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DETERMINATION OF GREENHOUSE GAS CONCENTRATION IN THE ATMOSPHERE BY EARTH REMOTE SENSING MEANS. CARTOGRAPHIC AND ANALYTICAL ASSESSMENT OF THE GEOSPATIAL DISTRIBUTION OF ITS VALUES

This article covers the issue of improving the methodology of remote determination of the concentration of greenhouse gases in the atmosphere using the Copernicus Program — Sentinel-5P and MOD11A2.061 Terra satellite systems, as well as the cartographic-analytical assessment of its geospatial distribution. The specified methodology provided for remote determination of the concentration of greenhouse gases CH_4, CO, and NO_2, development of maps of the distribution of the determined concentration on the territory of Ukraine, localization of areas of formation of the intensity of emission and sequestration of greenhouse gases taking into account data on the soil cover, abiotic conditions of the territory and anthropogenic influences, in particular, military activities. A set of maps of the geospatial distribution of CH_4, CO, and NO_2, greenhouse gas concentrations, the temperature of the Earth's surface within the warm period (01.05—30.10) during 2019—2022, as well as a map of the geospatial localization of the maximum concentrations of greenhouse gases within the warm period of the research time interval developed according to the results of emissions from soils, landscapes, production facilities, and combat zones.

It was determined that for the warm period of the year, on average for 2019—2022, the optimal temperature range within which the intensity of nitrogen dioxide emission on the territory of Ukraine reaches maximum values is from 13 to 19 °C. If the temperature of the Earth's surface exceeds the value of 20 °C, the volume of emission emissions is significantly reduced. It is shown that soils with different emission and assessment status are widespread in Ukraine during the warm period. In the South and Southwest of the state, soils with the highest emission capacity of methane to the atmosphere prevail, in particular Jc49-1/3a — Calcaric Fluvisols, Lg54-1a — Gleyic Luvisols, Kh31-2a — Haplic Kastanozems, Gh23-3a — Humic Gleysols.

In large cities, as well as in the territories of the South-East of Ukraine, where normal chernozems (Ch22-2a) / (normal chernozems) are common, the maximum concentration of NO_2 in the atmosphere is formed, which is caused by the influence of the high temperature of the earth's surface and the localized consequences of Russia's military aggression. It was revealed that over the past 4 years, there has been a trend of decreasing CO concentration, which indirectly indicates the negative impact of Russia's military aggression, a decrease in industrial production, and the relocation of production facilities to the west of the country.

Keywords: *RES, greenhouse gases, soils, emission, sequestration, landscapes, cartographic-analytical assessment.*

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INTRODUCTION

It is generally known that the significant increase in the temperature of the Earth's surface since the beginning of the industrial era (1750) has occurred by more than 1 °C is the result of an increase in the concentration of greenhouse gases in the atmosphere — CO_2, CO, CH_4, NO_2, and N_2O, as well as some other compounds, largely occurred as a result of human activity [3]. The emission of greenhouse gases by soils is an important factor in the anthropogenic impact on the climate because their use as a means of production of plant products is mainly intensive. Soils and agriculture are powerful sources of greenhouse gases, including carbon dioxide CO_2, methane CH_4, nitrogen dioxide NO_2, and nitrous oxide N_2O. At the 2015 UN Climate Change Conference in Paris, most countries agreed to reduce emissions of these gases in order to limit the increase in global surface temperature to 1.5 °C [19].

Thanks to the OCO-2 mission (NASA) and the Japanese GOSAT mission, it was possible to implement satellite remote sensing of the concentration of CO_2, i CH_4, NO_2, and N_2O [9]. The Sentinel-5p mission allows for obtaining satellite data on the concentration of NO_2, CH_4, CO, SO_2, HCHO, cloudiness, and aerosol concentration [14]. Their planned exploitation made it possible to create a database on the concentration of greenhouse gases in the atmosphere from space and to obtain the first information on the increase in the concentration of CO_2 and other greenhouse gases associated with man-made emissions. The implementation of these technologies contributes to the solution of two main tasks: the automation of monitoring observations of the concentration of greenhouse gases in the atmosphere (I) and the development of future missions aimed at verifying the accounting of greenhouse gas emissions (fiscal function), compliance with the obligations of individual countries within the framework of change agreements climate (II).

The purpose of research. The purpose of the research is to conduct a remote and cartographic-analytical assessment of the formation of the pool of greenhouse gases, depending on the characteristics of the soil cover and anthropogenic influences.

The object of study. Scientific and technological approaches to conducting remote sensing of the concentration of greenhouse gases in the atmosphere, cartographic-analytical assessment of the peculiarities of the formation of the pool of greenhouse gases within the territory of Ukraine.

Subject of study. Methodology for remote assessment of the concentration of greenhouse gases in the atmosphere, development of maps of its geospatial distribution, cartographic-analytical assessment of the formation of the pool of greenhouse gases taking into account data on the soil cover of Ukraine, abiotic conditions of the territory and anthropogenic influences, in particular, military activities.

***Research tasks included*:**

- assessment of the concentration of greenhouse gases by means of remote sensing of the atmosphere and atmospheric air temperature using current means of algorithmizing requests established for certain periods of the year and time intervals with the construction of highly informative cartograms of their geospatial distribution;
- automated generation of a soil map of Ukraine and its use as a basis for agrobiological localization of the concentration of greenhouse gases of agrogenic origin, in particular, CH_4, NO_2, and N_2O;
- cartographic-analytical assessment of the influence of temperature conditions of the atmosphere during the formation of the pool of greenhouse gases;
- development of a map showing the geographical distribution of peak greenhouse gas concentrations during the warm period in the territory of Ukraine.

Analysis of literature. To solve such tasks, several remote methods of atmospheric concentration studies are used, including the use of satellite observations to measure various parameters of the atmosphere, the most common of which include the following.

Application of spectral measuring systems. This method uses spectral measurements to determine the concentration of gases in the atmosphere. Different gases absorb and scatter light in different spectral regions, and the satellite can measure the spectral changes in the light to determine the concentration of the gases [18].

Use of radiometric observations. Some satellite systems measure the level of radiation emitted by the atmosphere, which makes it possible to determine the concentration of gases in the atmosphere. This method is based on the principles of molecular absorption and scattering, which allow obtaining information about the content of gases from measurements of radiation fields [6].

