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Climate monitoring as an indicator of the hydrological condition of the Siversky Donets river basin

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ABSTRACT

Formulation of the problem. Today, in changing climate conditions, it is very relevant to study the impact of regional climate change on the regime of hydrological indicators and ecological status of the Siversky Donets river basin within Kharkiv region.

Analysis of recent research and publications. Hydrometeorological studies are complex and large-scale. In the late 20th - early 21st centuries, a number of articles studied annual runoff of the rivers of Ukraine under the influence of atmospheric processes. Present-day changes in temperature and humidity of the territory affect the hydrological conditions of the rivers.

The aim of the work is to assess the relationship between climatic and hydrological indicators (environmental dynamics) of the Siversky Donets basin against the background of regional climate change. In these conditions, monitoring of climate, hydrological and environmental indicators, allows us to make further management decisions on water resources management.

Research methods are presented by statistical and cartographic analysis. The source data are a number of climatological, hydrological and environmental observations within the state network of the Ukrainian Hydrometeorological Center of the SES of Ukraine.

Problems of further research. Modern changes in climatic conditions in Ukraine are characterized by locality and rapidity. Considering the volume of water use from the river Siversky Donets, the question arises about the water supply of the region, optimization of its use and further rational management.

Presentation of the main research material. The dates of the ice cover have changed in recent years, and often ice phenomena may not occur at all. We can see significant warming in winter on the example of January air temperatures.

Summer temperatures are growing the fastest (by 0.37°C every 10 years), autumn temperatures are in the second place in terms of growth rate. which means that stable ice cover on most rivers of the Donets basin has been absent in recent decades, which clearly indicates a warming trend.

Practical value. Based on the main provisions of the national environmental policy of Ukraine on the use of water resources the study of changes in hydrological regime of rivers is of practical importance for sustainable management. Calculation of the IWP has revealed that most rivers belong to the third and fourth categories - "moderately polluted" and "polluted", but there are also absolutely catastrophic cases.

Research results. Heavy economic burden on the waterway will increase its over-regulation. In future, comprehensive assessment of climate change impact on the hydrological conditions of the rivers will determine the degree of change in the ecological state of the waterways, their rational use and protect.

Keywords*: environmental monitoring, natural environment, climate monitoring, ecological condition, hydrological indicators, regional climate change, Siverskiy Donets basin.*

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Formulation of the problem. Present-day changes in climatic conditions are one of the factors affecting the water resources conditions of the territories, creating an additional burden on the socio-economic ties of the country. The problem of climate risks is complex, as it affects not only the climate but also water resources, food problems, soil degradation, migration, demographic processes, uncontrolled

urbanization. The importance of adaptation to climate change is addressed in the EU's Strategy for Adaptation to Climate Change (2013). It includes several elements: from advising to disseminating new knowledge, exchanging information, strengthening the resilience of the most vulnerable sectors of the economy. Thus, global monitoring of the environment state allows us to determine the level of environmental safety and rational use, reproduction of natural resources, as well as to predict various threats, seeking measures to overcome them.

Growing anthropogenic pollution of the environment, reduction of quantitative and species status of biodiversity, scarcity of water resources, attracts the attention not only of scientists, but also of the world community. International legal instruments (UN Framework Convention on Climate Change, Kyoto Protocol, Paris Agreement, European Green Course) are aimed at consolidating global efforts, creating a global system of environmental monitoring to identify environmental changes and threats in general, and in individual regions of the planet. Ukraine follows the world experience, where monitoring studies are considered one of the measures to implement state environmental policy [6].

Current climate change, according to most countries, is a common concern of the humankind as its activities are believed to increase the concentration of greenhouse gases in the atmosphere, affecting natural ecosystems (UN Framework Convention on Climate Change, Kyoto Protocol, Paris Agreement). The need and importance of monitoring the climate system, development of measures to adapt to climate change is a current challenge, facing everyone at the local, national, regional and international levels. Thus, climate monitoring can be considered a factor in maintaining ecological balance, preservation of natural systems. It is aimed at optimal management of natural resources, prevention, minimization of losses and damages associated with the adverse effects of climate change, sustainable development of territories.

Analysis of recent research and publications. Hydrometeorological studies are complex and large-scale [1-12, 19-21], mainly concerning large areas (the Dnieper basin or the whole country).

In the late 20th - early 21st centuries, a number of articles studied annual runoff of the rivers of Ukraine under the influence of atmospheric processes [1-3, 5]. At the beginning of the 21st century, difference in fluctuations of annual air temperatures in both western and eastern Ukraine decreases, explained by the gradual increase in air temperature indicators. The North Atlantic fluctuations affect the formation of the temperature regime in winter. [1, 7-9]. The article covers the issues of interlatitudinal connections of temperature and pressure fields in the Atlantic-European sector, as well as the dynamics of thermal and humidity regimes in the territory of the Siversky Donets river basin. Moreover, Scandinavian fluctuations influence the river flow's variability [1, 7], determining hydrological characteristics of the upper part of the Dnieper river basin.

Climate change is also associated with floods, which are more common in Europe and vary in intensity, leading to higher economic costs. In recent decades, a number of scientists have investigated the regional climate responses [10-13]. In [17-18], the authors explain scientific and methodological approaches to calculating characteristic maximum runoff of the rivers of Ukraine. Despite the vast experience gained by scientists, the problem attracts attention due to the multifactorial nature of the studied phenomenon and regional formation features of maximum river runoff. Thus, the authors propose a universal approach, presenting the analyzed structures in the form of dimensionless complexes. They help to model the maximum runoff of the plain rivers of Ukraine, taking into account climate change, without using the initial data [17].

