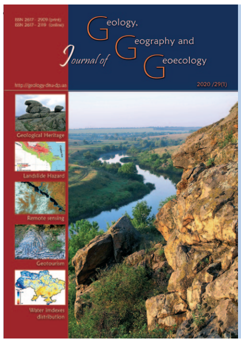

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Detection of Changes in Terrestrial Ecosystems of Ukraine Using Remote Sensing Data

Vadym I. Lyalko[1], Inna F. Romanciuc[1], Lesia A.Yelistratova[1], Aleksandr A. Apostolov[1], Viktor M. Chekhniy[2]

[1]State institution "Scientific Centre for Aerospace Research of the Earth Institute of Geological Science National Academy of Ukraine", Kyiv, Ukraine, i.romanciuc@gmail.com
[2]Institute of Geography, National Academy of Sciences of Ukraine, Kyiv, Ukraine

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Abstract. In recent years, Ukraine has been affected by climate change. This has led to frequent extreme weather events (heavy / high rains, floods, droughts, squalls). As a result of droughts, desertification is one of the most dangerous and transient consequences of modern climate change. The research is devoted to the diagnostic assessment of the modern climate of Ukraine. Remote sensing data and instrumental observations of 30 weather stations of Ukraine were used. Temperature increase was registered in the study area by all stations, which significantly affected the level of precipitation. At the moment there is not enough moisture for the Earth's surface. Precipitation in Ukraine is currently characterized by an uneven distribution. It leads to accelerated processes of soil degradation and it's fertility loss. The aim of the study was to identify areas prone to desertification using satellite imagery and meteorological observations. Over the past 17 years (2000-2017), the average air temperature in Ukraine has increased by 1.5 ºC. Particularly anomalous warming has been recorded in recent years, starting in 2015. During the XXI century, a slight decrease in precipitation was observed in Ukraine. Both a decrease in precipitation and an increase in temperature may lead to a decrease in soil moisture levels. According to ground meteorological data, the tendency of dryness in Ukraine was confirmed. Lack of water leads to prompt manifestation of this process. Water indexes were used to estimate the moisture content of surface soils. It is possible to assess the susceptibility of the desert area to climate change. Relevant quantitative information on water availability in Ukraine is provided. Two water indices (Normalized Difference Infrared Index NDII and Ratio Drought Index RDI) have been taken estimate the moisture content. It can be estimated from the MODIS MOD13C2 product data obtained from the MODIS satellite sensor and used for regional research. The main conclusion of this study is to determine the changes in natural terrestrial ecosystems in Ukraine. This was shown on the basis of temperature and humidity. Such trends may lead to changes in the biodiversity of the territory and loss of natural soil properties.

Key words: remote sensing data, desertification, water detection, climate change, soil moisture, water index

Використання матеріалів космічної зйомки для виявлення змін у природних зонах України

В. І. Лялько[1], І. Ф. Романчук[1], Л.А. Єлістратова[1], О. А. Апостолов[1], В. М. Чехній[2]

[1]Державна Установа "Науковий центр аерокосмічних досліджень Землі ІГН НАН України", Київ, Україна, i.romanciuc@gmail.com
[2]Інститут географії, Національна Академія наук України, Київ, Україна

Анотація. В останні роки України перебуває під діями змін клімату. Це призводить до частих екстремальних погодних явищ (зливи, посухи, шквали). Одним із найзагрозливіших і швидкоплинних наслідків сучасної зміни клімату є розповсюдження опустелювання, причиною якого є посуха. В дослідженні проведена діагностична оцінка сучасного клімату України. Використовувалися дані дистанційного зондування Землі. та інструментальних спостережень 30 метеорологічних станцій України. Підвищення температури у регіоні дослідження фіксується всіма розміщеними в ньому станціями. На фоні підвищення температури значну роль відіграють опади, яких наразі не вистачає для достатнього зволоження земної поверхні. Опади в Україні мають наразі характер нерівномірного розподілу, що призводить до пришвидшення процесів деградації ґрунтів та втрати їх родючості. Завданням дослідження є виявлення схильних до опустелювання територій за допомогою супутникових даних та метеорологічних спостережень. За 17 (2000–2017) років на території України температура повітря підвищилася на 1,5ºС. Особливо аномально теплими в Україні були останні роки, починаючи з 2015 року. В Україні за роки XXI століття йде незначне зменшення кількості опадів, що свідчить про незначне ослаблення опадоутворюючих процесів. Зменшення кількості опадів при підвищенні температури може призвести до погіршення вологозабезпеченості при поверхневих ґрунтів.

