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Using Sentinel 2A spectral-zone images for qualitative assessment of soils in the Northern Forest-Steppe of Ukraine

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Abstract: The research described in this paper is aimed at developing a methodology for remote determination of arable soil quality in the form of a bonita score using high-resolution spectral images. To achieve this goal, the dependencies between the values of the soil bonitet score and the spectral characteristics of satellite images of land cover areas were established. The geospatial models of soil cover scoring were verified, the results of which show a fairly high degree of correlation between the results of traditional soil scoring and remote sensing (NDSI, r = 0.91), the error value of the soil cover score for individual agricultural production groups of soils ranges from 1 to 12 points. It is found that despite the traditionally established use of vegetation indices to determine the state of crops, their use to determine the level of soil fertility is no less informative. It has been shown that the paired use of NDVI and NDSI values allows for the construction of relevant equations for remote determination of soil fertility, where the first of them acts as an auxiliary (clarifying) index, and the second as an effective working index.

Keywords: remote sensing, score, soil spectral image, spectral characteristics, geospatial models, vegetation index, working index, correlation and regression analysis, verification, relevance.

1. Introduction

It is well known that in many countries of the world, two groups of indicators are often considered important evaluation criteria for soil quality: the first group includes those that significantly increase crop yields and the second group includes those that significantly limit them.

Traditionally, in most developed countries of the world, the value of the qualitative assessment of arable land soils is reflected in the value of crop productivity or the monetary equivalent of its expression, which is logical.

Some scientists propose that the result of a qualitative soil assessment should, in addition to the traditional component of productivity, include an assessment of the environmental component, in particular their ability to use environmental factors (weather conditions) at the field level (Medvedev V. V., Plisko I. V., 2005).

In some countries of Eastern Europe, including Ukraine, the system of soil bonuses is an indicator of soil quality, which continues to function today. As you know, a grade is a measure of soil quality or productivity that is calculated relative to a standard and expressed in points. In Ukraine, there is a general soil grade that reflects the overall level of soil fertility, as well as partial grades that reflect their suitability for growing certain crops. The use of soil bonitas allows for more efficient management of land resources and their rational use.

An alternative to the traditional methods of determining the bonus point is its remote determination by means of remote sensing (RS). Traditionally, the use of remote sensing tools allows obtaining information on the particle size distribution, organic matter reserves, density and vegetative mass of vegetation, as well as other characteristics that can indirectly reflect the value of the bonus point.

Remote sensing data based on satellite images in the form of vegetation indices are traditionally used to determine the condition of crops and soils, mainly by taking into account the parameters of their fertility indicators. Cases of using vegetation indices directly to determine the value of the general soil fertility score are practically unknown.

In this article, we develop and propose a methodology for determining the bonus using remote sensing, which in the context of soil and land resources assessment can be used to monitor qualitative changes in the overall land use potential.

2. Object and subject of the study

The object of research is the use of remote sensing tools to determine soil quality.

The subject of the research is the development of a methodology for using multispectral satellite imagery in determining the value of soil quality (boning).

3. Purpose and objectives of the study

The aim of the research is to develop a methodology for remote determination of the value of the arable soil quality indicator in the form of a soil quality score, which, in particular, provides for the possibility of automated construction of highly informative cartographic material using high-resolution spectral images.

The objectives of the research were to establish the nature of the dependencies between the values of the soil bonitas score on the one hand and the spectral characteristics of satellite images of the soil cover on the other, with the subsequent construction of geospatial models of remotely determined soil bonitas scores based on remote sensing data.

The research objectives included:

- Development of remote sensing methodology, including the definition of approaches, the procedure for calculating vegetation indices of soil cover and the use of Sentinel 2A spectral-zone images to solve research problems;
- selection of the most informative vegetation (working index) to establish the relationship between the value of the soil bonitet score and its values in conditions of free and partially vegetated soils;
- determination of the values and parameters of the most commonly used indices of the studied soils;
- statistical and correlation-regression analysis of the data;
- development of equations of dependence between the values of soil bonitet scores and their reflective characteristics;
- building a geospatial model of the soil cover based on the soil bonitet score and verifying it
- This verification will allow us to establish the accuracy of the model and outline the prospects for its application.

4. Literature review

As is well known, soil grading is a comparative assessment of soil quality based on its main natural properties, which are sustainable and significantly affect the yield of crops grown in specific natural and climatic conditions (Article 190 of the Land Code of Ukraine). The purpose of its conduct in Ukraine is to establish the relative suitability of soils according to the main factors of natural fertility for growing crops and to identify groups of soils subject to economic evaluation.

