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FEATURES OF CLIMATE CHANGE ON UKRAINE: SCENARIOS, CONSEQUENCES FOR NATURE AND AGROECOSYSTEMS

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Abstract

Purpose: *The aim of this study is to investigate the basic features of climate change in Ukraine at 20th–21st centuries and to obtain an estimation of possible regional ecological consequences under influence of global warming.* ***Methods:*** *The empirical constants of the constructed semi-empirical models were estimated on the basis of the statistical analysis of materials of meteorological observations on meteorological stations of Ukraine for the XX century – beginning of XXI century. The obtained results can be used to construct scenarios of the possible climate change in Ukraine at global warming in the near future.* ***Results:*** *The climatic conditions of Ukraine have definitely reacted to global warming (the annual temperature increased by 0.6±0.2 ^{o}C/100 years and insignificant increase of the annual sums of precipitations (5–7% for 100 years)). The features of transformation of seasonal course of climatic fields of Ukraine of the temperature and atmospheric precipitations considered also. Taking into account global features of climate change are offered regional climate scenarios (temperature and precipitation) in Ukraine for the 2050.* ***Discussion:*** *The analysis of the basic ecological consequences of global warming, which already happened or can be in the nearest future in Ukraine is carried out: increasing level of the Black sea and Sea of Azov; the spatiotemporal transformation of steppe phytosystem structure; changes in Northern Sea of Azov maritime spits ecosystems; excitation of catastrophic events in Ukraine, desertification process development in southern and southeast regions of Ukraine, climate change impacts on agriculture, aspects of water resources.*

Key words: adaptation; agriculture; catastrophic events; climate change; desertification; ecological consequences; levels of the Black sea and the Sea of Azov; precipitation; scenarios; steppe phytosystem; temperature; vegetation changes; water resources.

1. Introduction

The modern global warming of climate in the future can potentially result in considerable changes in geophysical, geochemical and biological systems of Earth, and substantially influences on the ecological and socio–economic condition of life of people in different regions [1, 2]. List of the unfavourable ecological phenomena already presently show up intensively (raising of level of the World ocean, desertification, degradation of arctic and mountain glaciers, degradation of eternal frigidity etc) [1, 2]. Therefore, four questions have specific importance: How the regional climate has changed, what to expect in the future, what consequences can be shown and how to adapt to these changes? These questions were conceptually considered regarding to situation of Ukraine.

2. Analysis of the research and publications

The climatic conditions of Ukraine have definitely reacted to global warming. The analysis of data of instrumental observations of a network of meteorological stations of Ukraine in XX century showed that the annual temperature increased by 0.5–0.7 ^{o}C/100 years [3, 4, 5]. However, the average annual air temperature over the past twenty years (1991–2010 years) has increased by 1.0±0.2 °C compared to the 1961–1990 average [6]. In Ukraine, the new record indexes of maximal and minimum average monthly temperature were repeatedly fixed for 100 years. The periods of summer heat of repeatability and duration increase (with the temperature higher 25–30°C) [6]. The droughts began to take place more frequent and on large territories.

The annual sums of precipitations for the territory of Ukraine has only changed, however, significant changes occurred in the intensity and nature of their fall [3–7].

In the environment under the influence of global warming there are evident changes occurring, which have already led to some negative ecological and socio–economic consequences and will further accentuate them in the future.

One of the main consequences of global warming is the increase of level of World Ocean and levels of seas that are connected with Ocean [1]. It is as a result of expansion of warming seawater and discharge of ice from marine ices, mountains glaciers, ice caps, and the Antarctic and Greenland ice sheets to the oceans.

It is set that, for period (1971–2010) the warming the sea surface 0.11 °C/10 year in the upper 75 m and decreasing to about 0.015°C/10 year at 700 m [1, 2]. The reconstructed record of global sea level for 1881–2010 years reveals an average increase on 15–19 cm [1, 2].

Owing to global and regional climate change and by influence of World ocean there were held certain changes of sea level and a hydrological mode of the Black sea and the Sea of Azov and changes in ecosystems of coasts also [6, 8]. Understanding how much regional sea level can rise would help improve the design and implementation of cost–effective measures to protect against coastal inundation, salinization of groundwater and river estuaries, enhanced erosion, degradations or loss ecosystems and destruction of coastal infrastructure.

Another of the sensitive indicators environmental changes are the steppe ecosystem, maritime spits and coasts ecosystems [1, 2].

In a number of publications about researches of response of vegetative cover on the climate change in the different regions of Europe, Russian Federation, Ukraine and Bielorussia mark similar spatial and structural changes in natural associations, and also near tendencies of climate change [6, 9, 10]. They show up mainly in the change of moisture availability regions, increase of the biological productivity, activation of succession processes, displacement of natural habitats of large coenotic structures and etc. Intensity of change of between's coenocomponents in associations and orientation of these changes come forward the original marker of native natural process, limited possibilities of climatic descriptions of region and ability to self conditioning of phytoenvironment [9,10].

The following impacts from climate change on the aviation and related infrastructure can be expected: Heat waves; Changes of humidity and precipitation; Changes in average and extreme temperatures; Shortage of water; Desertification phenomena; Changes in Biodiversity (wildlife and ecosystems) and bio-factors - pollen, viruses, insects; Catastrophic events - landslides, flooding, fires; Regions features (specify and spatial distribution of extremes). Other kind of influences, generated by the climate changes are: Wildlife migration patterns and species type (especially birds), change in regions of food production; Supply of potable water; Infrastructure changes (constructions, architecture, colour and designs modes) as adaptive measures.

Agriculture is highly dependent on specific climate conditions. A large number of scientific papers concern to the problem of assessing the

impact of climate change on agriculture but understand the overall effect of climate change on our food supply can be difficult.

Changes in temperature, amount of carbon dioxide (CO_2), and the frequency and intensity of extreme weather could have significant impacts on crop yields [11-15]. The general conclusion of global studies, that tropical area may more likely suffer negative consequences. For Europe, the United States and Canada, and for Asia (including China) and the Pacific Rim, where many more studies have been conducted, the results generally range from severe negative effects (60,70%, or complete crop failure) to equally large potential yield increases [11, 14].

The change of climate will result in the substantial affecting our water resources. Some influences are felt already presently. It is expected that almost entire countries will test negative influences. Moreover, influence as a result of climate change will render a cascade effect on a health man, economy and society, and also on sectors, straight depending on water resources.

In some districts of Ukraine influence of change of climate shows up more obviously: the amount of natural calamities is increased, floods become more frequent in Carpathians, grow into the deserts of steppe in the South districts, off–shore districts began to be overheated, the sharp deficit of drinking–water is felt in central and east districts.

So, the most vulnerable to climate changes are the coastal regions of ocean and sea, the mountains, arid ecosystem (deserts and steppes) [16–18].

3. The problem statement

This article is devoted to the analysis of the basic features of transformation of a regional climatic regime of Ukraine at 20th–21st centuries and to obtain an estimation of possible regional ecological consequences in Ukraine under influence of future global warming.

4. Features of climate change in Ukraine

The climate of Ukraine is definitely reacted to global warming. The empirical data of observations were obtained from the network of meteorological stations and used for the analyses of long–term regional changes of climatic fields on Ukraine. The meteorological stations were chosen so that the following conditions were satisfied [5, 19]:

- the observations by meteorological stations have begun not later than 1900;
- the missing observations by meteorological stations do not exceed 30% for the period 1900–2000.

The following empirical data were used: average of monthly values (for temperature and precipitation) for the period 1900–2000, 1950–2010 and the climatic norms for the period 1961–1990.

Climatic field of annual and seasonal temperatures and the annual sum of precipitations for the Holocene Optimum (DT ~ 1^oC) were used also [20–22].

There are considered some possible changes of the following statistic parameters of atmospheric precipitation climate fields on the Ukraine in near future: meteorological norms (average for months), dispersion of average for months from year to year and coefficients of age linear trend of average for months.

The research of dependence of linear trend coefficients of meteorological parameters from time, geographical coordinates and altitude above sea ground represents a statistical problem of determination of “a very small signal on the extremely large noise”. Therefore, a resolve of this problem demands use of the specific statistical analysis of the empirical data. The method of a statistical assessment of the parameters that characterize a seasonal course of these parameters, their geographical distribution, coefficients of their century linear trends is worked out [5].

The new statistical assessments describing influence of height above a sea level on change of climatic conditions on the territory of Ukraine, connected with global warming are obtained and their statistical representation is proved.