За наземними метеорологічними даними була підтверджена тенденція посушливості в Україні. Нестача води, підвищення температури ведуть до більш швидкого прояву цього процесу. Для розрахунку вологовмісту при поверхневих ґрунтів були використані водні індекси. Це дозволило оцінити схильність території до опустелювання в умовах кліматичних змін. Надана відповідна кількісна інформація про вологозабезпеченість території України. Для розрахунків вмісту вологи були взяті два водних індекси Нормалізований Диференційний інфрачервоний індекс NDII та Індекс посухи RDI. Їх можливо розраховувати за даними продукту MOD13C2 з супутника MODIS та використовувати для регіонального рівня дослідження. Спираючись на отримані дані, головним висновком є виявлення змін у природних зонах, що показано на основі тепла та вологи. Таки тенденції можуть призвести до змін біорізноманіття території та втрати природних властивостей ґрунтів.

Ключові слова: дані дистанційного зондування Землі, опустелювання, вологовміст, кліматичні зміни, вологість ґрунтів, індекси вологості

Introduction. The effects of climate change that have emerged in recent decades have led to the expansion of desertification, which leads to droughts. Drought is causing enormous damage to many sectors of the economy as one of the greatest natural disasters. In its' negative consequences compared with other natural disasters, droughts are among the first.

Human activities significantly change the natural environment. This leads to the intensive decrease of biodiversity and productivity of ecosystem that turns into land degradation. In the UN Convention to Combat Desertification (UNCCD) it is defined as a form of dry land degradation (arid, semiarid, and dry sub-humid) provoked by climate and human activities (UNCED Report, 1992, UNCCD, 1994).Such definition is specified in the Annex I of UNCCD Regional Implementation for Africa (Gunin et al., 2004, UNCED Report, 1992). Thus an emphasis is placed on the territorial manifestation of desertification caused by climate. The other documents of Convention extend the investigated territory beyond drylands. The arid lands are supplemented with sub-humid and humid lands affected by degradation due to anthropogenic activity. This should be considered to evaluate the spreading of desertification. In the Annex II of Convention for Asia regional level, the term "parts of the territory that have suffered aridity or drought, or those that are under threat …" is used instead of "dryland" (Gunin et al., 2006, UNCED Report, 1992). The same is defined for the Annex III of Convention for Latin America and the Caribbean.

The territory covered by the convention is spreading more and more. The Annex IV is expanded to the Northern Mediterranean. It is characterized by "semi-arid climatic conditions over large areas, seasonal droughts, very high variability in rainfall, unexpected / random precipitation of high intensity" (Gunin et al., 2006, UNCED Report, 1992). Annex V of the Convention cover the Central and Eastern Europe. The territory is characterized by "a variety of land degradation in different ecosystems of the region. This takes into account the effects of drought and the risk of desertification in areas prone to water and wind erosion" (Gunin et al., 2006, UNCED Report, 1992). The main part of this territory is represented by humid lands. Land degradation here is also associated with the human activities. This territory is prone to episodic droughts, but the hazard of desertification is not significant. Annex V expands the area of the Convention operation. Here, the most actual is a struggle being waged with land degradation than with desertification. Later convention documents for Central and Eastern Europe deal with degradation, risks of desertification and drought.

At the national level, the concept of desertification is reflected in the National Programs to Combat Desertification (NPCD) of the Central and Eastern Europe countries. Within the Ukraine National Program the desertified areas of degraded lands are in sub-humid and humid regions.

That is, we should move away from the concept of "desertification", as shown in the documents on the implementation of the Convention. Additionally, we should talk about desertification within arid zones, and separately about the degradation of sub-humid and humid lands.

