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# ASSESSMENT OF FOREST VEGETATION POTENTIAL OF RECLAIMED AREAS AFTER ILMENITE MINING USING THE REMOTE EARTH SENSING METHOD

**Olha Shomko , Iryna Davydova** ✉

*Zhytomyr Polytechnic State University,*
*103, Chudnivska Str., Zhytomyr, 10005, Ukraine*
*div@ztu.edu.ua*

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**Abstract.** The mining of ilmenite has irreversible negative environmental impacts on the ecosystem of the area where mining companies operate. First of all, it leads to disturbance of the soil and vegetation layer, changes in the natural landscape, formation of depression sinkholes, which causes changes in water flow and water distribution in the mining area, lowering of groundwater levels, pollution of the atmosphere, soil and water bodies, and loss of species diversity of flora and fauna. In general, the mining process lasts for decades, during which time the territory is subject to irreversible changes and disturbances and requires high-quality restoration after the completion of ilmenite mining. The article suggests a methodology for assessing the forest vegetation potential of soils in areas disturbed by ilmenite mining using remote earth sensing (RES). Based on satellite images and spectral characteristics, we determined the parameters of soil type and moisture, as well as the vegetation and moisture index of the forest vegetation layer The results of the remote earth sensing were compared with the results of laboratory analyzes of soil samples from the territory operated by the branch of the Irshansk Mining and Processing Plant of PJSC UMCC. Normalized Difference Vegetation Index, Normalized Difference Moisture Index, soil type and moisture were calculated and identified using QGIS software from data obtained from free-access satellite images. The results showed that a combination of laboratory and remote sensing methods can be quite effective for studying areas disturbed by mining activities and the state of their recovery after reclamation.

**Keywords:** RES, soil type, moisture, NDVI, NDMI.

## 1. Introduction

Reclamation of territories after mining activities is of great importance for restoring the balance of ecological systems. At present, there is a problem of environmental restoration in the mining sites, especially in the area of soil reclamation and vegetation restoration (Shao et al., 2023). The main goal of reforestation of the research plots is to return the areas to a productive capacity to interact with the ecosystem, which will function to provide a variety of economic and environmental values (Macdonald et al., 2015).

Given the state of the war in Ukraine, mastering the methods of remote sensing of various territories and objects, the ability to monitor the state of the environment and analyze the impact of important factors on individual ecosystems from a distance, is extremely relevant. The aggression of the Russian Federation has made irreparable alterations to the development of scientific research of the territories of Ukraine. Large-scale destruction, ruined cities, agricultural fields, protected territories and large productive areas of Ukraine in general, landmined forests and fertile lands – these terrible consequences make it impossible to conduct quality field research and monitoring of the territories (Dmytruk, 2023).

The analysis of the effectiveness of remote earth sensing methods will allow to improve the quality of methods for restoring disturbed areas in the future, including assessment of the state of ecosystems before conducting field studies, and predicting the possibility of using various methods of reclamation and restoration of territories, which will be a crucial stage in the development and reconstruction of the territories of Ukraine (Furdychko et al., 2019).

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The purpose of the article is to study the forest vegetation potential of soils of areas disturbed by mining activities using of the remote earth sensing method.

## 2. Experimental part

For this study, we have chosen the operating territory of the branch of the Irshansk Mining and Processing Plant of PJSC UMCC near the villages of Irshansk, Lisivshchyna and Desiatyny, Korosten district, Zhytomyr region. The moisture content and particle size distribution of soils in the reclaimed areas of ilmenite mining were studied using the following methods (Shomko, Davydova, 2022):

1. Cluster sampling by the envelope method according to State Standards of Ukraine DSTU 4287:2004 and DSTU ISO 10381-2:2004.
2. Measurement of soil moisture by weight method in accordance with DSTU Б В.2.1-17:2009.
3. Determination of particle size distribution by the wet method.
4. Determination of particle size distribution by the sieve method.

