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ASSESSMENT OF NATURAL MOISTURE CONDITIONS ON THE EXAMPLE OF THE SOUTHWESTERN PART OF KYIV REGION

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Abstract. *The sustainability of agriculture in Ukraine directly depends on the level of natural soil moisture supply, which is significantly deteriorating under the influence of climate change. The article investigates the impact of these changes on the value of potential evapotranspiration (ETo) in the southwestern part of the Kyiv region (Central Forest-Steppe of Ukraine) based on the data from the Bila Tserkva weather station for the period from 1991 to 2020. The research methodology is based on the assumption that the assessment of the impact of climate change on the state of natural moisture supply can be performed provided that climate change itself is assessed according to the long-term dynamics of air temperature and precipitation in the period from 1991 to 2021 with the values of the same indicators in the period from 1961 to 1990 – the climatic norm. The potential evapotranspiration (ETo) was chosen as the criteria for assessing the impact of climate change on the state of soil moisture supply. The assessment results showed that the annual value of potential ETo increased by 9 %, which may indirectly indicate a deterioration in the conditions of natural soil moisture supply. This has important implications for agriculture, as an increase in ET can lead to a decrease in available moisture for plants, which will negatively affect crop yields. The study covers changes in average annual and average monthly air temperature, as well as precipitation by season and month. It has been established that over the past thirty years, Ukraine has been experiencing a deterioration in moisture conditions, which requires the adaptation of agricultural practices. Sustainable development of the agricultural sector is possible only if changes in the natural moisture supply are taken into account when developing management models and cultivation technologies. The results obtained indicate the need to introduce innovative agronomic technologies that adapt to current climate change.*

Keywords: *forecasting of moisture reserves, modeling, factors of influence, hydrothermal conditions, agriculture, climate change*

Relevance of the research. The sustainability of farming in Ukraine directly depends on the level of natural soil moisture supply. According to numerous studies conducted by various authors, Ukraine is one of the countries where climate change is characterized by the highest rates of increase in average annual air temperature in Europe. This so-called "hot" phase of climate change began in Ukraine in the late 70s and early 90s of the last century and continues today. Depending on the region of Ukraine, the rate of growth of the average annual temperature ranges from 0,6 to 0,8 °C (over 10 years).

The rapid increase in average annual temperature leads to a corresponding increase in total evaporation and potential evapotranspiration. And given that the amount of annual precipitation remains unchanged, climate change has led to the development of a progressive dehydration process throughout Ukraine, which is primarily manifested through the deterioration of natural soil moisture conditions and sustainable farming practices. In this regard, it is important for almost every business entity, regardless of ownership, to assess the state of natural soil moisture supply and trends in its changes under the influence of climate change as a basis for developing measures to minimize the negative impact of this process on the efficiency and sustainability of management.

Analysis of recent research and publications. In recent years, Ukraine's climate has been changing intensively: since 1991, each subsequent decade has been warmer than the previous one: 1991–2000 by 0,5 °C, 2001–2010 by 1,2 °C, 2011–2019 by 1,7 °C. In 10 regions of Ukraine, precipitation in 2014–2018 was 7–12 % less than normal [1–4].

In addition, there is a tendency to increase the area with insufficient precipitation (less than 400 mm) in the warm season. The climate has already become drier throughout the country. In particular, there were droughts in the following periods: spring drought in 2002, 2003; spring and summer drought in 2007, 2009 and 2012; autumn drought in 2011; winter and early spring drought in 2019; autumn drought in 2020 [5–6] .

Scientists both in Ukraine and globally are talking about climate change and the threat it poses to humanity. There are many different forecasts, and they are all disappointing for agricultural producers, since in most of the scenarios, from the most optimistic to the pessimistic, in regions where there is a significant shortage of water resources, changes will lead to a decrease in yields [7–10].

Average annual air temperature is one of the main parameters for assessing climate change. In Ukraine, it has risen by 1,2 °C over the past thirty years, and by 1,7 °C over the past 10 years. However, for effective agricultural management, it is important to know how not only the average annual air temperature is changing, but also the trends in average monthly and seasonal temperatures [11] .