The worked out models are based on representation of time dependency of the mentioned climatic characteristics in form of three items (annual component and two harmonic components) and approximation of the dependency from geographical coordinates [5].

The empirical constants of these models were obtained as a results of original statistical analysis of measurements’ data for the last 100 years, the comparison of modern epoch with the climatic paleoreconstruction of warm epochs and taking consideration the spatial connection of climatic field of temperature and precipitation [20-22].

It was found that changeability of land–surface temperature from year to year is approximated by normal (Gauss) distribution. There was considered the statistic hypothesis regarding the choice of the approximation scheme of changeability distribution

of atmospheric precipitation intensity on the basis of gamma–distribution or lognormal (log–Gauss) distribution [4].

The analysis of data of instrumental observations of a network of meteorological stations of Ukraine for last 100–130 years showed that its climatic conditions have reacted to global warming as follow [4, 5, 23-25]:

- the annual temperature increased by 0.6±0.2 °C/100 years which approximately coincides with estimations of a level of global warming (Fig. 1);

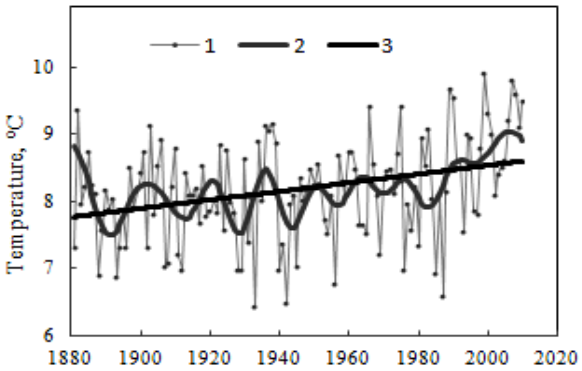

Fig.1. Century course of fluctuations of annual temperature in Ukraine for the period 1881–2010 (1 – empirical data, 2 – model, 3 – tendency)

- the effect of alignment of an annual temperature field was revealed: in northern and north–east regions the annual temperature increased by 1.0±0.2 °C/100 years; in southern and south–west regions of Ukraine – only by 0.5±0.1 °C/ 100 years;
- decrease of amplitude of a seasonal course of temperature by ~0.4–0.5°C (effect of continentalization): significant warming in the cold period of year (1.0–2.0 °C/100 years),for spring (1.5–2.0 °C/100 years); warming was insignificant in summer months (Fig.2);
- insignificant increase of the annual sums of precipitations (5–7% for 100 years) (Fig. 3);

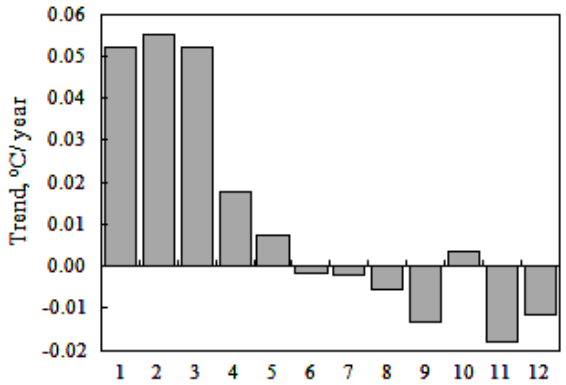

Fig.2. Tendencies in a seasonal course of temperature in Ukraine for the period 1950-2000

- decrease of the sum of precipitation for some months: winter, spring (May), summer (August), autumn (October– November) (Fig.4);

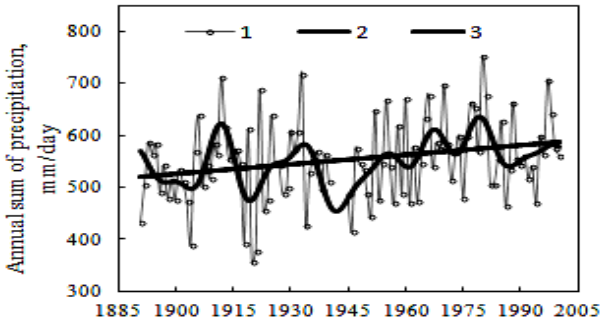

Fig.3. Century course of fluctuations of annual sum of precipitation in Ukraine for the period 1885–2005 (1 – empirical data, 2 – model, 3 – tendency)

- the effect of alignment of a climatic field of the annual sums of precipitations was revealed: in northern and north–west regions of Ukraine, where the annual sum of precipitations was relatively high (650–750 mm/year), it decreased approximately by 10–15%; in southern and south–east regions, where the annual sum of precipitations was relatively low (350–450 mm/year), it increased approximately by 10–15%;
- increase of repeated anomaly of high temperatures in May for the period 1891–2011 (in XX century ~16.5–17.5 °C and in XXI century ~18.0–18.8 °C).

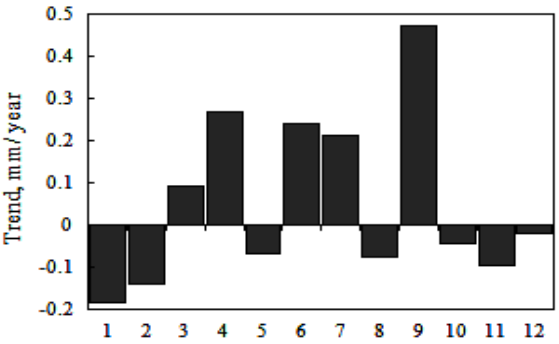

Fig.4. Tendencies in a seasonal course of precipitations in Ukraine for the period 1950-2000

On the basis of the statistical analysis of materials of meteorological observations on meteorological stations of Ukraine for the period of 1900–2000 the empirical constants were received and semi–empirical models were constructed [4]. The obtained results can be used to construct scenarios of the possible regional change of climatic conditions in Ukraine at global warming in the near future.

5. The regional scenarios of surface temperature change and precipitation in Ukraine for the 2050.

Taking into account the established trends features of transformation of the climatic fields of surface temperature change and annual sums of precipitation in the territory of Ukraine for the period of 1900–2000 and possible scenarios of future global climate changes, the scenarios of possible changes climate of Ukraine for the 2050 were developed, namely:

1. Scenarios of global surface temperature change for the end of the XXI century [1, 2]:

- It is likely than not to exceed 2°C for RCP4.5 – (D T ~ 2.0 ^{o}C)
- It is likely to exceed 2°C for RCP8.5 – (DT ~ 4.0 ^{o}C)

2. Semi–empirical models of transformation annual and seasonal course of climatic conditions (surface temperature change and precipitation) of Ukraine under influence of global warming for XX century [4, 5, 23, 25].

3. Climatic field of annual temperatures and the annual sum of precipitations for the Miculino ($125\cdot10^3$ years, DT ~ 2.0–2.5^{o}C) and Pliocene Optimum ($2.3–3.0\cdot10^6$years, DT~ 3.0–4.5^{o}C) [20–22].

Thus, regional scenarios of surface temperature change in Ukraine for the 2050 the following (Fig.5) [24]:

- Scenarios 1: it is likely than not to exceed (DT ~ 1.4±0.2 ^{o}C);
- Scenarios 2: It is likely to exceed (DT ~ 2.4±0.3 ^{o}C).

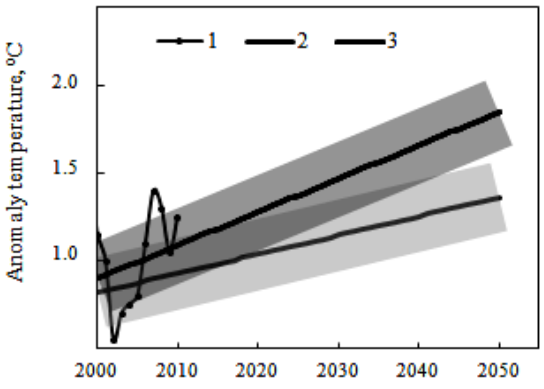

Fig. 5. Regional scenarios of surface temperature change in Ukraine for the 2050: 1 – empirical data, 2 – scenarios A (ΔT≈ 2^{o}C); 3 – scenarios B (ΔT≈ 4^{o}C)

Taking into account global and regional features of climate change the following are offered regional scenarios of precipitation change in Ukraine till 2050:

Scenarios 1: increase of the annual sums of precipitations on 10±5% and aridity of climate in the warm period of year (May and August).

Scenarios 2: differential territory distribution of annual sums of precipitations, namely increase in northern, northwest and northeast regions on 15±5 % and decrease in southern, southeast and southwest regions on 15± 5 %.

The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions [25].