The source of satellite images of the study area was Landsat 8 (Roy, 2016) from the USGS platform. They have several ranges depending on the wavelength (blue, green, red, infrared, thermal, and panchromatic). Panchromatic range is used to increase data resolution. Landsat 8 data has 11 bands, only three (Red, NIR, SWIR) are used for NDVI and NDMI analysis. The Landsat 8 data bands, wavelengths and their resolution are shown in Table 1.

*Table 1*

**Landsat 8 data bands by resolution and wavelength**

| Landsat-8 OLI and TIRS Band (μm) | | |
|---|---|---|
| Band 1 | 30 m Coastal/Aerosol | 0.435–0.451 |
| Band 2 | 30 m Blue | 0.452–0.512 |
| Band 3 | 30 m Green | 0.533–0.590 |
| Band 4 | 30 m Red | 0.636–0.673 |
| Band 5 | 30 m NIR | 0.851–0.879 |
| Band 6 | 30 m SWIR-1 | 1.566–1.651 |
| Band 7 | 30 m SWIR-2 | 2.107–2.294 |
| Band 8 | 15 m Pan | 0.503–0.676 |
| Band 9 | 30 m Cirrus | 1.363–1.384 |
| Band 10 | 100 m TIR-1 | 10.60–11.19 |
| Band 11 | 100 m TIR-2 | 11.50–12.51 |

Normalized Difference Vegetation Index (NDVI) is a simple quantitative indicator that reflects the amount of photosynthetically active biomass, determining the level of green vegetation. The use of NDVI is widely applied for regional mapping and analysis of various landscapes, assessment of resources and areas of biosystems. Typically, the calculation of NDVI requires a series of multi-temporal images, which allows obtaining a dynamic picture of the processes of changing boundaries and characteristics of different vegetation types, such as monthly, seasonal and annual variations. One of the advantages of the NDVI is the clear color gradation of the index and the availability of this tool for free use. NDVI is calculated by the formula (1) (Kshetri, 2018):

$$\text{NDVI} = \frac{NIR - Red}{NIR + Red}, \quad (1)$$

where *NIR* is the Near-Infrared (band 5); *RED* is the Red Light (band 4).

Normalized Difference Moisture Index (NDMI) is a commonly used indicator of water stress in plants, as it reflects the moisture level of the vegetation. It is used to determine the moisture content of vegetation and is calculated as the ratio between the values in the near infrared (NIR) and shortwave infrared (SWIR) ranges. The formula for NDMI is as follows (2) (Lastovicka, 2020):

$$\text{NDMI} = \frac{NIR - SWIR}{NIR + SWIR}, \quad (2)$$

where *NIR* is the Near-Infrared (band 5); *SWIR* is the Short-Wavelength Infrared (band 6).

The soil type of the study areas was identified in the QGIS 3.28 Firenze program based on the FAO Digital Soil Map of the World (DSMW), as recommended by the International Union of Soil Scientists (IUSS). The vector dataset is based on the FAO-UNESCO Soil Map of the World. The digitized world soil map at a scale of 1:5,000,000 in geographic projection (latitude-longitude) intersects with a template containing water-related objects (coastlines, lakes, glaciers, and rivers with a double line). The digital map of the world soils (excluding the African continent) was overlaid on a map of country boundaries from the World Data Bank II (with country boundaries updated to January 1994 at a scale of 1:3,000,000) obtained from the US government (FAO).

Soil moisture in the study area was determined in QGIS software using the JAXA Earth API plug-in (Sobue et al.) The JAXA Earth API software component is designed to provide various types of data from JAXA Earth observation satellites in a user-friendly format that facilitates efficient and rational use. One of the important features of the API is its integration with QGIS, popular free GIS software. The API includes an interface function that allows users to directly receive and display satellite data in QGIS.

## 3. Results and Discussion

According to the results of the study of the territory using remote earth sensing method, 2 types of soils were identified within the Korosten district by the classification of World Reference Base (WRB): Podzoluisols eutriques (De) та Luvisols gleyiques (Lg) (Fig. 1).

