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CLIMATE CHANGE & SUSTAINABLE DEVELOPMENT: NEW CHALLENGES OF THE CENTURY

MONOGRAPH

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Mykolaiv – Rzeszow 2021



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Petro Mohyla Black Sea National University, Ukraine
Rzeszow University of Technology, Poland



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edited by
Olena Mitryasova
Piotr Koszelnik

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The monograph is devoted to problems strategy of sustainable development as a road map of civilization; sustainable development of territories; sustainable use and protection of flora and fauna; environmental biochemistry, physiology and medicine; food technology in the context of sustainable development; monitoring of the atmosphere, hydrosphere and climate management; circular economy; rational use of water resources and wastewater treatment; rational use of land resources and reclamation of disturbed lands; environmental education for sustainable development..

The book is written for scientists, lecturers, postgraduate students, engineers and students who specialize in the field of environmental researches.

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Climate Change and Sustainable Development: New Challenges of the Century

*Dedicated to the 25th anniversary of
the Petro Mohyla Black Sea National University*

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ADAPTATION OF THE TERRITORIAL COMMUNITIES TO THE GLOBAL CLIMATE CHANGES

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ABSTRACT

Climate change is one of the modern challenges to humanity. Only a coordinated global macroeconomic and financial policy can halt the process of its changes. The research of climate changes in a wide range of meteorological values, including the study of the current state and forecasting change trends in thermal and humidification regimes of the surface air layer for the future is important in scientific and practical aspects. Not only air temperature, but also other characteristics: atmospheric circulation, humidification regime, duration of seasons, aridity, etc. against the background of global and regional climate warming is changing. Changes in air temperature determine the dynamics of landscapes, which cannot be characterized as optimal now. Moderate continental climate of Ukraine is gradually changing because of global warming, which will probably lead to the establishment of subtropical one.

It is especially important to solve the regional ecological and social-and-economic consequences of climate change, which are manifested on the territory of Ukraine.

Keywords: global climate changes, thermal regime, humidification regime, territorial communities, natural assets management, land use, agroclimatic resources.

INTRODUCTION

It is clear to scientists that the climate change has taken place and it will continue to do so. Discussions last over how much the climate can change and how to prevent it. Climate change is one of the modern challenges to humanity, because it concerns everyone. This challenge required the cooperation of all governments and countries, as well as significant resources. The markets themselves, of course, were not able to respond adequately. Only a coordinated global macroeconomic and financial policy can halt the process of climate change. The year of 2020 was to be decisive. That is, the scenario, which envisages keeping the planet's temperature at 2 °C (as in the Paris Agreement of 2015), says that there should be a peak of all greenhouse gas emissions in the year of 2020. If we manage to see a decrease after 2020, we will be able to hold the situation.

Over the past decades, the scientific literature and the media have widely discussed the issues of regional ecological and social-and-economic consequences on the territory of Ukraine from the global climate changes. Research of the age course of air temperature anomalies on the territory

of Ukraine during the XX - beginning of the XXI centuries found similarities with the age course of the global temperature.

RESEARCH METHODS

The research of climate changes in a wide range of meteorological values, including the study of the current state and forecasting change trends in thermal and humidification regimes of the surface air layer for the future is important in scientific and practical aspects.

RESEARCH AND DISCUSSION RESULTS

One of the most relevant scientific problems of the modern world is the global changes in the long-term weather regime, initiated by human economic activity. Solving the regional ecological and social-and-economic consequences of the climate change, which are manifested on the territory of Ukraine is especially important. If the intensity of global warming in the XX century was about 0.5°C and it was expected its increase, then the growth rate of annual temperature on average in Ukraine was 1.5 times faster than in global level over the past decade. This factor gives special importance to the problem of climate change in Ukraine over the last 10 years and requires detailed study. The research of climate changes in a wide range of meteorological values, including the study of the current state and forecasting change trends in thermal and humidification regimes of the surface air layer for the future is important in scientific and practical aspects. In this regard, attention is paid to the spatio-temporal features of changes in air temperature and amount of precipitation on the territory of Ukraine over the last 5 years to identify tendencies in heat supply of the territory.

The first three decades and forties of the XX century were the coldest ones. The highest increase in temperature was observed in the north and central regions of Ukraine, it was slightly less in the western and southern regions and it was not almost observed on the Crimean peninsula. The difference between the initial and final value of the temperature according to the trend in the period of 1901-2005 increased from 0.5°C to 1.2°C. The change in temperature indicators during 2010-2020 is a matter of concern. The increase in temperature is also characteristic for certain months of the year. This is especially true for winter and spring months, and for summer months – in the last decade of the XX and at the beginning of the XXI centuries. This can be compared with the generalized results of meteorological observations published by the Copernicus Climate Change Service, which confirmed the warming tendency in Europe.

Not only air temperature, but also other characteristics: atmospheric circulation, humidification regime, duration of seasons, aridity, etc. against the background of global and regional climate warming is changed. Changes in air temperature determine the dynamics of landscapes, which cannot be characterized as optimal now.

Moderate continental climate of Ukraine is gradually changing because of global warming. According to environmental specialists, climate zones have shifted by 1° – about 112 km in recent decades. According to the forecasts of the Finnish Meteorological Institute, Ukraine will have a subtropical climate by the year of 2100. This will naturally affect the flora and fauna, as well as the Ukrainian chernozems and crops that can be grown.

V. M. Babichenko, M. B. Barabash, S. Boichenko, O. A. Donich, O. K. Ivanova, O. O. Kosovets, V. A. Martazynova, O. Ye. Pakholiuk, O. H. Tatarchuk, V. M. Voloshchuk, V. Yeriemieiev, V. Yefimov and others considered the problems of climate change and its individual characteristics on the territory of Ukraine in their works.

The authors noted that climate changes were indisputable facts in the context of global warming and these changes had a negative impact on the general environmental condition at the global and regional levels while examining current climate changes and their manifestations. In particular, M. B. Barabash, O. H. Tatarchuk, studying the spatio-temporal dynamics, found the main patterns of temperature regime on the territory of Ukraine in the context of global

warming and noted a significant increase in temperature throughout the country. Analysis of changes in the sum of active temperature during the first decades of the XXI century proves the specified tendency to warming within the vegetative period in the future in the conditions of the forecasted warming of the global climate.

V. M. Babichenko, N. V. Nikolaieva, L. M. Hushchyna, considering the course of air temperature on the territory of Ukraine at the end of the XX and the beginning of the XXI century, mentioned that the average monthly air temperature over the past 15 years suffered significant changes compared to the climatic standard (1961-1990) because of the global climate change, which affected the transformation of the regional climate and certain meteorological values. The air temperature rose in most months and, in general, for the year it became slightly lower only in September, November and December.