6. The basic ecological consequences from the change of climate on the territory of Ukraine.

The main potential adverse effects of climate change for Ukraine include [3-8,26]:

- increase of level of the Black sea and the Sea of Azov;
- intensification of meridional circulation of the Black sea and the Sea of Azov an atmosphere which will result in increase of repeatability of some anomaly synoptic formations (extreme weather events) above Ukraine;
- activization of catastrophic shifts and deformations in mountain regions of Carpathians mountains and Crimea through changes of a regime of humidity, water balance, ground and subsoil waters;
- increase of repeatability of catastrophic floods in region of the Ukrainian Carpathians mountains caused by an intensification of heavy rains and intensified by wood cutting;
- frequent downpours and flooding can cause a deterioration of potable water quality entailing increased incidence of intestinal infectious diseases rarely reported in Ukraine (salmonella, hepatitis A, leptospirosis, etc.).
- structural drift and degradation of steppe phytosystems in Ukraine;
- sudden warming can cause drying entailing frequent fires;
- possibility of development of desertification process of southern and southeast regions of Ukraine.
- aspects of water resources: decreasing the total volume, the worsening of quality, the exhaustion of riverside ecosystems.

So, the most vulnerable to climate changes in territory of Ukraine are the coastal regions of the Black Sea and the Sea of Azov, the Carpathians and mountains of Crimea and steppe [6].

Some ecological consequences will be considered in detail

6.1.The reaction of level of the Black sea and Azov Sea on influence of global warming.

It is established, that the levels of the Black sea and Sea of Azov were increasing for last 100 years approximately with the same intensity as World ocean level [6, 8, 27-29].

For last 100–120 years the annual temperature in region of coasts of the Black sea and the Sea of Azov has increased on 0.5±0.1 °C/100 years, the annual sum of an atmospheric precipitation has increased on 10–15 %/100 years, the amplitude of a seasonal course of temperature has decreased (essential warming in the cold period of year). In Fig.6 is shown that the modern century course of a level of the Black sea (a) and the Sea of Azov (b) is increase on 15±3 sm/100 years and according to scenarios (RCP4.5 – (DT ~2.0 °C) for period 2050 level of seas will increase up to 25–35 sm [6,24,27-29].

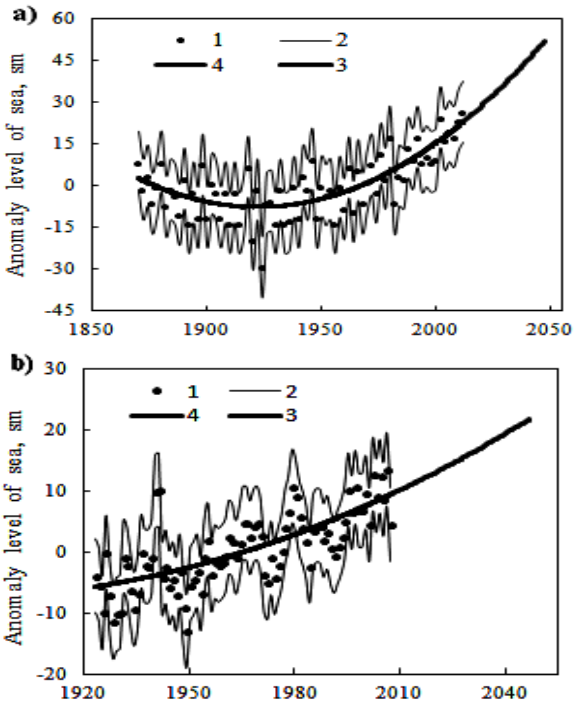

Fig.6. Century course of fluctuations of level of Black (a) and Azov (b) seas (1– empirical data, 2 – □ s, 3 – tendency)

The modern climate change, raising of a level of the Black sea and the Sea of Azov in conditions growing technogenic loading on environment (household, agriculture, tourism, transport, and industry), became the reasons of display of some the negative phenomena and processes for coasts ecosystems, namely [6, 24, 27-29]:

- an intensification of processes of abrasion, erosion, flooding of coast and sea maritime spits. For example, from 820 kms of the Azov coast of Ukraine collapses 480–500 kms of a coast from which about 150 kms were accumulative;
- change of characteristics of sea water (to decrease of salinity of waters (on 2–3 ‰) and a level of a transparency of water more than in 2 times (up to 2–8 м), expansion of zones hypoxia. For example, in the Black sea with 3 up to 40 thousand км^2, to increase of the area of zones of flowering of the seas in some times);
- degradations biological kinds (reduction of a population of the crustaceans, benthonic fishes and planktonic, reduction of individuals sea mammal almost in 20 times);
- amount has increased the one–celled organisms and jelly–fishes, and also harmful exotic organisms (on beginning of 90th general biomassa of migrant of Mnemiopsis leidyi in the pool of the Black sea was estimated in a 1 milliard of tons);
- increase of the death rate heightening effects of finfishess (periodic difficulty in breathing and mass death of ground biocenoses on considerable areas for the last 20 years of loss of the ground fauna were attained by 60 million tons, including finfishess are about 3 million tons);
- decline of volumes of fishing–out of fish in the Black sea and Sea of Azov for the last 10 years grew short in 5 times);
- diminishing of total river flow in seas (on 5–7% for 100 years in investigation of zaregulirovaniya of flow).

Tendencies in the change of environment of coasts of the Black sea and the Sea of Azov draw certain consequences for economic activity, (worsening of the sanitary–epidemiology state, decline of quality of recreational resources) and origin of threat the health of population [6].

6.2. The modern spatiotemporal transformation of Ukrainian steppe phytosystem structure under the influence of climate.

Under the influence of global warming in the environment there are evident changes occurring, which have already led to some negative ecological consequences and will further accentuate them in the future. One of the sensitive indicators of environmental changes is the steppe ecosystem.

The direct supervision of the phytocoenoses transformation processes was used as a basis of our long–term monitoring researches. The important

components of this monitoring are periodic large–scale geobotanical mappings of the basic ranges forming the network of nature protected areas: “Mykhaylivskyj Steppe”, “Provalskyj Steppe”; “Streltsivskyj Steppe”; “Kreidova Flora", “Khomutovskyj Steppe”, “Kamjani Mogyly", “Elanetskyj steppe”, two protected sites in the Black Sea Biosphere Reserve "Solonoozerne", “Potiivka”, and also the "Northern" site in “Askania–Nova” Biosphere Reserve [30, 31].

The monitoring and analysis of the main typological varieties of Ukrainian steppes during the period of 1967–2012 demonstrated the increasing of spatiotemporal transformation in the ratio of xeromorphic, mesomorphic and ligneous component structures of steppe. As shown in Fig.7, Ukrainian steppes in the second half of XX century – beginning of XXI century have an established trend towards the decreasing of xeromorphic component to 30±10% along with increasing of mesomorphic component to 10±5% and ligneous component to 20±10 % [31, 32].

Taking into account the established trends in steppe phytosystems for the period of 1967–2012 and possible scenarios of future climate changes [31, 32, 24], we developed such estimated scenarios of possible changes in ratios of ecobiomorphological components of Ukrainian steppe phytosystems for the first half of XXI century as:

1) provided that the established in XX century global warming trend will dominate till the end of the first half of XXI century, there will be an increase of annual temperature to 1.25±0.25oC along with the general increase in annual sum of atmospheric precipitations to 10±5%. As a result of that it is possible to expect the 1/3 reduction of xeromorphic component in the southern regions and its almost complete disappearance from the northern regions along with significant expansion of mesomorphic and ligneous components;

2) provided that the level of global warming will be more amplitudinous then, according to scenarios, we can expect in Ukraine temperature increase to 2.0±0.5^{o}C and differential distributions of precipitation on the territory (increase of precipitation sums in northern, north-western and north-eastern regions along with reduction of precipitation in southern, south-eastern and southwest regions to 15±5%), excessive humidity in northern regions, and climate aridity with desertification in southern ones. We can expect steppe phytosystems expansion in south-eastern regions of Ukraine on the bigger scales, than it happened in XX century.

However, it is necessary to notice, that the most probable warming level on the territory of Ukraine by the end of the first half of XXI century would be 1.25±0.25^{o}C. It means that we can expect steppe displacement processes of Ukrainian steppes - in particular, full degradation of xeromorphic component along with ubiquitous advance of meadow and forests vegetation on the place of steppe (Fig.7) [31].

