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Space-Time Modeling of Climate Change and Bioclimatic Potential of Steppe Soils

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Abstract: Climate change manifests itself in the intensity, frequency of climate anomalies and extreme weather phenomena at different levels of the hierarchy in space and time. Climate research is a complex interdisciplinary problem covering environmental, economic and social aspects of sustainable development of the world's countries. The study presents the results of space-time modeling and identifying regularities in climate change and also bioclimatic potential of the steppe soils in Ukraine applying specialized methods and GIS-technologies. The past 30 years are the most extreme period by the frequency of climate anomalies with a steady trend-cycle increase in the air temperature by 2°C and a reduction in the annual precipitation by 178 mm. It caused an increase in solar radiation reaching the earth surface by 7.2%, a decline in natural moisture by 66.4% and the hazard of soil washout by 80.5%, a reduction in climate energy expenses for soil formation by 21%, in bio-productivity of plants by 62% and in the potential of humus horizon capacity of steppe soils by 34.5%, that led to deterioration in the conditions of agricultural production, a decrease in crop productivity, self-regenerating and self-regulating functions of steppe soils. The obtained results are the basis for developing and introducing new measures for adaption to climate change at different economic levels.

***Keywords*:** Climate, Air temperature, Precipitation, Bioclimatic potential, Soil formation, Humus horizon, Steppe soils, Modeling, GIS-technologies

Climate change is one of the most important global challenges of the 21st century going beyond the scope of scientific studies being a complex interdisciplinary problem that covers environmental, economic and social aspects of sustainable development of the world’s countries. Climate change manifests itself in the intensity, frequency of climate anomalies and extreme weather phenomena at different levels of the hierarchy in space and time. For the past 30 years there has been a considerable increase in the frequency and intensity of dangerous weather phenomena causing a substantial economic loss, threatening steady functioning of landscape and aquatic ecosystems, and also human health and life. According to the predictions of many scientists, there will be a steady trend-cycle climate change (Wang et al 2019, Felice et al 2019, Dikshit et al 2021) causing considerable changes in the functioning of natural and artificial ecosystems, an increase in the frequency of signs of dangerous processes and consequences, degradation in the environment. The world scientists maintain that global climate change is caused by the factors: anthropogenic factors (Zhang et al 2019, Christidis and Stott 2021), an increase in the concentration of carbon dioxide (Paraschiv and Paraschiv 2020), radiative heating of the atmosphere because of absorption of infrared radiation under a dominating impact of convective heat transfer (Sorokhtin 2011), changing currents in the Arctic Ocean (the cold Labrador Current in the in the area of Greenland and the warm Gulfstream), causing periodical disastrous epochs of a steady decline and increase in the temperature regime in the Northern Hemisphere (Chaudhuri et al 2009, Weiser et al 2021). Climate at a regional level forms under the influence of the three most important factors: atmospheric circulation, solar insolation and topography (Lisetskii and Chepelev 2014). Therefore, need to take appropriate preventive measures, extensive implementation of basin management principles in the environment, application of advanced technologies to reduce the amount of carbon dioxide emissions and pollutants in the atmosphere, decreasing the area of arable lands and increasing the area of natural lands, using alternative sources of energy and technologies of energy supply, introduction of adaptive technologies and measures to uncontrolled climate change in different economic areas of the world’s countries etc.

An increase in anthropogenic load reduces the resistance of the environment to uncontrolled signs of climate change. Negative signs of anthropogenic climate change are especially evident in the Steppe zone (Lisetskii and Pichura 2016, Dudiak et al 2019). There has been a considerable decline in the supply of water resources and their quality (Pichura et al 2018, 2020), the natural hydro-network of small and medium rivers has been destroyed by 60% (Oti et al 2020, Lisetskii 2021), the frequency of droughts has increased (Assan et al 2020, Ukrainskiy et al 2020) and the frequency of the signs of erosion processes has risen (Dudiak et al 2019, 2020), the condition of land resources has deteriorated (Breus et al 2019, 2020, Lisetskii et al 2020) and crop productivity has also fallen (Domaratskiy et al 2018). Therefore, in order to farm effectively, substantiate nature conservation measures, regenerate natural resources and use them efficiently, adapt to new farming conditions and ensure sustainable nature management, it is necessary to consider space and time regularities of climate change and bioclimatic potential of territories. Analysis of the available sources shows that the issue of space-time modeling of climate change and evaluation of its impact on the formation of bioclimatic potential of territorial ecosystems aimed at the development and implementation of new adaptation measures at different economic levels is still topical and requires thorough examination. The purpose of the research is to model climate change and determine bioclimatic potential to establish trend-cycle changes in time and heterogeneity in spatial distribution of climate energy in the functioning of steppe soils.

MATERIAL AND METHODS

The study was conducted on the territory of the steppe zone of Ukraine (Fig. 1) (the total area is 167.4 thousand km^2), including the area of agricultural land (132.3 thousand km^2). Agricultural development of the region varies within 20-97%.