V. F. Martazinova, O. K. Ivanova pointed out that in accordance with global warming, changes in annual temperature were observed almost throughout Ukraine except the southern regions and this increase was 1.5-2.3°C in winter months. According to generalized theoretical researches, the authors considered the current manifestations of climate change, their possible consequences both at the global level and on the example of the territory of Ukraine and stated that climate change was an indisputable fact in the conditions of global warming, these changes negatively affected the general ecological state of environment and population. All this determines the need for further development of adaptive measures through appropriate comprehensive scientific researches by relevant sectoral, governmental and interstate programs.

A significant amount of work on the calculation and generalization of the climatic standards is performed by the specialists of Borys Sreznevsky Central Geophysical Observatory. In particular, since 2007, O. A. Donich, O. O. Kosovets, O. Ye. Pokhaliuk have conducted an annual analysis of the climatic features of the territory of Ukraine, which makes it possible to determine the manifestation of global warming within our country.

Sustainable development requires a clear approach to resource use. Each of us needs to learn constantly – to live by the principles of "life-long learning".

One of the main results of decentralization in Ukraine became the transfer of responsibility for the local development to the level of territorial communities, which requires a comprehensive approach to asset management in communities and is characterized by significant differences in views and opinions of experts and scientists. This issue became especially relevant in the context of systemic reforms, which stimulated the strengthening of the role and expansion of local government functions. At the same time, it has received increased attention for a long period of time in the developed countries and in the international arena.

Environmental issues – new requirements for a low-carbon economy, restrictions on access to drinking water, movement of dry areas to the north, which will disrupt traditional agricultural production, become great problems.

In these conditions, the winner will be the one who will start adapting communities to such challenges earlier, who will stimulate the development of local industries aimed primarily at the community market, who will have areas to accommodate residents from other cities and regions where the situation can be significantly worse.

For a long time, the issue of centralized management of natural assets, i.e. natural resources involved in economic turnover or used in the production of goods or providing services was raised at the international and state levels, and the introduction of the concept of participation, the main idea of which was taking into account the interests of all interested parts, was offered.

The idea of natural resources management with the participation of local communities which, despite various areas of implementation in practice based on clearly defined principles (subsidiarity, sustainability, fairness, answerability, efficiency, activity, adaptability,

environmental responsibility, inclusiveness) has become widespread. Qualitative management of natural assets at the level of territorial communities is connected with the powers of governing bodies in the sphere of provision of qualitative public services, including water supply and sewerage, land resources management, environment preservation, tourism development, etc. [12].

In Ukraine, communities uniting is still creating the preconditions for such further economic development, and the development of infrastructure which is not possible without land, territories, population is this basis. In addition to the legislative process, climatic conditions significantly influence the mechanism of land use.

According to NASA, on a global scale, the average air temperature in the year of 2016 was 0.99°C higher than in general in the XX century, and it increased by 1.1°C since the end of the XIX century. Experts' forecast is disappointing – if the increase in global temperature rises above 2°C, it will lead to catastrophic warming, which will have devastating consequences on the entire Earth [14].

Directly in Ukraine the air temperature has arisen by 0.8°C during the last two decades and Ukraine has already crossed the limit of 1.5°C. The system broke down which led to an increase in the number of dangerous weather events. According to the Ukrainian Hydrometeorological Institute, over the past 30 years, the number of cases of meteorological disasters in Ukraine has doubled, and their destructive power is constantly growing. Ukraine was included in the infamous list of countries that are leaders in the number of human victims of natural disasters. Unfortunately, not everyone understands the realities in which Ukraine finds itself. Recently, calculated new climatic standards which will allow assessing climatic conditions of the territory of Ukraine in a different way have been adopted. The climate is still moderate continental one. According to scientists, high temperatures will come to Ukraine after the year of 2030 [14].

Two thirds of Ukraine's lands have changed into a risky farming zone in recent years because of the climate changes. A shift of soil-and-climatic zones is observed; particularly critical periods – July-August are noticed. In particular, there was no precipitation at all in some regions of Ukraine during 4 months last year. Accordingly, this led to a reduction in the use of various biological products, as there was an understanding that the use of classical chemical plant protection products in conditions of insufficient moisture was more harmful to plants than beneficial. Today, farmers are forced to change approaches to land use, move away from the classic plowing technology, move to energy-saving technologies that provide minimal passing through the field, preserving of plant residues in the fields, reducing fuel and chemicals by 30-40%. Farmers are currently adapting to precision farming, to modern tillage technologies, without which they are uncompetitive.

Accordingly, the change in climatic conditions and non-observance of agricultural technology leads to the fact that the lands degradation is extremely rapid in Ukraine and this negative process is only accelerating. The Ministry of Agrarian Policy and Food estimates that today more than 6 million hectares of agricultural land need conservation. If, under the current conditions, the conservation mechanism is not introduced, the country will lose huge areas of fertile land every year.

The leadership of the Ministry of Agrarian Policy and Food of Ukraine has a very simple vision of the development of the agricultural sector in a ten-year cycle – minimizing the use of heavy plant protection products, reducing fuel use through the introduction of modern tillage technologies, expanding the volume of organic lands in Ukraine.

Ukraine is the number one country in terms of organic products export to Europe and wants to remain a leader and increase its production. Ukraine's agricultural sector is responsible for 98 million tons of CO₂ emissions, which is 24% of the country's total emissions, and "this is a very global figure".

Global climate change should stimulate re-equipment, modernization of the industry, introduction of new technologies, decarbonization of production, directly the issue of introduction of precision farming, rational use of water resources and interaction with sustainable environmental policies. The way out is very simple – either Ukraine re-equips the agro-industrial complex or agriculture will lose its leader positions. Agriculture is in full symbiosis with environmental policy [11].

As noted, the year of 2016 was recognized as the warmest on Earth since 1880 in the Southern and Northern Hemispheres. Its anomaly was +0.94°C, the year of 2015 took the second place with a deviation of +0.90°C, the year of 2014 took the third place with an anomaly of +0.74°C.

However, in Ukraine, the year of 2016 was only among the twenty warmest years since 1891, its average temperature was +9.5°C, which was 1.7°C higher than the climatic standard. The warmest weather was in Odesa and Kherson regions, where annual temperatures reached almost +12°C, the coldest weather was in Ivano-Frankivsk region, where the annual temperature at Pozhezhevska meteorological station was only +3.9 °C, and in Sumy region the annual temperature reached +7.2°C at Druzhba meteorological station. In Kyiv, the year of 2015 became the sixth among the warmest years since 1881 by the average annual air temperature of +9.5°C which exceeded the climatic standard by almost 2°C (1961-1990). In 2016, 33 temperature records were registered, which in 1.5 times less than in the record year of 2015. The "most productive" months in records were February (10 records) and April (7 records), which exceeded previous maxima, which is convincing evidence of global warming [7].

In general, winter in Ukraine was warmer by 3.4 °C as in recent years (Table 1). The deviation of the indicators from the climatic standard was 3.7 °C and 6.4 °C, respectively (Table 2). February was the only month of the year that had the largest positive deviation from the climatic standard; the absolute maximum temperature reached +22.7 °C in Izmail (Odesa region) on February 23. The absolute minimum air temperature of -25.6 °C was recorded in Chernivtsi region at Seliatyn meteorological station on February 20.