The period of active vegetation of crops has already been extended by 10 days or more. These are additional opportunities for growing all types of heat-loving crops. The effectiveness of precipitation decreases as the air temperature rises, and a 1 °C increase in temperature threatens Ukraine with the disappearance of the already small zone of sufficient moisture (Polissya and the western Forest-Steppe) and the transition of this zone to unstable and insufficient moisture. For several years in a row, the Polissya and Western Forest-Steppe regions have experienced extremely low precipitation.

In recent years, there has been a tendency to increase the area with insufficient rainfall in the warm season (less than 400 mm), which is necessary for growing all crops. The climate has already become more arid throughout the country [12]. Some of the benefits of warming are likely to be short-lived, and within 15–20 years, there will be a significant reduction in yields of most crops due to an increase in the frequency and intensity of droughts [13–14].

The rapid growth of thermal resources and almost unchanged amount of precipitation, both in summer and in spring and summer, is already leading to an increase in the frequency of droughts and their spread to the western and northern regions. Therefore, assessing the conditions of natural moisture supply in the regions that used to be classified as sufficiently moist and provided a stable high productivity of major field crops, but now are increasingly experiencing prolonged droughts and other climate risks is an urgent issue.

The study aims to assess the impact of climate change on the growth of potential evapotranspiration in the southwestern part of the Kyiv region.

Materials and methods. The research was conducted at the Institute of Water Problems and Land Reclamation of the National Academy of Agrarian Sciences of Ukraine by analyzing information obtained from the database of meteorological indicators, followed by their statistical processing.

The research is based on the assumption that the impact of climate change on the state of natural moisture supply can be assessed by evaluating climate change itself based on the long-term dynamics of air temperature and precipitation. The basis for such an assessment is archival data from the State Meteorological Station on the average monthly, seasonal, and annual air temperature, as well as the average monthly, seasonal, and annual precipitation. In our case, we used data from the weather station in Bila Tserkva (49 °48` N, 30 °7` E) for the period from 1961 to 2021. The choice of this observation period is based on the World Meteorological Organization (WMO) recommendations to use data from thirty-year periods for comparison. Climate change assessment is carried out by comparing the above data on temperature and precipitation in the period from 1991 to 2021 with the values of the same indicators in the period from 1961 to 1990 – the climate norm.

It is known that the only factors that affect potential evapotranspiration are climatic parameters. Therefore, ETo is a climatic parameter and can be calculated based on meteorological data. ETo expresses the maximum potential evapotranspiration loss in a specific area and for a specific time of year and is independent of crops or soil type.

The potential evapotranspiration (ETo) was chosen as the criteria for assessing the impact of climate change on the state of soil moisture supply. In the absence of solar radiation data at the meteorological station, we chose the alternative Hargreaves equation to estimate ETo [15]. For the calculation, we used the minimum set of input data and the maximum and minimum air temperatures.

$$ETo = 0{,}0023\left(T_{mean} + 17{,}8\right) \times \times \left(T_{max} - T_{min}\right)^{0{,}5} \times Ra \text{ mm}, \quad (1)$$

where ETo is the reference evapotranspiration, mm; T_{mean} is the average monthly air temperature, °C; T_{max} is the maximum monthly air temperature, °C; T_{min} is the minimum monthly air temperature, °C; Ra is extraterrestrial solar radiation, mm.

$$Ra = \frac{1}{\lambda} \cdot \frac{24(60)}{\pi} \times \times G_{sc} d_r \left[\omega_s \sin(\varphi) + \cos(\varphi)\cos\left(\delta\cos(\omega_s)\right)\right] \text{ mm}, \quad (2)$$

where Ra is extraterrestrial solar radiation, mm; G_{sc} is the solar constant, MJ-m^{-2}·day^{-1}; d_r is the inverse relative distance of the Earth-Sun, ω_s is the angle at sunset, rad; ϕ is latitude, rad; δ is solar declination, rad; λ is latent heat of vaporization, MJ·m^{-2}·day.

The Ra value was taken on the 15th day of each month from Appendix 2 of Table 2.6 [15].