The article [16] considers connection between extreme precipitation and floods, noting the impact of climate change on hydrological conditions of watercourses, which future analysis of regional risks should take into account.

Selection of previously unsolved parts of the general problem. The study of the large river basin within Kharkiv region is relevant because with the development of decentralization processes, it is important to understand what processes are taking place in a particular region, to make management decisions for effective adaptive environmental management.

Formulation of the purpose of the article. The aim of the work is to assess the relationship between climatic and hydrological indicators (environmental dynamics) of the Siversky Donets basin against the background of regional climate change. The source data are a number of climatological, hydrological and environmental observations within the state network of the Ukrainian Hydrometeorological Center of the SES of Ukraine and its regional branch - Kharkiv Regional Center for Hydrometeorology and the State Agency of Water Resources of Ukraine. In our research we used the following data: air temperature, precipitation for 1961 -2020 at 7 meteorological stations of the region, data on temperature, level and water consumption for the period 1961-2020 at 13 hydroposts; data on surface water pollution at 11 points of environmental monitoring for the period 1995-2020. The basis of the study is the spatio-temporal analysis of climatic and hydrological indicators of the Siversky Donets river basin, applying statistical, mathematical and cartographic methods.

Presentation of the main research material. Conditions of water resources largely determine the

living conditions of the population in the researched area. As the Siverskiy Donets basin is the most significant source of water for Kharkiv - the second largest city in Ukraine, it is important to study the long-standing changes that have taken place and will occur here in the future (Fig. 1). The tectonic basis of the basin are the Voronezh crystalline massif, the Dnieper-Donetsk depression and the spurs of the Donetsk folded structure, which correspond in relief to the Middle Russian Upland and the Poltava Plain. Rivers contribute to land erosion, the result of which is that about a third of the basin is prone to erosion, and about 5% of soils are heavily washed away, especially in the northwestern part of the basin.

Analysis of intra-annual changes in air temperature in Kharkiv region for the period 1991-2020 indicates its homogeneous nature: the minimum values of air temperature are typical for January and February (-5.0… -5.5ºC), during March - April it intensively grows, in July-August it reaches the maximum values (+ 20.5… + 22.0ºC). In recent decades, there have been recorded changes in the thermal regime of the seasons: winter air temperatures are above 0 °C, significant temperature fluctuations from positive to negative values are frequent, there is no stable snow cover.