Table 1. Deviations from the standard of average monthly air temperature (°C) and monthly precipitation (mm) in Ukraine by seasons (2016) [7]

Parameters		Winter*	Spring	Summer	Autumn
Temperature	Seasons	-0.3	10.4	21.0	8.1
	Standard (1961-1990)	-3.7	8.0	18.7	8.3
	Deviation	3.4	2.4	2.3	-0.2
Precipitation	Seasons	136	178	169	181
	Standard (1961-1990)	129	137	219	129
	Deviation	7	41	-50	52

*years of 2015-2016.

Table 2. Deviations from the standard of average monthly air temperature (°C) and monthly precipitation (mm) in Ukraine (2016) [7]

Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
2016	-5.1	2.6	4.4	11.7	15.0	20.1	21.8	21.1	15.5	6.9	1.9	-2.3	9.5
Standard	-5.2	-3.8	0.8	8.5	14.7	18.0	19.4	18.7	14.2	8.1	2.5	-2.0	7.8
Deviation	0.1	6.4	3.6	3.2	0.3	2.1	2.4	2.4	1.3	-1.2	-0.6	-0.3	1.7
2016	67	46	38	51	89	72	48	49	25	90	66	42	683
Standard	42	37	36	44	57	78	81	60	47	36	46	50	614
Deviation	25	9	2	7	32	-6	-33	-11	-22	54	20	-8	69

The amount of precipitation for winter exceeded the standard – 105% (136 mm) on the territory of Ukraine.

April was singled out against the background of high air temperature in most months of the year, when the temperature significantly exceeded the climatic standard in Ukraine by 3.2°C (Fig. 1) and took the 3rd place among the warmest months. The highest values of +30.7°C were recorded on April 18 by Sarata meteorological station (Odesa region).

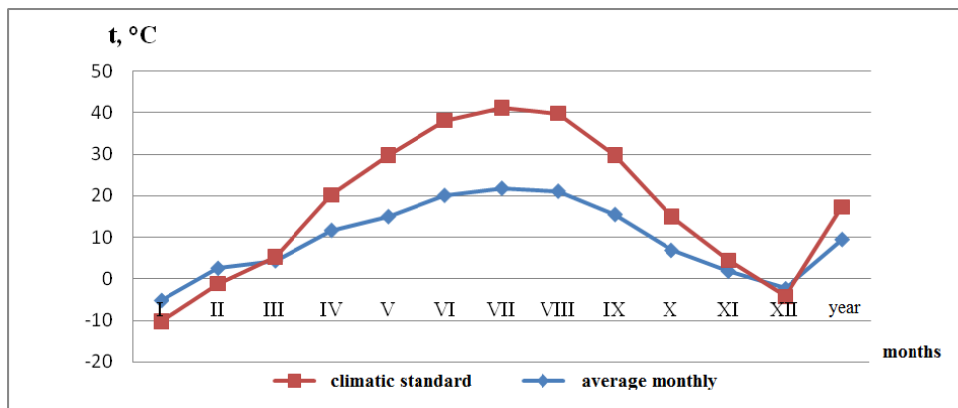


Fig. 1. Annual cycle of air temperature (Ukraine, 2016) [7]

Spring 2016 in the capital city was in the top ten warmest in the climate chronicle due to anomalous April. This spring was 2.4°C warmer than the standard in Ukraine and Kyiv, where it began on January 28, when the average daily temperature exceeded 0 °C in the direction of positive temperature indicators.

The peculiarities of spring 2016 included extremely humid May, when precipitation was 270% of the climatic standard. However, there was its deficit of 77% in the summer season. In addition, the highest daily precipitation in Ukraine was recorded on June 22 in Sumy region at Konotop meteorological station – 99.3 mm (Fig. 2)

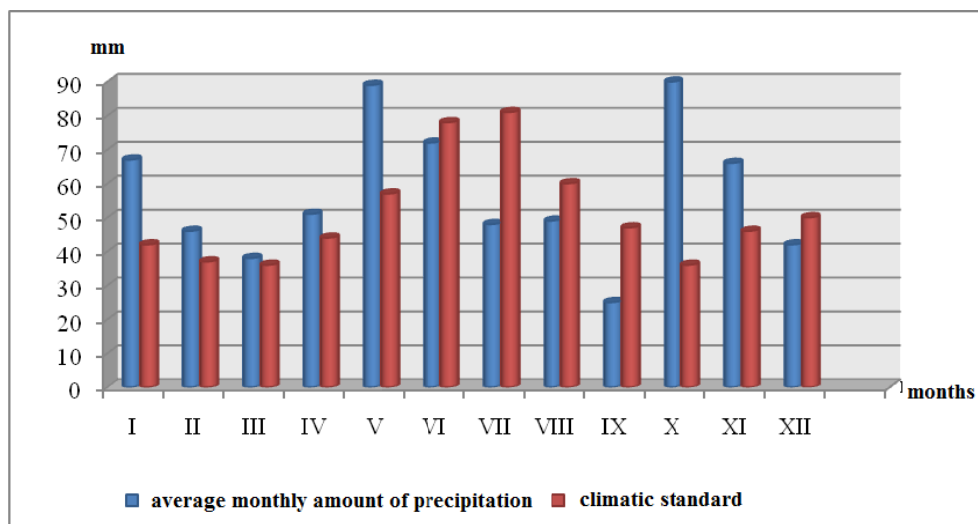


Fig. 2. Monthly amount of precipitation (Ukraine, 2016) [7]

All summer months turned out to be warmer than standard, especially July, which had an anomaly of +2.4°C. The absolute maximum temperature of +40.0°C was recorded on July 17 at Kupiansk meteorological station (Kharkiv region).

The warmest weather in autumn months in Ukraine was September 9 at Sarata station of Odesa region, where the absolute maximum air temperature reached +34.1°C. October had the largest negative deviation from the climatic standard: -1.2 °C among all the months of the year in Ukraine. The average temperature for the autumn season was slightly lower than standard – by 0.1-0.2°C because of cool October and November [7].

During the autumn months in Ukraine, precipitation was higher than standard – 140%. Its excess occurred at the expense of October, when almost 3 monthly precipitation standards were recorded.

December, as the first winter month in Kyiv, turned out to be almost 1.0°C warmer than standard. In general, the deviation from standard in Ukraine was -0.3°C. The lowest temperature was observed on December 17 that was -26.8°C at Troitske station (Luhansk region), the highest temperature – on December 11 that was +14.8°C at Izmail station of Odesa region. Precipitation in December as on the territory of Ukraine was slightly less than standard – 84%, respectively [7].

According to the American service NOAA, the year of 2017 was the third warmest on Earth since 1880. Its anomaly was +0.84 °C, the first place remained in 2016 with a deviation of +0.94°C, and second place was taken in 2015 with an anomaly of +0.90°C.