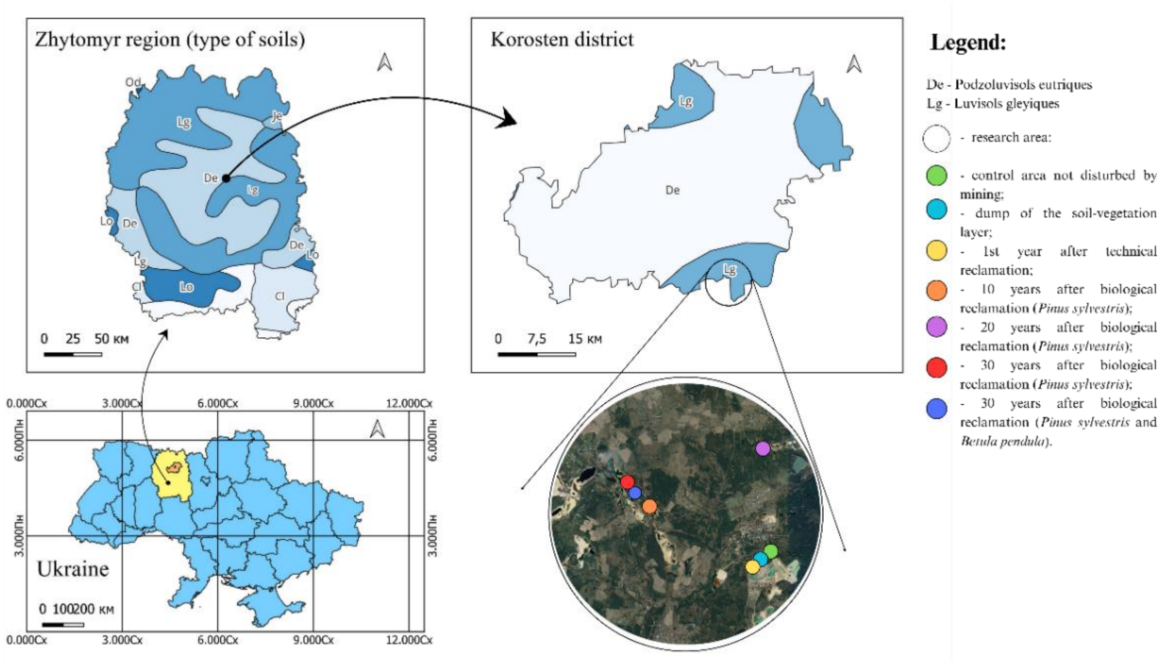


**Fig. 1.** Soil cover of the study area according to the World Reference Base for Soil Resources (WRB) classification

According to the description of the reference groups, the WRB classification (2014), luvisols are soils that have a higher clay content in the subsoil compared to the topsoil as a result of pedogenesis processes (especially clay migration) that led to the formation of the argic subsoil horizon (Ivanuk, 2017). Gleyic Luvisols and Albic Luvisols of the WRB classification according to the Canadian soil classification (Lavkulich et al, 2011; The Canadian system) correspond to Gray Luvisols.

In publications devoted to the study of gray forest soils in Ukraine, authors use different nomenclature (Pankiv, 2017). Taking into account the hypotheses of the origin of gray forest soils and their properties, the names of these soils are quite reasonable: light gray forest, gray forest, dark gray podzolic soil. The following approximate equivalents of the WRB (2014) nomenclature were proposed for the subtypes of gray forest soils of the Ukrainian classification: light gray forest – Albic Luvisols, gray forest – Haplic Luvisols, dark gray podzolic – Luvic Greyzemic Phaeozems. The names of the gleyed analogs of these soils are preceded by the qualifier “Gleyic” (Ivanuk, 2017).

Given that the study area is located in the Zhytomyr Polissia region, which is known for its wetlands and forests, soils with gley properties are not uncommon in this region. The combination of luvisols and gley features (Luvisols gleyiques) indicates that these soils can have characteristics of both well-drained and poorly drained soils, reflecting the diversity of natural conditions found in Polissia (Pankiv, 2017; Ivanuk, 2017).