Research results and discussion. The air temperature regime was assessed for the period from 1961 to 2021, according to the dynamics of changes in its absolute values and deviations from the norm (1961–1990). The results of this assessment are shown in Fig. 1.

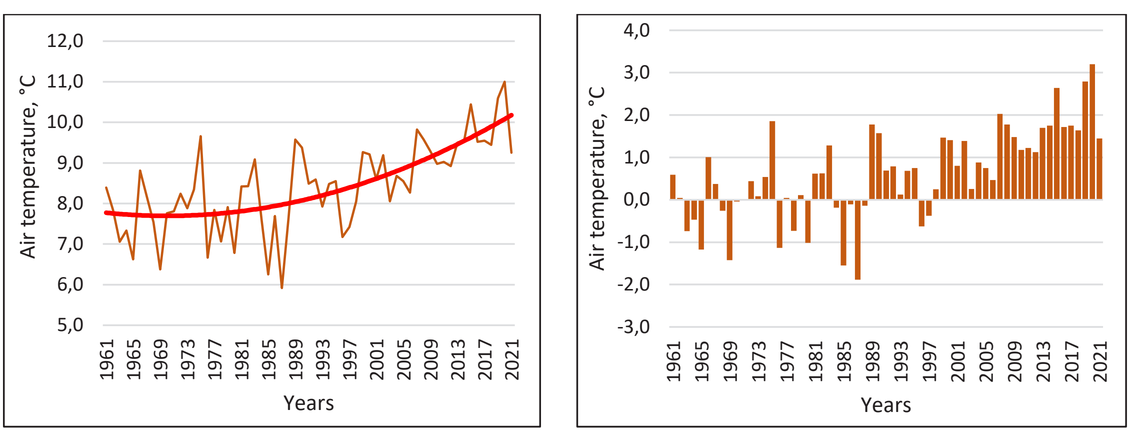
Fig. 2 shows the results of the assessment of the dynamics of seasonal air temperature values, and Table 1 shows the values of average monthly, seasonal and annual air temperature values for the entire assessment period (1961–2021).

The analysis of the data on temperature changes presented in Figures 1, 2 and Table 1 shows that the average annual air temperature for the period 1991–2020 increased by 1,2 °C, in winter by 1,6 °C, in spring by 1,1 °C, in summer by 1,5 °C and in autumn by 0,6 °C, i.e. the most intense temperature increase is in summer.

As for precipitation, the assessment of changes in which was made by the values of annual (Fig. 3), seasonal (Fig. 4) and monthly (Table 2) precipitation amounts for the same period as for the temperature, namely from 1961 to 2021, unlike the temperature, which is increasing, the amount of precipitation in both annual and seasonal (except for autumn) decreases. A slight increase in precipitation in the fall (up to 12 %) does not compensate for the decrease in annual precipitation.

The decrease in precipitation in the rest of the year against the backdrop of a clear increase in temperature is evidence of an increasingly arid climate, and, accordingly, a deterioration in the conditions for growing crops.

The value of potential evapotranspiration can be used to estimate the potential moisture consumption for a certain period (day, month, season, year) and its comparison with the moisture supply for the same period makes it possible to assess the moisture supply of the production process in crop cultivation [16]. In this case, there are several methods for determining potential evapotranspiration, which can be generally divided into calculated and experimental [17–22]. In our study, we used the Penman-Monteith method recommended by FAO as a reference method, which, according to many data on its use in different weather and climatic conditions, allows obtaining data close enough to the values