Lidar measurements. Lidar (optical radar) on a satellite is used to measure the concentration of gases in the atmosphere. A laser beam is emitted and the signal reflected from the atmosphere (reflected radiation) is measured, which makes it possible to determine the concentration of gases based on the change in the intensity of the reflected signal [2].

Temperature measurements. Data from satellite systems are used to measure the temperature in the atmosphere, which, following Fick's law, is related to the concentration of gases. For this purpose, infrared radiation of the atmosphere is used [13].

Remote satellite methods of studying the concentration of substances in the atmosphere allow for obtaining information about the composition and movement of various substances, which is important for monitoring their changes in the atmosphere and assessing the impact on the environment and human health. All of the above-mentioned satellite methods allow scientists to obtain information about the concentration of gases in the atmosphere over large areas and over a long period. This is important for monitoring environmental changes not only in the atmosphere but also in connection with anthropogenic activities and natural processes.

RESEARCH METHODS AND RESOURCES

To study the concentration and distribution of greenhouse gases on the territory of Ukraine (NO_2, CO, CH_4), data from the Copernicus Program — Sentinel-5P satellite system were used, which is equipped with the TROPOMI tool (TROPOspheric Monitoring Instrument) — a hyperspectral spectrometer with a close-up view, operating in the ultraviolet-visible range (270—495 nm), near-infrared (675—775 nm) and short-wave infrared (2305—2385 nm) ranges [5]. The orbital cycle is 16 days with a viewing range of 108° (≈2600 km) and a spatial resolution of the second level (L2) of 5.5×3.5 km^2, 7×3.5 km^2 until August 6, 2019, [12]. The GEE (Google Earth Engine) platform was used for data acquisition and processing, which allowed us to obtain updated third-level (L3) Sentinel-5P data. The average values of concentrations and temperatures were calculated using the reduceRegion method. During the research, data from the GEE resource was used in "offline" mode, which ensured higher accuracy of the results due to their better processing. At the same time, an algorithm similar to the studies using the "harpconvert" tool and "bin_spatial" operations conducted in [4] and [10] was used. Territorial timing of requests for GEE was provided with Open Street Map by forming polygons of the territory of Ukraine and algorithmizing the software code through "clip(roi)" (clipping of the data set).

The raw data were filtered with a coefficient >0.5 for all data sets except for the values of the coefficient for the concentration of NO_2 in the troposphere, the coefficient >0.75 [17]. This provided the differentiation of gases from the Earth's surface and the top of the atmosphere (TOA) [7] to the Kármán line [20] at an altitude of up to 100 km, and for NO_2 data separately for the tropospheric layer of the atmosphere at an altitude of 13—18 km; in the stratosphere at an altitude of up to 50 km [17].

Taking into account the nature of agrobiological processes in the soil during the cold period of the year (01.12—30.04) and the maximum slowing down of greenhouse gas emissions from the soil to the atmosphere, during research, the concentration of greenhouse gases was determined for the warm period of the year, which lasts from 01.05 to 30.10.

In general, the following data were used for the study:

• tropospheric_NO2_column_number_density, mol/m^2.

• CO_column_number_density, mol/m^2.

• CH4_column_volume_mixing_ratio_dry_air, molar fraction.

Units of measurement for data on the distribution of NO_2 and CO (mol/m^2), which reflects the amount of the substance in the atmosphere per 1 m^2 of the Earth's surface. The molar fraction describes the average amount of methane per unit of dry air in the vertical column of the atmosphere [1]. The cartographic material was developed using the Arc Map Arc GIS 10x software (ESRI). The classification of geospatial data by individual greenhouse gases for the construction of maps was carried out similarly by dividing them into 5 classes ("Natural Boundaries" method). Transformation of raster models into