The soil moisture of the study area was identified in August 2021, during the period of sampling and soil moisture research by the laboratory method (Fig. 2). JAXA publishes data on soil moisture content around the earth's surface, etc., observed by the Global Change Observation Mission – Water “SHIZUKU” (GCOM-W). The data shows the state of preservation of moisture that has fallen as rain or the state of drying of the soil.

According to the results of this identification, the soil moisture content of the research area ranged from 7.88 % to 8.26 % during August 2021. The comparative characteristics of soil type and moisture content in the study area using the two research methods are shown in Table 2.

Thus, the common aspect of the two methods is the confirmation of the presence of Luvisols gleyiques (Lg) in the tested soils and the coincidence in the moisture content of the reclaimed areas. The measured soil moisture has close average values according to the remote sensing data and laboratory studies (8.07 % and 8.51 %, respectively).

The difference is that laboratory tests allow for more detailed results, including the identification of specific types of sand and sandy loam, and also indicate the moisture dynamics for different samples of the study area. Given the impact of mining activities in the study area, the difference in soil types between those identified by RES method and laboratory tests is understandable. This is because the digitized map of soil types had been created for 20 years using the outdated WRB database at a time when ilmenite mining activities in the Korosten district were just beginning to develop. Therefore, it is necessary to improve the identification of soil types by RES method using a modern database, which will be investigated in the process of studying the forest vegetation potential of soils of reclaimed areas after ilmenite mining.