a) absolute values b) deviations from the norm

Fig. 1 – Dynamics of the average annual air temperature for 1961–2021, °C

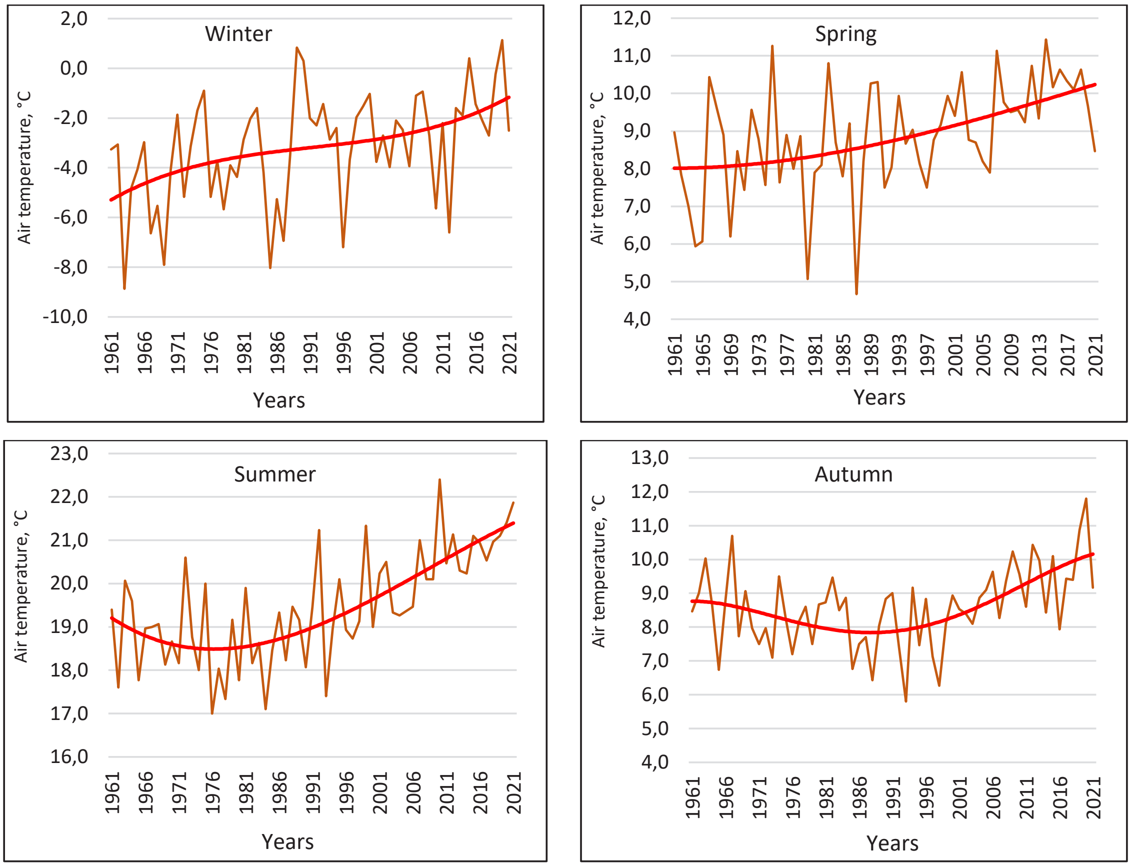
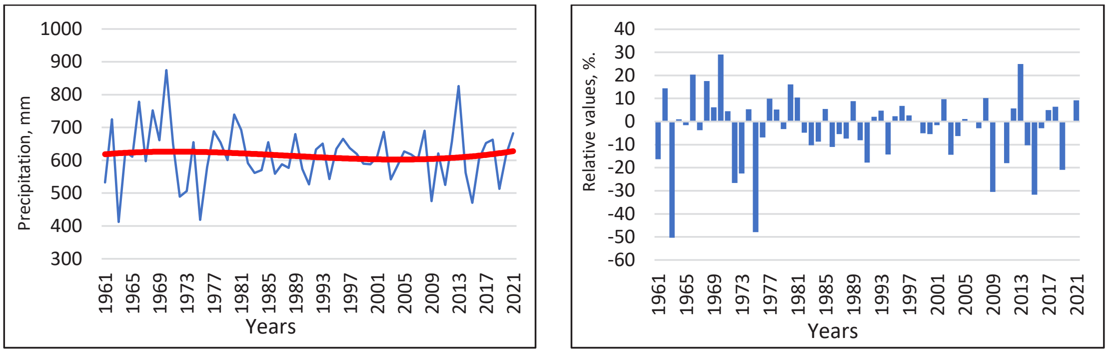