Space-time modeling of climate change and bioclimatic potential of steppe soils was performed on the basis of extrapolation of the data of 47 meteorological stations collected in 1990-2019. There are two approaches to determining effective climate energy through heat and

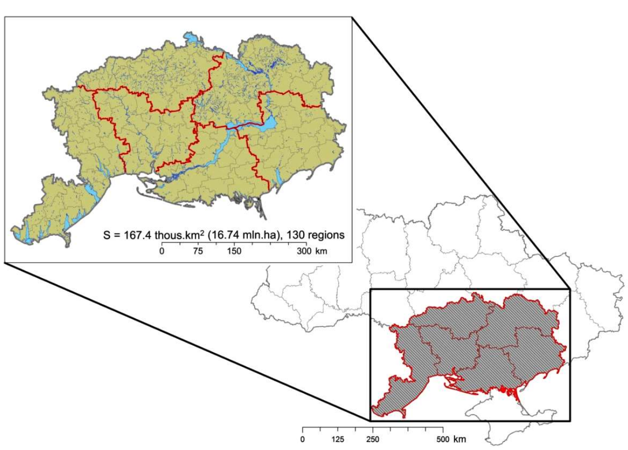


Fig. 1. Spatial characteristic of the territory of the steppe zone of Ukraine

moisture supply, proposed by Volobuiev (1974), Rasmussen and Tabor (2007). The previous research (Lisetskii and Pichura 2016) established a close exponential relation between the models of Rasmussen-Tabor (Q_{RT}) and Volobuiev (Q_V): Q_{RI} = 52.065 exp. (0, 001 Q_v); r^2 0, 93 determining the impact of climate energy on soil formation processes. It proves that the proposed approaches are complementary and allow approximation of identical conditions for the direction of climate energy, but the approach proposed by Volobuiev (1974) provides an additional possibility to determine climate impacts on the formation of soil horizon. Therefore, soil and climate studies use the method of bioenergetics research that allows modeling scenarios of climate impacts, given in energy equivalents, on the trends of soil development in time.The raster of spatial differentiation of climate energy expenses for soil formation (Q, MJ m^{-2}) in ArcGIS was calculated by the formula:

$$Q = 41.868 R \cdot e^{(-18.8 \frac{R^{0.73}}{P})}$$

where R – the balance of solar radiation, kcal cm^{-2}; P – the raster of the total annual precipitation, mm.

The calculation of spatial differentiation of the balance of solar radiation ®, kcal cm^{-2}) considering surface unevenness was performed by the formula:

$$R = R_0 \frac{\cos(s) \times \sin(h) + \sin(s) \times \cos(h) \times \cos(\psi_s - e)}{\sin(h)}$$

where R_0 – the value of radiation balance of horizontal surface for each month of the year, kcal cm^{-2}; h – the average daily solar altitude for each month, rad; ψ_s – azimuth of the normal projection to the slope on a horizontal plane, rad; s – the raster of slopes, rad; e – the raster of expositions, rad.

The calculation of the raster of spatial distribution of the maximum capacity of soil humus horizons (H_{lim}, mm) depending on Q was performed by the formula:

$$H_{\lim} = \frac{2000}{1 + e^{(5.346 - 0.00523 \cdot Q)}}$$

Space-time differentiation of bio-productivity of plants (the dry weight – F, t ha^{-1}) was calculated depending on climate energy expenses for soil formation by the formula (Pichura 2020):

$$F = 0.3202 \cdot \exp(0.003421 \cdot Q), r = 0.96$$

The coefficient of the hazard of soil washout (K_{gm}) for the territory of the Steppe zone of Ukraine was calculated depending on the average multi-year value of the total precipitation in May–September (X_{av}) with a high level of correlation R=0.726 and determination R^2=0.527 by the formula (Svetlichny 2018):

$$K_{gm} / (2.6 \cdot 10^{-6}) = 0.0174 X_{av}^{2.1}$$

where X_{av} – the average multi-year value of the total precipitation in May–September.

Zoning is performed by the gradation: 1 – the zone of high rainfall activity ($K_{gm} > 1500$), 2 – the zone of moderate rainfall activity (K_{gm} = 500-1500), 3 – the zone of low rainfall activity ($K_{gm} < 500$).

An important index for determining the intensity of the signs of dangerous washout and regulating irrigation norms in the Steppe zone is evaluation of changes in general climate moisture by the moisture coefficient of Vysotsky–Ivanov (K_H), measured by the ratio of the total annual precipitation (*Py*) and annual evaporation (*Ey*):

$$K_H = Py/ Ey$$

Zoning is performed by the gradation: K_H>1 – the territory (time period) with excessive moisture, K_H is about 1 – with optimal moisture, K_H = 1.0–0.6 – with unsteady moisture, K_H = 0.6–0.3 – with insufficient moisture (Ivanov 1948).

In order to evaluate annual evaporation, we used the method (Kolomyts 2010), implying that evaporation depends on average monthly air temperature of the warmest month (July– t_{max}) with high coefficients of correlation R=0.94 and determination R^2=0.88:

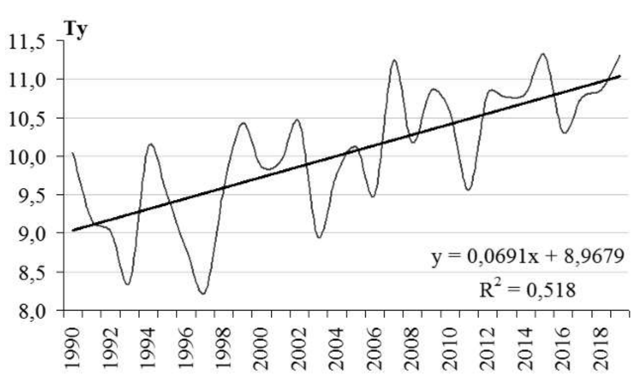
$$Ey = 1384-161.6t_{max} + 6.245t^2_{max}$$

Modeling and calculation of spatial distribution of the research indexes were performed by means of the software ArcGIS 10.1.