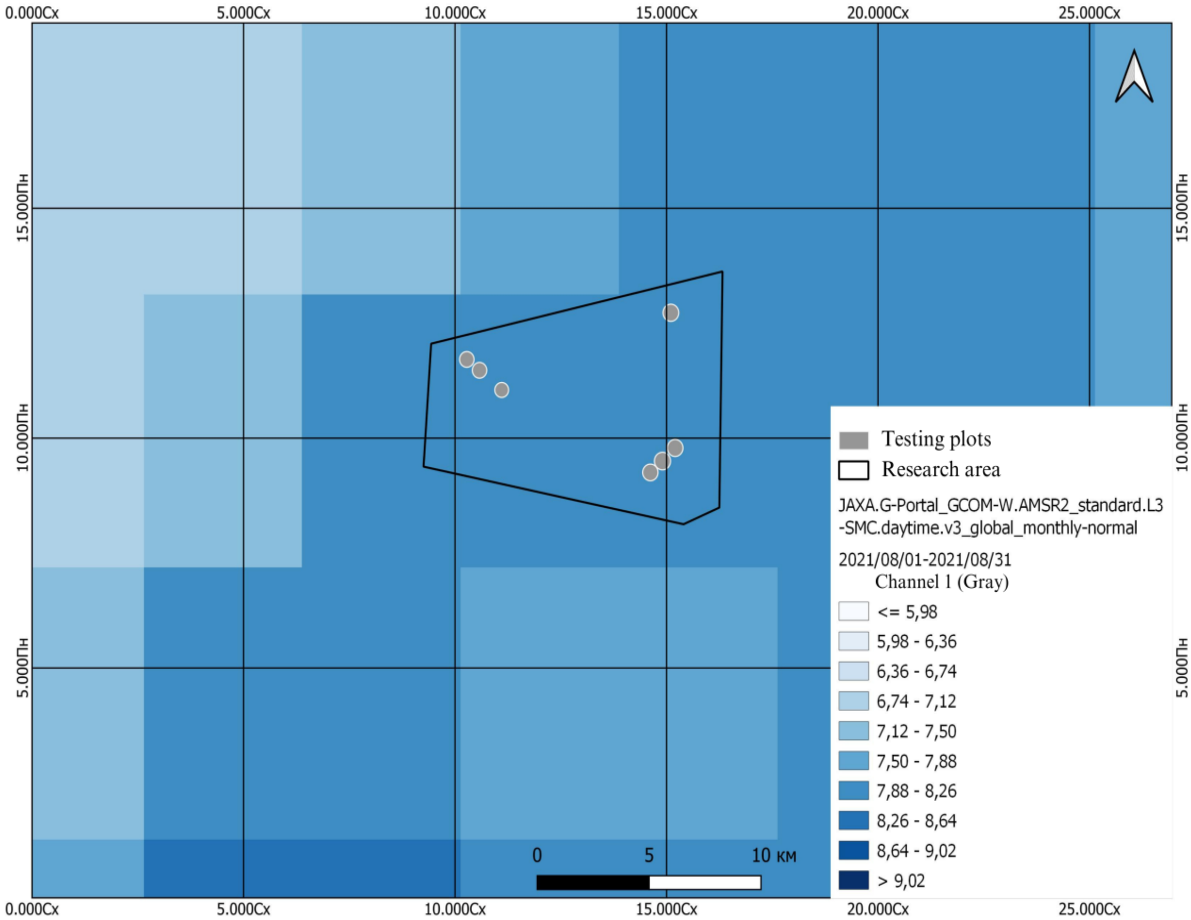


**Fig. 2.** Soil moisture content of the study area according to the JAXA Earth API software component

*Table 2*

**Characterization of reclaimed areas after ilmenite mining based on remote earth sensing and laboratory studies**

| Number | Reclamated areas | Remote sensing data | | Laboratory testing of soil samples | |
|---|---|---|---|---|---|
| | | Soil type | Moisture content, % | Soil type | Moisture content, % |
| 1 | Control plot | Luvisols gleyiques (Lg) | 7.88–8.26 | Sandy-loamy sandy (heavy sands) | 5 |
| 2 | Dump of the soil and vegetation layer | Luvisols gleyiques (Lg) | 7.88–8.26 | Silty-loamy sandy (light loamy sands) | 5 |
| 3 | 1-st year after technical reclamation | Luvisols gleyiques (Lg) | 7.88–8.26 | Sandy-loamy sandy (light loamy sands) | 11 |
| 4 | 10 years after biological reclamation (*Pinus sylvestris*) | Luvisols gleyiques (Lg) | 7.88–8.26 | Silty-loamy sandy (sands) | 5 |
| 5 | 20 years after biological reclamation (*Pinus sylvestris*) | Luvisols gleyiques (Lg) | 7.88–8.26 | Sandy-loamy sandy (light clay loam) | 5 |
| 6 | 30 years after biological reclamation (*Pinus sylvestris*) | Luvisols gleyiques (Lg) | 7.88–8.26 | Sandy-loamy sandy (sands) | 11 |
| 7 | 30 years after biological reclamation (*Pinus sylvestris* and *Betula pendula*) | Luvisols gleyiques (Lg) | 7.88–8.26 | Silty-loamy sandy (sands) | 17.6 |