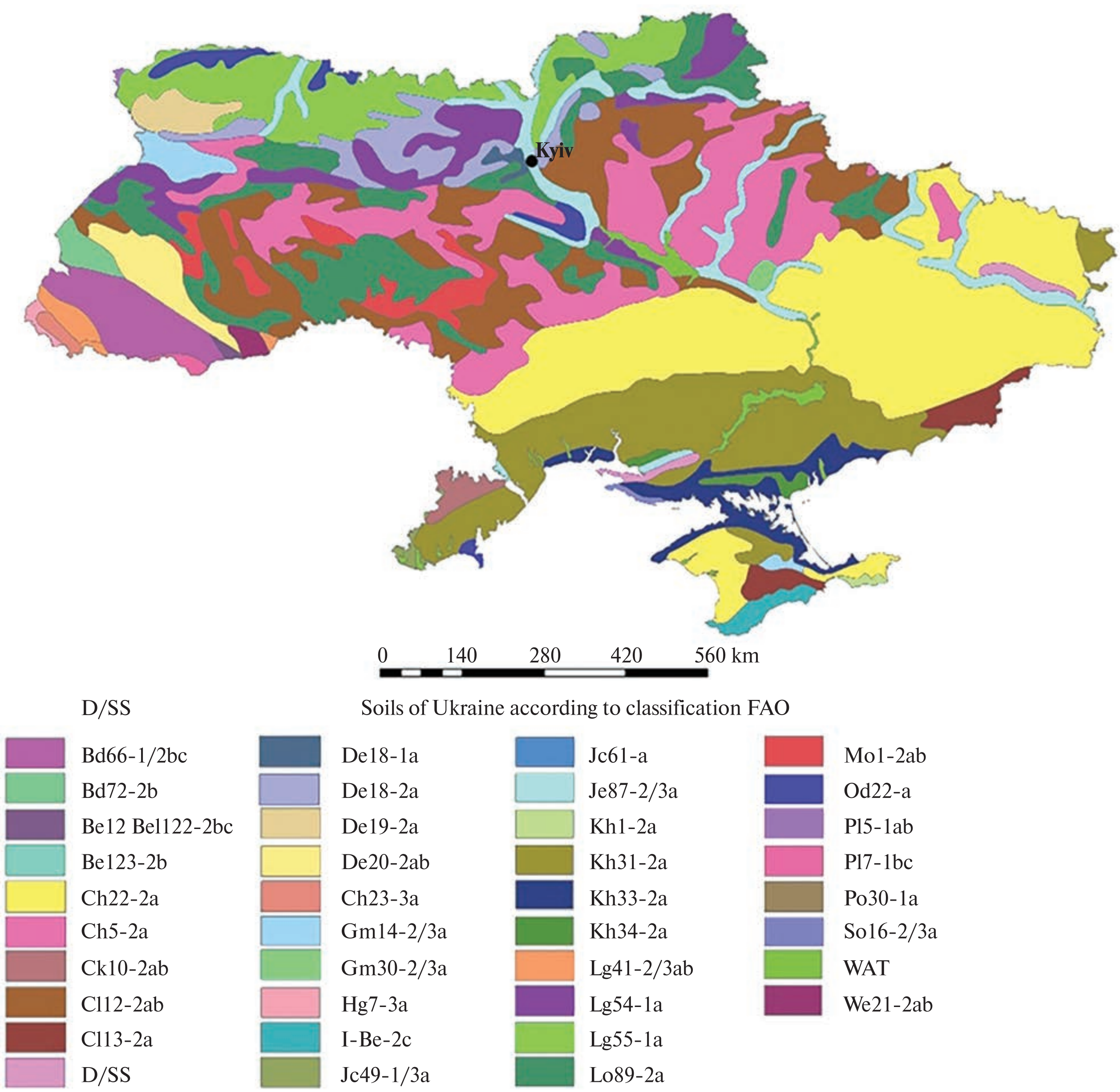

Figure 1. Map of soils of Ukraine

vector format was carried out using binary methods. Graphs were drawn up in the Microsoft Excel environment based on data obtained from GEE on average monthly values of gas concentrations.

RESEARCH RESULTS

To ensure the objectives of the research, a soil map of Ukraine according to the FAO classification [8] was used. The soil map of Ukraine contains 38 soil associations (Figure 1). Codes and names of soils by the FAO classification are given in Table 1.

The task of the research included conducting a geospatial analysis of the determination of greenhouse gas emission flows by soils and as a result of the influence of soil temperature, which required the development of appropriate cartograms. The cartogram

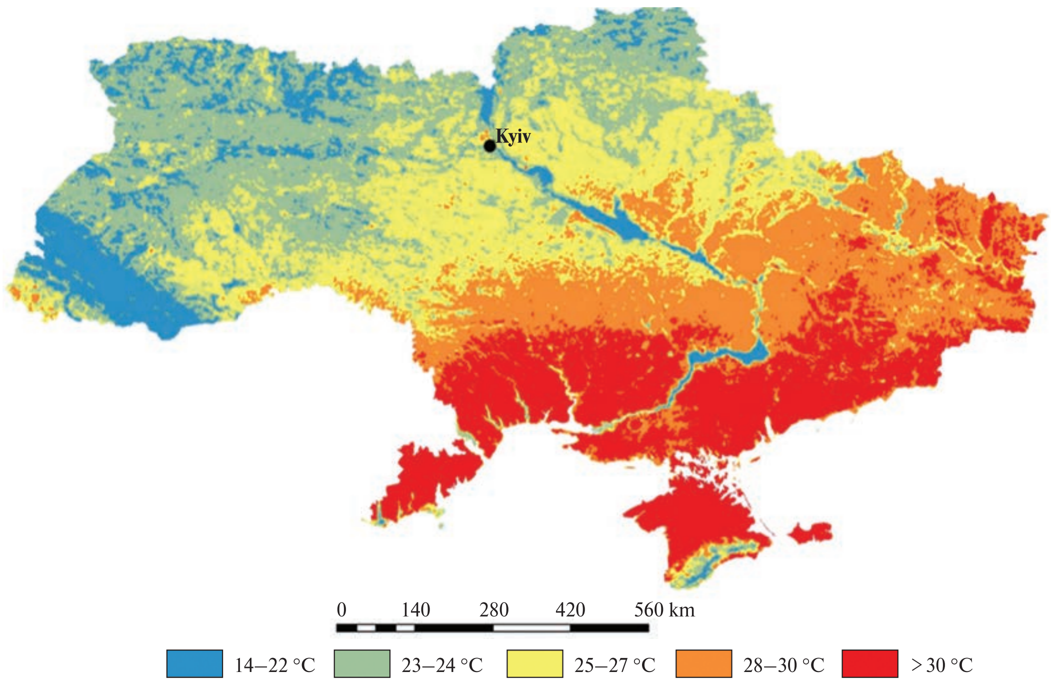

Figure 2. Map of the daytime land surface temperature within the warm period, 2019—2023, °C

Table 1. **Codes and names of soils in Ukraine according to FAO classification**

Bd	Dystric Cambisols	Hg	Gleyic Phaeozems	Od	Dystric Histosols
Be	Eutric Cambisols	L-Be Litho-sols	Lithosols-Eutric Cambisols	Pi	Leptic Podzols
Ch	Haplic Chernozems	Jc	Calcaric Fluvisols	Po	Orthic Podzols
Ck	Calcic	Je	Eutric Fluvisols	So	Orthic Solonetz
Cl	Luvic Cher-nozems	Kh	Haplic Kastano-zems	We	Eutric Planosols
De	Eutric Pod-zoluvisols	Lg	Gleyic Luvisols	D/ SS	Dunes and Shifting sands
Gh	Humic Gleysols	Lo	Orthic Luvisols	WAT	Inland Waters
Gm	Mollic Gleysols	Mo	Orthic Greyzems		

Figure 3. Fragments of query algorithms for constructing ▶ greenhouse gas concentration maps: *a* — request for NO_2-Code is written with the usage of source [17], *b* — request for COCode is written with the usage of source [16], *c* — request for CH_4Code is written with the usage of source [15]

