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**Borys Shulika***
PhD of Sciences (Geography), Associate Professor of the Department of Physical Geography and Cartography. The Faculty of Geology, Geography, Recreation and Tourism; e-mail: b.o.shulika@karazin.ua; shulika91@gmail.com;
ORCID ID: https://orcid.org/0000-0002-2427-4124

**Viktoriia Kabanova***
Bachelor of Geography. Department of Physical Geography and Cartography,
EPP «Physical Geography, Monitoring and Cadastre of Natural Resources». The Faculty of Geology,
Geography, Recreation and Tourism; e-mail:kabanova2021.9511896@student.karazin.ua, viktoriakabanovaforjob@gmail. com;
ORCID ID: https://orcid.org/0009-0008-0867-1825

*V. N. Karazin Kharkiv National University Svobody Square, 4, Kharkiv, 61022, Ukraine

# Trends of modern climate change in Kharkiv oblast

**The purpose of the article** is to identify and establish regular climate changes in Kharkiv Oblast, as well as to highlight individual variability in certain settlements.

**The main material.** In general, in Ukraine, the issue of climate change is a serious problem, because, according to research by both Ukrainian and international scientists, the country's climate has been changing for a long time. The main directions of these changes are an increase in the average annual and monthly air temperature, as well as fluctuations in precipitation throughout the year. The greatest threat to Ukraine in this context is the deterioration of conditions for growing various agricultural crops, since a significant part of the Ukrainian economy is focused on the primary sector.

And accordingly, the main task is a comprehensive analysis of the dynamics of climate change in the Kharkiv Oblast at the regional level. The study has identified the main trends and features of the transformation of the climatic regime in the region. Particular attention has been paid to assessing the impact of active hostilities on the accuracy and completeness of climatic observations, as well as on the formation of local microclimatic conditions within the region. Based on the data obtained, a climate change forecast has been made for individual settlements in Kharkiv Oblast. In addition, a number of recommendations have been formulated aimed at counteracting the negative consequences of climate change and adapting to new conditions.

**Conclusions and further research.** The general characteristics of the climate and the climatic features of the selected cities have been analyzed. As a result of changes in the global climate, local changes are also observed in the territory of Kharkiv Oblast. Statistical data and constant norms of temperature indicators have been analyzed, which allowed us to identify trends in climate change in 2010-2021. The main trends of climate change in Kharkiv Oblast have been identified, among which the trend of increasing average annual temperature has eeen highlighted, as well as the general increase in temperatures during each month, which has been more pronounced during the winter months.

A formula for predicting temperature changes in the territory of the city of Kharkiv has been created, which shows the linear nature of temperature changes in the city, and in connection with this, a list of recommendations for adaptation was created. For the adaptation of the agricultural sector of the economy, it is proposed to introduce state scholarships, subsidies and similar financial incentives for switching to more drought-resistant crops, as well as create state procurement programs for such crops.

**Keywords:** *temperature conditions, climate change, temperature trends, forecast, air temperature, soil temperature, humidity.*

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**Introduction.** The choice of this topic is due to the fact that the impact of active actions at the local level on climate change, both during their implementation and afterwards, still remains insufficiently researched in the scientific community (in most cases, the overall impact of military actions on the atmosphere of the planet as a whole is considered. Several organizations have considered this impact in both past and current wars [2, 12]. The main regions for the study were Vietnam, Kuwait, and Israel), that is, the country as a whole, rather than a separate region or area of study.

This topic is also quite relevant in the current state of affairs, since active hostilities are still underway in Ukraine, including Kharkiv Oblast, and the exact date of their completion is not known. Such stu dies would make it possible to prepare for the expected changes in the region's climate, namely, in the expected changes in air temperature, wind direction, and soil temperature.

**The relevance of the research topic** is due to the fact that at the beginning of the 21st century, the world community recognized that climate change is a problem. It is relevant to the world, and many intergovernmental organizations, such as the Intergovernmental Panel on Climate Change (IPCC) [9], are working on it. This poses a high risk to the global community, namely changes in such indicators as: an increase in the average annual temperature, rising sea levels, droughts, flooding and other natural disasters determine the most negative impact [10].

The international community has reached a consensus that one of the main climate threats is now considered to be global warming [8, 11]. Warming now has had a significant impact on all living conditions, from the construction sector [13, 14] to the agricultural sector [10]. The negative consequences of any climate change are likely to be most severe on the poor and vulnerable, who already lack the resources and opportunities to prepare for new challenges.

Undoubtedly, this is an important topic for the development of Kharkiv Oblast for several reasons. Firstly, Kharkiv Oblast has had and still has a fairly developed agriculture, and any changes would have an impact on the types and varieties of crops grown. In addition, any climate changes would have an impact on construction standards and similar industries.

**Background.** In Ukraine, this is a significant problem, as according to studies by Ukrainian and international researchers [14], the climate of Ukraine has already been changing for many years.. The main vectors of climate change are considered to be an increase in the average annual and monthly air temperature and a change in the amount of precipitation during the year. The main risk for Ukraine as a result of such changes is a change in the conditions for growing various agricultural crops, since a large percentage of the Ukrainian economy is focused on the primary sector of the economy.

As a result of such changes, a large percentage of GDP would directly depend on the effectiveness of one sector's adaptation to potential climate change (the most likely changes include an increase in average temperatures in all months of the year, an increase in the duration of thaws, a change in the length of the frost-free period, and the growing season [6]), so adaptations should begin now.