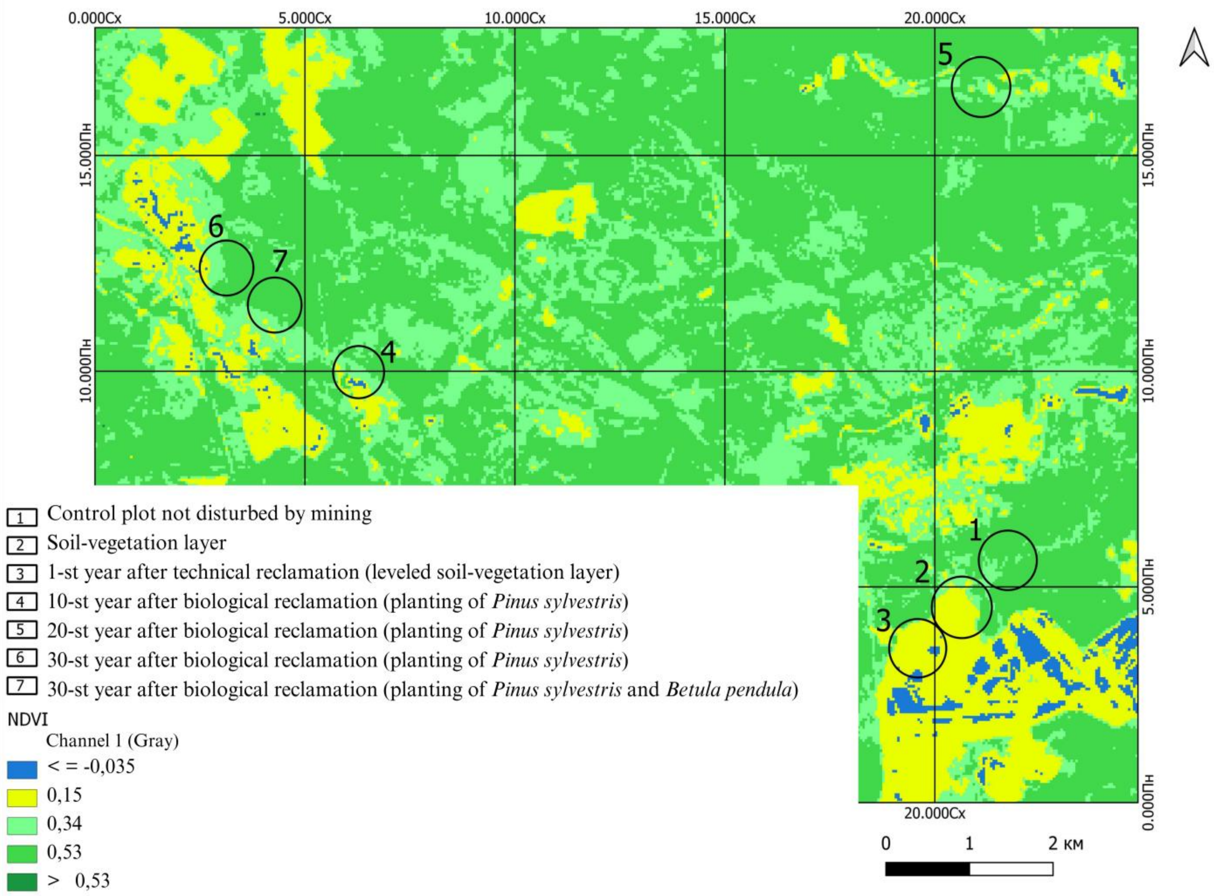


**Fig. 3.** Normalized Difference Vegetati

NDVI and NDMI are important indicators of the development of the forest vegetation layer of reclaimed areas, and the results of these indices of the research area are shown in Figs. 3 and 4, respectively.

The NDVI value can range from -1 to +1. A value close to +1 indicates a high activity of the forest vegetation layer, where open green vegetation reflects light well in the infrared and red spectrum. A value close to -1 may indicate water bodies or other non-vegetated areas where light is poorly reflected in the infrared spectrum. A value around 0 may indicate that there is no vegetation or that the plants are not showing vegetative activity. Thus, the most greened areas according to Landsat 8 satellite images in August 2021 were the control plot and the areas 20 and 30 years after biological reclamation. Typically, an NDVI value of 0.2 to 0.5 indicates the presence of scattered or sparse vegetation.

NDMI also varies from -1 to +1. A value close to +1 indicates a high level of moisture in the forest vegetation layer, which may indicate the presence of moisture. A value close to -1 indicates no moisture, or low moisture in the forest vegetation layer and the environment. The NDMI value indicates a low to moderate level of soil moisture in the study area. The control plot and the areas after 20 years of biological reclamation and 30 years (planting of *Pinus sylvestris* and *Betula pendula*) are the wettest of the 7 tested areas.

## 4. Conclusions

The article outlines the results of study the forest vegetation potential of soils of areas disturbed by mining activities using of the remote earth sensing method. Based on satellite images and spectral characteristics, we determined the parameters of soil type and moisture, as well as the vegetation and moisture index of the forest vegetation layer (Normalized Difference Vegetation Index (NDVI) and Normalized Difference Moisture Index (NDMI), respectively). According to the results of the study of the territory, 2 types of soils were identified by the classification of World Reference Base (WRB): Podzoluisols eutriques (De) та Luvisols gleyiques (Lg). The soil moisture content of the research area ranged from 7.88 % to 8.26 %.