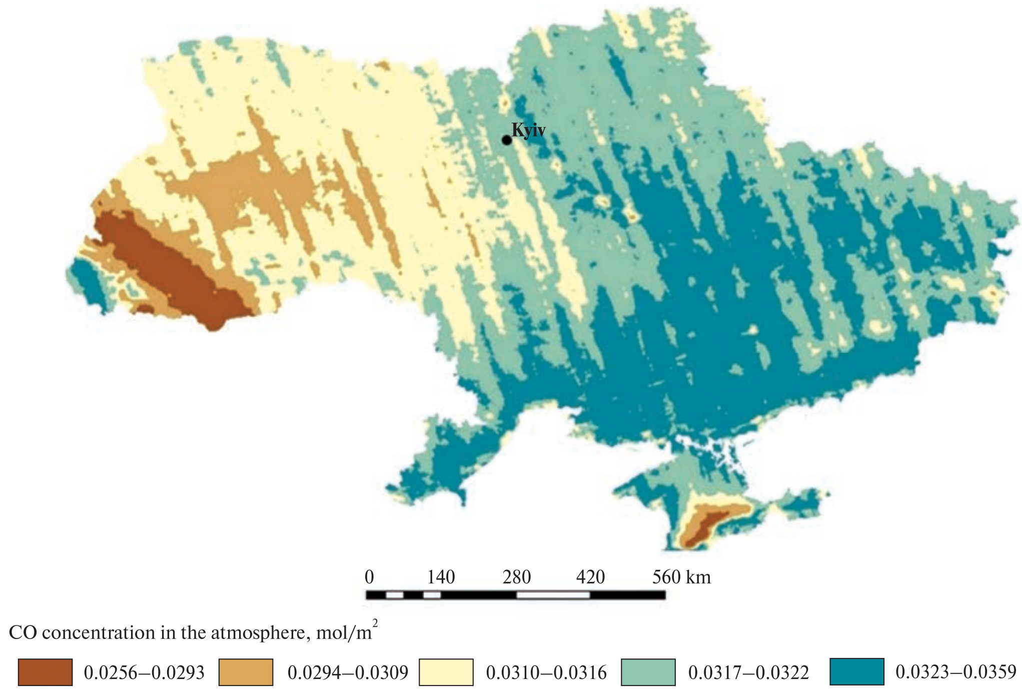

Figure 4. CO concentration cartogram, mol / m^2 within a warm period (2019—2023)

of the average annual daytime temperature of the Earth's surface was built using the MOD11A2.061 Terra resource, which is part of the NASA-ESA "Earth Observing System" (EOS) program. As known, it is equipped with a moderated spectroradiometer (MODIS), which provides recording of a large number of channels from visible to infrared spectra and allows obtaining data on day and night temperatures of the Earth's surface with a spatial resolution of 1 km.

Data on the average daily temperature of the Earth's surface for an 8-day period as of 10^{30} a.m. were used for research [11] (Figure 2). The maximum values of the temperature of the earth's surface are usual for the south and southeast of the country, the minimum values — for the Polissia zone of Ukraine, as well as the mountainous territories of the Carpathians and the Crimea (see Figure 2). Technical requests for data on the concentration of greenhouse gases according to the required terms and their statistical processing in terms of time intervals were performed on the basis of the GEE platform following the methodology in the JavaScript programming language. Examples of the algorithmization of requests for the construction of maps of the concentration of greenhouse gases based on the results of remote sensing are shown in Figure 3.

The cartogram of the CO concentration is shown in Figure 4. As you know, the value of carbon monoxide concentration mainly depends on the intensity of human activity, in particular man-made emissions of industrial enterprises, the burning of fossil fuels by vehicles, as well as the intensity of its deposition in soils (see Figure 4). Determining factors in the formation of the CO emission pool are the presence of large cities with population concentration and the significant, compared to other regions, density of production in the central-eastern and eastern regions of Ukraine (see Figure 2). However, over the past 3 years, a clear trend of decreasing CO concentration has emerged, which indicates a decrease in industrial production and the relocation of production facilities to the west of the country (Figure 5). The military aggression of the Russian Federation is an additional disincentive to the transfer of production facilities. The specially marked trend is prominently noticed when comparing the concentration values for the period April-June 2019 with the corresponding periods

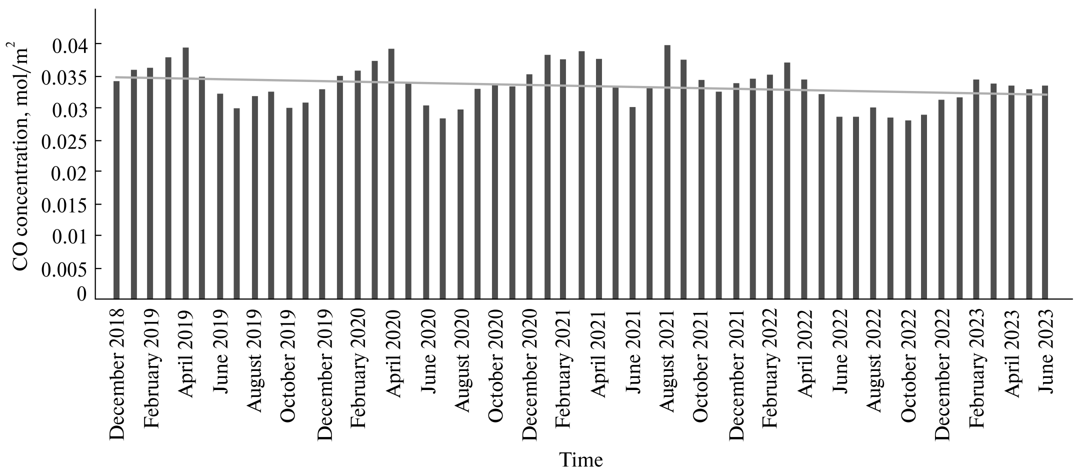

Figure 5. CO concentration dynamics in the atmosphere during the period (12.2018—06.2023)

of 2020, 2021, and 2022, which is confirmed by the negative trend line (see Figure 5).

The situation with geospatial differentiation in the methane atmosphere is naturally different. The map of the average annual concentration of methane in atmospheric air is presented in Figure 6. The highest values of CH_4 concentration are associated with the compact formation of floodplain soils with signs of hydromorphism in the channels of large rivers (Jc49-1/3a — Calcaric Fluvisols / Carbonate Fluvisols, Lg54-1a — Gleyic Luvisols / Clay Luvisols). In the south of Ukraine, saline soils with close groundwater and signs of waterlogging are common (Kh31-2a — Haplic Kastanozems, Gh23-3a — Humic Gleysols). The formation of a high emission pool of methane on the specified soils is due to the course of organic matter decomposition processes in them, which continue in anaerobic conditions. The functioning of soils in conditions of long-term moistening can lead to the formation and emission of CH_4 into the atmosphere. At the same time, the lowest values of methane concentration are confined to water bodies, mountainous areas, and coastal areas with poor soils, in particular Kh33-2a / normal chestnut soils — chestnut saline soils in a complex with salt marshes (Ukrainian classification) and intensive movement of air masses. The CH_4 concentration dynamics within the studied period were presented in Figure 7.