Knowledge of the patterns of territorial distribution and regional features of soil cover allows us to more accurately determine the level of their fertility on the accepted 100-point scale. The obtained results of soil grading are an important component of land valuation and are necessary for calculating its objective value

A significant contribution to the research and development of soil rating methodologies in Ukraine was made by: V.I. Kuzmychov (1969), A.I. Siryi (1987) and L.Y. Novakovskyi, O.P. Kanash, A.V. Derevytskyi and others (1992) (in press) and others. The most commonly used indicators of soil properties were: organic matter content, indicators of agrochemical state, particle size distribution, moisture content, agrophysical and other indicators. A separate group of indicators included modification features that were taken into account at the level of correction factors, in particular for irrigation and drainage.

The methodology of soil grading by V.V. Medvedev and I.V. Plisko (2006), which was improved in 2013, minimized the impact of correction factors and expanded the main indicators, which provided a more objective assessment of soil as a natural body and an object of economic activity.

Despite the large number of soil rating methods in Ukraine, most of them have both positive and negative features. At the same time, the use of different methods on the same soils leads to significant differences in the values of the bonus score, which can reach 25% or more I.V. Plisko (2019).

Obviously, the choice of approaches and assessment criteria plays a crucial role and significantly affects the result of such an assessment. For the calculation of the score, the methods and, as a result, the reliability of obtaining the initial values of soil property indicators used for the calculation play an important role.

Given the above, the possibility of using remote sensing tools to obtain initial values of soil property indicators is quite relevant. However, the reliability of the data obtained in this way may be insufficient, primarily due to the problem of their legal recognition for soil grading.

So far, there are no known cases of using remotely obtained indicators for conducting soil grading in the classical sense, which is primarily due to the lack of effective remote sensing tools at the time of the last grading.

Many scientists solve the issue of obtaining data on the particle size distribution, organic matter, nutrients, soil moisture and other characteristics using spectral images of various satellite systems, in particular, based on the NDSI index: (Romeu Gerardo and Isabel P. de Lima, 2022) - to determine the level of salinity, (Phuong Ha Tran, Anh Kim Nguyen, Yuei-An Liou, Phung Phi Hoang and Hung Thanh Nguyen, 2018) - to determine the level of salinity against the background of climate change, to study the organic matter content of soils of Central Polissya (Zatserkovnyi, P.I. Trofymenko, V.I, Zubova and others, 2017) to study the nutrient content and salinity of the drained soils of Central Polissia.

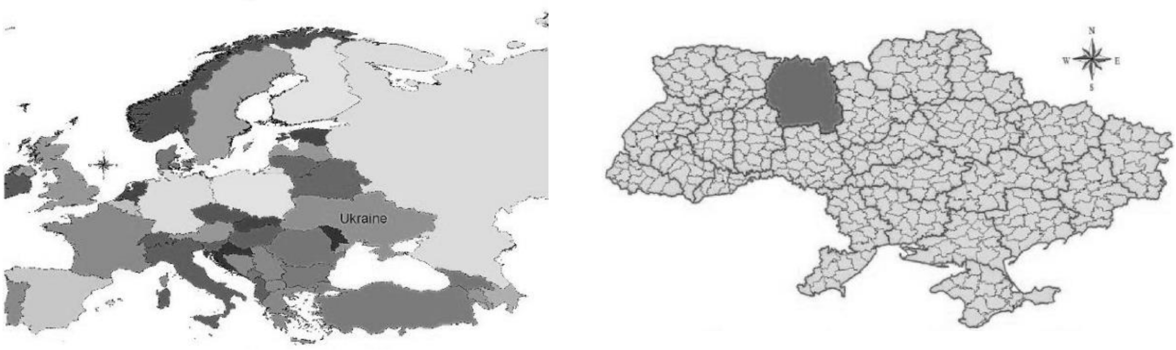
It is quite revealing that the level of soil fertility largely depends on the reserves of organic matter and particle size distribution, which in turn largely form the corresponding spectral image of the soil.

In general, most of the results indicate the high efficiency of using Sentinel 2A spectral images and the sufficiently high reliability of determining soil property indicators, primarily with the participation of NIR1/Red, NIR2/Red and NIR1/NIR2 bands.