In Ukraine, the year of 2017 shared the third place with the year of 2013 among the warmest years since 1891; its average temperature was +9.6°C, which was 1.8°C higher than climatic standard. The warmest weather was in Mykolaiv region, the annual temperature in Mykolaiv city reached almost +13°C, and the coldest one, as always, was in Ivano-Frankivsk region, where the annual temperature at Pozhezhevska meteorological station was only +3.9°C, and in Zakarpattia – the annual temperature reached +4.1 °C at Plai meteorological station. In 2017, 24 temperature records were recorded, which was slightly less than in 2016. The largest number of temperature records was recorded in September (7) and April (6), all of them exceeded previous maxima, which was convincing evidence of continuing global warming. [8].

In general, winter in Ukraine, as in recent years, was warmer by 0.4°C. In February, the deviation from the climatic standard was 1.4°C, the absolute maximum temperature was observed on February 28 in Chernivtsi city and reached +19.3°C. The absolute minimum air temperature, which was -26.8°C, was recorded on February 9 at Lebedyn meteorological station (Sumy region), but the lowest winter temperature (-29.0°C) was recorded on January 8 at Slavske meteorological station (Lviv region). The amount of precipitation during winter was below standard – 111 mm (86%) (Tables 3, 4).

Table 3. Deviations from the standard of average monthly air temperature (°C) and monthly amount of precipitation (mm) in Ukraine by seasons (in 2017) [8]

Parameters		Winter*	Spring	Summer	Autumn
Temperature	Seasons	-3.3	9.8	20.8	9.7
	Standard (1961-1990)	8.0	18.7	8.3	8.0
	Deviation	1.8	2.1	1.4	1.8
Precipitation	Seasons	111	134	206	127
	Standard (1961-1990)	129	137	219	129
	Deviation	-18	-3	-13	-2

*years of 2016-2017

Table 4. Deviations from the standard of average monthly air temperature (°C) and monthly amount of precipitation (mm) in Ukraine (2017) [8]

Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
2017	-5,4	-2,3	5,8	9,0	14,6	19,6	20,5	22,2	16,4	9,0	3,6	2,6	9,6
Standard	-5,2	-3,8	0,8	8,5	14,7	18,0	19,4	18,7	14,2	8,1	2,5	-2,0	7,8
Deviation	-0,2	1,5	5,0	1,5	-0,1	1,6	1,1	3,5	2,2	0,9	1,1	4,6	1,8
2017	35	34	28	47	45	49	68	34	58	60	45	81	584
Standard	42	37	36	44	57	78	81	60	47	36	46	50	614
Deviation	-7	-3	-8	3	-12	-29	-13	-26	11	24	-1	31	-30

March was singled out against the background of high air temperature in most months of the year, when the temperature significantly exceeded the climatic standard in Ukraine by 5.0°C. The highest temperature (+24.0°C) was observed on March 22 at Khust meteorological station (Zakarpattia region). In general, spring in Ukraine was 1.8°C warmer than standard [8].

The characteristic feature of the year of 2017 was the deficit of precipitation throughout the year, but the least of its fell in June – only 63% of the climatic standard. June was among the twenty driest months since 1891 according to observations. However, at the same time, the greatest monthly amount of precipitation in June in Ukraine was recorded at Mizhhiria meteorological station (Zakarpattia region) – 183 mm, and the least – only 5 mm was recorded at the meteorological stations of Nyzhni Sirohozy and Strilkove (Kherson region) and Loshkarivka (Dnipropetrovsk region).

Thus, in Ukraine the amount of precipitation was slightly less than standard – 95%, but its distribution by seasons was uneven [8].

All summer months in Ukraine turned out to be warmer than standard, especially August, which had an anomaly of +3.5°C. August was on the 7th position among the warmest months for 137 years of observations. The absolute maximum air temperature (+40.6°C) was recorded on August 7 at Melitopol meteorological station (Zaporizhzhia region).

In autumn months, the absolute maximum air temperature (+35.5°C) was recorded on September 18 at Huliaipole meteorological station (Zaporizhzhia region) and repeated on September 21 at Komisarivka meteorological station (Dnipropetrovsk region) [8].

The average temperature for the autumn season in Ukraine exceeded the standard by 1.4°C due to the fact that all autumn months turned out to be warmer than climatic standard. In autumn, the area was humidified by 98%.

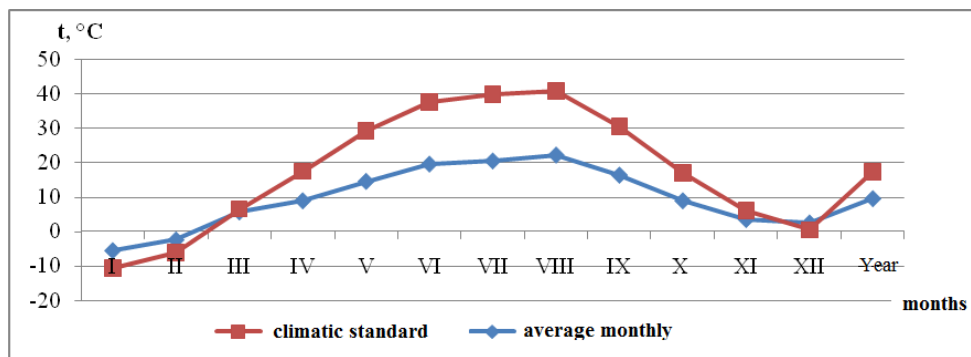


Fig. 3. Annual cycle of air temperature (Ukraine, 2017) [8]

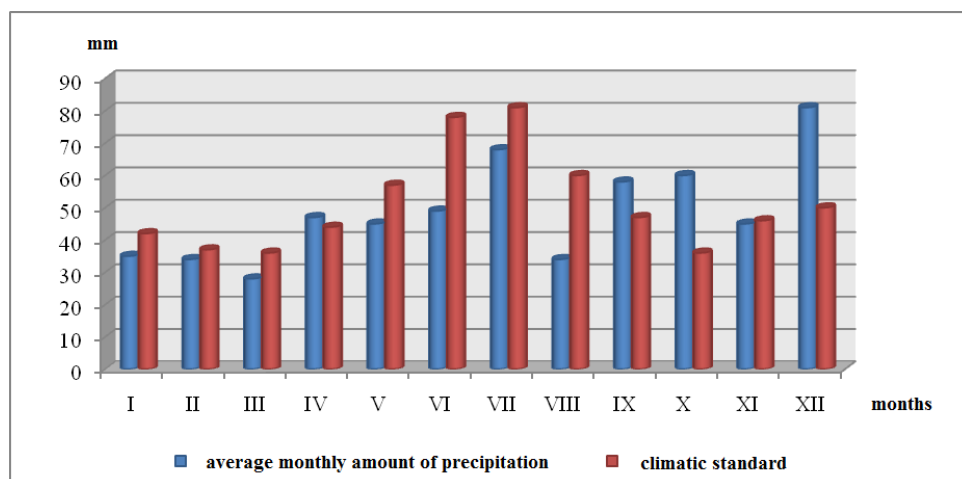


Fig. 4. Monthly amount of precipitation (Ukraine, 2017) [8]

December, as the first winter month, turned out to be 4.6°C warmer than standard. It took the second place among the warmest months according to all observations in Ukraine after 1960. The lowest temperature in Ukraine, -12.2°C, was observed on December 20 at Pozhezhevska meteorological station (Ivano-Frankivsk region), and the highest one, +17.3°C, – on December 2 at the meteorological stations of Vylkove (Odesa region) and Kolomyia (Ivano-Frankivsk region). The amount of precipitation in December on the territory of Ukraine was much higher than standard – 1.5 climatic standards. By the way, only in December, precipitation was measured the most in Ukraine among all the months of the year. Most of them were recorded at Pozhezhevska meteorological station (Ivano-Frankivsk region) – 266 mm, and the least – at Khorly meteorological station (Kherson region) – only 14 mm (Fig. 3, 4) [8].