The history of climate research in Ukraine stretches back several centuries. The first meteorological stations in modern Ukraine began to appear at the beginning of the 19th century in such settlements as Kyiv, Odesa, Poltava, and others. In the middle and at the end of the 19th century, climate research was more of a point-based rather than a general one. Research has been conducted by individual scientists (such as Klosovskyi O.V.) and considered the specifics of the cities and areas where the research has been conducted.

Regular meteorological observations have been conducted in the territory of the city of Kharkiv since 1891. They have been conducted on the basis of the V.N. Karazin Kharkiv National University. In 1921, the Ukrainian Hydrometeorological Center has been established [7].

The last time in the history of Ukrainian climatology the climate of individual large cities has been considered was during the 1980s, when a series of monographs was actively being developed, which included works on the climate of Kyiv, Kharkiv, Dnipro (at the time of publication – Dnipropetrovsk), Poltava, Lutsk, Lviv, Odessa, Vinnytsia, Chernivtsi. After the collapse of the USSR, the development of further works in this series partially stopped. Despite the decision made in 2008 to resume writing and publishing monographs in this series, only one monograph has been revised – "Climate of Kyiv" in 2010.

Currently, there are 187 stations on the territory of Ukraine, some of which are currently located in temporarily occupied territories. Access to the exact number of meteorological posts and stations during military operations is partially limited. Some meteorological stations have ceased operation due to military operations, as a result of which some data for certain meteorological stations are missing.

Currently, climatological studies at stations are being conducted using indicators such as air temperature, soil temperature, air humidity, atmospheric pressure, wind speed, cloudiness, snow cover thickness, and the like [15].

**The purpose of the article** is to identify and establish regular climate changes in the territory of Kharkiv Oblast, as well as to highlight individual variability in certain settlements.

To implement and achieve the goal, the following **tasks** have been set:

1. Analysis the dynamics of climate change in Kharkiv Oblast at the regional level.

2. Identification of the main trends and features of climate change in the Kharkiv region.

3. Separation the impact of active hostilities on the accuracy and completeness of climatic observations,

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as well as on local microclimatic conditions in Kharkiv Oblast.

4. Creation of a climate change forecast for selected settlements of the Kharkiv Oblast.

5. Development recommendations for combating and adapting to these changes.

**Presentation of the main material.** Each region of planet Earth has its own climatic characteristics. As a result, some areas are more likely to experience specific trends in temperature, precipitation, wind speed and direction, and other climatic indicators.

The climate of Kharkiv Oblast is defined as temperate continental. Winter is characterized by instability. There is a predominance of mild winters with frequent thaws and unstable frosts. Summer is characterized by heat [5].

There are an average of 1850 hours of sunshine per year, while there are slightly less than 100 cloudy days. The annual amount of precipitation is 520 mm and varies from part of the region. The distribution of precipitation is more subject to meridional dependence than to latitudinal dependence. The western part of the region has an average higher annual amount of precipitation, and is 570 mm. The wettest months of the year are 6-7. There is a meridional dependence in the amount of precipitation (in the western regions up to 20 mm more precipitation than in the eastern ones). During the year, precipitation falls more evenly in the western regions of the region.

Agroclimatic zoning is such that most of the region is located in the temperate arid zone, and some parts of the western and northern parts of the region are in the zone of insufficient moisture, which is characteristic of the steppe [1].

The average temperature is 21°C in summer and -7°C in winter. The coldest months of the year are 1-2, the warmest are 7-8. The average air temperature increases from north to south.

Winter (the period where average daily temperature drops below 0°C) begins on the tenth of November and lasts from 125 days (south of the region) to 135 days (north of the region). Summer (the period where average daily temperature rises above 15°C) begins on the tenth of May.

The sum of average daily temperatures above 0°C in the region is on average 3170°C, above 5°C - 3080°C.

Climatic conditions in different parts of Kharkiv Oblast are not the same (Table 1), which in turn has a direct impact on the distribution of vegetation and the formation of biotopes.

The northern regions of the region could be characterized by a more severe climate, as well as a longer cold period along with a smaller annual air amplitude (Table 1), and accordingly the southern regions of the region have a warmer and shorter winter period, higher average annual temperature, and hotter summers.

Any region has its own individual characteristics of the climatic regime. Thus, some territories have greater risks of forming certain trends in air temperature, soil, precipitation, speed of wind and other climatic indicators.

*Table 1*

**Climatic conditions in different parts of Kharkiv Oblast**

| Climatic conditions | Northern parts of the region | Southern parts of the region |
|---|---|---|
| Average annual air temperature, °C | +7,2 | +8,6 |
| Average January temperature, °C | -7,5 | -6,5 |
| Average July temperature, °C | +19,5 | +21 |
| Absolute temperature minimum, °C | -36 | -40 |
| Absolute temperature maximum, °C | 41 | 40 |
| Duration of the cold period, days | 135 | 120 |

Detecting climate anomalies is not a new topic for Ukrainian scientists. Vira Balabukh, a leading Ukrainian climatologist, has had already conducted research on all-Ukrainian climate anomalies with other scientists for several years.

In general, in the territory of Kharkiv Oblast in recent years there has been an increase in the number of natural meteorological phenomena, which is a sign of climate fluctuations. A statistically significant trend is observed. This can be defined as one of the manifestations of the redistribution of atmospheric precipitation, which is a reaction to the increase in temperature near the earth's surface.