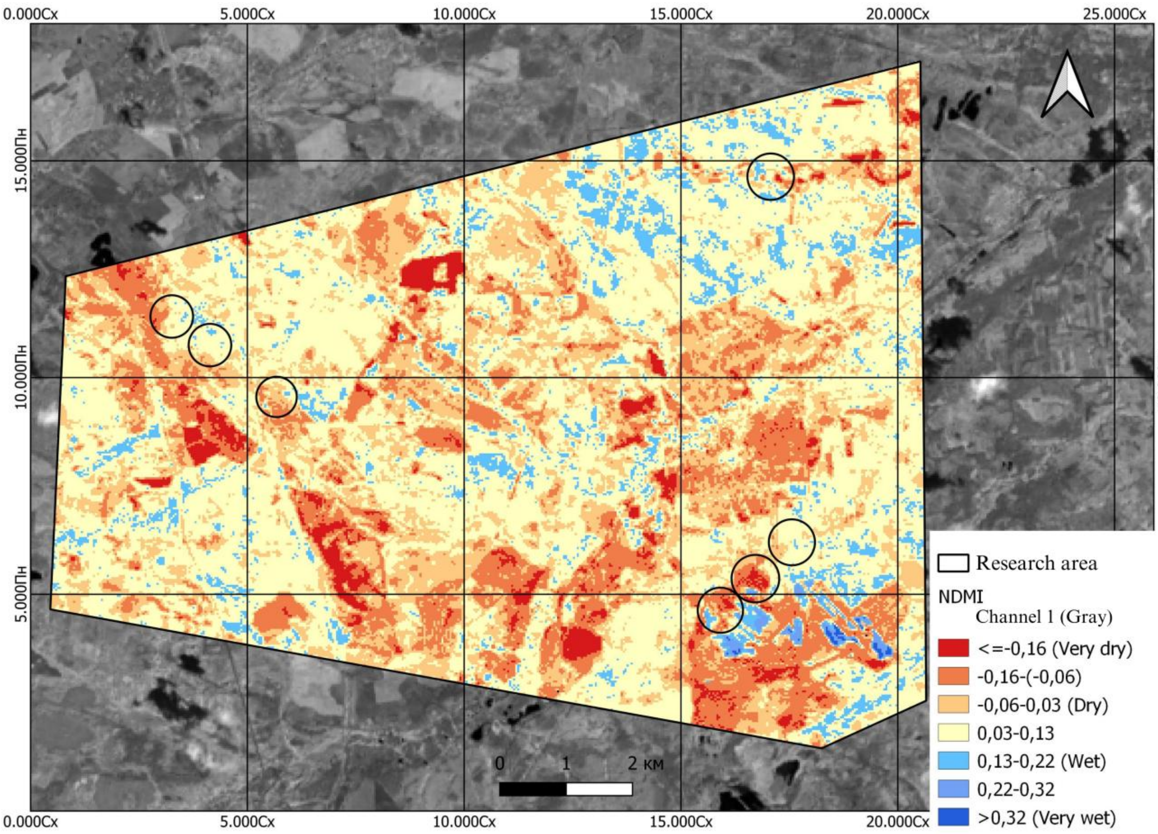


**Fig. 4.** Normalized Difference Moisture Index (NDMI) of the forest vegetation layer in the research area

The results of the remote earth sensing were compared with the results of laboratory analyzes of soil samples. In general, both methods complement each other. Remote sensing can provide a broader overview, and laboratory tests can provide detailed information on individual indicators. Remote sensing data is the primary source for analyzing environmental processes on a local and global scale. This data is used to identify changes over the past decades. Remote sensing data (such as Landsat, Sentinel, Spot image, etc.) is very useful for visualizing, classifying, and analyzing terrain. This data can be categorized by resolution, electromagnetic spectrum, energy source, image carrier, and number of bands. The higher the resolution of the satellite data (spatial, spectral, radiometric, temporal), the higher the degree of accuracy will be achieved during the survey.

The idea of combining remote and laboratory research of territories is relevant and effective in terms of studying ecological systems and dynamic changes that result from anthropogenic disturbances in this case.