Ukraine, like every country, is vulnerable to climate change. Every year, our economy suffers considerable losses from natural disasters. Due to that, we have to take measures to mitigate and adapt our country to climate change. Global climate change also affects Ukraine by increasing the average air temperature and uneven distribution of precipitation, which can lead to significant changes in its climate and agricultural zones. The most significant consequence of climate change is not only gradual warming, but also increase of the number and intensity of extreme weather events: severe droughts, extremely hot days, etc. Therefore, there is an urgent need to adapt to climate change in certain sectors of the Ukrainian national economy. The urgency of this problem was confirmed by the Resolution of the Cabinet of Ministers of Ukraine dated on August 18, 2017, No. 20. As a result, a Coordination Council for Combating Land Degradation and Desertification was established. We are pleased to be a temporary consultative body of the Cabinet of Ministers of Ukraine until 2021 in order to coordinate the formation and implementation of state policy on sustainable land use and protection, land degradation and combating desertification, mitigation of the consequences of drought.

In accordance with the recommendations of the Convention in case of Ukraine it is necessary to determine the boundaries of drylands and humid areas that may become arid. Special attention has to be paid on droughts in the context of climate change. Droughts are the strongest factor in the development of desertification processes. So, it is necessary to determine the peculiarities of spatial distribution of soil moisture within the territory of Ukraine.

At present, the feasibility of remote sensing data usage for desertification monitoring is no longer in doubt. Remote sensing technologies allow prompting identification and soil degradation risks assessment and Earth surface monitoring. There is a large number of scientific publications, both locally and globally, that demonstrate the benefits of satellite monitoring, as well as the use of satellite data for soil and vegetation monitoring (Boke-Olen et al., 2018; Lyalko et al., 2018; Kokhan et al., 2018; Zholobak et al., 2018; Movchan et al., 2014).

The task of the research is to identify areas susceptible to desertification in Ukraine by using water spectral indexes estimation based on remote sensing data processing.

Materials and methods. Diagnostic estimation of the modern climate of Ukraine is based on the data of instrumental observations. The values of monthly air temperatures and precipitation, soil temperatures at depths of 5, 10, 15, 20 cm were obtained from 30 meteorological stations. During the selected period of 2000 - 2016, the data were collected from 30 meteorological stations. The trend towards increased drought in Ukraine has been confirmed. Water scarcity and temperature increase lead to a faster manifestation of this process. In this case, water plays a leading role in both climate change and land degradation processes. The study is focused on the water exchange, with the application of all technologies, including aerospace research.

In order to determine the soil moisture for Ukrainian territories, the MOD13C2 data obtained by the MODIS / TERRA satellite were used. The MOD13C2 product is the monthly data of two vegetation indices: Normalized Difference Vegetation Index NDVI and Enhanced Vegetation Index EVI, as well as monthly spectral data in next bands: blue, red, NIR and MIR, with a spatial resolution of 0.05 degrees. MODIS (MOD13C3) is the most convenient product for regional studies of water supply and average values calculations over the years. According to Land Processes Distributed Active Archive Center (LP DAAC) (https://lpdaac.usgs.gov/products/mod13c2v006/), the MIR band in the MOD13C2 product is in the spectral range of 2105-2155 nm, which corresponds to the range of SWIR2 of the Landsat and Sentinel-2 satellites.

The MOD13C2 product is the sixth version and represents the Vegetation Index (VI) value in each pixel of the image. It includes two main vegetation layers. The first is the Normalized Vegetation Index (NDVI) obtained using the AVHRR radiometer which was developed by the National Oceanic and Atmospheric Administration (NOAA). The second vegetation layer is the Advanced Enhanced Vegetation Index (EVI), which is highly sensitive to biomass. While creating a monthly product, MOD13C2, the algorithm accepts all MOD13A2 products that are overlapped during the month period of scanning using an average timing value. All entrance pixels are of 1 km spatial resolution (nominally 6x6). As a rule, inputs are either transparent, clouded or mixed. Data can be obtained from the official website of the US National Geological Survey or the Earth Resource Surveying and Exploration Center (EROS), as well as from the Land Processes Active Archive Data Center (https://lpdaac.usgs.gov/). Averaging schemes could be applied as follows: if all the input pixels were transparent, all of it would be averaged to get one output value. If all the input pixels were clouded, the pixels data would be estimated from the historical database. If the input pixels were mixed (the part is transparent, part is clouded), only transparent pixels would be averaged to get one output value.