The author's analysis of air and soil temperature indicators, air humidity, and wind directions and strength has been carried out based on data from the Kharkiv AMSH weather station, Lozova, and Bogodukhiv. The data has been provided for 2010-2023. Several periods would be considered - 1910-1980, 1961-1990, 2010-2021, 2010 - 1st half of 2022, 2011-2023.

Analysis of temperature deviations from climate norms for the periods 1910–1980 and 1961–1990 has helped to identify how temperatures changed over time. It also made it possible to compare these changes with temperature trends before and after the start of active hostilities in Kharkiv.

During the period 2010-2021, the temperature regime of the city changed slightly compared to the period 1910-1980. However, in general, a gradual increase in temperature has been observed, and in the latter period these changes became more noticeable (Table 2).

Based on statistical data, it can be concluded that the average air temperature at the Kharkiv AMS weather station increased during the period 2010–2021. In particular, in the winter and summer months it increased by 2-2.5°C compared to the period 1910-1980. Compared to information from the climate cadastre for the period 1961-1990, there is an increase in the average annual temperature and the average temperature of most months (except for the summer months). At the same time, the warmest and coldest

months of the year remained the same - this part of the temperature regime has not changed.

To begin the study, data series from Kharkiv were selected to identify existing trends in the region and further focus the research as effectively as possible.

*Table 2*

**Monthly average air temperature, °C, according to Kharkiv AMS**

| Period | Period 1910-1980 | Period 1961- 1990 | Period 2010-2021 | Period 2022-2023 |
|---|---|---|---|---|
| 1 | -7,3 | -7 | -4,8 | -2,5 |
| 2 | -6,1 | -5,7 | -3,4 | -2 |
| 3 | -1,2 | -0,3 | 1,9 | 4,9 |
| 4 | 8,3 | 8,9 | 10,2 | 10,9 |
| 5 | 15,3 | 15,6 | 17,1 | 15,9 |
| 6 | 19,2 | 19 | 21,1 | 19,5 |
| 7 | 20,9 | 20,4 | 22,9 | 22 |
| 8 | 19,8 | 19,5 | 22,4 | 23,2 |
| 9 | 14,2 | 14,1 | 15,9 | 17,5 |
| 10 | 6,8 | 7,3 | 8,4 | 9,5 |
| 11 | 1,3 | 1,3 | 2,8 | 3,5 |
| 12 | -3,7 | -3,3 | -1,5 | 0 |
| Year | 7,3 | 7,5 | 9,4 | 10,2 |

The graph (Fig. 1) shows the air temperature in Kharkiv for 2010-2023. Based on the data visualization, it can be seen that in the studied period of 2023, a sharp decrease in the average daily temperature in winter can be seen. It can also be noted that a more uniform distribution of temperatures throughout the entire period of the 2nd half of 2022-2023 has been observed. These changes are characteristic of Kharkiv (compared to previous studied periods), and are more pronounced than annual changes in previous periods [3].

In general, it can be noted that the existing temperature increase trends in the city have intensified. This indicator will be further compared with indicators in other cities.

Graphs comparing average temperatures for January and July have also been created to study changes in average temperatures for individual months in the city (Fig. 2-3).

These two months were chosen as a representation of the coldest and warmest months of the year in the city.

The graph above (fig. 2) shows changes in the average air temperature in Kharkiv in January for the period 2010–2023. The visualization shows that the general trend of increasing air temperature is maintained. It can also be noted that the air temperature in recent years has warmer “peak” coldest days, which continues in the graph for 2023, in which such temperature drops have not been observed at all.

There is also a fact that in the figure a drop in the dependence of air temperature on the date can be observed, which may indicate that the temperatures of the last research period are not characteristic compared to the previous ones.

The incompleteness of data for the period of 2022 is due to the fact that no observations have been conducted at the Kharkiv AMS station at that time.

The graph above (Fig. 3) shows changes in the average air temperature in Kharkiv in July for the period 2010–2023. From the visualization, it can be understood that in Kharkiv in July for the last decade, a gradual decrease and leveling of the average air temperature has been observed. Also in Fig. 3, a trend can be observed - the absence of sharp «peak» temperatures.

It can also be seen that the temperature trend line on both graphs is almost identical, showing the lack of a connection between active military operations and summer temperatures over a short distance.

It is also necessary to consider such an important indicator as air humidity. This analysis was carried out on the basis of relative humidity indicators, namely average and minimum daily values.

Relative air humidity is characterized by two main factors, namely absolute humidity and air temperature, which, in turn, means that relative air humidity depends on the wind regime, namely on wind directions.

In particular, according to the National Academy of Agrarian Sciences of Ukraine, the change in relative humidity and temperature in Ukraine repeats general trends - the sign is expressed less intensely in the north and east of the country.

The situation with the period where the sign is most pronounced is stable during the observation period and does not coincide with the thermal regime of the air and soil. The months with the highest relative humidity are the winter months - the month with the highest relative humidity is December, during which the average daily relative humidity is 87.63% on average, the second in a similar sign is January with an average daily relative humidity of 86.02%. The relative humidity continues to fall until August, when it reaches a minimum of 55.17%. In general, there are 3 clear periods in relation to the months - the wet period (November-February, relative humidity in the area of 80-85%), the dry period (April-September, relative humidity is 55-60%) and the transitional months.