## References

Dmytruk, Y., Cherlinka, V., Cherlinka, L., & Dent, D. (2023) Soils in war and peace. *International Journal of Environmental Studies*, *80:2*, 380–393. doi: https://doi.org/10.1080/00207233.2022.2152254.

FAO Digital Soil Map of the World (DSMW). (2024). Retrieved from https://data.apps.fao.org/map/catalog/srv/eng/catalog.search#/metadata/446ed430-8383-11db-b9b2-000d939bc5d8

Furdychko, O. I., Drebot, O. I., Kuchma, T. L., & Ilienko, T. V. (2019). Otsinka ekosystemnykh posluh lisiv za danymy dystantsiinoho zonduvannia Zemli. *Ahroekolohichnyi zhurnal*, *4*, 6–16. doi: https://doi.org/10.33730/2077-4893.4.2019.189436.

Ivaniuk, H. (2017) Siri lisovi grunty u riznykh klasyfikatsiinykh systemakh. *Visnyk Lvivskoho universytetu. Seria heohrafichna*, *51*, 120–134. Retrieved from http://nbuv.gov.ua/UJRN/VLNU_Geograf_2017_51_15

Kshetri, T. B. (2018). NDVI, NDBI, Calculating using Landsat 7,8. Retrieved from https://www.researchgate.net/publication/327971920

Lastovicka, J., Svec, P., Paluba, D., Kobliuk, N., Svoboda, J., Hladky, R., & Stych, P. (2020). Sentinel-2 Data in an Evaluation of the Impact of the Disturbances on Forest Vegetation. *Remote Sensing, 12(12)*, 1914. doi: https://doi.org/10.3390/rs12121914

Lavkulich, L. M., & Arocena, J. M. (2011). Luvisolic soils of Canada: Genesis, distribution, andclassifi cation. *Canadian Journal of Soil Science*, *91*(5), 781–806. doi: https://doi.org/10.4141/cjss2011-014

Macdonald, S. E., Landhäusser, S. M., Skousen, J., Franklin, J., Frouz, J., Hall, S., Jacobs, D. F., & Quideau, S. (2015). Forest restoration following surface mining disturbance: challenges and solutions. New Forests, 46, 703–732. doi: https://doi.org/10.1007/s11056-015-9506-4

Roy, D. P., Kovalskyy, V., Zhang, H. K., Vermote, E. F., Yan, L., Kumar, S. S., & Egorov, A. (2016). Characterization of Landsat-7 to Landsat-8 reflective wavelength and normalized difference vegetation index continuity. *B Remote Sensing of Environment*, *185*, 57–70. doi: https://doi.org/10.1016/j.rse.2015.12.024

Pankiv, Z. P. (2017). *Grunty Ukrainy: navchalno-metodychnyi posibnyk*. Lviv: LNU imeni Avana Franka.

Shao, Y, Xu, Q, & Wei, X. (2023). Progress of Mine Land Reclamation and Ecological Restoration Research Based on Bibliometric Analysis. *Sustainability*, *15*(13), 10458. doi: https://doi.org/10.3390/su151310458

Shomko, O. M., & Davydova, I. V. (2022). Fizyko-mekhanichnyi sklad gruntiv rekultyvovanykh terytorii pislia vydobuvannia ilmenitu na Zhytomyrskomu Polissi. *Tekhnichna inzheneria*, *1*(89), 166–175. doi: https://doi.org/10.26642/ten-2022-1(89)-166-175

Sobue, S., Tochigi, Y., Kawamura, K., Ikehata, Y., Segami, G., Sugita, N., Hamamoto, K., & Kuroiwa, K. (2023). Jaxa earth observation dashboard with COG and WMS/WMTSS. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLVIII-4/W7-2023*, 209–216. doi: https://doi.org/10.5194/isprs-archives-XLVIII-4-W7-2023-209-2023

Soil Classification Working Group (1998). *The Canadian System of Soil Classification, 3rd ed*. Agriculture and Agri-Food Canada Publication, Ottawa.