According to the American service NOAA, the year of 2018 became the fourth warmest on Earth since 1880 in the Southern and Northern Hemispheres. Its anomaly was +0.79°C, the year of 2016 remains in the first place with a deviation of +0.95°C.

In Ukraine, the year of 2018 took the third place among the warmest years, starting with 1891; its average temperature was +9.7°C, which was 1.9°C higher than climatic standard. The warmest weather was in Odesa region, where the annual temperature reached 12.7°C at Vylkove meteorological station, and the coldest, as always, was in Ivano-Frankivsk region, where the annual temperature was only +4.7°C at Pozhezhevska meteorological station, and in Zakarpattia where the annual temperature reached + 5.1°C at Plai meteorological station [9].

In general, winter in Ukraine, as in recent years, was warmer by 2.9°C (Table 5). The absolute maximum temperature of +14.3°C was reached at Yaremcha meteorological station (Ivano-Frankivsk region) on January 6. The absolute minimum air temperature of -27.0°C in winter was recorded at Hlukhiv meteorological station (Sumy region) on February 27.

The amount of precipitation during winter significantly exceeded standard and it was 172 mm (133%) (Table 6) [9].

Only March and November were colder than standard by 1.9°C and 1.0°C, respectively, against the background of high air temperature in most months of the year in Ukraine. The lowest temperatures of -26.9°C were observed at Drohobych meteorological station (Lviv region) on March 2. April had a significant deviation from the climatic standard towards warming – by 4.3°C. April became the warmest in Ukraine and in the capital during the whole observation period. The warmest weather in Ukraine, +30.0°C, was at Khust meteorological station

(Zakarpattia region) on April 29. The hottest day with the temperature of +33.9°C was on May 31 (Voznesensk meteorological station (Mykolaiv region). May took the third position in Ukraine in the ranking among the warmest months since 1881 [9].

Table 5. Deviations from the standard of average monthly air temperature (°C) and monthly amount of precipitation (mm) in Ukraine by seasons (2018) [9]

Parameters		Winter*	Spring	Summer	Autumn
Temperature	Seasons	-0.8	9.9	21.2	9.6
	Standard (1961-1990)	-3.7	8.0	18.7	8.3
	Deviation	2.9	1.9	2.5	1.3
Precipitation	Seasons	172	127	196	110
	Standard (1961-1990)	129	137	219	129
	Deviation	43	-10	-23	-19

Table 6. Deviations from the standard of average monthly air temperature (°C) and monthly amount of precipitation (mm) in Ukraine (2018) [9]

Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
2018	-1,9	-3,1	-1,1	12,8	18,0	20,1	21,4	22,1	16,6	10,8	1,5	-1,4	9,7
Standard	-5,2	-3,8	0,8	8,5	14,7	18,0	19,4	18,7	14,2	8,1	2,5	-2,0	7,8
Deviation	3,3	0,7	-1,9	4,3	3,3	2,1	2,0	2,4	2,4	2,7	-1,0	0,6	1,9
2018	46	45	74	17	36	80	95	21	54	28	28	69	593
Standard	42	37	36	44	57	78	81	60	47	36	46	50	614
Deviation	4	8	38	-27	-21	2	14	-39	7	-8	-18	19	-21

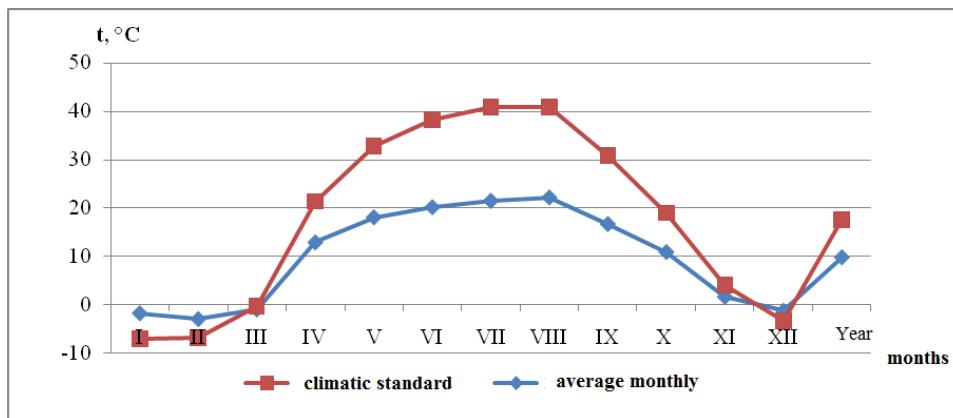


Fig. 5. Annual cycle of air temperature (Ukraine, 2018) [9]

Spring was almost a month shorter than climatic standard. The humidification regime in spring conformed to normal due to wet March.

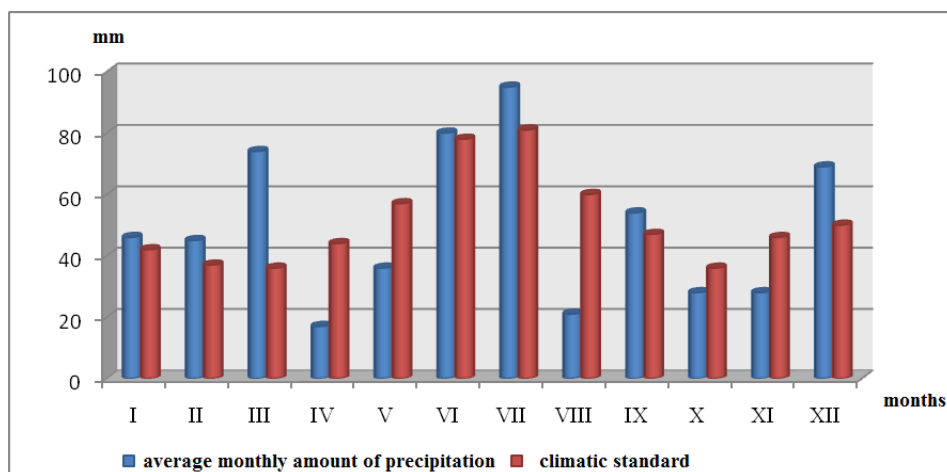


Fig. 6. Monthly amount of precipitation (Ukraine, 2018) [9]

The characteristic feature of the year of 2018 was the deficit of precipitation in April and August – 39 and 35%, April became the 7th among the driest months since 1891, and August took the second place in this ranking of years in Ukraine. August 2018 was extremely dry in Zaporizhzhia, Dnipropetrovsk, Donetsk, Mykolaiv, Kherson, Odesa regions, there was no precipitation at all; at the same time the highest monthly amount of precipitation in August in Ukraine was recorded at Seliatyn meteorological station (Chernivtsi region) – 98 mm.