During the summer season, there is a greater difference in the average and minimum relative humidity than in the winter and transitional months. In recent years, there has been a slight change in humidity indicators, namely a decrease in the number of days in the winter wet period with 100% humidity.

Annual values will be presented for analysis, as well as January and July values to search for changes in individual periods.

As can be seen from the graphs (Fig. 4, 5), humidity indicators in the territory of Kharkiv are stable, with a slight tendency to decrease over time. The difference between the average and averaged minimum humidity of each year is relatively stable and is 15-18%.

By analyzing the graphs in the figures (Fig. 6-7), it can be seen that in the case of air humidity in Kharkiv,

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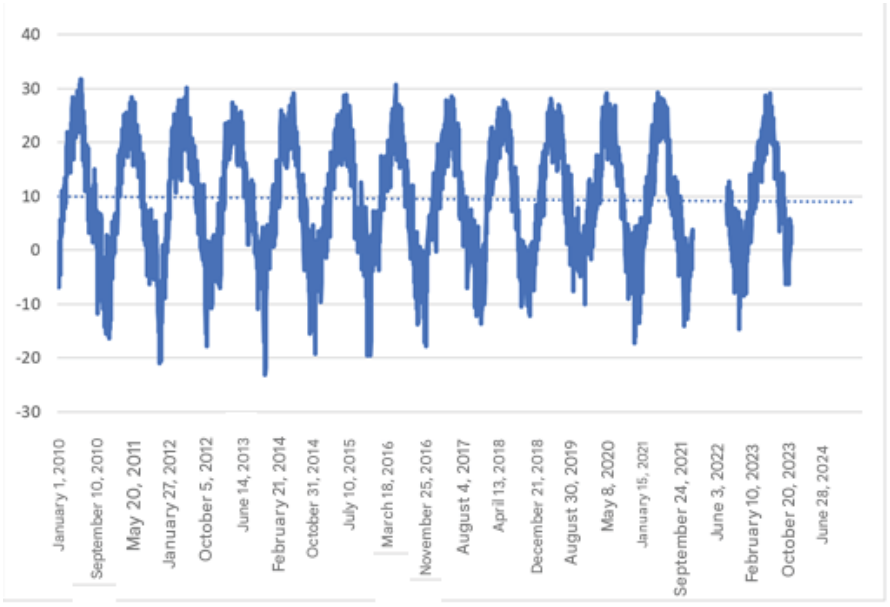


*Fig. 1. Temperature change graph for Kharkiv (period January 2010 – December 2023). Author's graph*

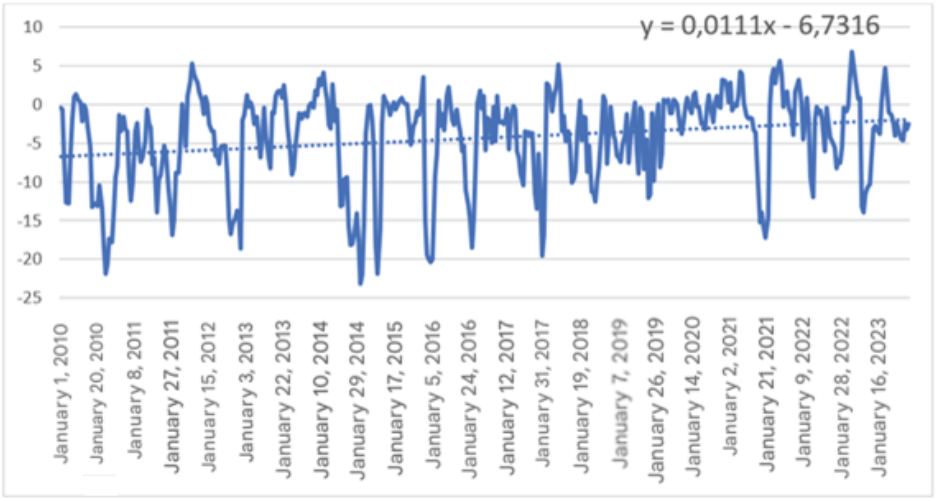


*Fig. 2. Graph of changes in average air temperature in January in the territory of Kharkiv (2010-2023)*

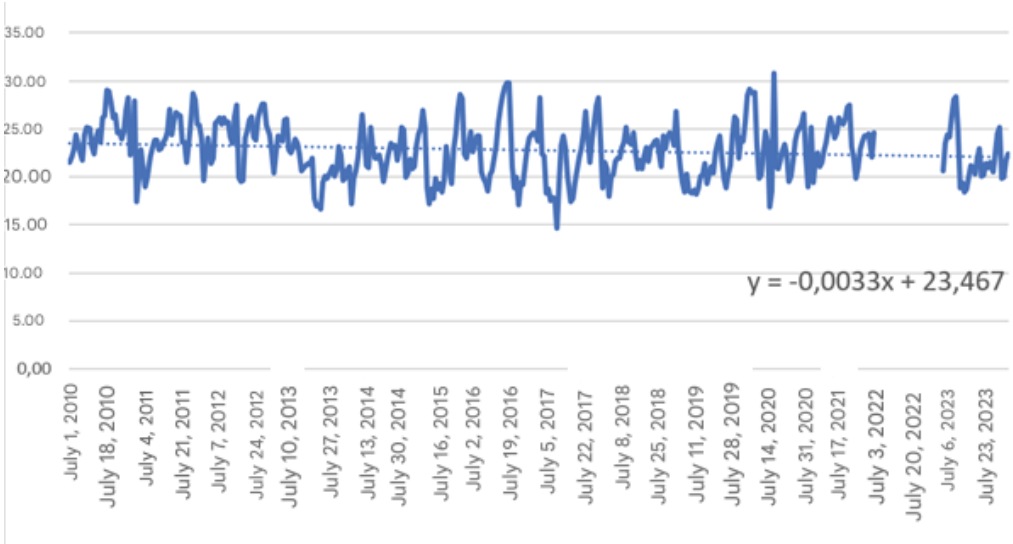


*Fig. 3. Graph of changes in average air temperature in July in the territory of Kharkiv (2010-2023)*

