms the significant impact of climate change on river runoff formation.

Operational hydrological observations and the authors' field studies conducted during 2021–2025 indicate the persistence of low-water conditions in the Sula River, manifested in consistently reduced discharge values compared to the long-term average. According to official data from the Ukrainian Hydrometeorological Center (On the Water…, 2025) and the Regional Water Resources Office (Weekly Information…, 2025), the water availability of the Sula River in 2025 amounted to less than 10–20% of the monthly norm, and during some periods reached only about 9–12%, corresponding to conditions of persistent low water. All the observations presented are consistent with the identified long-term trend toward decreasing river water discharge and confirm the persistent nature of low-water conditions in the contemporary period.

5. Conclusions

Thus, during the study period, the Sula River is in a low-water phase. A stable downward trend is observed for all studied runoff characteristics, with the turning point in the river's water availability phases beginning in 1989. Mean annual air temperatures (based on observations at the Romny meteorological station) for the period 1979–2020 show a stable upward trend, as do total evaporation values; in contrast, the annual precipitation shows a weak decreasing trend, and the increase in precipitation during the warm season is offset by higher evaporation during this period. Analysis of the water balance components of the Sula River basin for the periods 1979–1999 and 2000–2020 revealed that annual atmospheric precipitation has changed little (a decrease of 1.8%), evaporation increased by 7.1% in the second observation period, while the runoff layer decreased significantly by 43.3%. The calculated Pearson correlation coefficients between mean annual water discharge of the Sula River and mean annual air temperature, as well as between minimum water discharge and sunshine duration, indicate an inverse correlation: as air temperature and sunshine duration increase, water discharge decreases, with a high magnitude of correlation. The relationship between mean annual water discharge and annual precipitation indicates direct dependence: as precipitation increases, water discharge also increases; however, the correlation is low, which is explained by the low runoff coefficient (8%). This low value and its reduction in the second observation period, from 13.9% to 8%, i.e., more than one-third, is accompanied by a regular increase in the aridity coefficient of 7.3%. Thus, an increase in mean annual air temperature leads to higher evaporation, which, against the background of a slight decrease in precipitation, results in a reduction of the river runoff layer.

The reduction in river runoff and the intensification of low-water conditions caused by climate change, combined with significant anthropogenic pressure, contribute to the drying up of certain water bodies during low-flow periods, limit water use opportunities in the region, and create conditions for increased concentrations of pollutants, deterioration of water quality, and intensification of eutrophication processes within aquatic ecosystems of the basin. The identified trends of climate change and increasing low-water conditions have persisted beyond the study period, emphasizing the importance of continuous monitoring. The results obtained may be used to improve regional water resources management, environmental monitoring, and the development of adaptation measures within the Sula River basin. Among the priority climate adaptation measures, it is advisable to recommend the restoration of the water-retention capacity of catchments (denaturalization of floodplains and wetlands, reduction of land plowing intensity, restoration and conservation of forests), reduction of anthropogenic pressure on the river and its basin, as well as revision of approaches to flow regulation and the functioning of land reclamation systems.

Further research will focus on extending the observation period, assessing the role of anthropogenic factors in the reduction of river water availability, and applying hydrological modeling to forecast future changes in river runoff under different climate scenarios.

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