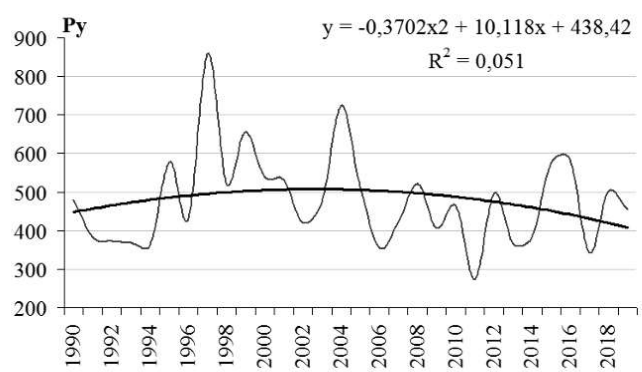
RESULTS AND DISCUSSION

The Steppe zone of Ukraine is referred to the territories of risky agriculture by extreme climate conditions, signs of droughts and wind erosion. The territory is characterized by a high level of agricultural land development, the area of farmlands was 13235.5 thousand hectares (21.92% of the total area of Ukraine) on January, 2019. The area of natural lands is about 14%, including forests and other woodland areas (6.1%), followed by territories covered with surface water (6.91%) and open wetlands 0.97%. A high degree of agricultural land development (77.83%) and arable territories (66.76%) of the Steppe zone causes a low level of ecological stability of the landscapes in terms of soil conservation measures. More that 60% of the irrigated lands of Ukraine are located in the territory of the Steppe zone, without the temporarily occupied territories, making about 1324.1 thousand ha, 461.2 thousand ha (34.8%) of these territories are irrigated. Extensive use of land resources in the Steppe zone caused imbalance in the natural state of soil fertility, its considerable deterioration, ecological imbalance in the environment, a decline in the efficiency and rate of natural soil formation processes, an increase in energy expenses for obtaining steady crop yields. In particular, negative environmental processes intensified by climate change cause large-scale manifestation of wind erosion, salinization and alkalization of steppe soils. It deepens the problem of examining soil condition and soil functioning under high anthropogenic pressure and climate change.

Changes in the air temperature and precipitation: There has been a trend-cycle increase of the average air temperature and a decline in the total annual precipitation in the Steppe zone of Ukraine. The cycle components of the multi-year formation of climate indexes were: air temperature (8 years) and precipitation (11 years). The past 30 years (Fig. 2a) are considered to be the most extreme period by the frequency of climate anomalies that doubled causing an increase in the temperature regime by a cyclic-linear regularity (R=0.72, R^2=0.52) and led to an increase in the average annual temperature by 2°C at the average increase rate of 0.07°C per year. Cyclicity of the changes in precipitation in the Steppe zone is within asynchronous



a



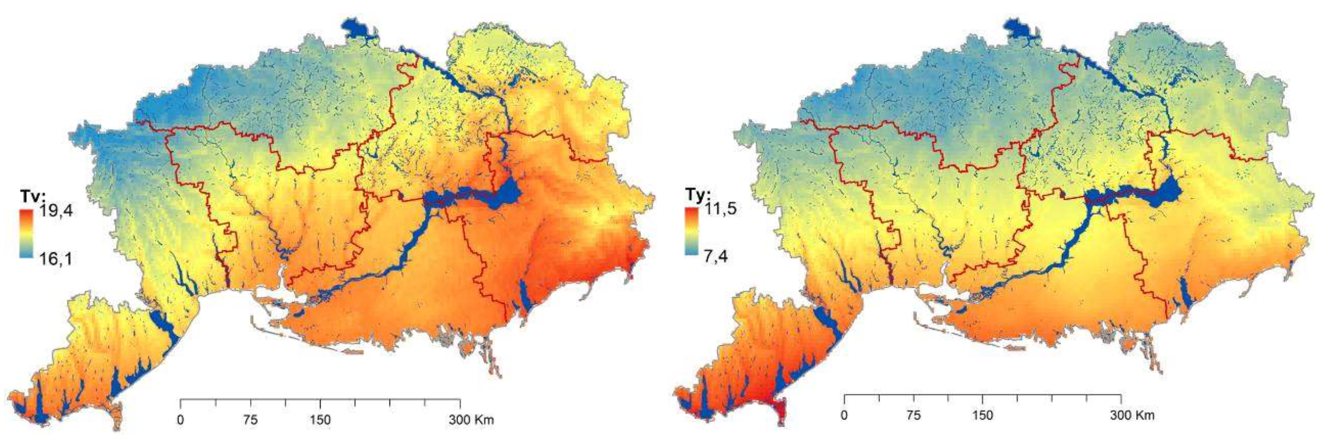
b

Fig. 2. Dynamics of the average annual air temperature (*a* – *Ty*, °C) and the total precipitation (*b* – *Py*, mm) within the territory of the Steppe zone of Ukraine in 1990-2019

regularity of changes with respect to the temperature regime. In 1990–2019, 35% of years with anomalous amounts of precipitation were registered, in particular (Fig. 2b) 8 years with severe and 4 years with very severe anomalies. Over the past 30 years it has caused a reduction in the total annual precipitation by 178 mm at the reduction rate of 7.12 mm per year.