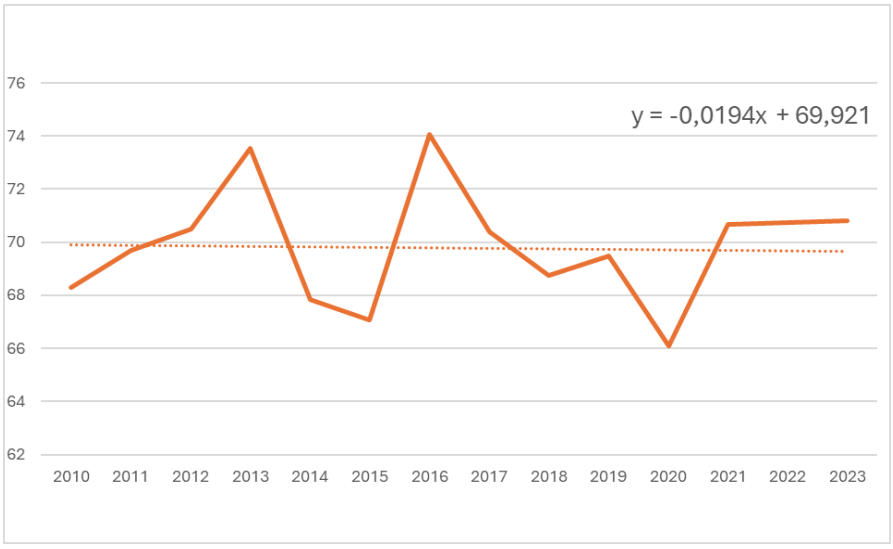


*Fig. 4. Average annual average air humidity (in percent) in the territory of Kharkiv (2010-2023)*

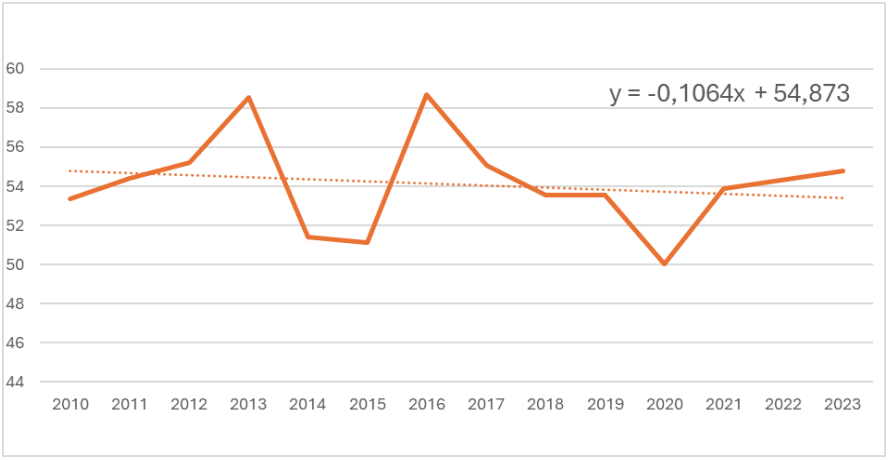


*Fig. 5. Average annual minimum air humidity (in percent) in the territory of Kharkiv (2010-2023)*

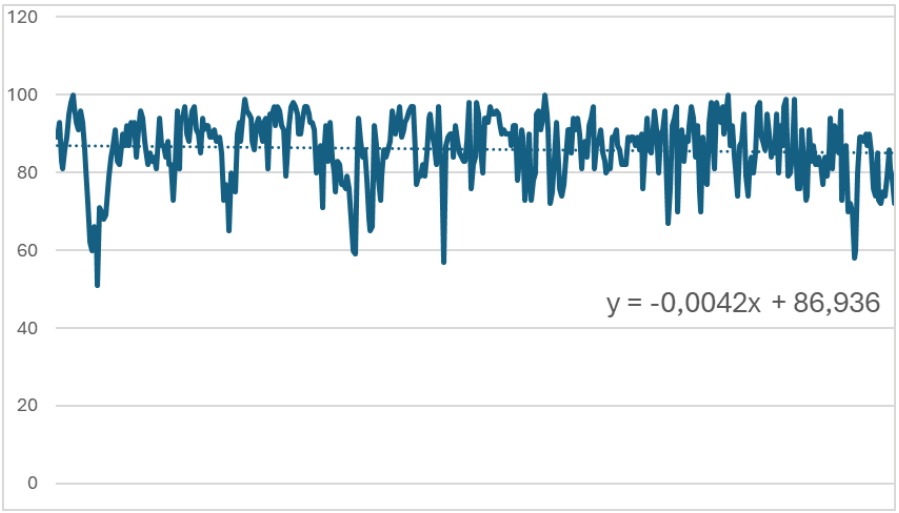


*Fig. 6. Average relative humidity in January in the territory of Kharkiv (2010-2023)*