In general, Ukraine received precipitation close to the standard – 97%, but their distribution by seasons was uneven [9].

All summer months turned out to be warmer than standard, especially August, which had an anomaly of +3.4°C and got into the top ten warmest in Ukraine. Thus, hot maxima of air temperature of +38.2°C were recorded at the meteorological stations of Kherson (Kherson region) and Rozdilna (Odesa region) on August 16 and 17.

The highest temperatures in autumn months were observed at Smila meteorological station (Cherkasy region) on October 18, where the absolute maximum air temperature reached +27.3°C.

Despite the fact that September and October were much warmer than climatic standard, the average temperature during the autumn season in Ukraine was only 1.3°C higher than standard [9].

Generally, the territory of Ukraine was moistened by 85%.

Meteorological winter came two weeks earlier in relation to the climatic standard. On the territory of Ukraine, the lowest temperatures were observed at Seliatyn meteorological station (Chernivtsi region) on November 30. It should be noted that a stable snow cover was formed in Kyiv as early as November 15 which lasted for 3 months.

December, as the first winter month, in Ukraine was 0.6°C warmer than standard. The highest temperatures in Ukraine of +12.0°C were observed at Yaremcha meteorological station (Ivano-Frankivsk region) on December 4. Precipitation in December in Ukraine was much higher than standard – 138% of the average indicators. The largest number of them was recorded at Pozhezhevska meteorological station (Ivano-Frankivsk region) – 152 mm, and the smallest one – at Sarata meteorological station (Odesa region) – only 16 mm [9].

According to the American service NOAA, the year of 2019 became the second one after the year of 2016 among the warmest ones on Earth since 1880 in the Southern and Northern Hemispheres. Its anomaly was + 0.95 °C.

In Ukraine, the year of 2019 took the first place among the warmest ones since 1891, its average temperature was +10.5°C, which was 2.7°C higher than climatic standard. The warmest weather was in Odesa region, where the annual temperature at Vylkove meteorological station reached +13.8°C, and the coldest weather, as always, was in Ivano-Frankivsk region, where the annual temperature was only +5.0°C at Pozhezhevskya meteorological station and in Zakarpattia, where the annual temperature at Plai meteorological station was + 5.1°C. 34 temperature records were recorded, the great number of which was registered in June and December: 10th and 9th, respectively. These records exceeded previous maxima, which is convincing evidence of continuing global warming [10].

Standard during previous winter was exceeded by 2.2°C (Table 7). Winter in Kyiv was also mild, especially due to warm February, the deviation from the climatic standard of temperature in which was 4.8°C (Table 8).

In Ukraine, the positive temperature deviation in February was 4.4°C. Last winter in the capital lasted 111 days, which was 6 days less than the climatic standard. It was the fourth in duration among all the winters of the XXI century, despite its mildness. In Ukraine, the absolute maximum air temperature of +13.6°C in January was registered in Odesa region at Izmail station (January 29). On February 28, the maximum was +17.0°C at Chernivtsi station. The absolute temperature minimum of -25.8°C in winter was recorded in Cherkasy on January 22 [10].

The amount of precipitation during winter was higher than standard because of wet December, when in Kyiv, for example, there were almost 1.5 monthly precipitation standards: 110% (142 mm) on the territory of the country and 105% (154 mm) in the capital.

Table 7. Deviations from the standard of average monthly air temperature (°C) and monthly amount of precipitation (mm) in Ukraine by seasons of 2019 [10]

Parameters		Winter*	Spring	Summer	Autumn
Temperature	Seasons	-1.5	10.3	21.2	10.7
	Standard (1961-1990)	-3.7	8.0	18.7	8.3
	Deviation	2.2	2.3	2.5	2.4
Precipitation	Seasons	142	157	150	87
	Standard (1961-1990)	129	137	219	129
	Deviation	13	20	-69	-42

* years of 2018-2019.

Table 8. Deviations from the standard of average monthly air temperature (°C) and monthly amount of precipitation (mm) in Ukraine (2019) [10]

Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
2019	-3.7	0.6	4.7	10.0	16.2	22.7	20.1	20.8	15.7	10.7	5.6	2.5	10.5
Standard	-5.2	-3.8	0.8	8.5	14.7	18.0	19.4	18.7	14.2	8.1	2.5	-2.0	7.8
Deviation	1.5	4.4	3.9	1.5	1.5	4.7	0.7	2.1	1.5	2.6	3.1	4.5	2.7
2019	56	17	23	41	92	53	53	44	24	29	34	37	503
Standard	42	37	36	44	57	78	81	60	47	36	46	50	614
Deviation	14	-20	-13	-3	35	-28	-28	-16	-23	-7	-12	-13	-111

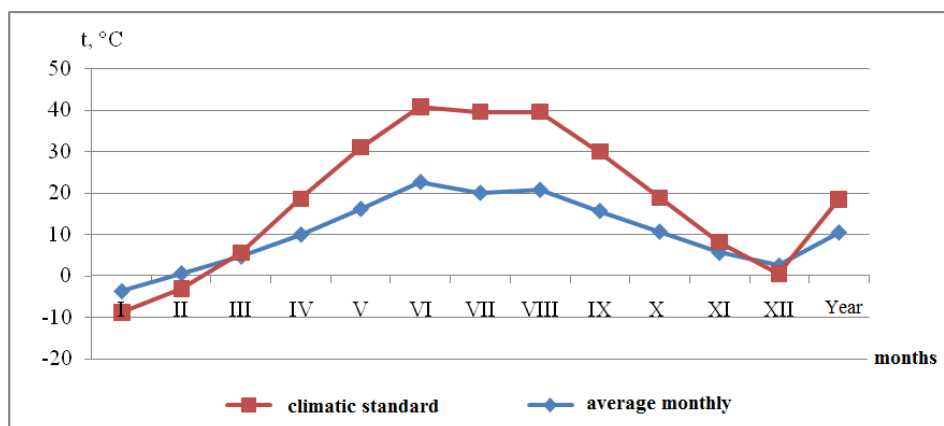


Fig. 7. Annual cycle of air temperature (Ukraine, 2019) [10]

The characteristic feature of the year of 2019 was the fact that all the months turned out to be warmer than climatic standard.