Several water indexes have been analyzed: DSWI (normalized difference infrared index), SR-SWIR (simple ratio SWIR), RDI (ratio drought index) (Abdullah et al., 2018) and NWI (normalized water index) (Sakhatsky, 2010). The possibility of using MOD13C2 product data for its estimation has been defined. Two indexes can be used for soil moisture content mapping over Ukraine: NDII (normalized difference infrared index) and RDI (ratio drought index). The MOD13C2 product contains the data of spectral bands that are applicable for these indexes estimation. These indexes are calculated using the formulas:

$$NDII = (NIR - SWIR1)(NIR + SWIR1) \quad (1)$$

$$RDI = SWIR1NIR \quad (2)$$

To estimate these indices for MOD13C2 data, the formulas acquire the following form:

$$NDII = (NIR - MIR)(NIR + MIR) \quad (3)$$

$$RDI = MIR1NIR \quad (4)$$

where, NIR - the monthly spectral brightness in near-infrared range, MIR - the monthly spectral brightness in shortwave infrared range.

The 2007 year was chosen for the research, as the local climate during that year was affected by drought. One of the most abnormal years at the global and regional scale is 2015. Year 2016 was chosen as a typical year of the XXI century with temperature increment. MOD13C2 monthly products were received for the period from April to October 2007, 2015 and 2016.

All data processing from MOD13C2 product was performed using the ERDAS Imagine imagery processing software. The work was carried out at the several stages:

1) Conversion of the input data of the MOD13C2 product from the .hdf format into .img format. The img format is the raster image in the Erdas Imagine. The conversion is done using Import / Export module. The following is Type - HDF Raster;

2) Seven channel images are formed. The images are made monthly from April to October. The years of study include 2007, 2015 and 2016. It is estimated for NIR and MIR bands with Interpreter module and Layer Stack function;

3) The MOD13C2 product data is presented worldwide. For the further work it is necessary to separate the territory of Ukraine in the NIR and MIR channels. It is done using the Subset tool of the Erdas Imagine and the Ukraine border in aoi format. Fig. 1. demonstrates the data obtained from NIR channel for the territory of Ukraine;

4) The conversion of NIR data and MIR on the territory of Ukraine with the rectangular coordinate system UTM / WGS84, 36 zone is released using Project function of Erdas Imagine software. A metric coordinate system should be used for the territory of Ukraine;

5) The estimation of the water indexes NWII and RDI values using the formulas (3), (4) for each month. Corresponding averages are estimated for 2007, 2015 and 2016 using Erdas Imagine, namely Spatial Modeler / Model Maker. On Fig. 2. a model is demonstrated calculating the values of NWII and RDI water indices according to the formulas (3), (4) for 2007 in the Erdas Imagine software (Fig. 2).

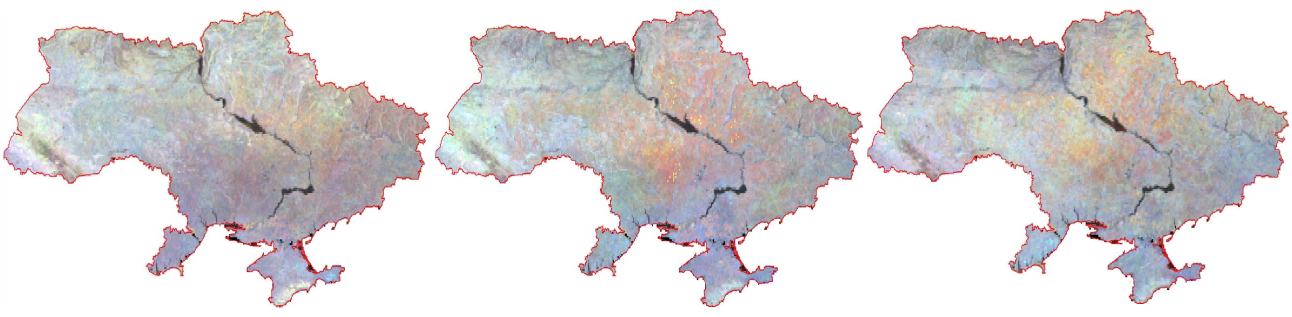
Results and discussion. Table 1 shows the air temperature deviation from the normal average in Ukraine during the years of the XXI century. For 17 years (2000 - 2017) the air temperature in Ukraine has increased by 1.5 ºC. In particular, the last years since 2015 were abnormally warm relatively to normal average annual temperature in Ukraine.