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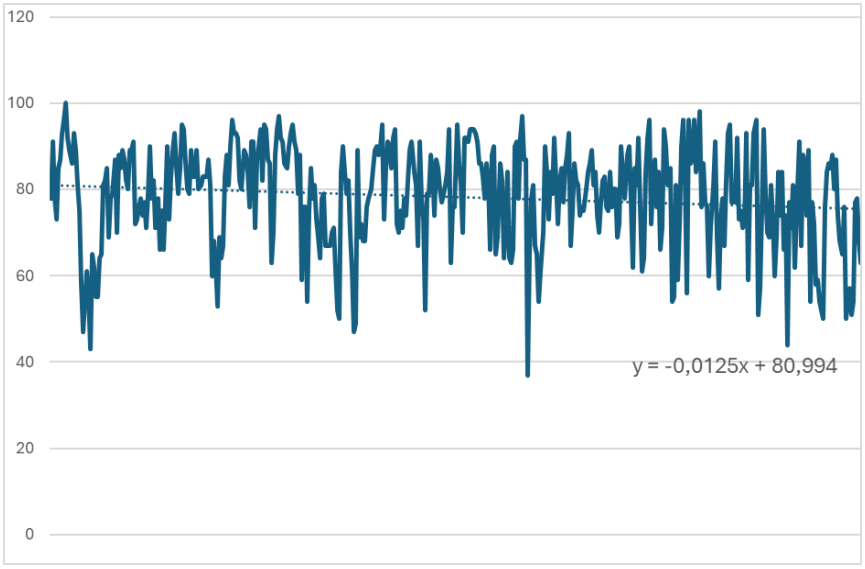


*Fig. 7. Average minimum relative humidity in January in the territory of Kharkiv (2010-2023)*

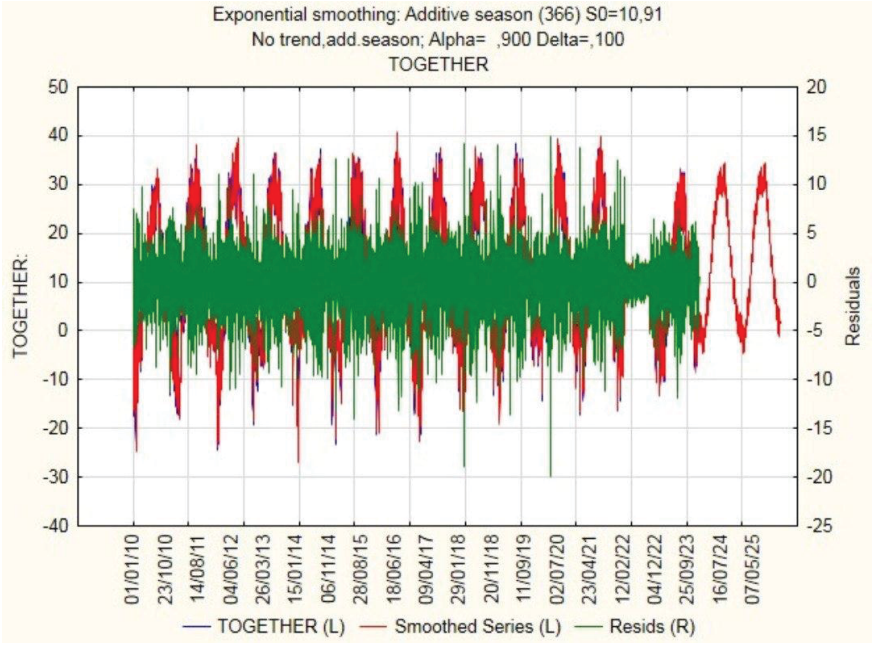


*Fig. 8. Graph of forecast of temperature changes in Kharkiv for the data period January 2010 – December 2023 to January 2026. Author's graph*

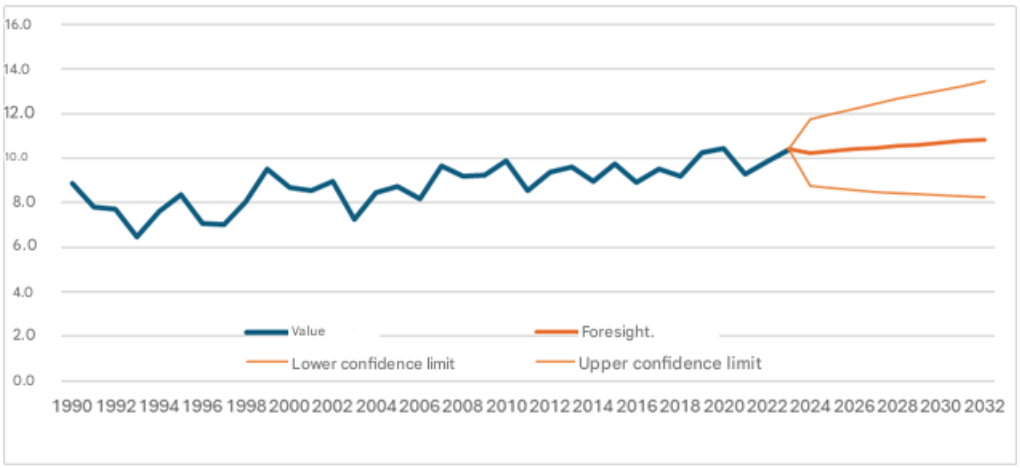


*Fig. 9. Forecast graph of changes in the average annual temperature of Kharkiv for the data period 1990 – 2023 to 2032*