Analysis of spring temperature regime showed that the highest temperature of $+23.0^{\circ}\text{C}$ was observed at Mohyliv-Podilskiy meteorological station (Vinnytsia region) on March 18. March indicators had a significant deviation from the climatic standard towards positive values by 3.9°C (Fig. 7). In general, the month entered the top ten warmest months in Ukraine and in the capital for the entire period of observations. In Kyiv, the temperature record of the maximum air temperature of $+17.7^{\circ}\text{C}$ was recorded on March 8. In April, the highest indicator of $+29.0^{\circ}\text{C}$ was observed at Berehove meteorological station (Zakarpattia region) on April 26. The hottest day of May was its last day at the meteorological stations of Voznesensk (Mykolaiv region) and Pavlohrad (Dnipropetrovsk region) when it was $+33.6^{\circ}\text{C}$. Spring 2019 in Kyiv took the fourth place in the ranking of the warmest ones since 1881 [10].

The amount of precipitation during the spring season was slightly higher than standard. This became possible due to wet May, when there was 1.5 monthly standard of precipitation in the capital. In general, May took the sixth position among the wettest ones since 1891.

The characteristic feature of the year of 2019 was the deficit of precipitation, except for mentioned May (Fig. 8). In May 2019, 305 mm of precipitation fell at Yaremcha meteorological station in Ivano-Frankivsk region. At the same time, the least monthly amount of precipitation was recorded in Odesa region at Zatyshshia meteorological station – only 9 mm.

Thus, there was recorded 82% of the precipitation standard in spring in Ukraine.

All summer months turned out to be warmer than standard, especially June with an anomaly of $+4.7^{\circ}\text{C}$ and it became the warmest one in the history of Ukraine. In Ukraine, hot maxima air temperatures of $+36.9^{\circ}\text{C}$ were recorded at the meteorological stations of Voznesensk (Mykolaiv region), Kherson (Kherson region) and Izium (Kharkiv region) on June 22 and 23 [10].

In autumn, 9 temperature records were observed, which allowed it to take the eighth position in Ukraine. The warmest weather was at Strilkove meteorological station (Kherson region) on October 3, where the absolute maximum air temperature reached $+28.6^{\circ}\text{C}$.

The average temperature for the season in Ukraine was 2.5°C higher than standard due to the fact that the autumn months were much warmer than climatic standard [10].

In autumn, the territory of Ukraine was moistened by an average of 70% of the average long-term values.

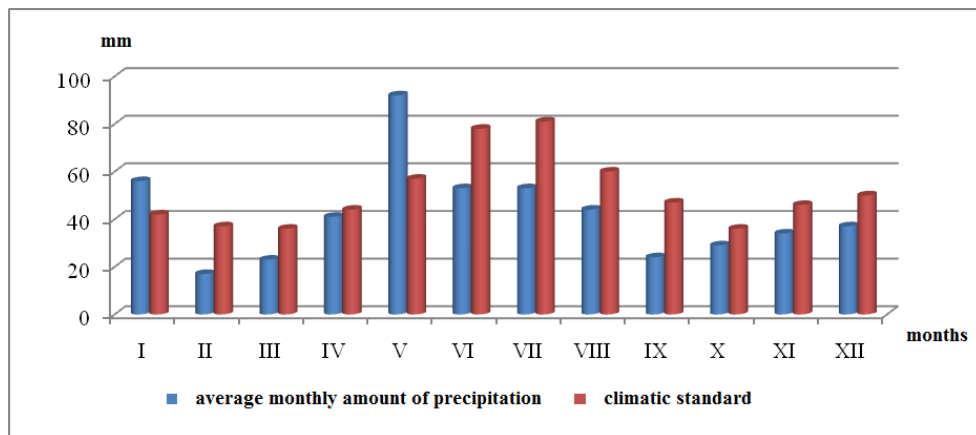


Fig. 8. Monthly amount of precipitation (Ukraine, 2019) [10]

Taking into account abnormally warm December, there was no meteorological winter on the territory of Ukraine, which happened for the first time in the history of all observations. In Ukraine, the maximum value of air temperature of +19.2°C was recorded at Izmil meteorological station (Odesa region) on December 22.

Precipitation on the territory of Ukraine fell on average 37 mm, i.e. 74% of standard. Most of it was recorded in December at Plai meteorological station (Zakarpattia region) – 170 mm, and the least – at Mohyliv-Podilskiyi meteorological station (Vinnytsia region) – only 12 mm [10].

According to the American service NOAA, the year of 2020 became the second warmest one on Earth since 1880. Its positive anomaly was 0.98°C.

In Ukraine, the year of 2020 took the first place among the warmest ones since 1891; its average temperature was +10.6°C, which was 2.8°C higher than climatic standard (1961-1990). The warmest weather was in Odesa region, where the average annual temperature at Vylkove meteorological station reached 13.6°C, and the coldest one, as always, was in Zakarpattia region – annual temperature was only +4.7°C at Play meteorological station, and annual temperature reached + 4.8°C at Pozhezhevska meteorological station (Ivano-Frankivsk region). The year of 2020 in Kyiv by an average annual air temperature of + 10.9°C, which exceeded the climatic standard by 3.2°C (1961-1990), became the warmest one since 1881 [11].

In general, winter in Ukraine turned out to be the warmest for the whole period of observations. Its temperature was 5.3°C higher than climatic standard (Tables 9, 10).

There was no stable transition of the average daily air temperature over 0°C towards negative values during calendar winter of 2019-2020. All winter months had positive average monthly temperatures, and in general it was +2.0°C in December-February. Climatologists of the CGO noted that meteorological winter in Kyiv did not come for the very first time for 140 years, and the air temperature below -10°C was not observed. This fact is explained by the global warming, the pace of which, unfortunately, is accelerating.

The amount of precipitation was 100 mm (Table 10), which was 70% of seasonal standard. Stable snow cover was not formed [11].

Table 9. Deviations from the standard of average monthly air temperature (°C) and monthly amount of precipitation (mm) in Ukraine by seasons (2020) [11]

Parameters		Winter*	Spring	Summer	Autumn
Temperature	Seasons	1.6	9.2	21.1	11.4
	Standard (1961-1990)	-3.7	8.0	18.7	8.3
	Deviation	5.3	1.2	2.4	3.1
Precipitation	Seasons	120	138	172	124
	Standard (1961-1990)	129	137	219	129
	Deviation	-9	1	-47	-5

* years of 2019-2020.

Table 10. Deviations from the standard of average monthly air temperature (°C) and monthly amount of precipitation (mm) in Ukraine (2020) [11]

Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
2020	0.4	1.8	5.9	8.9	12.8	20.8	21.4	21.0	17.6	12.7	3.9	-0.1	10.6
Standard	-5.2	-3.8	0.8	8.5	14.7	18.0	19.4	18.7	14.2	8.1	2.5	-2.0	7.8
Deviation	5.6	5.6	5.1	0.4	-1.9	2.8	2.0	2.3	3.4	4.6	1.4	1.9	2.8
2020	23	60	24	15	99	88	58	26	48	52	24	39	555
Standard	42	37	36	44	57	78	81	60	47	36	46	50	614
Deviation	-19	23	-12	-29	42	10	-23	-34	1	16	-22	-11	-59

Absolute maximum air temperature of +19.1°C was observed on February 27 at Bilhorod-Dnistrovskiyi meteorological station (Odesa region). The absolute minimum air temperature of – 23.2°C in winter was recorded at Kyrylivka meteorological station (Zaporizhzhia region) on February 9.