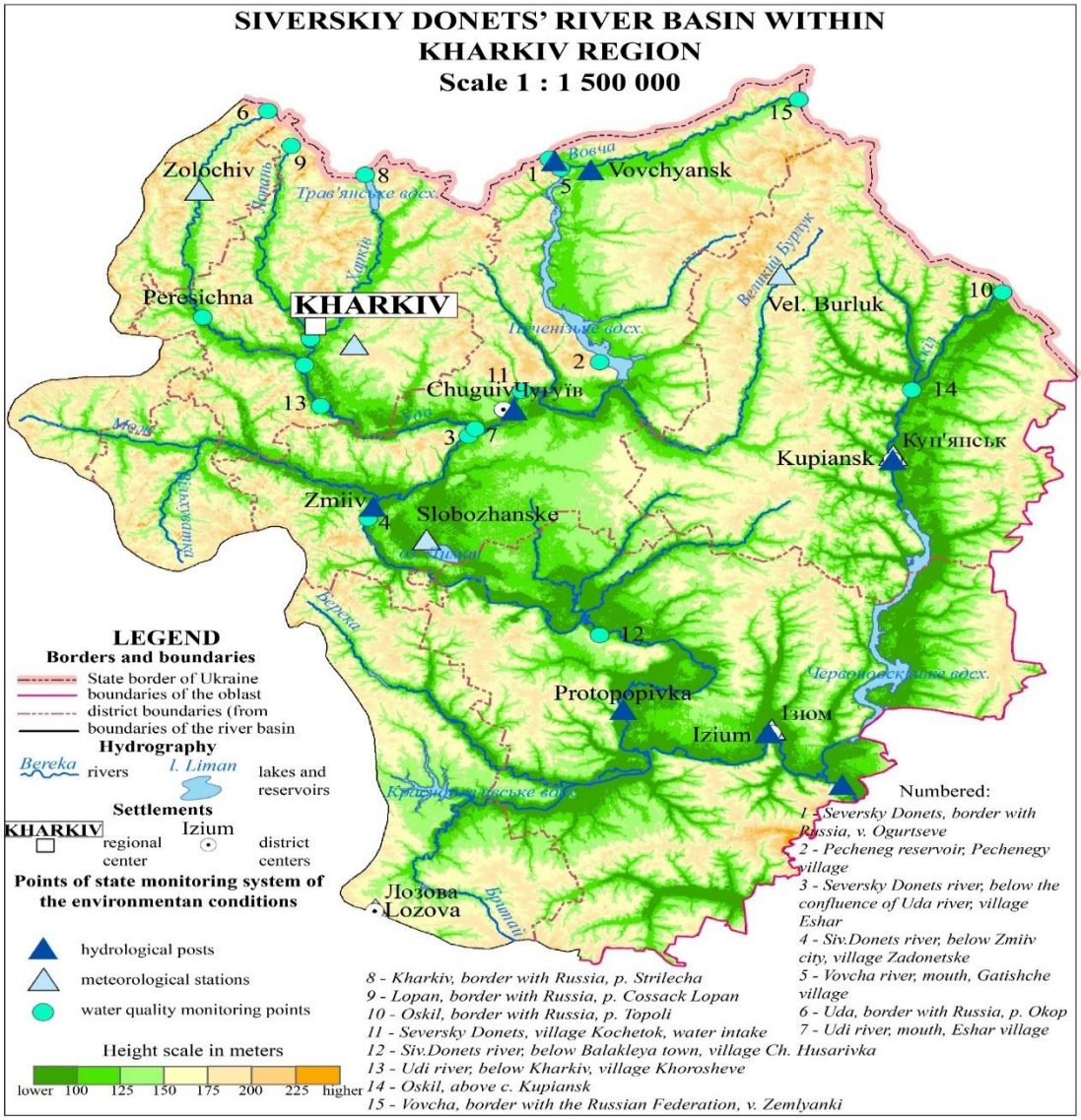

Fig. 1. Siverskiy Donets river basin within Kharkiv region

In spring and autumn, the air temperature is unstable: the average spring air temperatures in the river basin are characterized by a vivid increase in the south-east from + 8.5 ° C to + 9.25 ° C in the direction of Kharkiv-Izyum. In autumn, air temperatures are mainly sublatitudinal in nature, increasing from + 8.0 °C to + 8.5 ° C to the south.

Precipitation is characterized by significant randomness: 550 mm / year and more recorded in the central part of the basin, in the north and south of the basin - they are up to 525 mm / year. The analysis of the precipitation amount during the year at most meteorological stations in the Siversky Donets basin is similar. In the north of the basin, there are three

relative peaks - in June, October and December (Fig. 2), while in the south there are two - in June and December (Fig. 3). Minimum precipitation is in March and April. During the summer, there are two thirds of the annual rainfall.

Temperature regimes of the river are very similar according to various hydroposts, only in the south temperature values gradually increase. During December-March, the river is often covered with ice and snow. In the spring, after the ice melts, the water in

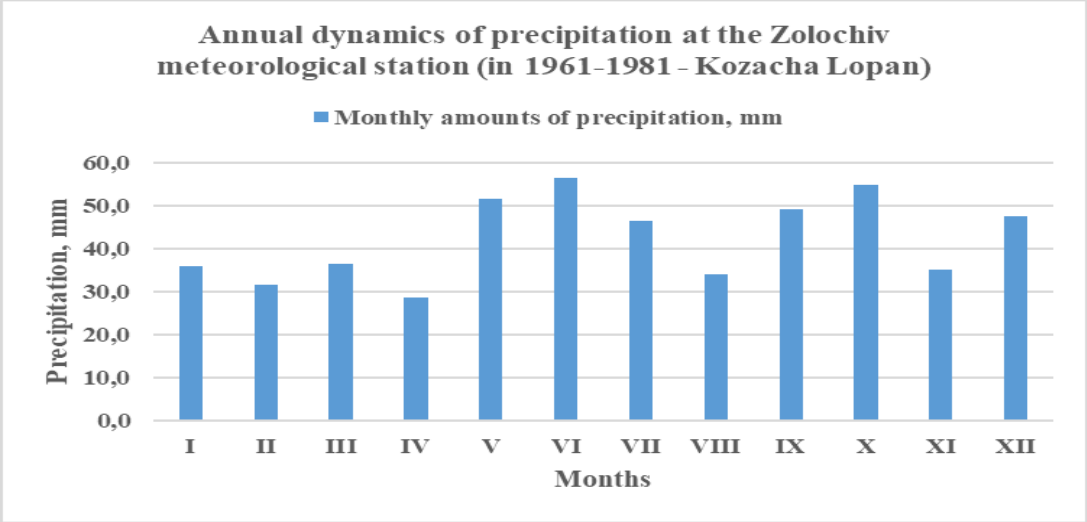

Fig. 2. Precipitation dynamics at Zolochiv station

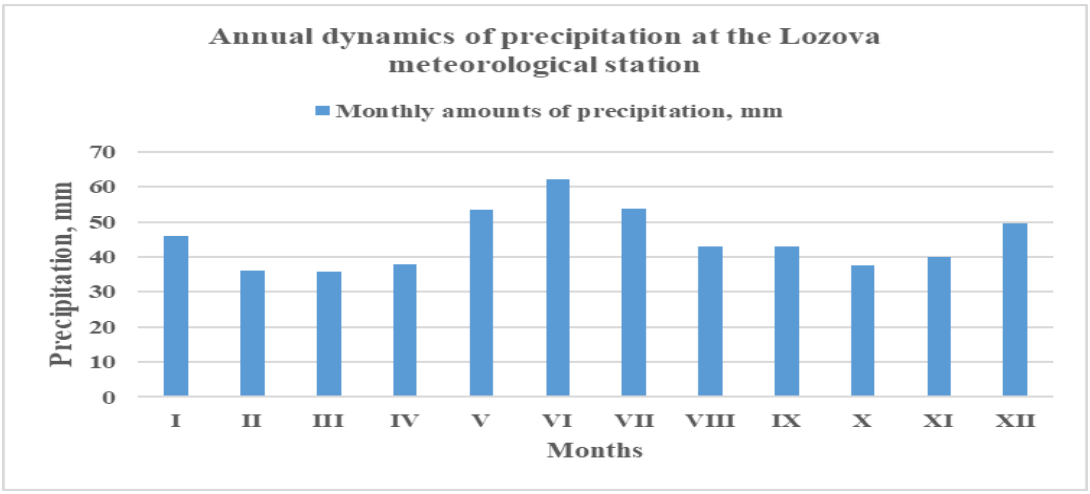

Fig. 3. Precipitation dynamics at Lozova station

the rivers begins to warm up rapidly and by June the temperature reaches + 22ºC and above. The average water temperature is slightly higher than the air temperature, as the stations do not take night water temperature measurements. During July-August, the water temperature remains at 23-24ºC, then it goes down, and in late November – early December reaches 0°C.