A rapid increase in the concentration of CH_4 in the atmosphere is observed, as evidenced by the corresponding trend. Taking into account the above and the decrease in the intensity of industrial production, it should be stated that the main sources forming the emission pool of CH_4 are soil and agricultural production. In this aspect, deterioration of the hydrological regime of soils, in particular as a result of a decrease in the level of groundwater, leads to an increase in methane emissions. Such a decrease occurs as a result of the increase in atmospheric temperature and the general dehydration of soil and land resources in the northern hemisphere, which has been observed in recent years. In the case of a decrease in the level of groundwater and the arrival of additional oxygen from the air, the decomposition of organic residues intensifies, and the emission of CH_4 and other biogenic gases, including NO_2, increases.

The map of nitrogen dioxide concentration is presented in Figure 8. These cartograms allow us to conclude that the maximum values of NO_2 concentration are confined to large cities with a significant density of industrial production, as well as areas with long-term intensive mechanical impact on soils with a high content of organic matter (eastern Ukraine). According to the soil map, soil associations Ch22-2a / normal chernozems / ordinary chernozems with medium humus accumulation (Ukrainian classification) are common within the specified territories. The determined impact is a consequence of the large-scale movement of vehicles against the background of high temperatures of the Earth's surface,

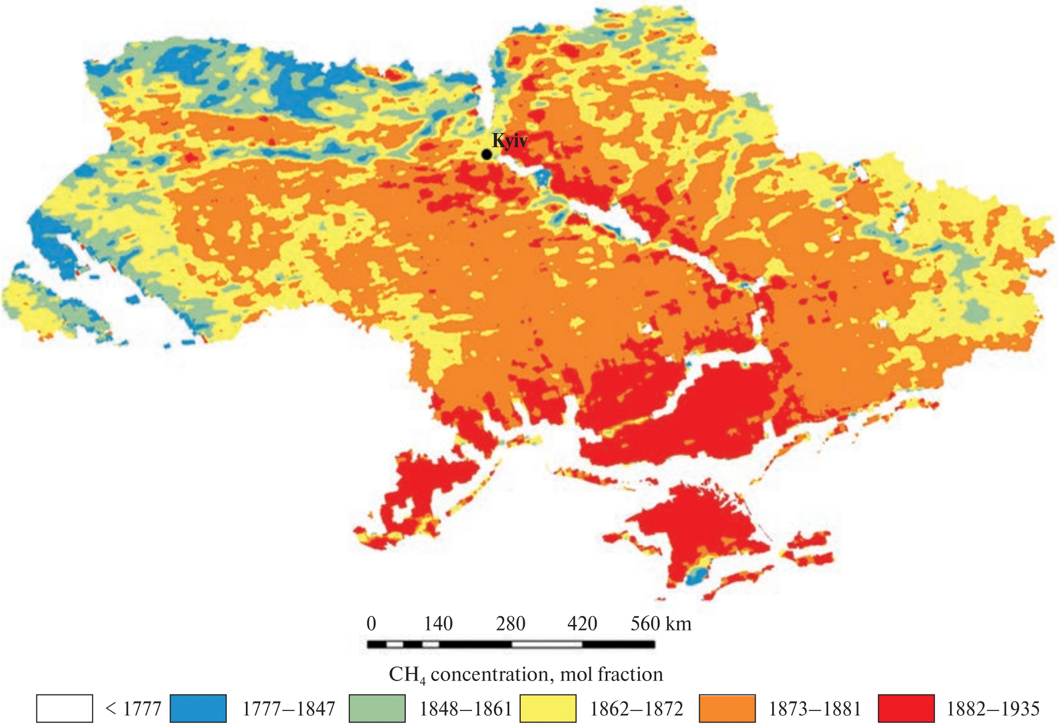

Figure 6. Map of the average annual methane concentration within the warm period (2019—2022)

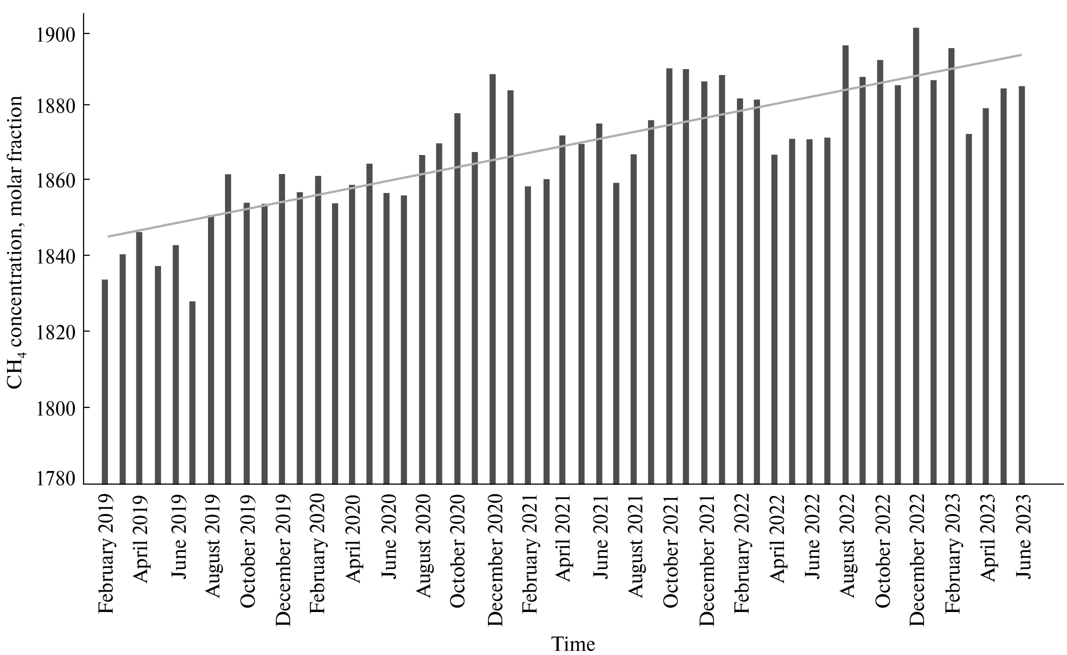

Figure 7. Dynamics of methane concentration in the atmosphere (02.2019—07.2023)