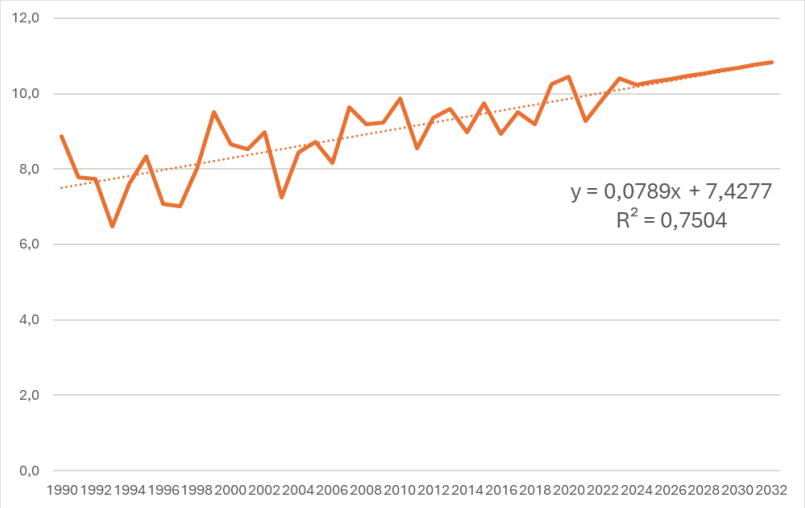


*Fig. 10. Graph of visualization of trends in changes in average annual air temperature taking into account the forecast*

no significant changes in trends are observed. There is also no dependence in the average and minimum air humidity and time. January 2023 is drier than previous years, but not dry enough to have an impact on existing trends.

Climate change is the change in various parts of the climate system that extends over years. A climate change projection is a mathematical model that shows the likelihood of certain changes in the long-term norms of various parts of the climate system.

The relevance of climate change forecasting lies in the fact that climate change has an impact on most aspects of human life, while forecasting changes would provide an opportunity to prepare for them.

To forecast the temperature regime of the city of Kharkiv, a graph was created (Fig. 8) with a forecast of average daily temperatures for 2 years. The forecast was made in the Statistica software.

As a result of data visualization, it was found that compared to the forecast for the period 2010-2021, the forecast for the period 2010-2023 has several features. First, it is noted that the average expected summer temperature is one degree lower than the average expected summer temperature for a shorter period, and it is stable. Second, the second graph of the forecast of changes shows an increase in the average winter temperature, which has not been observed in the graph of the temperature forecast for the period 2010-2021 [4].

A graph of the forecast of changes in the average annual temperature in the city until 2033 has also been created in the Excel software environment (Fig. 9, 10).

In the classic version of linear multiple regression, the graphs show the trend equation and the value of the coefficient of determination $R^2$, which helps to assess how reliable the forecast is. This coefficient is used in statistics to determine how strongly the dependent and independent variables are related to each other. Its value shows how much of the change in the dependent variable could be explained by the model.

In other words, $R^2$ shows how closely the model reflects the real data. In classic linear multiple regression models, the $R^2$ value ranges from 0 to 1. The closer it is to 1, the better the model is considered.

As a result of creating the graphs, the formula for the predictive model of climate change in the territory of the city of Kharkiv has been obtained:

$$\mathbf{y = 0{,}0789x + 7{,}4277}$$

It has been derived using a linear trend, as it brings the coefficient of determination as close as possible to 1 (**$R^2 = 0{,}7504$**).

As a result of the analysis of this model, it can be concluded that the average annual temperature increase rate is 0.0789 degrees Celsius, while the minimum average annual temperature would be 7.4277 degrees Celsius.

Let us consider in more detail the issue of recommendations for adaptation to changes. In the case of the Kharkiv region, several projects to combat climate change are currently being implemented, including:

- Action Plan for 2025-2027 for the implementation of the Kharkiv Region Development Strategy for 2021-2027 (new edition), approved by the decision of the Regional Council dated April 24, 2025 No. 1150 –VIII
- Program of economic and social development of Kharkiv Oblast for 2025
- development strategy of Kharkiv region for 2021-2027
- Report on the strategic environmental assessment of the state planning document of the comprehensive environmental protection program of Kharkiv Oblast for 2021-2027

Creation of recommendations for combating and adapting to climate change would require taking into account the above documents.

The standard protocol for combating would be to strengthen strategies that focus on the existing anthropogenic influence on air temperature.

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The standard protocol for combating would be to strengthen strategies that focus on the existing anthropogenic influence on air temperature.

To combat heat stress, it is proposed to introduce similar solutions: informing the population about the possibility of dangerous heat during the day, increasing green areas in the city, which would contribute to the absence of direct sunlight on the soil surface and, as a result, its heating, as well as creating points for prompt assistance to the population in the event of heat stroke.

**Conclusions.** The problem of climate change and the impact of active military operations in Ukraine is quite important, and this particularly applies to the Kharkiv region. For Ukraine, as a country with an agrarian-focused economy, climate change is a relevant topic, and the country's further economic stability would largely depend on effective forecasting of changes and adaptation to the two aforementioned problems.