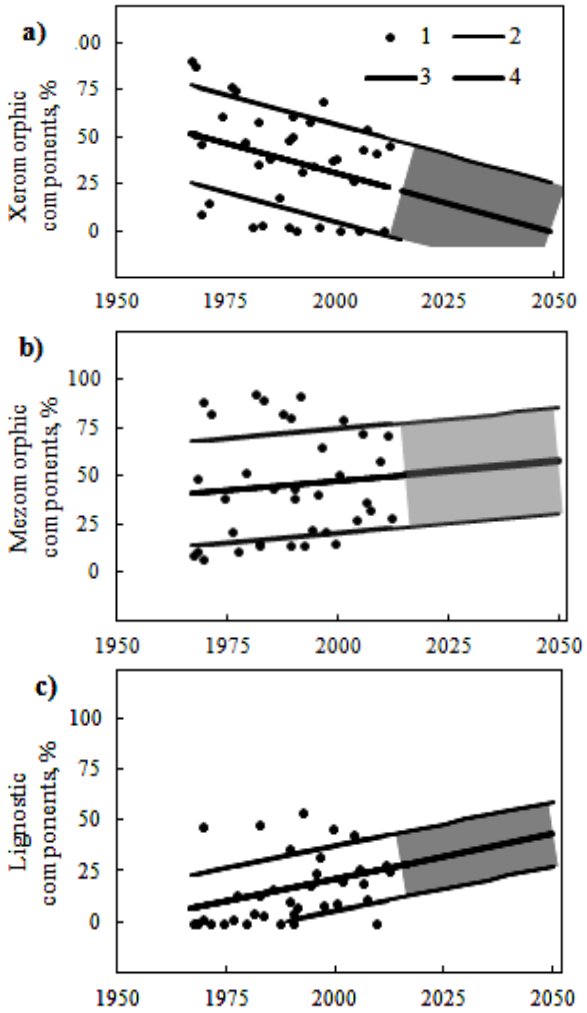

Fig. 7. Time changes of xeromorphic (a), mesomorphic (b) and ligneous (c) components of Ukrainian steppe phytosystems (1 – empirical data, 2 – a root–mean–square deviation, 3 – the linear trend for the period 1967–2012 and 4 – scenarios estimations with possible inter–annual fluctuations

6.3. Northern Sea of Azov maritime spits ecosystems changes in the light of modern tectonic and climate change.

Inventorization of vegetation of 10 nothern Sea of Azov maritime spits at the territory of Ukraine (Kryva, Samsonova, Bezimenna, Shyrokyns'ka,

Liapyns'ka, Bilosarajs'ka, Berdians'ka, Obytichna, Stepaniv'ka and Fedotova) was carried out in accordance with the principles of dominant and floristically classifications of vegetation with further fixing the modern condition of spits vegetation on the large–scale (1:10000) maps.

Reinventorial mapping monitoring of 7 spits (Kryva, Samsonova, Bezimenna, Liapyns'ka, Bilosarajs'ka, Berdians'ka, Obytichna) was carried out by comparison of present spits vegetation large–scale maps with the similar previous maps made by S.A. Postrygan' and F.Ya. Popovych in 30th of XX century [33, 34].

It is established the increasing of meadow–halophytic, water–swamp and internal estuary aquatic vegetation on the background of the reduction of solonchak, sand–shell steppe and littoral vegetation during last 70 years (Fig.8). Such of changes testify the common trends of spits changes – their flooding and washing out.

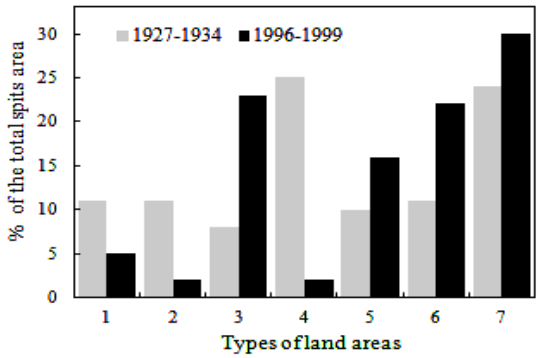

Fig. 8. The distribution of the main types of land areas on 7 nothern Sea of Azov maritime spits (Kryva, Samsonova, Bezimenna, Liapyns'ka, Bilosarajs'ka, Berdians'ka, Obytichna) according to reinventorial mapping monitoring data during 70–year time period (1927–1934 – S.A.Postrygan' and F.Ya. Popovych investigations data [33, 34], 1996–1999 – our investigations data): 1 – littoral vegetation, 2 – sand–shell steppe vegetation, 3 – meadow–halophytic vegetation, 4 – solonchak vegetation, 5 – water–swamp vegetation, 6– internal estuary aquatories, 7 – radically transformed lands and residential areas.

We suppose such changes are connected with specific natural factors – tectonic lowering of a continental crystal plate moving shelf in a zone of the Sea of Azov coast arrangement, acceleration of a modern stage of the Black sea transgression and anthropogenic–caused reasons – general sea pollution and intensive raising of the World ocean level, caused by global warming [35–38].

Such tendencies have become menacing for International Wetlands, International Bird Areas and National reserves integrity, for settlements and recreational institutions of the northern Sea of Azov maritime spits.

Monitoring was aimed at a scientifically based recommendations of spits nature protection and unwasteful use of spits nature.

6.4. The effect of excitation of catastrophic events in territory Ukraine.

The climatic catastrophic phenomena, such as droughts, floods, extremely cold or warm winter, occurring at a large scale and great intensity are rather rare events. These phenomena, typically, occur only a from few times till 10–20 times per century [39–43]. Because of this, statistically estimating the basic characteristics of the dynamics of repeatability of these events is difficult. The instrumental observations are not helpful because of the short time–series. It is therefore necessary to use other proxy data as well. In our opinion, different historical records and manuscripts are most suitable for this purpose. These records were very carefully compiled and described in the monasteries located in territory Europe [39-43].

On the basis of the analysis of historical records and manuscripts repeatability of the following catastrophic processes and phenomena in territory of Europe in last millennium is considered: droughts, rainy summers, high waters, cold winters, late spring, a cold in the beginning of a summer, catastrophic storms and thunder–storms etc.

The statistical analysis of obtained empirical time–series of repeatability of catastrophic processes and the phenomena shows that their long–term dynamics on the territory of Ukraine does not represent usual a stationary Poisson's flux of events. The rating of intensity of catastrophic climatic–ecological phenomena in territory of Ukraine was always higher when the global temperature deviated more strongly in this or that side from some optimum level, than the index of climatic anomaly was higher [44, 45]. This idea is put in a basis of semi–empirical models of dynamics of repeatability catastrophic climatic–ecological events (Fig. 9). It is proved, that the obtained effect has not only regional character. In addition, it was obtained for other physic–geographical regions of Europe [43-46].

Semi–empirical models for rating of intensity of climatic catastrophic phenomena in Ukraine as function of index of climatic anomality are constructed. A scenario of possible dynamics of repeatability of climatic catastrophic phenomena in

the territory of Ukraine at the further global warming is considered [45]. The modern global warming on 0.6±0.1 °C became reason the increase of repeatability of the catastrophic phenomena in Ukraine almost in ~2 times, and at a further warming of climate of repeatability of the catastrophic phenomena can be higher till 2–5 times in comparison with pre–industrial epoch (see Fig.9) [45].

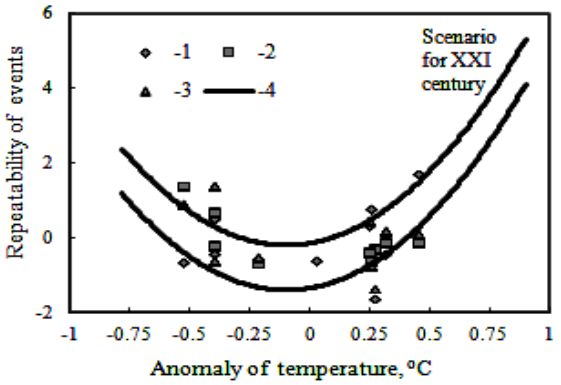

Fig. 9. The scenarios of the rating of repeatability of climatic catastrophic phenomena in Ukraine as function of index of climatic anomality: 1 – droughts, 2 – flooding, 3 – catastrophic storms, 4– model

6.5. About possibility of desertification process development in southern and southeast regions of Ukraine.

Among the regional geoecological processes provoked by global warming, the most adverse for Ukraine is possibility of desertification in southern and southeast regions – as a result of slow displacement to the middle latitudes of northern periphery of subtropical anticyclones zone and, as consequence, geographical displacement and spatial transformation of natural zones.