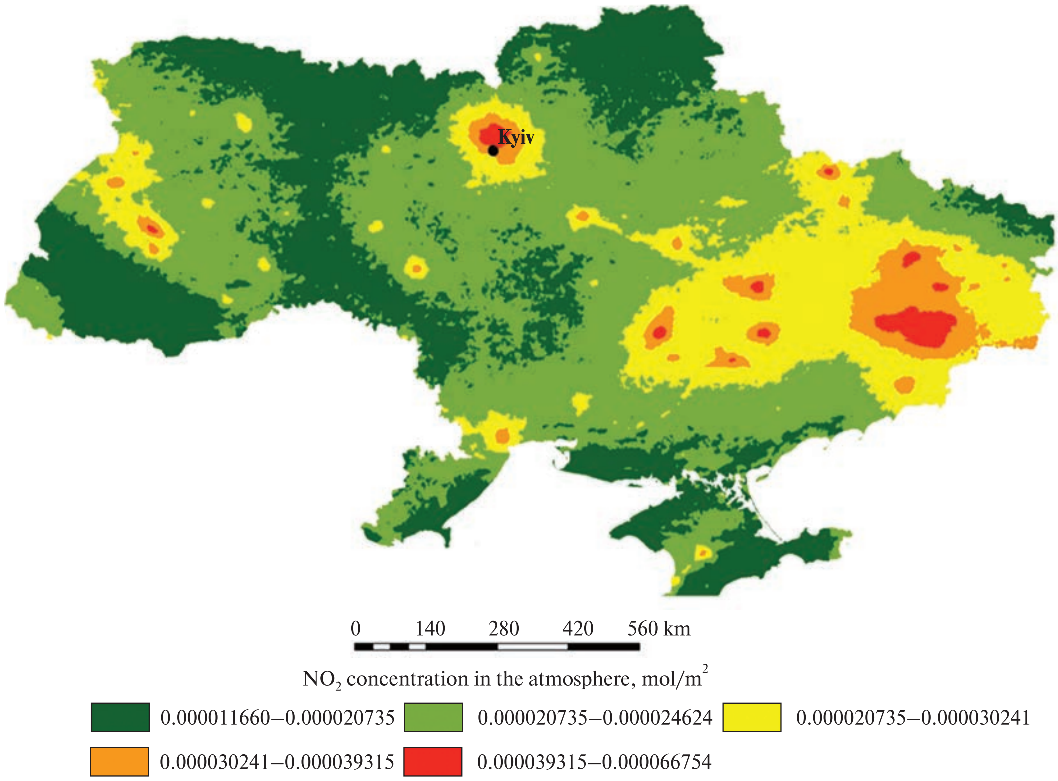

Figure 8. Cartogram of the average annual concentration of nitrogen dioxide within the warm period (2019—2022)

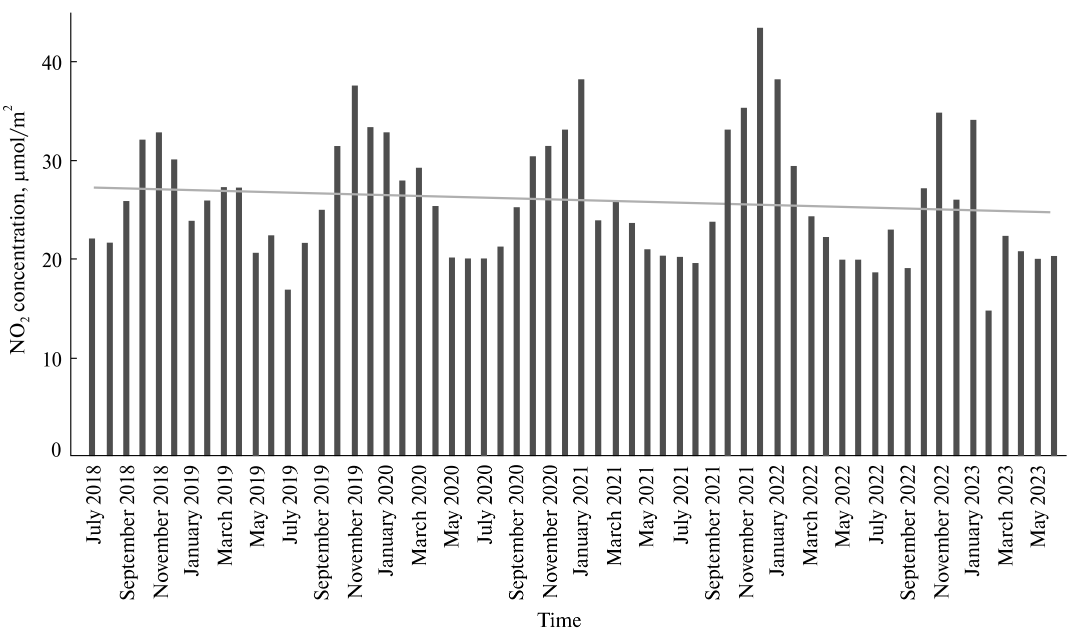

Figure 9. NO_2 dynamics concentration in the atmosphere (07.2018—05.2023)

for example, in the case of intense hostilities, which are known to have been ongoing on the territory of Ukraine since February 2022 (see Figure 8). The dynamics of the concentration of nitrogen dioxide shown in Figure 9 determines the negative trend in the formation of its volumes in the studied territory. However, it does not fully reflect the conditions of formation of the NO_2 pool from soils and landscapes. It should be noted that a significant part of NO_2 emissions is also formed due to anthropogenic influence, which is a well-known fact. The graph data testify to the course of two mutually opposite processes in the soil: the strengthening of NO_2 emission with an increase in concentration in the cold period (January 2019, 2020, and 2022), due to a warm winter and intensive decomposition of organic matter (I), and a slowdown in emission and a decrease in concentration in the beginning of the warm period (May) (2019, 2020, 2021, and 2022) (II). The specified features of the formation of emission flows of gases are the result of a global increase in the temperature of the earth's surface against the background of a lack of moisture in the soil, which caused a slowdown in NO_2 emissions in the warm period.

Table 2. **The weighted average values of gas concentrations and coefficients of variation CV over the study period**

Year	NO_2, 10^{-5} mol/m^2	CO, mol/m^2	CH_4, molar fraction
2019	2.28483	0.031853635	1845.667224
2020	2.27446	0.031532057	1864.914416
2021	2.28131	0.034693848	1872.515200
2022	2.11986	0.029348408	1881.296439
CV, %	3.58	6.89	0.81

Table 3. **Correlation coefficients between greenhouse gas concentration values and the land surface temperature**

Year	NO_2	CO	CH_4
2019	–0.78	0.24	–0.42
2020	–0.76	–0.81	–0.74
2021	–0.95	–0.13	–0.93
2022	–0.55	0.33	–0.52
2019—2022	–0.72	–0.16	–0.41*

Note. * minimally significant coefficient $r_{min} = 0.41$.