The dates of the ice cover have changed in recent years, and often ice phenomena may not occur at all. At the same time, the peculiarity is that according to the hydropost Bezlyudivka (Uda), winter temperatures are on average 2-3ºC higher than at other posts, which is due to discharges from industrial enterprises, household facilities,etc.

The water regime of the Siversky Donets and its tributaries has a pronounced spring flood, in summer and winter - low tide (Fig. 4). At the same time, we notice significant over-regulation of the Siversky Donets and Oskil rivers by reservoirs. According to the post in Pechenigy, spring floods are less pronounced than in others, as it is located near the dam of the Pechenigy reservoir. Water drains gradually over several months there, reducing the contrast of the summer flood plain. Accordingly, on the one hand, anthropogenic intervention can make the water regime more stable, and on the other - transformation of a narrow winding riverbed, the presence of an artificial lake causes a number of problems.

First, due to the increase in the water area, evaporation from the surface increases, and because the water in the reservoir moves slowly in contrast to the river, it stagnates and leads to gradual overgrowth of reed which pumps out water and additionally pollutes

the reservoir. As a result, in an effort to conserve more water within the reservoir, man reduces the total water content of the river and contributes to additional pollution of the river water.

Indicators of the module and the runoff layer characterize water supply of the territory. The modulus of runoff in the Donets basin varies between 2 and 4 $l / s \cdot km^2$, where its greatest value is around the city of Kharkiv. This is explained by numerous measures to "flood" the city's rivers in the first half and mid-twentieth century. The runoff layer varies between 60-100 mm, with the highest values observed in the north of the basin (due to more precipitation), as well as around Kharkiv.

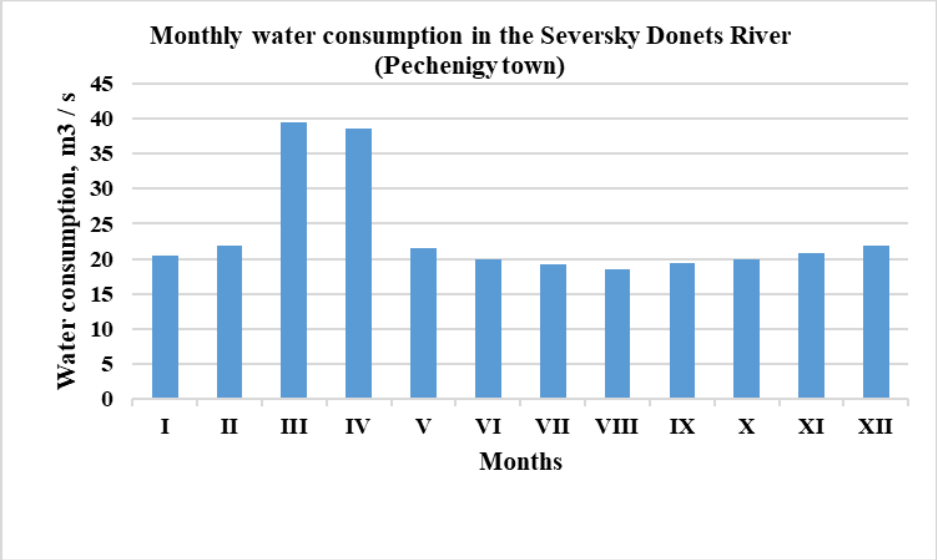

Fig.4. Dynamics of water consumption in the Siversky Donets (village of Pechenigy)

Prolonged industrial exploitation of water bodies, as well as pumping water for extensive agriculture, have led to the degradation of water resources. Currently, due to the lack of a systematic environmental policy, the region's rivers and reservoirs are in poor condition. Calculation of the IWP has revealed that most rivers belong to the third and fourth categories - "moderately polluted" and "polluted", but there are also absolutely catastrophic cases. We are talking about the rivers around the city of Kharkiv - the Uda, the Lopan and the Kharkiv, which have IWP of the fifth and sixth categories (Table 1).

Analysis of air temperature for two periods (1961-1990, 1991-2020) allows us to determine the trend of climate change for the project period 2021-2050. We can see significant warming in winter on the example of January air temperatures (Fig. 5). Average July temperatures are not rising so fast, but the trend towards warming is obvious.