An increase in the frequency of anomalous high temperatures and a decline in the amount of precipitation have caused deterioration in the conditions of agricultural production, self-regenerating and self-regulating functions of soils, a reduction in the rate of soil regeneration, leading to a decline in their fertility, maintaining a negative tendency to soil degradation, losses in crop yields and deterioration in food security of the country.The results of the spatial modeling allowed establishing zonal regularities of climate preconditions for differentiation of the functioning of steppe soils. The average air temperature in 1990–2019 in the Steppe zone of Ukraine changed from 16.1 to 19.4°C in the direction from the North to the South during the growing season (Fig. 3a), and the average annual was within 7.4–11.5°C (Fig. 3b). The highest value of the air temperature was registered in the southern part of the Steppe zone. Zonal climate changes in the functioning of soils depend on the principle of the limiting factor, i.e. bio-productive potential of soil s, plant growth, the amount and stability of their yields depend on the substance, whose concentration is minimal. Moisture is the limiting factor in the Steppe zone. In particular, background characteristics of the zonal changes in heat and moisture supply explain the specificity and multi-year rhythmicity of the conditions of agricultural production.

Spatial differentiation of precipitation during the growing season in the territory of the Steppe zone of Ukraine in 1990-2019 ranged from 182 mm to 382 mm from the southern part to the northern part (Fig. 4a). Theannual precipitation ranged from 321 mm to 607 mm (Fig. 4b). The highest value of precipitation is registered in the north-western and the north-eastern parts of the Steppe zone.There were considerable variable changes (V = 6-10 %) of the average annual indexes in the growing season, in particular, the air temperature and the total precipitation were within V = 27-32%. Retrospective analysis of the dynamics of the air temperature and precipitation indicates to a steady cyclic increase in the average annual air temperature and a decline in the precipitation. An increase in the precipitation over some periods of time was not productive, because of rainfalls causing flood processes and water erosion. Climate change is characterized by an uncontrolled dynamic process that affects the functioning of all components of ecosystem, including the space-time differentiation of climate energy expenses for soil formation processes and the formation of natural soil fertility. The dependence of soil formation on climate is an unsteady temporal process, characterized by cyclicity and amplitude, and also by a change in the trend of moisture supply (total precipitation) and energy (solar radiation).



a *B*

Spatial function of value distribution *Tv*:

$$Tv = -23,271 - 2,904x - 0,036x^2 + 4,215y - 0,091y^2 + 0,115xy,\ r^2 = 0,79$$

Spatial function of value distribution *Ty:*

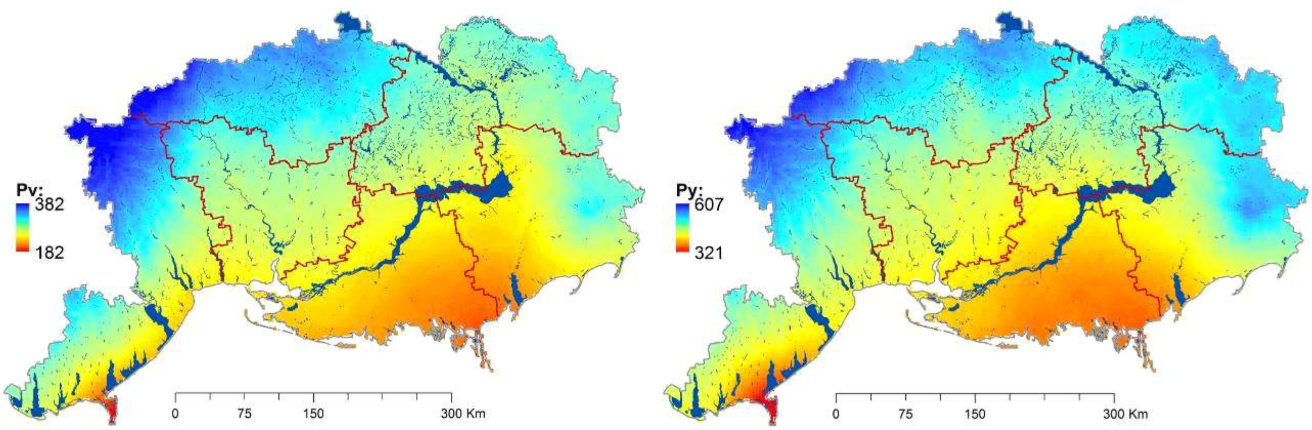
$$Ty = 148,909 - 2,604x - 0,021x^2 - 3,215y - 0,006y^2 + 0,086xy,\ r^2 = 0,91$$

where, x – longitude, decimal degrees, y – latitude, decimal degrees

Fig. 3. Spatial differentiation of the air temperature in the territory of the Steppe zone of Ukraine in 1990–2019: *a* – the average value in the growing season (*Tv,* °C); *b* – the average annual value (*Ty,* °C)

Moisture deficit in the conditions of the Steppe zone and the necessity to obtain high yields have caused the development of irrigated agriculture in these regions. Intensive agriculture in irrigated lands using obsolete machinery and technologies has led to irreversible processes of deterioration in their environmental-reclamation condition (Pichura and Breus 2015, Martsinevskaya et al 2018), flooding, salinization, alkalization and excessive irrigation have caused degradation in soil horizons, excessive and unreasonable exploitation of surface water resources.