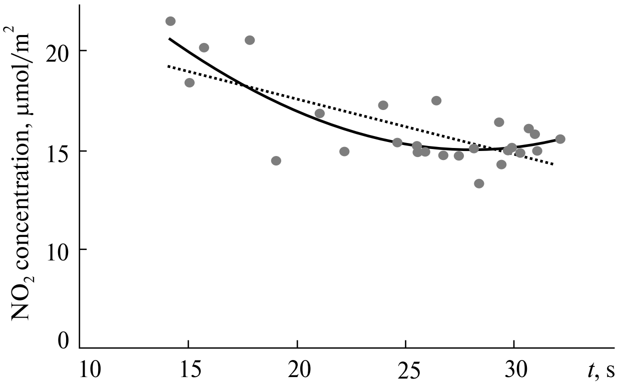

Figure 10. Graph of dependence between NO_2 concentration and daily land surface temperature (05.2019—06.2023)

The weighted average values of gas concentrations and coefficients of variation are given in Table 2.

The values of the coefficients of variation in the distribution of gas concentrations by year are determined by the influence of various factors, in particular: weather fluctuations within natural and climatic zones; the intensity of industrial production and the functioning of urban landscapes; mechanical impact on soils; reduction of the area of forests and forest plantations as a result of military operations; disruption of the structure of cultivated areas of agricultural crops. The relatively high variability over the years and the decrease in CO emissions are caused, as noted, by the relocation of production facilities to the west of the country, which lasted until the middle of 2023 and continues to this day (see Figure 5).

The results of the analysis of the link between the concentration of greenhouse gases and the temperature of the earth's surface within the territory of Ukraine are shown in Table 3.

The negative values of the correlation coefficients between the values of the concentration of biogenic greenhouse gases in the atmosphere, primarily CH_4 and NO_2, and the daytime temperature of the earth's surface within the warm period indicate a general tendency of a short-term slowdown of emission flows from soils during discrete measurement of the concentration (at 1030). High values of soil temperature and a decrease in the amount of precipitation lead to a general decrease in the moisture supply of agricultural land, which causes a slowdown in the emission

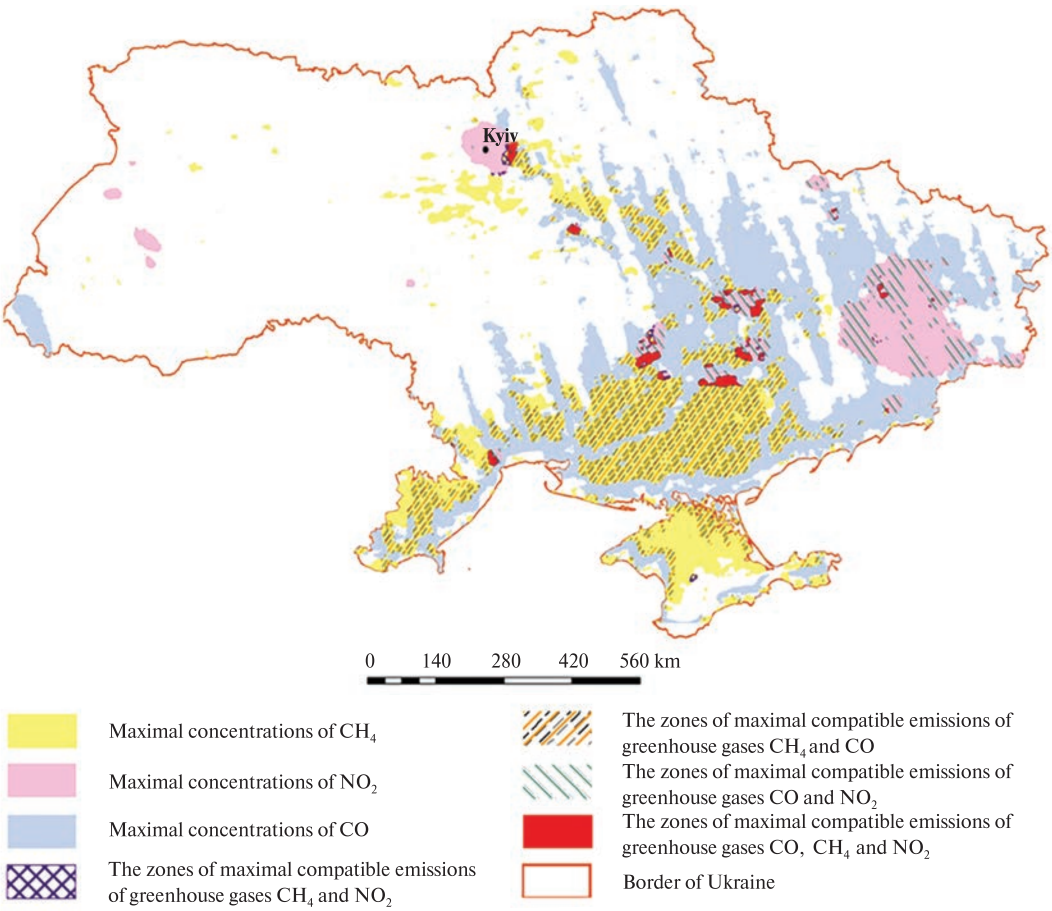

Figure 11. Map of the geospatial localization of the maximum concentrations of greenhouse gases in the warm period of 2019—2022 in the atmosphere based on the results of their emission from soils, landscapes, production facilities, and combat zones

of most greenhouse gases. The nature of the relationship between the NO_2 concentration and the temperature of the Earth's surface during the warm period is shown in Figure 10. The intensity of nitrogen dioxide emission reaches maximum values in the temperature range from 13 to 19 °C, which is optimal. In the case of exceeding the soil temperature limit of 20 °C, the volume of emissions decreases significantly (see Figure 10). Therefore, excessively high values of the temperature of the earth's surface (soil) significantly limit the concentration of NO_2 in the atmosphere. The identified regularity indirectly indicates that the volumes of NO_2 emissions from soils and landscapes may exceed the volumes of its entry into the atmosphere due to man-made emissions and are mainly of biogenic origin.