Statistical analysis of time series (from 1901 to 1995) of zonal monthly temperatures and sums of precipitation in North Hemisphere (for a land) from UEA/CRU data base [46]. Estimate of zonal surface "equator–pole" temperature was provided with use of semi–empirical model of zonal surface temperature transformation, which was published in [46].

Hypothesis concerning possible displacement of a subtropical anticyclones zone to the north at corresponding levels of global warming in a certain measure confirm: calculations on mathematical models of «Nuclear winter» type [47]; results of paleoclimatic reconstruction of climatic fields of the annual atmospheric precipitation sums [20] and estimations of modern monthly average displacement of the centre of subtropical anticyclones zone to middle latitudes at decrease of monthly average meridional difference of "equator–pole" temperatures in troposphere [47].

Zone of subtropical anticyclones is on the descending branch of "Hadley cell", where mainly downward air movements are dominated in the troposphere. This zone corresponds to the subtropical minimum of precipitation. Penetration of subtropical anticyclones zone to temperate latitudes is sharply limited on its northern periphery by active hydrodynamic influence of the synoptic atmospheric activity at latitudes of 50 ± 10°.

At low levels of global warming (up 1–2?C) in the area of the northern periphery of subtropical anticyclones zone, which, to a certain extent only close to the southern regions of Ukraine, is characterized by a slight increase in the annual amount of precipitation, associated with an increase in the absolute water vapour content in the atmosphere (by Clapeyron–Clausius law). Such an effect is observed in the modern period – the annual amount of precipitation has risen by 10–15% in the south–eastern regions of Ukraine for the last 100 years [48].

But, with higher level of global warming (that we can expect somewhere in the second half of the 21–st century – the first half of the 22nd century), the intensity of the upward and downward movements in the "Hadley cell" will greatly increase. And despite the intensification of synoptic activity in the temperate latitudes, including due to increased meridional character of atmospheric circulation (reliably established that this effect is always in the case of global warming), the northern periphery of the subtropical anticyclones zone will shift to north and cover the south–eastern regions of Ukraine. Global warming is accompanied by a decrease in the "equator–pole" temperature difference and empirically proved that it can lead to certain transformation of latitudinal positions of subtropical low precipitation zone and temperate latitudes high precipitation zone [49].

Using the semi–empirical modelling, a group of authors discover the dimensionless parameter, which is characterizing the spatial transformation of a subtropical low precipitation zone corresponding to a zone of subtropical anticyclones [49].

As a result was established that at global temperature incising on 1?C there will be a displacement of low precipitation zone position on 2? latitudes to a direction of middle latitudes. At

global warming on 3–4?C the basic zone of a subtropical precipitation minimum in Northern hemisphere will be displaced to 34±5? of north latitude, and it means that northern periphery of a zone of subtropical anticyclones will cover all southern territory of Ukraine (Fig.10).

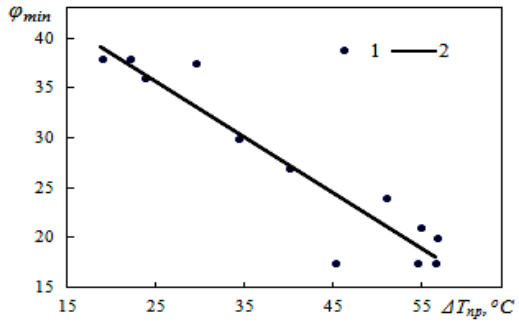

Fig.10. Comparison of the latitudinal position of the subtropical low precipitation zone (φ_{min}) and the monthly average "equator–pole" temperatures difference (ΔT) in the Northern Hemisphere: 1 – empirical data; 2 – linear approximation. Source from [49].

On the basis of worked out semi–empirical models of displacement of a subtropical low precipitation zone at different levels of global warming were received estimations of its position in the future. Displacement of northern periphery of a subtropical anticyclones zone can lead not only to a possible reduction in the amount of precipitation, but also to a sharp intensification of the evaporation process. This process represents potential danger of desertification in southern and southeast regions of Ukraine, since second half of 21–st century, if modern tendency of global warming will be kept (especially if global warming will attain 3–4?C).

6.6. Climate change impacts on Agriculture.

Analysis of the climate change impact on agriculture in Ukraine shows that global warming in the next decades will have heterogeneous positive and negative effects depending to agro–climatic zones (Table 1) [50-52]. Plant growing and plant protection are the most vulnerable sectors of agriculture under conditions of climate change.

Research of the climate change impact on global agriculture already covered a significant area of world food crops. In Ukraine such type of research conducted for major crops – winter wheat and maize, which have the largest contribution to gross grain production in the country [50-52].

With the realization such scenarios of climate change as GFDL, UKMO or GFDL–30% is reason to believe that expected weather conditions will be favourable for cultivation of winter wheat in Ukraine. Particularly expected following changes [50-52]:

- shift the timing of winter wheat sowing at 40–50 days later;
- increase of temperatures during winter dormancy by 4–8?C;
- reduction of negative temperatures sum, which characterize the wintering conditions, by 3–4 times;
- reduce the period of wintering on 1.5–2.0 months;
- favourable conditions for the photosynthetic productivity of crops and improving the overall crop productivity in 1.2–1.4 times;
- terms of ripeness phase occurrence will be earlier on 1–2 month.

Table 1. Specified evaluation criteria and indicators of vulnerability to climate change for agriculture sector of Ukraine Source from: [52]

Possible vulnerability criteria	Specified indicators of vulnerability
Crop yields	Reduced of spring crops yields
Sown areas structure	Changing of sown areas structure. Moving the boundaries for crop cultivation areas
Terms of maturation and harvesting	Reduction of crop growing period
Area of rainfed and irrigated farming	Increase of irrigated land
Quality of cereals	Reduction of grain nutrient content

For early spring crops, meteorological conditions will not change significantly or somewhat worse by increasing aridity and extremely weather events. It may result in lower yields due to reduced spring crops growing season and their earlier ripening.

The influence of warming on maize productivity showed the following [50-52]:

- shift of the onset of all phenological phases on an earlier date;
- reduce the growing season by an average of 10–20 days for early and 30–40 days for medium and late hybrids;
- significant increase in crop yields for middle, mid–late and late hybrids.
- the main measures to adapt agricultural production in Ukraine may be the following:

- increasing the share of winter crops in the sown areas structure;
- expansion of cultivation area for late spring grain crops and oilseed plants;
- shift the timing of sowing for spring crops at earlier dates and for winter crops – at a later dates, ensuring efficient use of soil moisture reserves;
- use in the southern regions of crop varieties with short vegetation period, which will receive two or three harvests per year;
- implementation of retain moisture tillage technologies, etc.

An important consequence of climate change will be the increase of extreme weather events number, and shift climatic zones of Ukraine to the north [49]. Such effects we experience already. To avoid the negative effects of climate change, it need improve the land management system and use practices of crop selection to prevent land degradation and desertification.

6.7. Aspects of water resources.

The 2015 was selected as indicator of trend. The general hydrological situation in the basins of Ukrainian rivers and reservoirs was rather dangerous due to smallest volume of water in the reservoirs over all period of their exploitation in 2015 year. Such situation occurs due complicated climate conditions (phenomenon of climate aridization), and increased water consumption.

The intensive water pollution by waste water from industrial enterprises and municipal companies, wastewater from animal farms, surface run of snow melting and rain waters contaminated pollutants from the agricultural and urban areas, exploitation of water transport makes the situation in Ukraine even more complicated [53, 54].

State of most as small as large rivers of Ukraine continues steadily to deteriorate. To some extent climate conditions may result in reduction of water volume in water bodies due to increased evaporation caused by elevation of surface temperature and precipitation reduction [54].

At the present moment, water reservoirs and pounds accumulated approximately 58 billion m^3 of water. This volume exceeds the annual flow from all rivers of country. Regulation of most of rivers reached or even exceeds the upper economic and environmentally sound water–allowable limit up to the point of environmental destruction (above 75% of total length of channels at optimum 25–30%) dramatically reduced and often totally destroyed river self–purification capacity [54].

Systematic analysis of current trends in climate change, environmental state of river basins of Ukraine and peculiarities of management and protection of water resources showed that most urgent problems are the followings [55-57]:

- increase of temperature at water surface of water bodies;
- reduction of the water content of water bodies due to increased evaporation upon increased surface temperatures and reduced rainfall, especially in the upper and middle part of the basins; processes of soil degradation resulting from the intense ravine and planar erosion, subsidence of loess rocks, water logging and raising water table of groundwater;
- increase of frequency and intensity of steamy fog around the reservoir which forms due to difference between ambient temperature and temperature above water in cooling pond;
- intensive alga blooms and, consequently, occurrence of fish mortality due to reduced oxygen content in water, slow water exchange and the formation of stagnation zones;
- intensification of river pollution during low water periods – due to waste water discharges by municipalities and industries without adequate treatment, inefficient treatment plants or no treatment.