Fig. 2 – Dynamics of seasonal air temperature values for 1961–2021, °C

1. Changes in average monthly, seasonal and annual air temperature values for 1991–2020 compared to 1961–1990, °C

Months/seasons	Years			
	1961–2021	**1961–1990**	**1991–2020**	**± to 1961–1990**
January	−4,5	−5,6	−3,3	2,2
February	−3,1	−4,1	−2,1	2,0
March	1,8	0,9	2,7	1,8
April	9,5	8,9	10,0	1,1
May	15,3	15,0	15,5	0,5
June	18,7	18,2	19,2	1,1
July	20,0	19,1	20,9	1,8
August	19,5	18,7	20,3	1,6
September	14,6	14,2	14,9	0,7
October	8,5	8,3	8,7	0,4
November	2,6	2,3	2,9	0,5
December	−2,2	−2,4	−1,9	0,5
Winter	−3,2	−4,0	−2,4	1,6
Spring	8,9	8,3	9,4	1,1
Summer	19,4	18,7	20,1	1,5
Autumn	8,6	8,3	8,8	0,6
Year	8,4	7,8	9,0	1,2



absolute values, mm relative values, % to the norm

Fig. 3. Dynamics of annual precipitation for 1961–2021

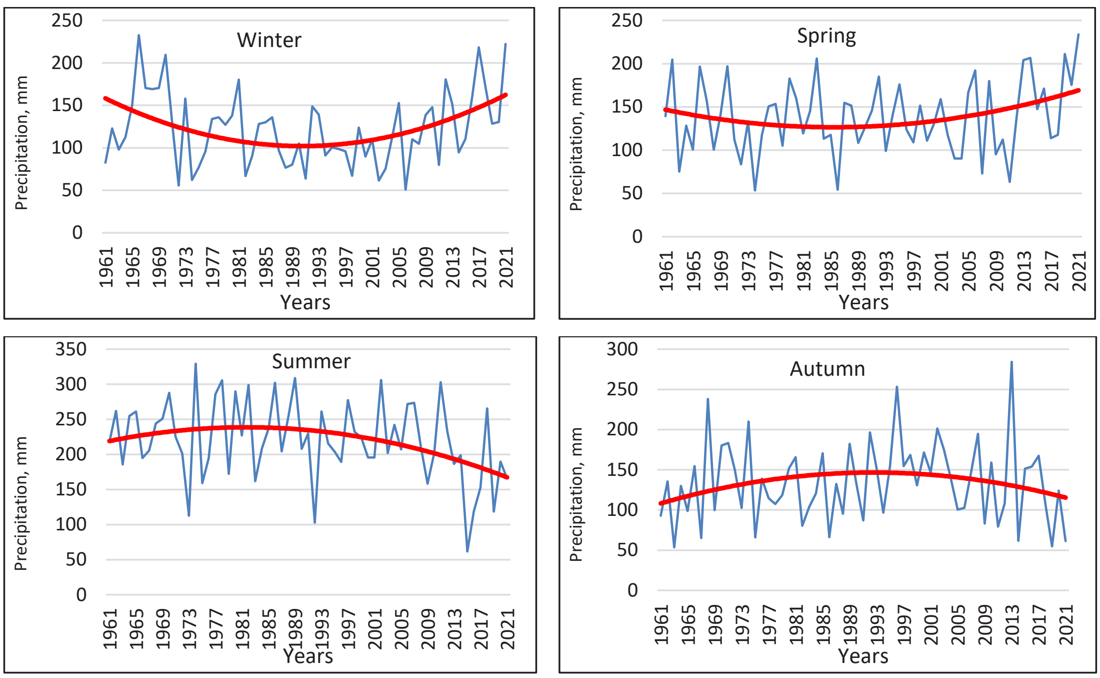


Fig. 4. Dynamics of seasonal precipitation for 1961–2021, mm

2. Changes in monthly, seasonal and annual precipitation over 1991–2020 compared to 1961–1990, mm

Months/seasons	Years			
	1961–2021	1961–1990	1991–2020	± to 1961–1990, %, %.
1	2	3	4	5
January	40	41	38	−3
February	37	38	35	−3
March	36	34	38	4
April	42	45	40	−5
May	60	54	62	8
June	77	76	79	3
July	83	91	76	−15
August	61	68	53	−15
September	52	47	57	10
October	37	34	42	8
November	45	47	44	−3
December	45	45	44	−1