Changes in the solar radiation and climate energy expenses for soil formation: Distribution of solar radiation is an important climate component of crop yield formation and an object of modifying agro-landscape microclimate. Space-time differentiation of solar radiation depends on cyclic movement of temperature regime and morphometric characteristics of topography. In particular, the value of radiative balance and moisture coefficient have asynchronous movement. In 1990-2019 the f the balance of solar radiation increased by 7.2% (from 51.5 to 55.2 kcal cm^{-2}) at the average annual increase rate of 0.2 kcal cm^{-2} per year (Fig. 5*a*). The process of evaporation from the surface is more intensive when there is an increase in solar radiation, as a result, it causes a decline in the coefficient of soil moisture and low yields.



A ***b***

Spatial function of value distribution *Pv*

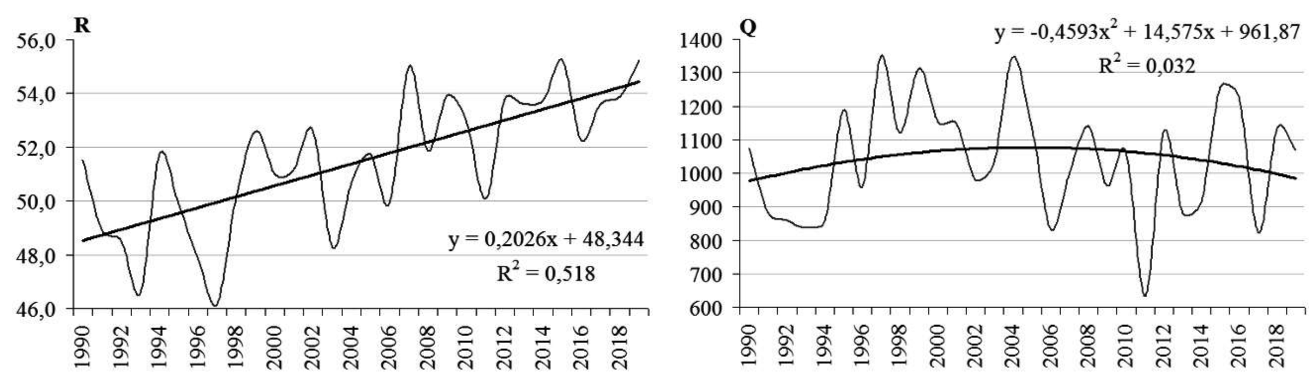
$$Pv = -4218,089 - 84,729x + 3,475x^2 + 221,238y - 0,875y^2 - 3,219xy,\ r^2 = 0,78$$

Spatial function of value distribution *Pv*

$$Py = -7728,96 - 249,927x + 5,848x^2 + 473,386y - 3,429y^2 - 2,985xy,\ r^2 = 0,85$$

where, x – longitude, decimal degrees, y – latitude, decimal degrees

Fig. 4. Spatial differentiation of precipitation (*P,* mm) in the territory of the Steppe zone of Ukraine in 1990–2019: *a* – the total precipitation in the growing season (*Pv,* мм); *b* – the total annual precipitation (*Py,* mm)



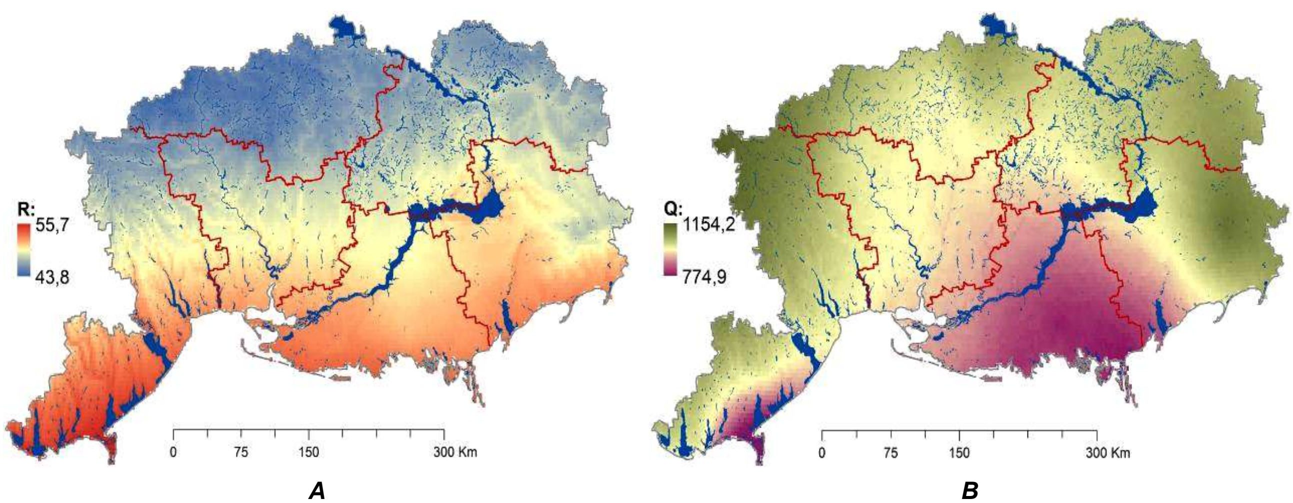
A ***B***

Fig. 5. Dynamics of the balance of solar radiation (*a* – *R*, kcal cm^{-2}) and climate energy expenses for soil formation (*b* – *Q*, MJ m^{-2}) within the territory of the Steppe zone of Ukraine in 1990-2019