Notable warming was recorded during 1980-

Table 1

Index of water pollution in the rivers of the Siversky Donets basin within Kharkiv region

River	Observation point	Average IWP (1995-2020 pp.)	Water quality class
Siversky Donets	Ogirtseve	4,00	V. Dirty
Siversky Donets	Chuguiv (beyondthe town)	0,99	II. Clear
Siversky Donets	Chuguiv	2,24	III. Moderately polluted
Siversky Donets	Zmiiv	1,75	III. Moderately polluted
Siversky Donets	Izyum	3,72	IV. Polluted
Kharkiv	Tsyrkuny	4,18	V. Dirty
Lopan	Kharkiv	5,53	V. Dirty
Lopan	Kozacha Lopan	3,36	IV. Polluted
Udy	1 km	7,00	VI. Very dirty
Udy	10 km	3,70	IV. Polluted
Oskil	Kupiansk	3,61	IV. Polluted
Vovcha	Vovchansk	1,17	III. Moderately polluted

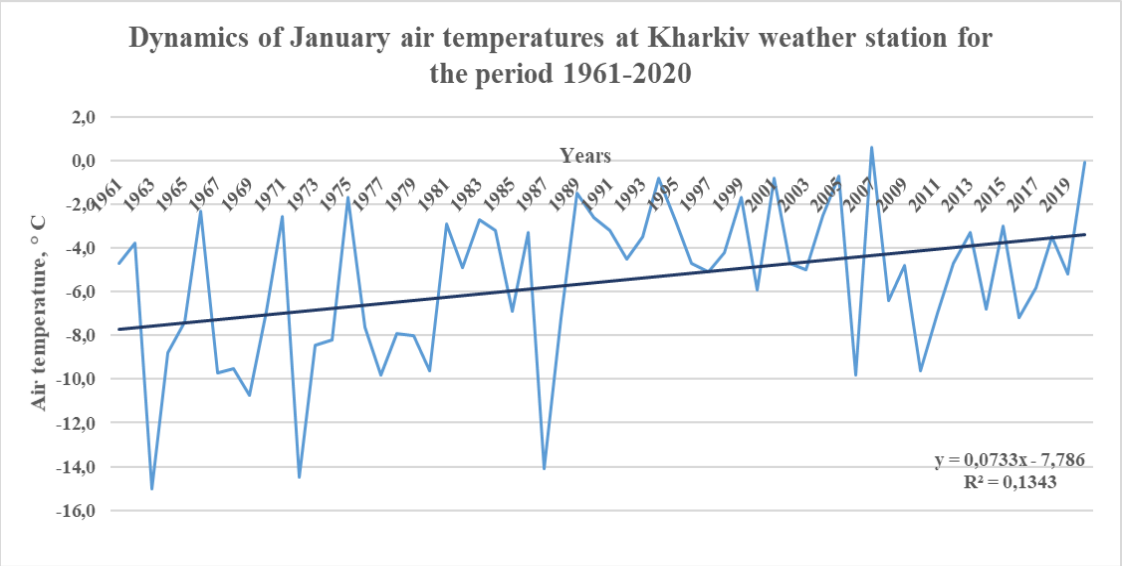

Fig. 5. Dynamics of January air temperatures in Kharkiv in 1961-2020

1990, 2000-2008, after the abnormally hot summer of 2010, air temperature growth is accelerating.

The growth rate of air temperature in January was almost twice as fast as in July for the period 1961-2020: at the meteorological station Zolochiv by 0.9 °C every 10 years, at the stations Velykyi Burluk, Izyum and Lozova – by 0.7 °C every 10 years. The temperature regime in July is characterized by an increase of 0.4 °C every 10 years at almost all stations.

Analysis of the rising air temperatures for the two periods 1961-1990 and 1991-2020 in the river basin indicates an increase of 2.7 °C and 3.3 °C in January, respectively. The highest temperature rise is observed in Zolochiv and Velykyi Burluk, while the lowest is in Kharkiv, Kupyansk and Izyum.

July air temperatures are characterized by 1.8°C increase in Kharkiv, by about 1.5 °C – in other cities. Average annual temperatures are characterized by an increase of 1.1-1.5 °C. A characteristic feature of the Siversky Donets river basin is decreasing precipitation, indicating drought.

In winter, rivers are often covered with ice. However, January temperatures are considered zero. July water temperatures are an important indicator of changes in summer temperatures. The data of most of the involved hydroposts indicate a rise in water temperature, except for Kozacha Lopan, where a slight decrease is noticeable. At the same time, the rate of this growth is rather insignificant compared to air temperatures, as water heats up and cools more slowly due to its high heat capacity, and accordingly, the long-term dynamics will also be less noticeable.

Average seasonal temperatures are an additional marker of changes in the thermal regime of surface waters of the Donets basin. Summer temperatures are growing the fastest (by 0.37 °C every 10 years), autumn temperatures are in the second place in terms of growth rate, followed by spring and winter temperatures.

Relatively low rate of changing indicators characterize winter-spring water temperatures, where the growth is the highest for meteorological values. The reason for this discrepancy is the lack of measurements of water temperature when it is under the ice cover, i.e. from late November to early December and early to mid-March. Accordingly, winter temperatures, which were previously absent in hydrological yearbooks, are now recorded, which means that stable ice cover on most rivers of the Donets basin has been absent in recent decades, which clearly indicates a warming trend.

Peculiarities of the territorial distribution of changes in the thermal regime of water are the increase in the values of July temperatures for all hydroposts, except for Kozacha Lopan. The average annual values of water temperature also increased at all hydro posts, except for Kozacha Lopan. This can be explained by the anthropogenic load on the territory, where there are numerous enterprises – industrial and municipal not far from the hydropost, and therefore, their discharges lead to a significant increase in water temperature.

Water bodies have undergone changes in the hydrological regime: the long-term dynamics of water flow (Fig. 6) indicates a tendency to reduce the volume of water passing through the cross section of the Siversky Donets and its tributaries. However, this process does not occur at the same speed in different parts of the basin. The most noticeable decrease in water consumption in two periods is typical for the hydroposts Ogirtsevo, Zmiiv, Protopopivka and Izyum. The tributaries of the Siversky Donets have less water consumption in Bezlyudivka and Vovchansk. At the same time, water consumption in Pechenigy and Kozacha Lopan has hardly changed.