7. How to adapt to climate changes: pilot ideas in respect of water aspects as critical and manageable.

Increased irreversible losses of water and reduced water volume of watercourses with a gradual temperature increase and rainfall decrease is observed in Ukraine [57-59]. The answer to this challenge should be a change in attitude to water: maximum economy, adequate pricing, termination of pollution, groundwater use, maximum treatment and swivel water use, recovery of natural rivers, lakes, flood plains, deltas, coastal zones, swamps and wetlands, reduced surface area of reservoirs. Except given measures, it is necessary to save forests (and green plantation in cities) because vegetation (forests) normalizes level of temperature, accumulates dust, regulate relative humidity, contribute in improving of air composition and purity, reduce noise impact, perform wind and snow protective functions.

For minimization of water expenditures, in the cities, first of all it necessary to known haw correct use water. One from most popular example of sustainable water using is reducing of fresh (drinking) water using for technical purposes (irrigation of green spaces, the fire extinguishing systems, etc) replacing it on the technical, rainy specially treated water. In addition, as mentioned above, it is necessary to increase number of green spaces, parks and "green" infrastructure objects (green of parking, green roofs)

Accordingly, the adequate revision of the Water Code, and national strategies in water management, education of water users and sustainable water consumption. Ratification of the Protocol on Strategic Environmental Assessment introduced the new legal instrument to be applied *inter alia* to the water management schemes and plans. The necessary revision of the draft law on Environmental Impact Assessment, its expert discussion and approval by the Verkhovna Rada of Ukraine currently shall be accelerated in Ukraine to full extent address to water saving issue in each investment project [60-61].

8. Conclusions

The characteristics of a present global warming and reaction of climatic conditions of Ukraine on global warming are considered. The analysis of data of instrumental observations of a network of meteorological stations of Ukraine for last 100–130 years showed that its climatic conditions have reacted to global warming as follow: the annual temperature increased by 0.6±0.2 ^{o}C/100 years, insignificant increase of the annual sums of precipitations (5–7% for 100 years). The features of transformation of seasonal course of climatic fields of Ukraine of the temperature and atmospheric precipitations considered also.

The basic ecological consequences of global warming, which already happened or can be in the nearest future on the territory of Ukraine, are following:

- the modern century course of a level of the Black sea and Sea of Azov is increasing on 15±3 sm/100 years and according to scenarios (RCP4.5 – DT ~ 2.0 ^{o}C) for period till 2050 level of seas will increase up to 25–35 sm. Tendencies in the change of environment of coasts of the Black sea and Sea of Azov draw certain consequences for economic activity, (worsening of the sanitary–epidemiology state, decline of quality of recreational resources) and origin of threat the health of population;
- the analysis of ratio of the basic ecobiomorphological components in steppe community of the Ukrainian steppes in second half XX century - the beginning of XXI century showed the tendency to decrease xeromorphic component on 30±10% and the return tendency to increase mezo–morphic on 10±5% and lignostic component on 20±10 %. On the basis of the established tendencies were received scenarios estimations of possible changes in ratio ecobiomorphological community steppes of Ukraine for first half XXI century: degradation xero–morphic component on 30±15 % in southern regions and almost full its disappearance in northern regions and increase of borders of distribution mezo–morphic component on 10±5 % and lignostic component on 20±10 %;
- significant changes in the state of vegetation of nothern Sea of Azov spits during last 70 years - the increasing of meadow–halophytic, water–swamp and internal estuary aquatic vegetation on the background of the reduction of solonchak, sand–shell steppe and littoral vegetation. Such of changes testify the common trends of spits changes – their flooding and washing out. Such changes are connected with specific natural factors – tectonic lowering of a continental crystal plate moving shelf in a zone of the Sea of Azov coast arrangement, acceleration of a modern stage of the Black sea transgression and anthropogenic–caused reasons – general sea pollution and intensive raising of the World ocean level, caused by global warming;
- the concepts of a rating of catastrophic climatic–ecological events and an index of climatic anomaly are entered. The effect of excitation of catastrophic events on the territory of Ukraine (increase of intensity or repeatability as a result of a deviation of temperature of Europe in this or that side from some optimum level) is established and proved. Semi–empirical model and scenarios of repeatability of catastrophic climatic–ecological events as a function of index of climatic anomaly was worked out;
- on the basis of worked out semi–empirical models of displacement of a subtropical minimum of a zone climatic field of an atmospheric precipitation at different levels of global warming are received estimations of its position in the future. Displacement of northern periphery of a zone of subtropical anticyclones represents potential danger of desertification of southern and southeast regions of Ukraine, since second half of 21 century if modern tendency of global warming will be kept (especially if global warming will attain 3–4^{o}C);

- the analysis of the climate change impact on agriculture in Ukraine shows that global warming in the next decades will have heterogeneous positive and negative effects depending to agro–climatic zones. Plant growing and plant protection are the most vulnerable sectors of agriculture under conditions of climate change;
- the systematic analysis of current trends in climate change, environmental state of river basins of Ukraine and peculiarities of management and protection of water resources showed that most urgent problems are the followings: increase of temperature at water surface of water bodies, reduction of the water content of water bodies due to increased evaporation upon increased surface temperatures and reduced rainfall, especially in the upper and middle part of the basins; processes of soil degradation resulting from the intense ravine and planar erosion, subsidence of loess rocks, water logging and raising water table of groundwater;

The answer to the climate change and water resources crises challenge should be a change in attitude to nature and water: maximum economy, adequate pricing, termination of pollution, groundwater use, maximum treatment and swivel water use, recovery of natural rivers, lakes, flood plains, deltas, coastal zones, swamps and wetlands, reduction of the surface area of reservoirs. As new legal instrument the updated Water Code of Ukraine lined up to European water legislation and the Protocol on Strategic Environmental Assessment shall be applied widely. Further development of Ukraine as a strong democratic state is impossible without strict and obligate compliance with environmental legislation as a way on which depends experience, craft, environmental knowledge and level of sustainable development of state and society in future.

References

[1] Climate change 2013: The Physical Science Basis. – Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Changes UNEP/WMO, 2013. 1552 p. Available at: http://www.ipcc.ch/report/ar5/wg1/.

[2] IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp. Available at: http://www.weadapt.org.

[3] В.М Волощук, С.Г Бойченко (2003)[The Climate of Ukraine (red. Lipinskyy, VM; Dyachuk, VA; Babichenko, VM)[. Kyiv: *Rayevskyy Publishing*.–344 p. (In Ukraine).

[4] Boychenko S.(2008) *Semi–empirical models and scenarios of global and regional changes of climate*. Kyiv, Naukova Dumka 2008. 310 p (In Ukrainian).

[5] Voloshchuk V.M., Boychenko S.G (2003) *Scenarios of possible changes of climate of Ukraine in 21 century (under influence of global anthropogenic warming)*. "The Climate of Ukraine" Kiev:Raevsky. 2003. P. 308–331 (In Ukrainian).

[6] Climate change in Eastern Europe: Belarus, Moldova, Ukraine. ENVSEC, Zo? environment network, 2012. 60 p. Available at: http://www.preventionweb.net/publications/view/29358.

[7] Buksha I.F (2009). *Assessment of Ukrainian Forests Vulnerability to Climate Change Regional Aspects of Interactions in Non –boreal Eastern Europe*. – Springer Science + Business Media B.V. P. 143–156.

[8] Yeremeyev V., Yefimov V (2003).,[Regional aspects of global climate change] // *Visnyk NANU*. N2. P.7–14. (In Russian).

[9] Novikova N.M., Volkova N.A., Ulanova S.S., Shapovalova I.b., Vyshivkin A.A.(2011) *Return reactions of ecosystem on the change of the water mode of territories in a steppe area.* Arid ecosystem. –T. 17.– N 3. P. 38–48 (In Russian).

[10] Shvidenko A. (2009) *Non–boreal Forests of Eastern Europe in a Changing World: the Role in the Earth Systems.* Regional Aspects of Interactions in Non – boreal Eastern Europe. Springer Science. Business Media B.V. 2009. P. 123–133 (In Russian).