According to different models further air temperature increase is expected in Ukraine. By the end of the XXI century, it can increase by 0.7-3.0 ºC (“soft” scenario B1) in comparison to the period of 2001 - 2010, or by 2.6-4.6 °C (“hard” scenario A2) (Nakicenovic et al., 2000).

It’s all happening against the backdrop of rainfall fluctuations. Fig. 3 shows deviations from the average amount of precipitation in Ukraine for the XXI century. It is clear that in the period of 2010 - 2016, the average amount of precipitation in Ukraine in the period of 2010-2016 was less than the average. There is a slight decrease in the amount of precipitation according to the data of in situ measurements. This indicates a slight weakening of the deposition processes.

Reducing the amount of precipitation with simultaneous temperature increase can lead to soil moisture deterioration.

The condition of the soil cover, namely the soil temperature regime, has been studied. Temperature regime is a combination of all phenomena of soil accumulation and heat exchange. Temperature regime is determined by estimation of soil temperature at different depths (5, 10, 15, 20 cm). This indicator was taken as a baseline for meteorological stations. Such depths characterize the arable layer. This soil layer is sensitive to changes in the thermal regime on the



a b c

Fig. 1. Highlight of the Ukraine territory from MOD13C2 product in the NIR channel: a) for 2007 year; b) for 2015 year; c) for 2016 year.

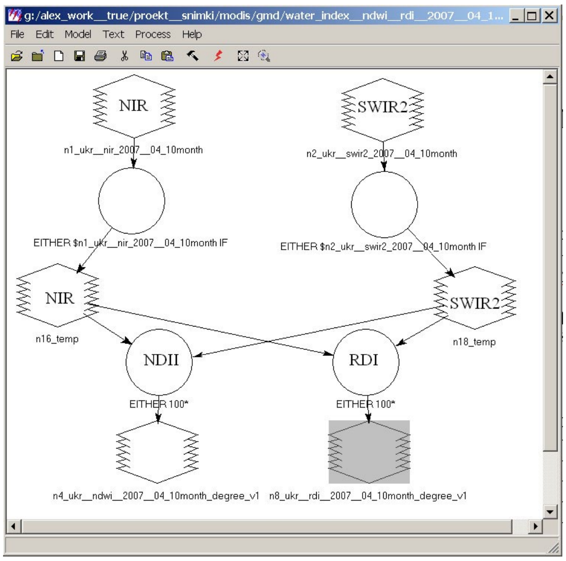


Fig. 2. Model for estimation of the values of NWII and RDI water index by the formulas (3), (4) for 2007.

surface and takes an active part in the formation of the surface air temperature regime.

Figure 4 and 5 demonstrates the soil temperature deviation at depths of 5, 10, 15, 20 cm in the forest-steppe (Fig. 4) and steppe (Fig. 5) zones for the period of 2000-2016. The received data is deviated from the climatic norm of 1961-1990. Soil is warmed up due to temperature increase. There are no negative deviations of the soil temperature at all the depths. Dry years and its' peaks are distinguished on the plots. For the forest-steppe zone one of the peaks belongs to 2007, which is confirmed by meteorological data.

Considering the received diagnostic estimation of modern climate changes it can be assumed that the negative climatic tendencies will aggravate over time in Ukraine.

Climate monitoring at different time scales can detect short-term wet periods during long dry periods and vice versa. Indexes can be used to simplify complex relationships and serve as a useful tool for informing users. Water indexes were used to estimate the soil moisture content. It is possible to assess the desertification inclination areas under climate change conditions and provide relevant quantitative information about the water availability of Ukraine. Indexes are presented as intensity and duration estimate of the moisture transfer process, which were obtained quantitatively. The most two common indices, NDII and RDI were taken. They can be estimated using the MOD13C2 MODIS product and used for regional research.

Table 1. Air temperature deviation (ΔT ºC) from the climatic norm on the territory of Ukraine for 2000 - 2017 years.