Anthropogenic intervention (presence of a regul-

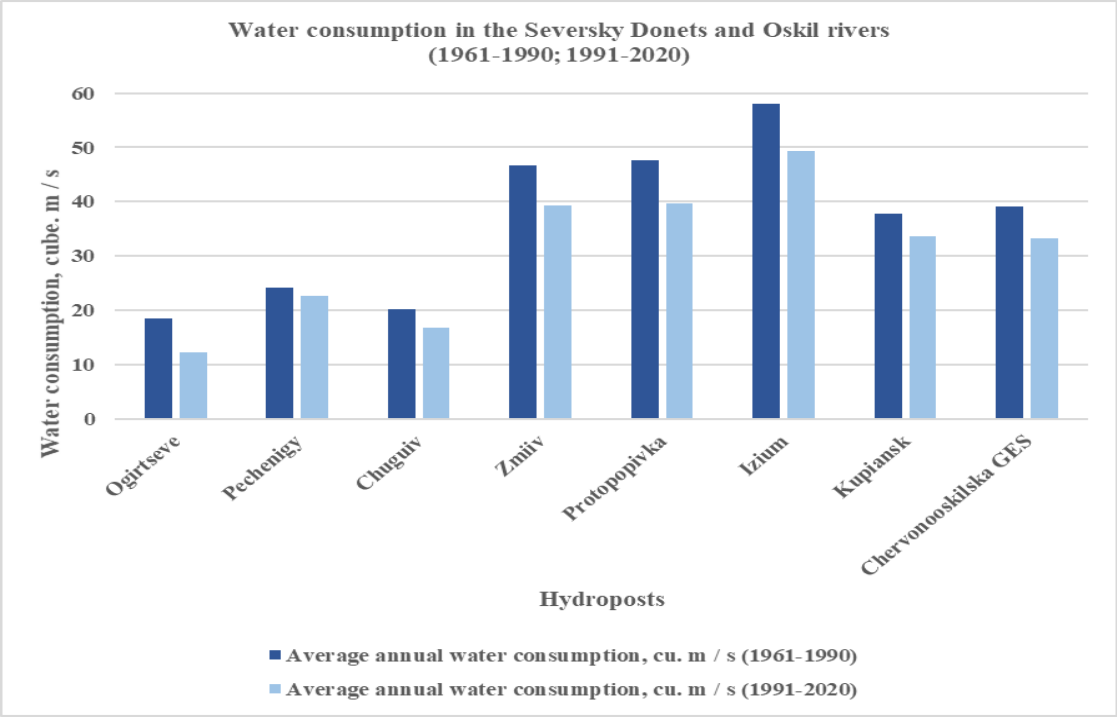

Fig. 6. Water consumption:1961-1990;1991-2020.

ated reservoir) plays an important role in the former case, while in the latter - insignificant amounts of water consumption seems insignificant.

The authors analyzed the relationship between climatic and hydrological parameters using correlation coefficients for two pairs of indicators: air temperature – water temperature and precipitation - water consumption. The connection was calculated for 5 meteorological stations and 5 hydroposts because a number of hydroposts are relatively far from meteorological stations (more than 20 km). There is a close relationship of air and water temperatures of 0.8 (Fig. 7). The intra-annual distribution of the correlation coefficient is characterized by quite noticeable changes: it reaches its highest values in March, July and September.

Small values of the correlation coefficient characterize precipitation influence on runoff formation: the maximum correlation is in summer during the period of maximum precipitation and a short-term in-