[11] Bazzaz, F., Sombroek, W.(1996) [Global climate change and agricultural production: direct and indirect effects of changing hydrological soil and plant physiological processes]. FAO, Rome, Italy. Available at: http://www.fao.org/docrep/w5183e/w5183e00.htm#Contents

[12] Bolin, B., Doos, B.R., Jaeger, J., Warrick, B. Eds. (1987) [The Greenhouse Effect, Climatic Change and Ecosystems]. SCOPE–V.29. *Wiley & Sons, New York*. Available at: http://www.scopenvironment.org/downloadpubs/scope29/contents.html

[13] Lobell, D.B. and Field, C.B.(2007) [Global scale climate–crop yield relationships and the impacts of recent warming] //*Environ. Res. Lett.* V2. –p.1–7. Available at:

http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1151&context=publichealthresources

[14] Parry, M. L.(1990) [Climate change and world agriculture.] *London: Earthscan Publications Ltd*,– 57 p. Available at: http://www.ciesin.org/docs/004–038/004–038a.html

[15] Parry, M.L., J.H. Porter and T.R. Carter,(1990) [Agriculture: climate change and its implications]. *Trends in Ecology and Evolution*,. V.5.–p. 318–322.

[16] Alexander LV., Tapper N, Zhang X, Lynch A, Fowler, Tebaldi C.(2009) [Climate Extremes: Progress and Future Directions]. *Editorial for Special Issue of International Journal of Climatology*. V.29. P. 317–319/. doi: 10.1002/joc.1861

[17] Babaev A.G (1996). Problems of arid land development. *Moscow University Press*, 1996. –282 p.

[18] Serrano I.V., Gonz?alez–Hidalgo S.M., de Luis J.C., Ravent?os M, J.(2004). Drought patterns in the Mediterranean area: the Valencia region (eastern Spain). *Climate Research.–№26*. –P.5–15.

[19] Boychenko S. Voloshchuk V. (2007) [The stochastic semi–empirical model of space–temporal transformation of the modern climate of Ukraine] *Ann. of the National Academy of Science of Ukraine*. N1. P.105–109. Available at: http://www.nbuv.gov.ua./portal/all/repotrs/ 2007–01/07–01–20.pdf

[20] Borisenkova I.I., Zubakov V.A., Lapenis A.G (1992). [Reconstructions of global climate of warm epoches of the pas] *Meteorology and hydrology*. N8. C.25–37. (In Russian).

[21] Velichko A.A. (2002) [Stability of a landscape environment and it bio– and a geovariety in view of dynamics latitude values] *Izvestia AS RF geography*. N5. P.7–21 (In Russian).

[22] Velychko A.A., Klimanov V.A.(1990)[Climatic conditions in Northern hemisphere 5–6– thousand years ago] *RAS News, ser.geography*. N5. P. 32–52.(In Russian).

[23] Voloshchuk V., Boychenko S., Stepanenko S, Trofimchuk A.(2004) [Semi-empirical scenarios of possible global and regional ecological consequences associated with further global warming] *A Gateway to Sustainable Development. Proceedings of the 30th International Conference Pacem in Maribus*. –Sevastopol,–P.624-635.

[24] Boychenko S.(2015) [Features of climate change and consequences for Ukraine]/ [Conference «Climate Change, environment and modern city]» Available at: http://www.ukma.edu.ua/idex.php/news/2117–konferentsiia–zminy–klimatu–navkolyshnie–seredovyshche–tasuchasne–misto.

[25] Voloshchuk V.M., Boychenko S.G (2008). [Semi–empirical models and scenarios of existential transformation of a zone climatic field of precipitation over the Northern hemisphere and the climatic field of precipitation over the territory of Ukraine of the global warming] // *Some problems of cloud physics. Collected papers of memorial issue dedicated to prof. S.Shmeter*. Moscow, CAO. C.411–448 (In Russian).

[26] Boychenko, S.G., Voloshchuk, V.M. (2005) [Transformation of zonal climate field of surface air temperature under global warming] . *Geophysical Journal*, – N 3. – p. 444–453. Available at: http://www.igph.kiev.ua/rus/journal.html#

[27] Goryachkin Yu.N., Ivanov V.A.(2008) [Climate Changes and dynamics of coast of Ukraine*]*/ *Ann. of the National Academy of Science of Ukraine*, N10. p.118–122. Available at: http://nbuv.gov.ua/UJRN/dnanu_2008_10_23

[28] Goryachkin Yu.N., Ivanov V. A (2006). *Black sea level: the pas, nastoyaschee and future*: Marine hydrophysic institute: Sevastopol,– 210 p.

[29] Iliin Yu.P., Fomin V.V., Diakov N.N, Gorbach s.b.(2009) *Hydrometeorological terms of seas of Ukraine*. Tom 1: A Sea of Azov. Ukrainian research hydrometeorological institute: Sevastopol – 401 p.

[30] Tkachenko V.S (2004). *Phytocoenotic monitoring of the reserve successions in the Ukrainian Steppe Nature Reserve.* – Kyiv.: Phytosociocenter. 184 p. (In Ukrainian).

[31] Tkachenko V., Boychenko(2014) [Structural drift of phitosystems steppe of Ukraine under influence of climatic changes and scenarios for first half XXI centure] // *Ann. of the National Academy of Science of Ukraine.* N4. P. 172–180.(In Ukrainian).

[32] Tkachenko V.S., Boychenko S.G. (2014) [The modern spatiotemporal transformation of ukrainian steppe phytosystem structure under the influence of climate changes and scenarios for the first half of XXI century] // *4th Ukrainian Conference Earth Observations for sustainable development and securiry (GEO–UA 2014),* Kyiv, Ukraine, 2014. Kyiv, Naukova dumka, 2014. – 97 p. (In Ukrainian)/ Available at: http://geoss–conf–2014.ikd.kiev.ua/wp–content/uploads/2014/06/zmist.pdf.

[33] Popovych F. Ya.(1936) [The vegetation of Obitochna nothern Sea of Azov maritime spit]

Collection of Scientific Papers, Kyiv, Kharkiv, pp. 33–102 (In Ukraine).

[34] Postrygan' S.Ya. (1939) [The vegetation of nothern Sea of Azov maritime spits]. *Scientific Notes of Kharkiv State Pedagogical University*, no.1. Kharkiv, Kharkiv State Pedagogical University Edition, pp. 269–319 (In Ukrainian).

[35] Tyshchenko O.V. (1999) [The age–long changes monitoring of vegetation of nothern Sea of Azov maritime spits] *Scientific Bulletin of Ukrainian State Forestry University*, iss. 9.11, Lviv – p. 115–119 (In Ukraininian).

[36] Tyshchenko O.V. (2000) [Environmental management and protection of nothern Sea of Azov maritime spits]. *Reports of Taras Shevchenko University of Kyiv,* Iss. 32. Kyiv, Kyiv University,.- pp. 47–48 (In Ukraininian).

[37] Tyshchenko O.V. (2006). *The vegetation of nothern Sea of Azov maritime spits*. Kyiv, Phytosociocentre, 2006. -156 p. (In Ukraininian).

[38] Tyshchenko O.V (2000).[Long–term changes and the protection of Sea of Azov maritime spits vegetation] *Proceedings of VII* Youth Conference *of botanists in St. Petersburg,* St. Petersburg, pp. 207–208 (In Russian).

[39] Borisenkov Ye.P., Pasetsky V.M. (1988) *The thousand–year annals of extraordinary natural phenomena*. Mysl, Moscow. –524 c.

[40] Borisenkov Ye.P., Pasetsky V.M (2002). *The annals of unusual natural phenomena for 2,5 millennium*. – Sankt–Petersburg: Gidrometeoizdat – 536 p (in Russian).

[41] Borisenkov, Ye. P. and Pasetsky, V. M (2003).: *Chronicle of Unusual Natural Events During the Last 2.5 Millennia*, Gidrometeoizdat, St. Petersburg.

[42] Buchinsky I.E.(1954) *Sketches of the climate of the Russian Plain in the historical epoch*. – Leningrad: Gidrometeoizdat. –351 p. (in Russian).

[43] Br?zdil R, Pfister C, Wanner H, von Storch H, Luterbacher J (2005) [Historical climatology in Europe] // *The state of the art. Climatic Change*.– N70. p.363–430.