2000	***2001***	***2002***	***2003***	***2004***	***2005***	***2006***	***2007***	***2008***
1,5	1,1	1,6	0,5	0,9	1,0	0,7	2,2	1,9
2009	***2010***	***2011***	***2012***	***2013***	***2014***	***2015***	***2016***	***2017***
1,7	1,7	1,4	1,3	1,7	1,7	2,8	1,8	2,0

Normalized Differential Infrared Index (NDII), developed by Hardinsky (Hardinsky et al., 1983; Abdullah et al., 2018), Gao (Gao, 1996). Relative Drought Index (RDI) was proposed by Pinder (Pinder et al., 1999; Abdullah et al., 2018). These indexes are applicable within the infrared bands for content monitoring of water vegetation. Vegetation cover changes were used to detect a vegetation stress period caused by drought.

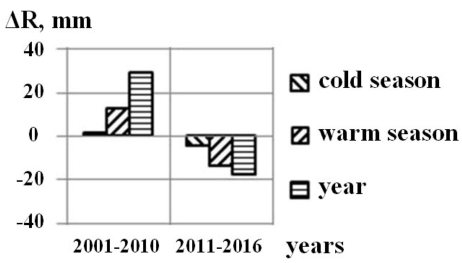


Fig. 3. Deviation of the average amount of precipitation in Ukraine over the 2000 - 2016 years (Elistratova et al., 2018).

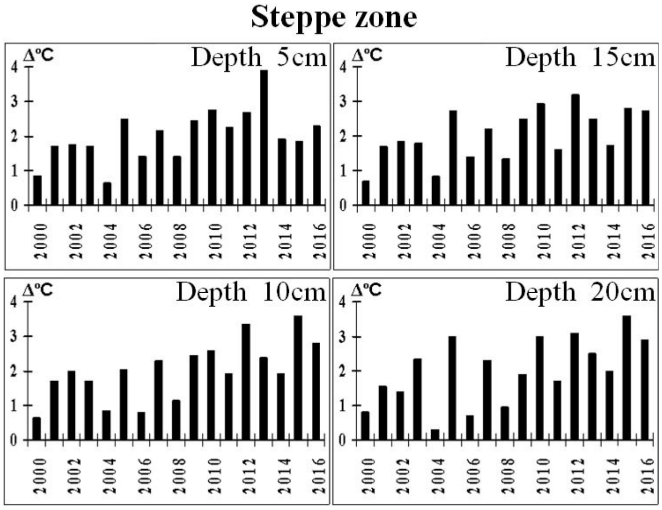


Fig. 4. Deviations of soil temperature values from the average multi-year period 1961-1990 at different depths in the forest steppe natural zone.

The indexes were estimated for the warm period of the year (April-October). These months were chosen due to the vegetation cover period. The average values of indexes for each three year period were calculated within the next step. The result of calculations allowed classifying the territory by soil humidity degree (Fig 6). The gradations of water indexes are shown in different colors in Table 2.

The number and seasonality of precipitation distribution, high temperatures are a significant factor of temporal changes of borders between the natural geographic areas in Ukraine.

The main sources of soil moisture are atmospheric precipitation and groundwater. Atmospheric drought forest zone. It shows up as a lack of moisture for the plants. Therefore, the main problem is referred to the increased dryness, when in condition of warmer and drier climate more precipitation for evapotranspiration balance is needed. The whole process of trend changes in air temperature and precipitation within the framework of modern changes will be aggravated by the frequency and severity of extreme situations (heat waves and droughts).In some cases, prolonged atmospheric drought causes hydrological drought – drying of small water objects. The analysis of Figure 3 showed the sharp moisture deficiency within the steppe zone (IV in Figure 3). For all years, the NDII and RDI indices of moisture availability in the steppe

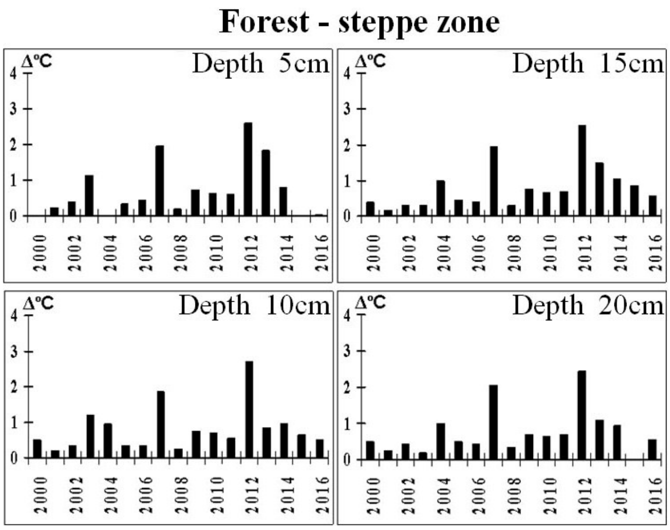


Fig. 5. Deviations of soil temperature values from the average multi-year period 1961-1990 at different depths in the steppe natural zone.