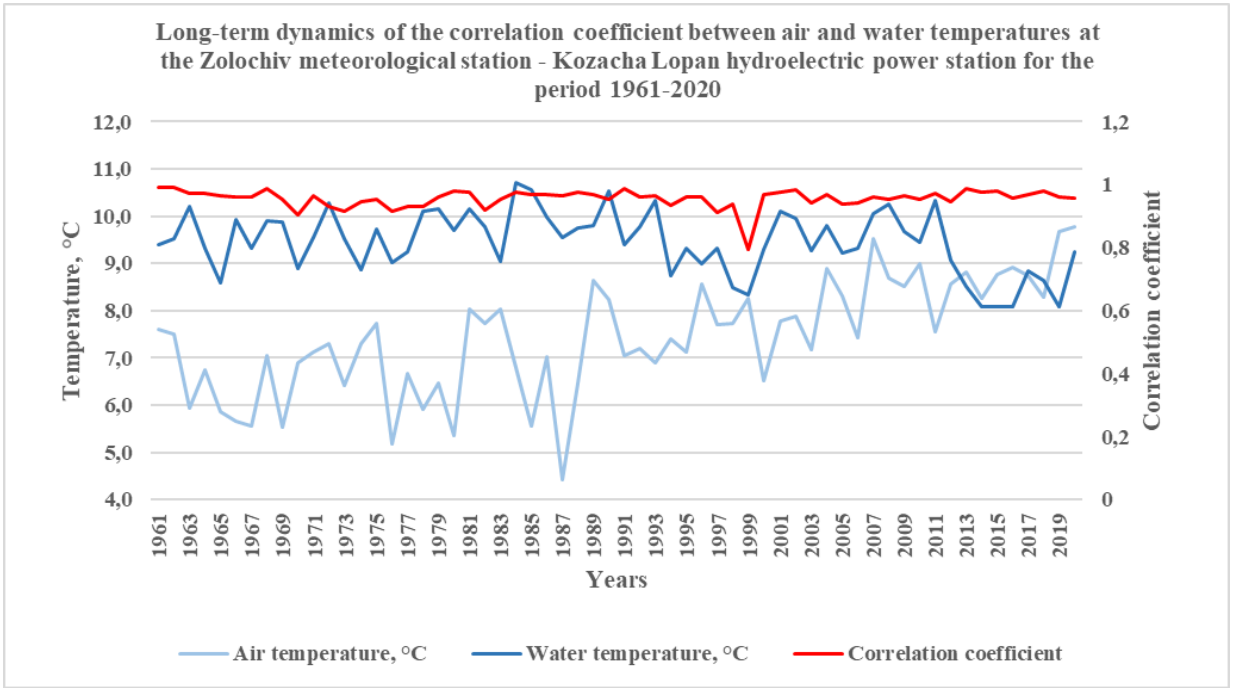

Fig. 7. Long-term dynamics of the correlation coefficient between air and water temperatures at Zolochiv meteorological station - Kozacha Lopan hydropost, 1961-2020

crease in water consumption in the middle of summer. In spring, during the spring floods, when the amount of precipitation decreases, the coefficient is inverse. A similar situation is in August, when water consumption begins to rise, and precipitation reaches its minimum.

The significance of the obtained coefficients was checked by calculating the Student's criterion (Table 2), which indicates statistically significant relationships.

The correlation analysis confirmed a strong relationship between air and water temperatures. At the same time, the intra-annual distribution is characterized by a change in the coefficient, depending on the ratio of different temperatures. That is, the strongest relationship is observed in summer, when the temperature stabilizes, and the minimum – in periods of active heating and cooling. The relationship between precipitation and water consumption is average, as water consumption in the spring coincides with the minimum precipitation, and underground sources play a considerable role in the summer, too.

The projection of future changes in the main meteorological and hydrological values is important because it is the basis for ecological assessment of the territory. The project changes were built by comparing two periods: 1961-1990, 1991-2020. The authors calculated the rate of changes in the characteristics and their transfer to the forecast period (2021-2050), using regression equations. Further increases in air temperatures are expected in January and July at all meteorological stations in the direction from northeast to south, southwest (Fig. 8). The highest temperatures will be observed in Kharkiv, Kupyansk and Izyum.

The article emphasizes that the amount of precipitation will change ambiguously (Fig. 9): mostly there will be a decrease of precipitation in the territory of Kharkiv region by 20-60 mm.

We can also expect changes in the main characteristics of water bodies: their temperature and costs. Average annual water temperatures will change in the direction of growth (0.3-0.5 °C), seasonal fluctuations will be typical for autumn and spring. In the future, water consumption will continue to decline mostly in the central part of the Donets River (Zmiiv, Protopopivka), as well as on the Uda river (Bezlyudivka). To a lesser extent, this applies to the area of the Pechenigy reservoir, where significant over-regulation of the river hinders the shallowing

Table 2

Calculation of Student's criterion for the correlation coefficient between air and water temperatures at meteorological stations and Kupyansk hydroposts

Months	January	February	March	April	May	June	July	August	September	October	November	December
r	0,45	0,55	0,90	0,38	0,81	0,85	0,82	0,60	0,83	0,54	0,55	0,53
t	1,89	2,63	16,50	1,46	7,67	10,50	8,15	3,13	8,63	2,54	2,57	2,45
σ	0,24	0,21	0,05	0,26	0,11	0,08	0,10	0,19	0,10	0,21	0,21	0,22
α	12	12	12	12	12	12	12	12	12	12	12	12