The amount of precipitation in winter in Ukraine was close to standard – 93% (120 mm) [11].

The characteristic feature of the year of 2020 was the fact that all months of the year were warmer than climatic standard, except for May, which turned out to be unusually cool with air temperature below the standard by 1.9°C.

In March, the warmest weather with +24.7°C was at Guliaipole meteorological station (Zaporizhzhia region) on the 9th. The first month of calendar spring had a significant positive deviation from the climatic standard by 5.1°C and took the third place in the ranking of the warmest months in Ukraine since the beginning of observations (Fig. 9).

In April, the highest temperature in Ukraine of +26.3°C was observed at Shepetivka meteorological station (Khmelnitskyi region) on the 29th [11].

Thus, Ukraine received below-standard precipitation – 90%, because its deficit was observed for almost the entire year.

Summer months turned out to be warmer than standard, especially June, which had an anomaly of +2.8°C. It became the 11th in the ranking of the warmest months in the history of observations in Ukraine. The hot maximum air temperature of +37.2°C was recorded at Troitske meteorological station (Luhansk region) on June 13.

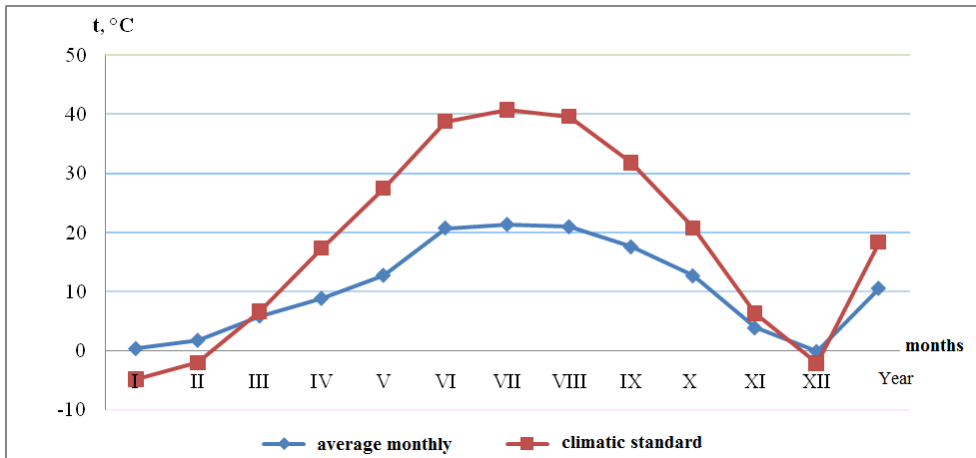


Fig. 9. Annual cycle of air temperature (Ukraine, 2020) [11]

6 temperature records were set in autumn, which turned out to be the warmest season with the fourth position in the ranking of the warmest seasons in Ukraine. The warmest day was at Vylkove meteorological station (Odesa region) on October 7, where the absolute maximum air temperature reached +27.9°C.

Autumn months were much warmer than climatic standard, so the average temperature during the season in Ukraine was 3.1°C higher than usual. In autumn, the amount of precipitation was close to the average annual values – 98% [11].

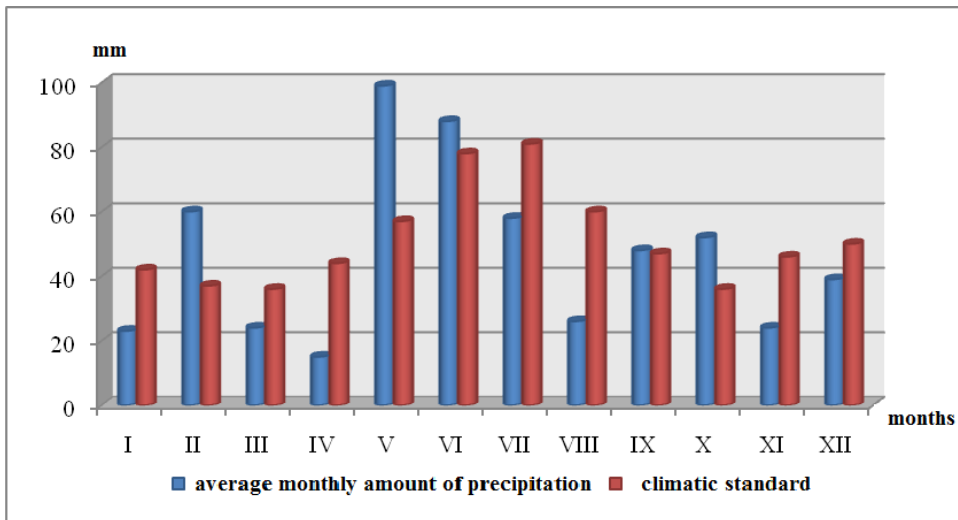


Fig. 10. Monthly amount of precipitation (Ukraine, 2020) [11]

December 2020 began with real winter and ended as a warm autumn. On December 5 and 29, the maximum values of air temperature of +15.9°C were recorded at the meteorological stations of Berehove (Zakarpattia region) and Izmail (Odesa region).

Precipitation in Ukraine for a month was 39 mm or 78% of standard. Its largest number was recorded at Mizhghiria meteorological station (Zakarpattia region) – 113 mm, and the smallest one – at Askania-Nova meteorological station (Kherson region) – only 14 mm [11].

CONCLUSIONS

Thus, forecasted changes in climatic conditions by the middle of the XXI century, namely – changes in the thermal regime (rise in summer temperature and increase in the duration of the warm and growing season, increase in the number of hot days, corresponding decrease in the duration of the cold period); change of the humidification regime (redistribution of precipitation between periods and months, change of the precipitation structure – decrease in number of rainy days and increase in daily amount of precipitation, increase in pounding rains; general tendency of temperature rise cannot be compensated by increase in the number of precipitation for separate periods; causing the development of soil water erosion by pounding rains, the cold period will be wetter and warm period will be arid, possible increase in the number of days with rain in winter, a significant change in agro-climatic resources (sums of active air temperatures and growing season, change in humidity and hydrothermal coefficient; coverage of the southern regions by aridization processes; further change in the boundaries of soil-and-climatic zones; increase in water shortages for the needs of plants causes concern and requires responsible action by the leadership of the united territorial communities, the agricultural sector). Expansion of the rights of local government requires qualitative management of natural assets. Managing in conditions of insufficient moisture means to be prudent, thinking over own actions in advance with the understanding that moisture is one of the most valuable resources, which is becoming more and more expensive from year to year.

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