The research program provided for the development of a map of the geospatial distribution of the areas of maximum concentrations of greenhouse gases within the warm period of years. Binary methods and topological overlay methods were used for this task, in particular, their most suitable types, namely intersect and union, which made it possible to obtain a highly informative cartogram (Figure 11). There is a clear territorial determination of the highest values of the concentration of greenhouse gases in two or three of them. Large areas of agricultural landscapes and traditionally dense placement of industrial production lead to significant volumes of emissions of gases of anthropogenic origin, including agrogenic. An additional determining factor for the increase in NO_2 and CO emissions is the military aggression of the Russian Federation on the territory of Ukraine, the consequences of which form a tangible emission pool of greenhouse gases entering the atmosphere from man-made sources.

Therefore, the most emission-significant are the southern and southeastern territories of Ukraine with a powerful soil and resource potential, a significant share of industrial, energy, and other facilities, and favorable temperature conditions for the course of greenhouse gas emissions from the soil. The rest of the territory of Ukraine has a less significant potential for greenhouse gas emissions. However, throughout the territory, there are lands, soils, and water bodies that provide chemical and biological binding of carbon gas compounds (decarbonization of the atmosphere) and nitrogen gas compounds (nitrogen fixation).

CONCLUSIONS AND PERSPECTIVES OF FURTHER RESEARCH

The methodology for remote determination of the concentration of greenhouse gases in the atmosphere using the Copernicus Program — Sentinel-5P satellite system and the MOD11A2.061 Terra resource was improved, which provided for the following: remote determination of the concentration of greenhouse gases CH_4, CO, and NO_2, development of maps of the geospatial distribution of the determined concentration; carrying out a cartographic and analytical assessment of the formation of the pool of greenhouse gases, taking into account the data on the soil cover of Ukraine, the temperature regime of the territory and technogenic influences due to the high-intensity military conflict.

A set of cartograms of the geospatial distribution of the concentration of greenhouse gases CH_4, CO, and NO_2, and the temperature of the earth's surface during the warm period (01.05—30.10) during 2019—2022 has been developed. The map of the geospatial localization of the maximum concentrations of greenhouse gases within the warm period of 2019—2022 contains data on zones of increased emission danger, which require the state to strengthen control over the volumes of gas inflows into the atmosphere.

It was established that for the warm period of the year on average for 2019—2022, the optimal temperature range, within which the intensity of nitrogen dioxide emission on the territory of Ukraine reaches maximum values, is from 13 to 19 °C. If the temperature of the earth's surface exceeds the value of 20 °C, the volume of emission emissions decreases significantly. A promising direction of research is the development of algorithms that automate calculations of greenhouse gas emission and sequestration volumes on agricultural land in absolute units, in particular, $kg/m^2/s$ and kg/ha/h.

In the future, it is expedient to use the obtained data to substantiate the deficit-free balance of carbon and nitrogen in soils in agricultural production and to minimize the negative effect of the greenhouse effect.

So, it should be stated that in Ukraine, there is a localized distribution of soils with different emission and evaluation status. It is obvious that soils should be evaluated in the context of two components: as a means of production of agricultural products (I) and as an important component of the biosphere, which ensures the emission and binding of greenhouse gases (II). A fairly important direction of improvement of land evaluation works can be the separate evaluation of soils according to the above-mentioned principle. At the same time, it should be understood that the specified feature should be taken into account already at the stage of land evaluation zoning of the territory.

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ВИЗНАЧЕННЯ КОНЦЕНТРАЦІЇ ПАРНИКОВИХ ГАЗІВ В АТМОСФЕРІ ЗАСОБАМИ ДИСТАНЦІЙНОГО ЗОНДУВАННЯ ЗЕМЛІ. КАРТОГРАФО-АНАЛІТИЧНА ОЦІНКА ГЕОПРОСТОРОВОГО ПОШИРЕННЯ ЇЇ ЗНАЧЕНЬ

В даній статті висвітлено питання удосконалення методології дистанційного визначення концентрації парникових газів в атмосфері з використанням супутникових систем Copernicus Programme — Sentinel-5P й MOD11A2.061 Terra, а також картографо-аналітичну оцінку її геопросторового поширення. Означена методологія передбачала: дистанційне визначення концентрації парникових газів CH_4, CO та NO_2, розроблення картограм поширення визначеної концентрації на території України, локалізацію ареалів формування інтенсивності емісії та секвестрації парникових газів з урахуванням даних про ґрунтовий покрив, абіотичних умов території та антропогенних впливів, зокрема військової діяльності.

Розроблено комплекс картограм геопросторового поширення значень концентрації парникових газів CH_4, CO та NO_2, температури земної поверхні в межах теплого періоду (01.05—30.10) протягом 2019—2022 рр., а також картограму геопросторової локалізації максимальних концентрацій парникових газів у межах теплого періоду часового інтервалу досліджень за результатами емісії з ґрунтів, ландшафтів, об'єктів виробництва та зон бойових дій.

Встановлено, що для теплого періоду року, у середньому за 2019—2022 рр., оптимальний температурний діапазон в межах якого інтенсивність емісії двоокису азоту на території України набуває максимальних значень становить від 13 до 19 °C. У випадку перевищення температури земної поверхні значення 20 °C, обсяги емісійних викидів істотно зменшуються.

Показано, що на території Україні в межах теплого періоду поширено ґрунти з різним емісійно-оціночним статусом. На Півдні та Південному Заході держави переважають ґрунти з найвищою емісійною здатністю метану до атмосфери, зокрема Jc49-1/3a — Calcaric Fluvisols, Lg54-1a — Gleyic Luvisols, Kh31-2a — Haplic Kastanozems, Gh23-3a — Humic Gleysols.

У великих містах, а також на територіях Південного Сходу України, де поширено нормальні чорноземи (Ch22-2a) / (чорноземи звичайні), формується максимальна концентрація NO_2 у атмосфері, яка зумовлена впливом високої температури земної поверхні та локалізованими наслідками військової агресії росії.

Виявлено, що за останні чотири роки намітилися тенденція зниження концентрації CO, що опосередковано свідчить про негативний вплив воєнної агресії росії, зниження промислового виробництва та релокацією виробничих потужностей на захід держави.

***Ключові слова**:* ДЗЗ, парникові гази, ґрунти, емісія, секвестрація, ландшафти, картографо-аналітична оцінка.