Spatial differentiation of the balance of solar energy in the territory of the Steppe zone of Ukraine in 1990–2019 ranged from 43.8 to 55.7 kcal cm^{-2} from the northern part to the southern part (Fig. 6a). The highest value of the balance of solar radiation was registered in the southern part of the Steppe zone.Cyclicity of changes in precipitation and asynchronous movement of solar radiation causes a decline in climate energy expenses for soil formation processes. For instance, the annual climate energy expenses for soil formation (Q, MJ m^{-2}) within the territory of the Steppe zone in 1990-2019 ranged from 632.3 to 1350.0 MJ m^{-2} (Fig. 5b), its minimal value was registered in 2011 and its maximum value in 1997. The annual climate energy expenses for soil formation fell by 21% (from 1350 to 1067.6 MJ m^{-2}) at the average annual rate of 9.0 MJ m^{-2} per year in 1997-2019. A negative tendency to a decline in the dependence of soil formation processes on climate leads to a decrease in the rate of natural capability of regenerating soil fertility and an increase in the time necessary for conservation of degraded and low-productive farmlands. The spatial differentiation of climate energy expenses for soil formation in the territory of the Steppe zone of Ukraine in 1990–2019 ranged from 774.9 to 1154.2 MJ m^{-2} from the southern part to the northern part (Fig. 6b). The highest value of climate energy expenses for soil formation was registered in the northern part of the Steppe zone.

Changes in the bioclimatic potential of soils: Spatial heterogeneity of soil cover within the Steppe zone is caused by the interaction of bioclimatic, litholytic, geomorphological and historical-genetic factors. In particular, the temperature regime and the regime of soil and air moisture have determined the zonal differentiation of bioclimatic potential of soils that characterizes the state of the atmosphere as a basic part of the environment and the functioning of soil. Under conditions of continuous climate change, bioclimatic potential allows determining space-time regularities of changes in the potential of crop productivity, the rate of accumulation of organic matter and regeneration of soil fertility. Bioclimatic potential of soils is determined by the value of bio-productivity of plants. The bio-productivity of plants (F) varied within 2.8–32.4 t ha^{-1} depending on climate conditions of the Steppe zone of Ukraine in 1990–2019 (Fig. 7*a*), minimal in 2011and maximum in 1997. Climate-dependent bio-productivity of plants fell by 62% (from 32.4 to 12.3 t ha^{-1}) at the average annual rate of 0.45 t ha^{-1} per year in 1997-2019.

The considerable heterogeneity (about 73%) in the differentiation of bio-productivity of plants in the territory of the Steppe zone of Ukraine in 1990-2019 was observed and ranged from 4.5 to 16.7 t ha^{-1} from the southern part to the northern part (Fig. 8*a*). The highest value of bio-productivity of plants was registered in the north-western and the north-



Spatial function of value distribution *R:*

$$R = 485,526 - 7,633x - 0,061x^2 - 9,423y - 0,016y^2 + 0,251xy,\ r^2 = 0,88$$

Spatial function of value distribution *Q:*

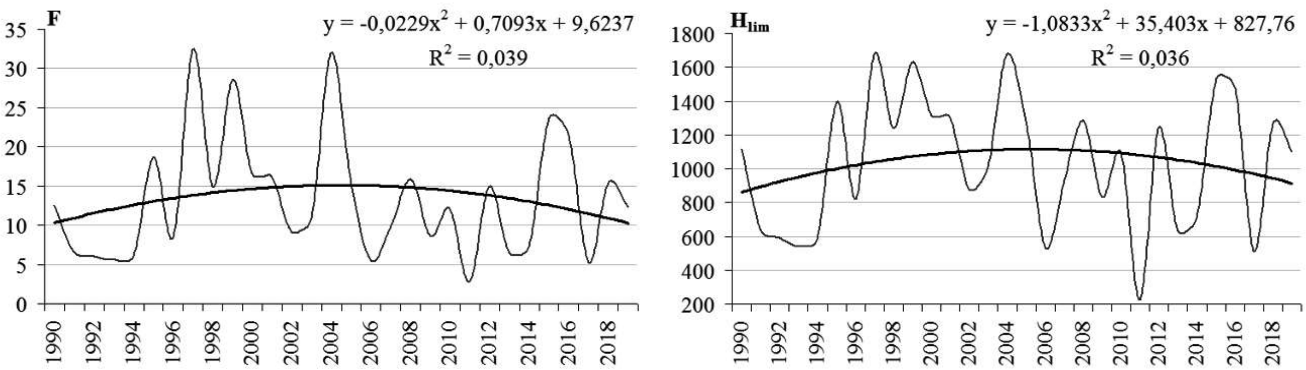
$$Q = -22066,35 - 593,60x + 2,18x^2 + 1344,96y - 14,46y^2 + 2,18xy,\ r^2 = 0,83$$

where, x – longitude, decimal degrees, y – latitude, decimal degrees

Fig. 6. Spatial differentiation of climate energy features in the territory of the Steppe zone of Ukraine in 1990–2019: *a* – radiative balance of the surface (R, kcal cm^{-2} per year); *b* – climate energy expenses for soil formation (Q, MJ m^{-2})