[44] Boychenko S.G.(2003) [Frequency of catastrophic phenomena in Ukraine under the influence of global warming] // *Water Resources Systems – Hydrological Risk, Management and Development (Proceedings of symposium HS02b held during IUGG2003 at Sapporo, 2003)*. IAHS Publ. – N281. p. 18–25. Available at: http://www.igph.kiev.ua/rus/ journal.html#

[45] Boychenko S. (2010) [The scenarios of repeatability of catastrophic climatic phenomena in Europe and Ukraine under the influence of climate changes (with use of historical records and manuscripts for the last millennium)]//*Geophysical journal*, V.32, N4, P.23–25. Available at: http://www.igph.kiev.ua/rus/ journal.html#

[46] Golubyatnikov, L.L, Yamagata, J., Alexandrov, G.A. (2002). [Stochastic generator of monthly precipitation and average temperatures values]. *Bulletin of the Russian Academy of Sciences, Physics of the atmosphere and ocean series*. – V.38(1). – p. 47–55.

[47] The Physical bases of climate and climate modeling (Report of the International Study Conference in Stockholm,1974). GARP Publicatoins series no16,1975. p.271.

[48] Boychenko S.G., Voloshchuk V.M., Serdjuchenko N.N.(2006) [Parametrization of displacement of a subtropical minimum of an atmospheric precipitation in Northern hemisphere at global warming] // *Reports of National Academy of Sciences of Ukraine*, №9. – C.134–139.

[49] Boychenko, S.G. (2005) [About transformation of natural areas in the territory of Ukraine with further global warming: the equilibrium and non–equilibrium models, scenarios] / *Ecology and Environmental Safety*,.– No.1– P.53–58. (In Russian).

[50] Polevoy, A., Kulbida, N., Adamenko, T., Trofimova, I.(2007) [Modelling of influence of changes of a climate on agroclimatic conditions of cultivation and photosynthetic productivity of a winter wheat in Ukraine]. /*Ukrainian Hydrometeorological Journal*, N2. p.76–91 (in Ukrainian). Available at: http://www.nbuv.gov.ua/ old_jrn/natural/Uggj/2007_2/Polevoy_Kulbida_Ada menko _Trofimova.pdf

[51] Polevoy, A.N. (2010) [Simulation of photosynthesis in green leafy plants type C_3 and C_4 with changes in the concentrations of CO_2 in the atmosphere]. *Problems of Ecological Monitoring and Ecosystem Modelling. Moskow, Institute of Global Climate and Ecology of Roshydromet and Russian Academy of Sciences*, V. 23., p. 297–315. (In Russian).

[52] Stefanovska, T.R.(2010) [Vulnerability of Ukraine agriculture to climate change]. / Ecological Safety, 2010. N1(9). p. 62–66. Available at: http://www.kdu.edu.ua/ekb_jurnal/2010_1(9)/pdf/62 .pdf

[53] DEFRA: News from DEFRA–August 2010. Available at:

ttp://archive.defra.gov.uk/environment/climate/documents/interim2/acc–news–1008.pdf.

[54] Feyen L., Dankers R.(2009) [Impact of global warming on streamflw drought in Europe]: J Geophys Res. V. 114, D17116, 17 p.

[55] State Statistics Service of Ukraine (2014), "Statystychnyi schorichnyk Ukrainy za 2013 rik" *Statistical Yearbook of Ukraine 2013*, Kyiv, Ukraine.

[57] Boychenko S.,R Gavrilyuk., G. Veremiychik., G.Kolomiets., Ya.Movchan., O. Tarasova., S.Savchenko., T.Strava.(2015) [Water and water resources of Ukraine: issues of environmental management under conditions of climate change (on example of situation on the Southern Bug Granite-Steppe Bug region)]. *Region- 2015: strategy of optimal development: materials of international scientific and practical conference.* - K.: KNU of V.N.Karazin, P.254-257.

[58] Boychenko S. R. Gavrilyuk N. Movchan,Ya. Movchan., O. Tarasova.,V.Sharavara., S.Savchenko (2015) [Water supply and water drainage: challenges and concepts of responses (context of climate change and exhaustion of water resources)]. *Materials of I international scientific and practical conference «Water supplying and water drainage: projecting, exploitation, monitoring* Lviv : ZUKTS– P. 61–62

[59] Boychenko S., R.Havryliuk, Ya.Movchan, O. Tarasova, V. Sharavara, S.Savchenko (2016) [Water supply and water discharge: challenges and concept of responces – context of climate change and exhaustions of water resources*]* // *Water supply and Wastewater removal : edited by Henryk Sobczuk, Beata Kowalska.* – Lublin: Lublin University of Technology, 2016 (Printed by : TOP Agencja Reklamowa Agnieszka Łuczak). P. 3–14. (0,47 друк. арк.) ISBN: 978-83-7947-200-0

[60] ZaporozhetsO., Ia. Movchan, O. Tarasova (2013) [Methodology and criteria of the renewable energy EIA under the ecosystem approach] // *8th International Green Energy Conference*, Kyiv, Ukraine, June 17-19

[61] Movchan Yaroslav.(2008) *Econet in the framework of sustainable development //Social and economic potential of sustainable development*.Textbook, editors Luc Hens and Leonid Melnyk.- Sumy, University Book, - pp. 103-108.

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Особливості кліматичних змін в Україні: сценарії, наслідки для природи та агроекосистем

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Мета: Метою дослідження є аналіз основних особливостей зміни клімату в Україні в XX-XXI століттях, і отримати оцінку можливих регіональних екологічних наслідків під впливом глобального потепління. **Методи:** Емпіричні константи в побудованих напівемпіричних моделях були оцінені на основі статистичного аналізу матеріалів метеорологічних спостережень на метеостанціях України протягом XX ст. і початку XXI ст. Отримані результати використовуються для побудови сценаріїв можливих зміни клімату в Україні при глобальному потеплінні в найближчому майбутньому. **Результати:** Кліматичні умови України відреагували на глобальне потепління (середньорічна температура підвищилася на 0,6± 0,2°С/за 100 років і незначне збільшення річної суми опадів на 5-7% протягом 100 років). Особливості трансформації сезонного ходу кліматичних полів температури і атмосферних опадів в Україні розглядається також. Беручи до уваги глобальні зміни клімату, пропонуються регіональні сценарії клімату (температура і атмосферні опади) в Україні до 2050 року.

Обговорення: Аналіз основних екологічних наслідків від глобального потепління, які вже сталися або можуть проявитися в найближчому майбутньому в Україні, проведено: підняття рівня Чорного і Азовського морів; просторова трансформація структури степових фітосистем; зміни в північній частині Азовського моря екосистем морських кіс; збудження катастрофічних погодних явищ в Україні, розвиток опустелювання в південних і південно-східних областях України, вплив змін клімату на сільське господарство, аспекти водних ресурсів.

Ключові слова: адаптація; атмосферні опади; водні ресурси; екологічні наслідки; зміна клімату; зміна рослинності степів; катастрофічні явища; опустелювання; рівні Чорного і Азовського морів; температура; сільське господарство; сценарії.

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Особенности климатических изменений в Украине: сценарии, последствия для природы и агроэкосистем

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Цель: Целью исследования является анализ основных особенностей изменения климата в Украине в XX-XXI столетиях, и получить оценку возможных региональных экологических последствий под влиянием глобального потепления. **Методы:** Эмпирические константы в построенных полуэмпирических моделях были оценены на основе статистического анализа материалов метеорологических наблюдений на метеостанциях Украины в течение XX ст. и начале XXI ст. Полученные результаты используются для построения сценариев возможного изменения климата в Украине при глобальном потеплении в ближайшем будущем. **Результаты:** Климатические условия Украины определенно отреагировали на глобальное потепление (среднегодовая температура повысилась на 0,6±0,2°C/100 лет и незначительное увеличение годовой суммы осадков на 5-7 % в течение 100 лет). Особенности трансформации сезонного хода климатических полей температуры и атмосферных осадков в Украине рассматривается также. Принимая к вниманию глобальные изменения климата, предлагаются региональные сценарии климата (температура и атмосферные осадки) в Украине к 2050 году. **Обсуждение:** Анализ основных экологических последствий от глобального потепления, которые уже произошли или могут проявиться в самом близком будущем в Украине, выполнен: повышение уровней Черного и Азовского морей; пространственное преобразование структуры степных фитосистем; изменения в северной части Азовского моря экосистем морских кос; возбуждение катастрофических погодных явлений в Украине, развитие опустынивания в южных и юго-восточных областях Украины, воздействие изменений климата на сельское хозяйство, аспекты водных ресурсов.

Ключевые слова: адаптация; атмосферные осадки; водные ресурсы; изменение климата; изменение растительности степей; катастрофические явления; опустынивание; сценарии; сельское хозяйство; температура; уровни Черного и Азовского морей; экологические последствия.

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