Table 2 (ending)

1	2	3	4	5
Winter	122	124	117	−7
Spring	138	133	140	7
Summer	220	235	208	−27
Autumn	135	128	143	15
Year	615	620	608	−12

of actual evapotranspiration, but it requires a significant amount of input data, some of which should be obtained from direct measurements. Given this circumstance, an attempt was made to find a simpler method for determining potential evapotranspiration, namely, using only the value of the average monthly temperature. The dependence of the potential evapotranspiration on the average monthly air temperature obtained using this approach is shown in Fig. 5.

Comparison of the values of potential evapotranspiration calculated by the Penman-Monteith method and the dependence shown in Fig. 5 (Fig. 6) made it possible to calculate the correction factors (Table 3) to the experimental dependence of potential evapotranspiration on the average monthly air temperature (Fig. 5). Further comparison of the values of potential evapotranspiration calculated with their use with the data of calculation by the Penman-Monteith method (Fig. 7) showed a sufficient level

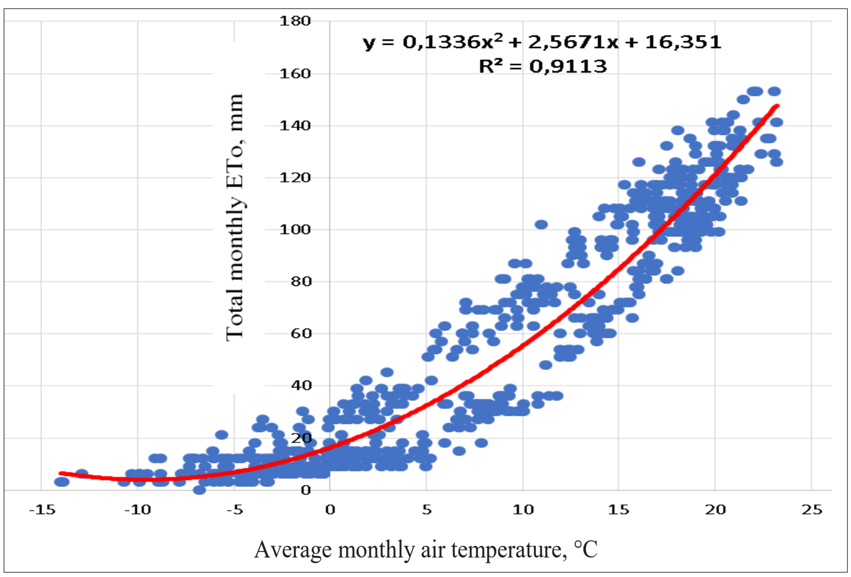


Fig. 5. Dependence of total monthly potential evapotranspiration on the average monthly air temperature, mm

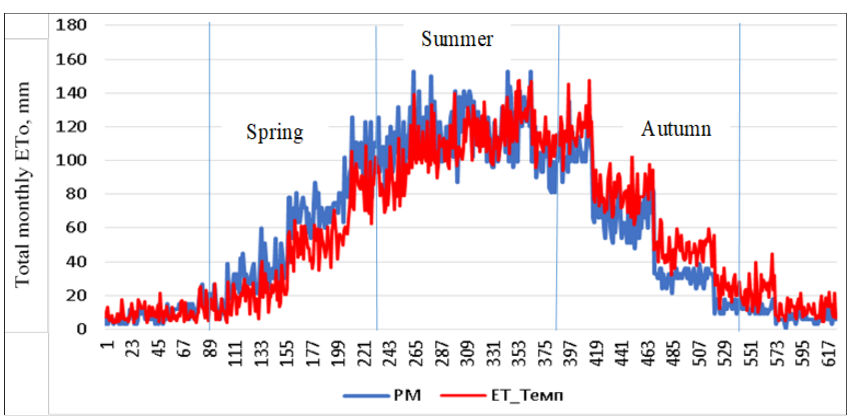


Fig. 6. Potential evapotranspiration calculated by the Penman-Monteith method and based on the average monthly air temperature, mm

of coincidence of the calculation results for practical purposes, which led to the conclusion that it is possible to use the dependence shown in Fig. 5 in combination with the correction factors (Table 3) in conducting forecast calculations of potential evapotranspiration for their further use to assess the level of soil moisture supply.