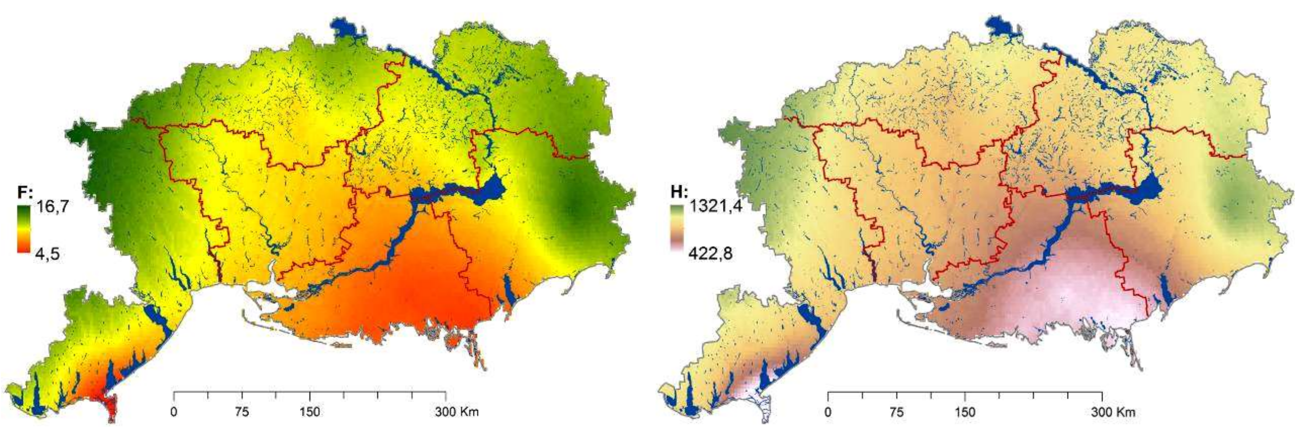
eastern parts of the Steppe zone.Spatial distribution of the data on climate energy expenses for soil formation (*Q*) allowed determining space-time regularities of the zonal-cyclic changes in the formation of the potential of the capacity of soil humus horizon (H_{lim}, *мм*) in the territory of the Steppe zone. Climate dependence of the change H_{lim} in 1990–2019 ranged from 226.5 to 1684.2 mm (Fig. 7*b*), minimal was in 2011 and maximum in 1997. The H_{lim} fell by 34.5% (from 1684.2 to 1102.4 mm) at the average annual rate of 19.7 mm per year from 1997 to 2019. The spatial differentiation of the potential of soil humus horizon in the territory of the Steppe zone of Ukraine in 1990–2019 ranged from 422.8 to 1321.4 mm from the southern part to the northern part (Fig. 8*b*). The highest average H_{lim}, was registered in the north-western and the north-eastern parts of the Steppe zone. In particular, the development of irrigated reclamation in the Steppe zone has caused a considerable increase (1.5 times) H_{lim} (Lisetskii and Pichura 2016), that leads to systematic manifestation of leaching, transportation of organic substances to lower soil horizons poorly accessible for plants and, as a result, to a decline in agriculture efficiency and top soil fertility.

Changes in the hydro-meteorological conditions of soil washout: Space-time regularities of accelerating degradation of soil cover and unpredicted signs of yield destruction are mainly determined by differentiation of the eroding regime of rainfalls, characterized by the hydro-



a *b*

Fig. 7. Dynamics of bio-productivity of plants (*a* – by dry weight – *F*, t/ha) and capacity of soil humus horizon (*b* – H_{lim}, *mm*) within the territory of the Steppe zone of Ukraine in 1990-2019



A *b*

Spatial function of value distribution *F*

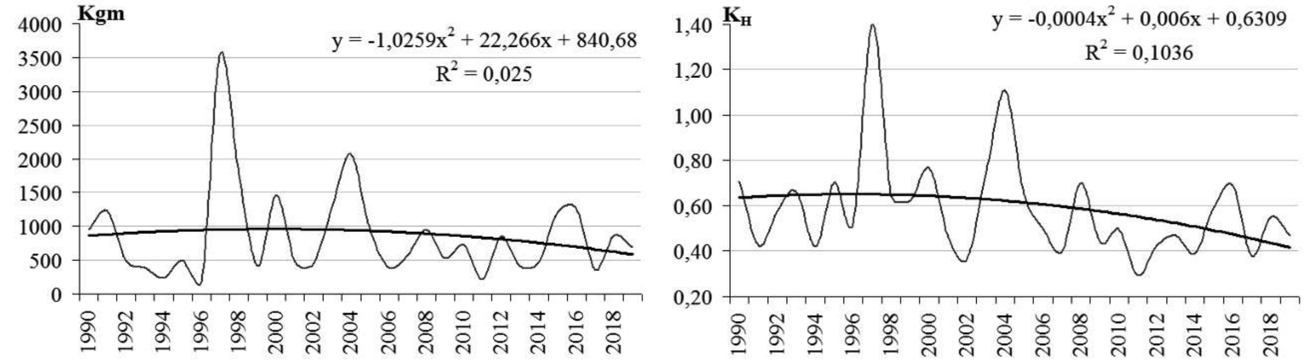
$$F = -764,186 - 21,251x + 0,306x^2 + 45,90y - 0,473y^2 + 0,018xy,\ r^2 = 0,83$$

Spatial function of value distribution *H*

$$H = -57111,06 - 1527,44x + 18,78x^2 + 3405,55y - 36,69y^2 + 5,79xy,\ r^2 = 0,81$$