leads to soil erosion under conditions of deep groundwater level, in Ukraine it is the most part of the steppe, forest-steppe, temperate deciduous forest zone and separate areas of the coniferous-deciduous zone correspond to: dry, very dry, strong dry and, in particular, for 2007 (where there was a strong extreme drought) - a catastrophically dry range of index values. Comparison of this indexes with the actual data was in previous studies (Lyalko et al., 2015, 2019). This is the most critical region of Ukraine in this regard.

According to our calculations, the process of drought is in full swing from 2007 to 2016. With further predicted warming of Ukraine, the climatic conditions of 2007 may be permanent. The significant changes may occur in both the air temperature and humidity.

With regard to the forest-steppe zone (number III), in the years with the highest air temperature (2007), the ranges of water values (dry, very dry) indicate the characteristic climatic conditions of the steppe zone. Thus, the index values that used to belong to the steppe zone are territorially displaced in the forest-steppe zone. This may indicate the pronounced manifestations of natural changes in zoning only in the second half of the XXI century.

The assessment of water indexes also indicated the proliferation of the processes of moisture deficit increasing during the growing season and on the territory of the temperate broad-leaf forests (Number II).

The zone of mixed coniferous forests (coniferous-leaved) in number I can not be attributed to zones of sufficient or excessive humidity, obviously due to