Using this methodological approach, the dynamics of the annual potential evapotranspiration for the period 1961–2021 was assessed (Fig. 8) and changes in monthly values of potential evapotranspiration for the period 1991–2020 compared to the period 1961–1990 (Table 4).

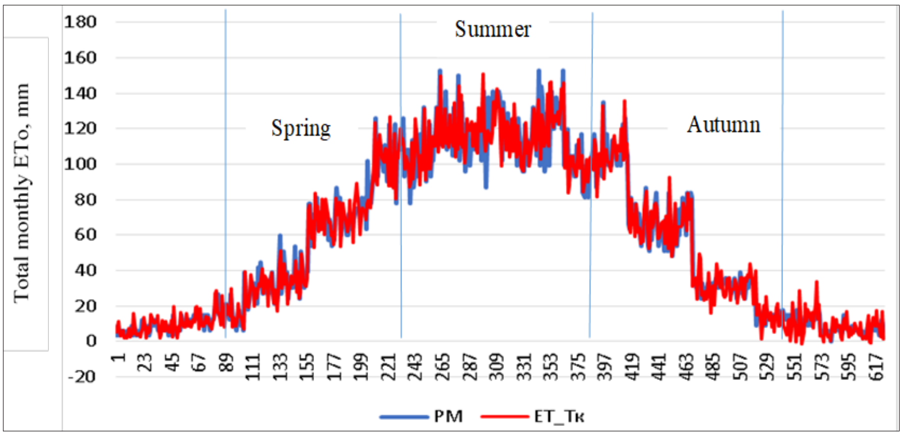


Fig. 7. Potential evapotranspiration calculated by the Penman-Monteith method and based on the average monthly air temperature with a correction factor, mm

3. Correction factors for calculating potential evapotranspiration based on average monthly air temperature

Months											
I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
−2	3	11	19	18	11	−1	−12	−14	−16	−11	−5

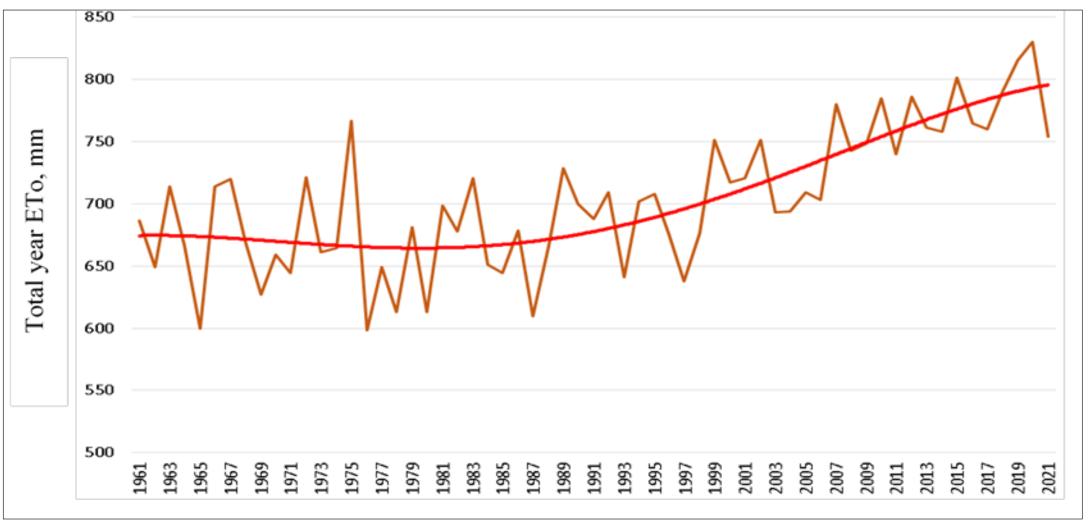


Fig. 8. Dynamics of annual potential evapotranspiration for 1961–2021, mm

4. Changes in monthly values of potential evapotranspiration for 1991–2020 compared to 1961–1990, mm

Years	Months											Year
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
1961–2021	7	14	34	72	105	123	121	106	68	32	14	7	703
1961–1990	6	13	31	69	103	119	113	99	66	31	13	7	670
1991–2020	8	16	36	75	107	127	128	112	71	33	15	8	735
±1961–1990	2	3	5	6	4	8	14	12	5	2	2	2	65