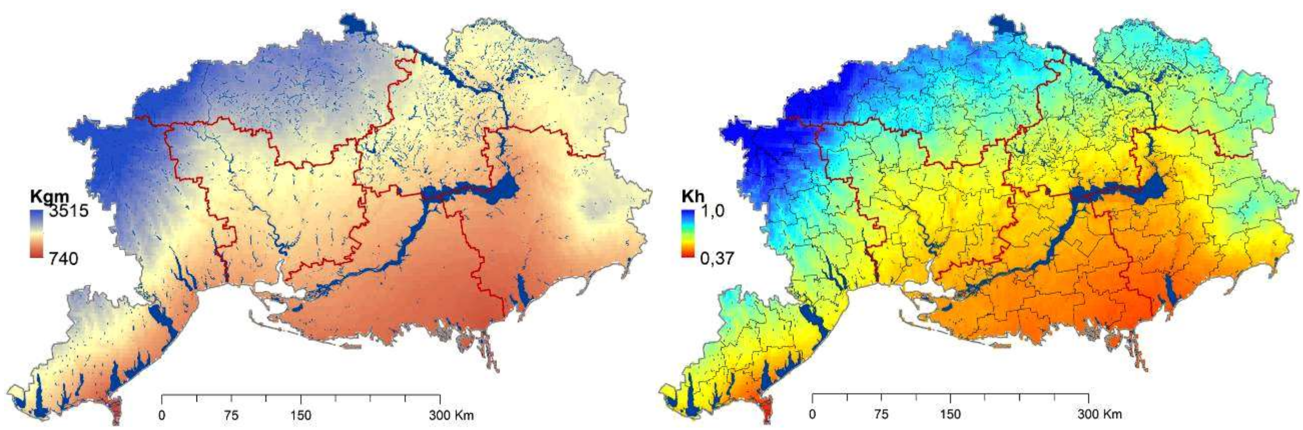
where, x – longitude, decimal degrees, y – latitude, decimal degrees

Fig. 8. Spatial differentiation of bioclimatic potential in the territory of the Steppe zone of Ukraine in 1990–2019: *a* – plant bio-productivity (*F*, т га$^{-1}$); *b* – maximum capacity of soil humus horizon (H_{lim}, mm)



A *B*

Fig. 9. Dynamics of the hydro-meteorological coefficient of the hazard of soil washout ($a - K_{gm}$) and the moisture coefficient of Vysotsky-Ivanov ($b - K_H$) within the territory of the Steppe zone of Ukraine in 1990-2019



a *b*

Fig. 10. Spatial differentiation of the hydro-meteorological conditions of soil washout in the territory of the Steppe zone of Ukraine in 1990–2019: *a* – the hydro-meteorological coefficient of the hazard of soil washout (K_{gm}); *b* – the moisture coefficient of Vysotsky-Ivanov (K_H)

meteorological coefficient of the hazard of soil washout (K_{gm}). In the period of 1990-2019 the K_{gm} ranged from 208.9 (2011) to 3552.6 (1997) (Fig. 9*a*). During 1997 to 2019 the hydro-meteorological coefficient fell by 80.5% (from 3552.6 to 691.7) at the average annual rate of 47.7 per year. There were 12% of the years with high rainfall activity, 52% of the years with moderate rainfall activity and 36% of the years with low rainfall activity. The spatial differentiation of K_{gm} in the territory of the Steppe zone of Ukraine in 1990–2019 ranged from 740 to 3515 from the southern part to the northern part (Fig. 10*a*), its highest value was in the south-western part of the Steppe zone. The results of the calculations made it possible to determine that in of 1990-2019 the moisture coefficient (K_H) ranged from 0.29 (2011) to 1.4 (1997) (Fig. 9*b*). In the period of 1997-2019 the moisture coefficient fell by 66.4% (from 1.4 to 0.47) at the average annual rate 0.018 per year. According to the classification, there were 8% of the years with excessive moisture, 44% of the years with unsteady moisture and 48% of the years with insufficient moisture.

The spatial differentiation of the moisture coefficient in the territory of the Steppe zone of Ukraine in 1990–2019 ranges from 0.37 to 1.0 from the southern part to the northern part (Fig. 10*b*). The highest K_H was in the north-western part of the Steppe zone.

CONCLUSIONS

The modeling allowed determining space-time regularities of climate change and bioclimatic potential of steppe soils. The past 30 years are considered to be the most extreme period by the frequency of climate anomalies with a steady trend-cycle increase in the air temperature by 2°C and a decline in the total annual precipitation by 178 mm. It caused an increase in the solar radiation reaching the soil surface by 7.2% and a decline in climate energy expenses for soil formation by 21% that reduced the rate of natural capability of regenerating soil fertility. In particular, there has been a decline in bio-productivity of plants by 62% and is used to determine bioclimatic potential ranging from 4.5 to 16.7 t ha^{-1} in steppe soils. There has been a reduction in the coefficient of natural moisture by 66.4% and that of the hazard of soil washout by 80.5%. Low values of the corresponding coefficients characterize insufficient moisture content in steppe soils and a low level of rainfall activity. Changes in climate energy expenses for soil formation caused a decline in the potential of humus horizon capacity of steppe soils by 34.5% that led to deterioration in the conditions of agricultural production, a reduction in the yields, self-regenerating and self-regulating functions of steppe soils. The results of space-time modeling of climate change and the examination of its impact on the formation of bioclimatic potential of steppe soils must be a basis for the development and implementation of new measures for adaptation to climate change at different economic levels.

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