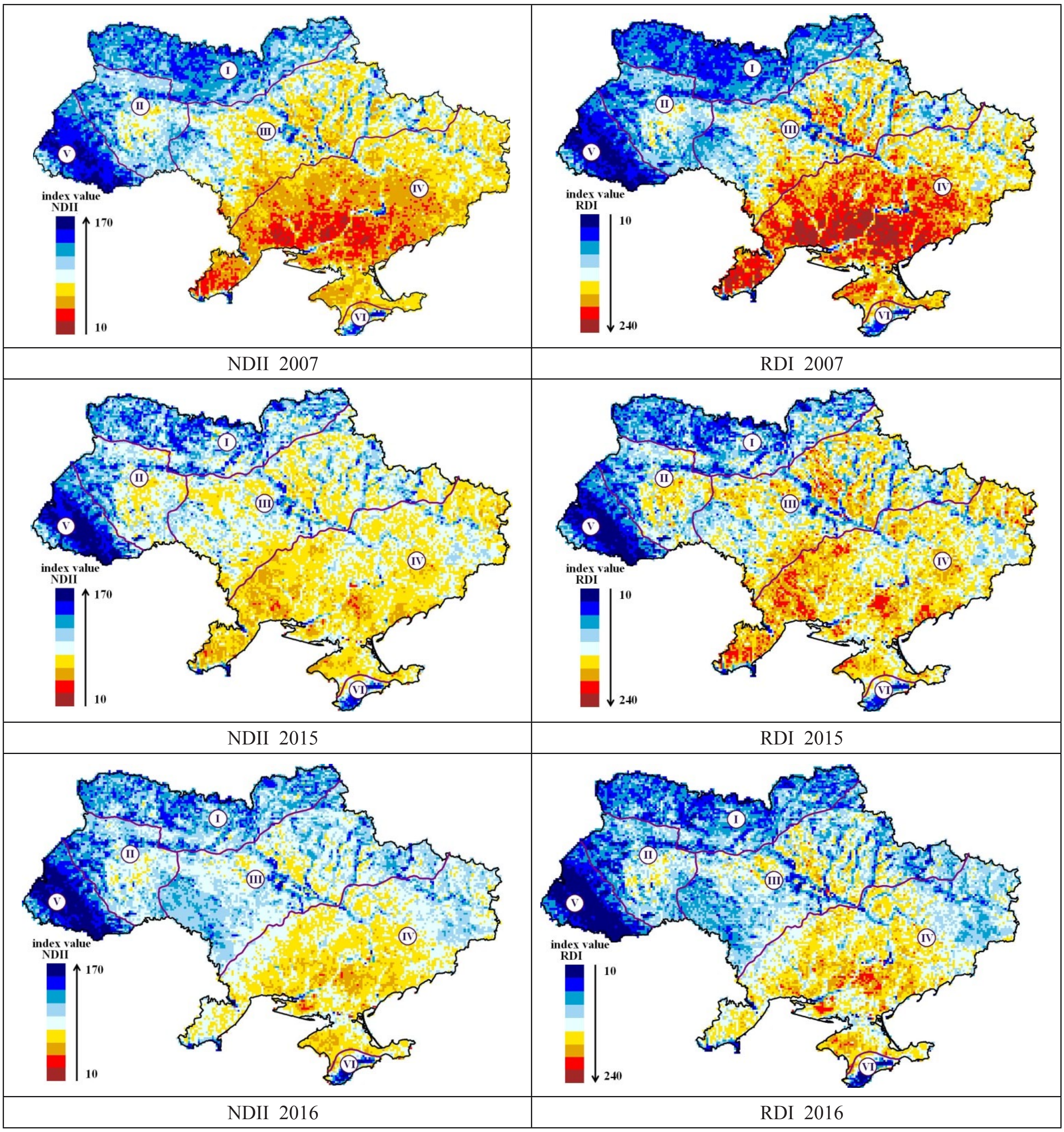


Fig. 6. Map of NDII and RDI water indexes distribution of Ukraine scale 1: 3700000.
I - zone of mixed (coniferous-deciduous) forests, II - zone of temperate broad-leaf forests, III - forest steppe zone, IV - steppe zone, V - Ukrainian Carpathians, VI - Crimean Mountains.

Table 2. Moisture of Ukraine and the corresponding NDII and RDI moisture indexes values.

№	Moisture content	NDII		RDI	
		color	index values	color	index values
1	Extremely moistened		>160		<126
2	Strongly moistened		150…160		126...136
3	Enough moistened		140…150		137...147
4	Moist		130…140		148...158
5	Not enough moistened		120…130		159…169
6	Arid		110…120		170…180
7	Highly dry		100...110		181…191
8	Strongly dry		90…100		192…205
9	Extremely dry		<90		>205

the variability of natural landscape conditions and a wide range of consequences of land reclamation. The ranges of calculated water indexes show the following categories: sufficient and strong moisture, so there are no changes in plant species within this territory.

Taking into account the results of the research, it can be noted that the growth of Ukraine's arid climate under the conditions of modern climatic changes and displacement of natural-climatic zones will have a significant impact on the landscape, especially on its biota. Such changes will be manifested in the replacement of zonal types of vegetation, shifting the boundaries of forests, changing the ratio of forest formations and forest types, reducing the resistance of forests to pests and diseases, its dryness. Thus, for the current period this process is especially noticeable in the southern regions of Ukraine.

Conclusions. Uncertainties in terms of feedback to the impact of climate change on natural ecosystems can be significant. On the one hand, currently there is not enough evidence that the expected reaction (changes in the zones boundaries, replacement of plant groups from one to the other, or its' complete loss) can be manifested promptly. However, received results of estimating the NDII and RDI water indices according to the MODIS multispectral satellite imagery data, make it possible to conclude this. In the future, significant losses in biodiversity should be expected as a result of the high temperatures and water stress effects. There will be a change in the natural zoning, as the main factor in the formation of natural zones is the balance of heat and moisture balance in Ukraine. It has been established due to the course of further climate change effects (air temperature increment). If the existing tendencies of aridity growth remain unchanged, the semi-desert zone may gradually shift to the territory of the modern steppe zone. The forest-steppe will be transformed into a steppe zone, and the transformation of temperate-broadleaved forests into a forest-steppe zone, respectively, will lead to the reduction of the forest-steppe zone. Only the speed of these changes remains a contentious issue.

This effect is very unfavorable from the environmental point of view. It may lead to the disappearance of some types of natural systems that are sensitive to climate change. It is necessary to carry out adaptation measures to reduce the negative impact on the use of natural resources at the state level.

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