The analysis of the results of this table shows that the growth of potential evapotranspiration occurs in all months of the year, but the largest increase is observed in the summer months – by 8 mm in June, 15 mm in July and 13 mm in August. In general, the growth rate of potential evapotranspiration is 65 mm per year.

Conclusions. Temperature changes show that the average annual air temperature over the period 1991–2020 increased by 1,2 °C, in winter by 1,6 °C, in spring by 1,1 °C, in summer by 1,5 °C, and in autumn by 0,6 °C, i.e. the most intense temperature increase is in summer.

Regarding precipitation over the same period of research, it was found that, unlike temperature, which is increasing, precipitation is decreasing in annual and seasonal (except for autumn) terms. A slight increase in precipitation in the fall does not compensate for its decrease in the annual context.

There is an increase in potential evapotranspiration throughout the year, with the largest increase in the summer months. In general, the growth of potential evapotranspiration is 65 mm per year.

Summarizing the results of the assessment of climate change on the growth of potential evapotranspiration, it should be noted that climate change has caused a significant (9 %) increase in the annual value of potential evapotranspiration, and, accordingly, a deterioration in the conditions of natural moisture supply of soils in the Central Forest-Steppe of the Ukraine. This circumstance must be taken into account when growing crops.

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ОЦІНКА УМОВ ПРИРОДНОГО ВОЛОГОЗАБЕЗПЕЧЕННЯ НА ПРИКЛАДІ ПІВДЕННО-ЗАХІДНОЇ ЧАСТИНИ КИЇВСЬКОЇ ОБЛАСТІ

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Анотація. *Сталість ведення землеробства в Україні безпосередньо залежить від рівня природного вологозабезпечення ґрунтів, що значно погіршується під впливом кліматичних змін. У статті* *досліджується вплив цих змін на величину потенційної евапотранспірації (ETo) в південно-західній частині Київської області (Центральний Лісостеп України) на основі даних метеостанції м. Біла Церква за період з 1991 по 2020 роки. В основу методології досліджень покладено припущення, що оцінку впливу змін клімату на стан природного вологозабезпечення можна виконати за умови оцінки самих змін клімату за даними багаторічної динаміки температури повітря та опадів в період з 1991 по 2021 рр. зі значеннями цих же показників в період з 1961 по 1990 рр. – кліматична норма.. В якості критеріїв оцінки впливу змін клімату на стан вологозабезпечення ґрунтів обрано потенційну евапотранспірацію (ETo). Результати оцінки показали, що річна величина потенційної ETo зросла на 9 %, що опосередковано може свідчити про погіршення умов природного вологозабезпечення ґрунтів. Це має важливі наслідки для сільського господарства, оскільки зростання ETo може призвести до зменшення доступної вологи для рослин, що негативно вплине на врожайність культур. Дослідження охоплює зміни середньорічної та середньомісячної температури повітря, а також кількість опадів в розрізі сезонів і місяців. Встановлено, що протягом останніх тридцяти років в Україні спостерігається тенденція до погіршення умов вологозабезпечення, що потребує адаптації сільськогосподарських практик. Сталий розвиток аграрного сектору можливий лише за умови врахування змін в природному вологозабезпеченні при розробці моделей господарювання та технологій вирощування. Отримані результати свідчать про необхідність впровадження інноваційних агрономічних технологій, які адаптуються до актуальних змін клімату.*

Ключові слова: *прогнозування вологозапасів, моделювання, фактори впливу, гідротермічні умови, сільське господарство, зміни клімату*