The results obtained allow us to formulate the following conclusions:

1) During the study of literary sources on the topic of the study, the general characteristics of the climate and the climatic features of the selected cities were analyzed. The dynamics of climate change at the regional level indicates a gradual warming of the climate: the average annual air temperature is increasing, periods of abnormal heat and prolonged droughts are becoming more frequent. As a result of changes in the global climate, local changes are also observed in the territory of Kharkiv Oblast.

2) Statistical data and constant norms of temperature indicators have been analyzed, which had allowed us to identify trends in climate change in 2010-2021. The main trends in climate change in Kharkiv Oblast were identified, among which the trend of increasing the average annual temperature has been highlighted, as well as the general increase in temperatures during each month, which has been more pronounced during the winter months. Also, as a result of the analysis, the features of changes in the climatic regime of selected settlements have been highlighted. Additionally, these indicators have been compared with the features of the climatic regime of another city in the studied region.

3) The general trends of climate change have been compared with the general and average values for the region, and regularities were identified. The trends of climate change were compared with the indicators of the Kharkiv AMS. Both unique changes in the climatic regime of each of the studied settlements have been identified, as well as changes that are characteristic of the territories located in direct proximity to the combat demarcation line, where a decrease in the accuracy of climate monitoring has been recorded, as well as possible local changes in the microclimate caused by large-scale destruction, destruction of forest areas and infrastructure.

4) A formula for predicting temperature changes in the city of Kharkiv has been calculated, which shows the linear nature of changes in the temperature regime in the city, and in connection with this, a list of recommendations for adaptation has been created.

5) To adapt the agricultural sector of the economy, it has been proposed to introduce state scholarships, subsidies, and similar financial incentives for switching to more drought-resistant crops, as well as creation of state programs for the purchase of such crops and their further processing and use to create a guaranteed livelihood during the transition of agricultural farms.

In conclusion, it could be noted that in the territory of Kharkiv Oblast, changes can be observed that have been directly or indirectly caused by military actions in some of the studied factors. The results of this study can become the basis for more global studies that would cover larger territories and longer time periods.

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**Борис Шуліка** - кандидат географічних наук, доцент кафедри фізичної географії та картографії факультету геології, географії, рекреації і туризму Харківського національного університету імені В.Н. Каразіна; e-mail: b.o.shulika@karazin.ua, shulika91@gmail.com; ORCID ID: https://orcid.org/0000-0002-2427-4124
**Вікторія Кабанова** - бакалавр географії кафедри фізичної географії та картографії, ОПП «Фізична географія, моніторинг і кадастр природних ресурсів», факультет геології, географії, рекреації і туризму Харківського національного університету імені В.Н. Каразіна; e-mail: kabanova2021.9511896@student.karazin.ua, viktoriakabanovaforjob@gmail.com; ORCID ID: https://orcid.org/0009-0008-0867-1825

## ТЕНДЕНЦІЇ СУЧАСНИХ КЛІМАТИЧНИХ ЗМІН НА ТЕРИТОРІЇ ХАРКІВСЬКОЇ ОБЛАСТІ

**Метою цієї статті** є виявлення та встановлення закономірних змін клімату на території Харківської області, а також у виділення окремої мінливості у певних населених пунктах.

**Основний матеріал.** Загалом, в Україні, питання зміни клімату становить серйозну проблему, адже, згідно з дослідженнями як українських, так і міжнародних науковців, клімат країни вже тривалий час зазнає змін. Основними напрямами цих змін є підвищення середньорічної та середньомісячної температури повітря, а також коливання обсягів опадів упродовж року. Найбільшу загрозу для України в цьому контексті становить погіршення умов для вирощування різних сільськогосподарських культур, оскільки значна частина української економіки орієнтована на первинний сектор.

І відповідно основним завданням є всебічний аналіз динаміки змін клімату Харківської області на регіональному рівні. У межах дослідження було визначено основні тенденції та особливості трансформації кліматичного режиму в регіоні. Особливу увагу приділено оцінці впливу активних бойових дій на точність і повноту кліматичних спостережень, а також на формування локальних мікрокліматичних умов у межах області. На основі отриманих даних було здійснено прогноз змін клімату для окремих населених пунктів Харківської області. Крім того, сформульовано низку рекомендацій, спрямованих на протидію негативним наслідкам кліматичних змін і адаптацію до нових умов.

**Висновки.** Було проаналізовано загальну характеристику клімату, та кліматичні особливості обраних міст. Внаслідок змін у глобальному кліматі спостерігаються і локальні зміни на території Харківської області. Проаналізовано статистичні дані та сталі норми температурних показників, що дозволило виділити тенденції змін клімату у 2010-2021 рр. Визначено основні тренди кліматичних змін у Харківській області, серед яких було виділено тренд на підвищення середньої річної температури, а також загальне підвищення температур протягом кожного місяця, що проявлялося більш виражено протягом зимових місяців.

Було розраховано формулу прогнозу зміни температур на території міста Харків, який показує лінійний характер змін температурного режиму на території міста, у зв'язку з чим було створено список рекомендацій для адаптації. Для адаптації сільськогосподарського сектору економіки пропонується введення державних стипендій, субсидій та аналогічного фінансового заохочення переходу на більш посухостійкі культури, а також створення державних програм закупівель подібних культур.

**Ключові слова:** *температурні умови, зміна клімату, тренди температур, прогноз, температура повітря, температура грунту, вологість.*

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