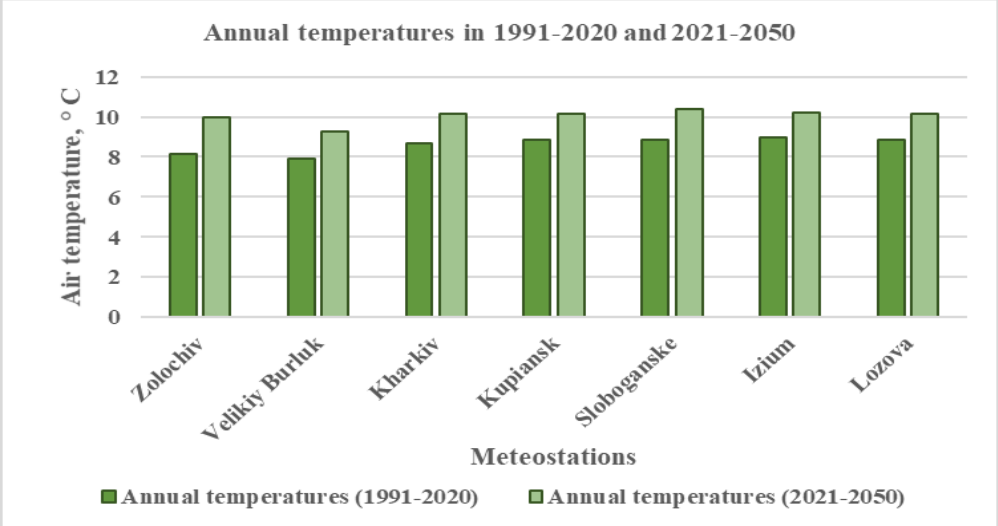

Fig. 8. Projections of annual air temperatures

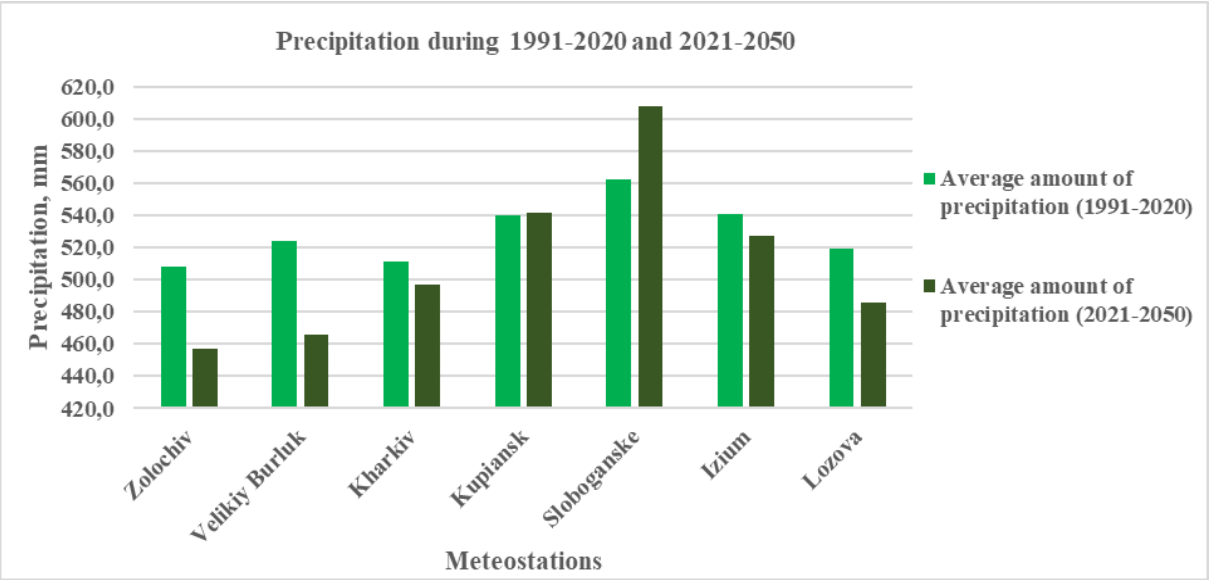

Fig. 9. Projections of precipitation amount

process.

Conclusions. The results of the study indicate the relevance of identifying factors that have the greatest impact on changes in the hydrological characteristics of water resources. Research has shown that the maximum relationship exists between air and water temperatures. Precipitation influence on the runoff formation is characterized by small values of the correlation coefficient with maximum influence in summer.

The identified projections of future changes in air temperature are characterized by their further rise. The change in the amount of precipitation will obviously depend on a variety of fluctuations, although we can note a predominant tendency to their reduction.

Climate change a are an important factor in the formation of the modern regime of water resources, so their projections are aimed at making the right management decisions on the use and restoration of water resources.

Therefore, in the future, according to the air temperature, the water temperature is expected to increase, water consumption will continue to decrease mostly in the central part of the Siversky Donets basin. The water content of the rivers is declining at a fairly significant rate: by 2050, the average water consumption will be 40-50% of the cost in the previous period. Heavy economic burden on the waterway will increase its over-regulation.

In future, comprehensive assessment of climate change impact on the hydrological conditions of the rivers will determine the degree of change in the ecological state of the waterways, their rational use, allowing us to implement measures to reduce the negative impact and protect water resources.

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Кліматичний моніторинг як індикатор гідрологічного стану басейну річки Сіверський Донець

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Вивчення впливу регіональних змін клімату на режим гідрологічних показників та екологічний стан басейну річки Сіверський Донець у межах Харківської області є актуальним, оскільки даний водотік із супутніми річками та іншими водними об'єктами є найважливішим джерелом води для східної частини України, особливо для урбанізованого міста Харків та промислового району Донбасу. Сучасні зміни температурно-вологісного режиму території відбиваються на гідрологічному стані річок, які стають маловодними та характеризуються погіршенням свого якісного стану. Враховуючи об'єми водокористування, які припадають на річку Сіверський Донець, виникає питання про водозабезпеченість регіону, оптимізацію його використання та подальше раціональне управління. Метою роботи виступає взаємозв'язок між кліматичними та гідрологічними показниками (оцінка динаміки екологічного стану) басейну Сіверського Дінця на тлі регіональних змін клімату. Моніторинг кліматичних, гідрологічних та екологічних показників дозволяє приймати подальші управлінські рішення щодо управління водними ресурсами під час кліматичних змін. Основними завданнями дослідження є визначення взаємозв'язків між кліматичними та гідрологічними показниками басейну річки Сіверський Донець та їх проєкцій. В результаті проведення кореляційного аналізу була підтверджена наявність сильного зв'язку між температурами повітря і води. У внутрішньорічному розподілі характерним є зміна коефіцієнта в залежності від співвіднесення ходу різних температур, тобто найсильніший зв'язок помітний влітку, коли температура стабілізується. Встановлено середній зв'язок між опадами та витратами води, оскільки хід витрат води навесні співпадає із мінімумом опадів, а влітку значну роль відіграють підземні джерела. Дослідження впливу змін кліматичних показників на гідрологічні дає можливість встановити стан еколого-гідрологічних умов річок за умов антропогенного навантаження на тлі подальших змін кліматичних показників, що матимуть різноспрямовані тенденції.

***Ключові слова**: моніторинг довкілля, природне середовище, кліматичний моніторинг, екологічний стан, гідрологічні показники, басейн річки Сіверський Донець, регіональні зміни клімату.*

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