Given the fact that the formation of the spectral image of the earth's surface with differentiation by individual soil areas is largely subject to the influence of two main components of soil fertility - organic matter reserves and particle size distribution (to some extent, mineralogical) composition of soils, remote sensing tools can be an effective tool for remote determination of their qualitative assessment score. Other variable conditions that change the spectral characteristics of soils can be taken into account (shielding by vegetation, illumination, roughness, moisture, etc.) or standardized on the image, which minimizes their impact on the final result of remote sensing of soil quality score. The proposed approach provides for the practical combination of several vegetation indices, significantly expanding the established ideas about the possibilities for building equations of dependence between the values of the bonitet score and indices.

5. Research methods

The study was conducted on arable agricultural land located in Ukraine on the territory of Romanivska separate territorial community (UTC) of Zhytomyr district, Zhytomyr region. The research area includes the village of Buldychiv. Buldychiv (φ = 50°06′49″ N and λ = 27°47′48″ E) and Shevchenko settlement (φ = 50°05′49″ N and λ = 27°47′48″ E). Shevchenko settlement (φ = 50°05′44″N 27°47′13″E). The rivers Fastivka and Kamianka and Ruda flow through the study area (Fig. 1).



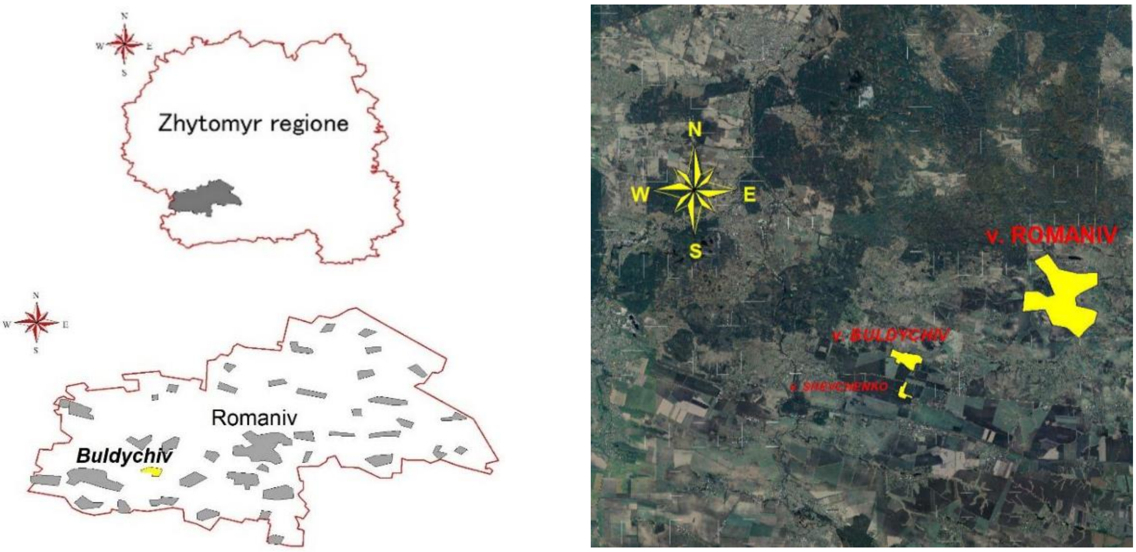


Fig. 1. Location of the research area.

The area has a temperate continental climate with humid summers and mild winters. The relief of the territory is related to the geological structure. The region has significant areas of moraine and moraine-zandrine plains with ridge and hill relief.

During the research, remote sensing methods were applied. Spectroscopic images of Sentinel-2A were used, which were obtained from the Copernicus Open Access Hub resource. The time of image acquisition is synchronized with the completion of field work to prepare fields for sowing winter crops. This time period is characterized by a short-term (up to 2-3 weeks) relatively small amount of vegetation on the soil cover, which allowed us to geographically distinguish soil areas with characteristic spectral characteristics.

According to the results, the multispectral image S2A_MSIL2A_20221020T092031_N0400_R093_T35UNR_20221020T135654, (date and time of acquisition - 20.10.2022 at 09:20:31.024Z) was adjusted accordingly with the following characteristics: search accuracy Aot: 0.0, percentage of cloud cover: 5.79, percentage of cloud shadow: 1.97, no dark areas.

Remote sensing methods were used to determine the shielding of soils by vegetation and to identify clear areas of soil cover.

The study was carried out on the basis of ArcMap 10.4.1 software. The existing map of agricultural production groups of soils at M 1 : 10000 was used as a cartographic basis (Fig. 2).

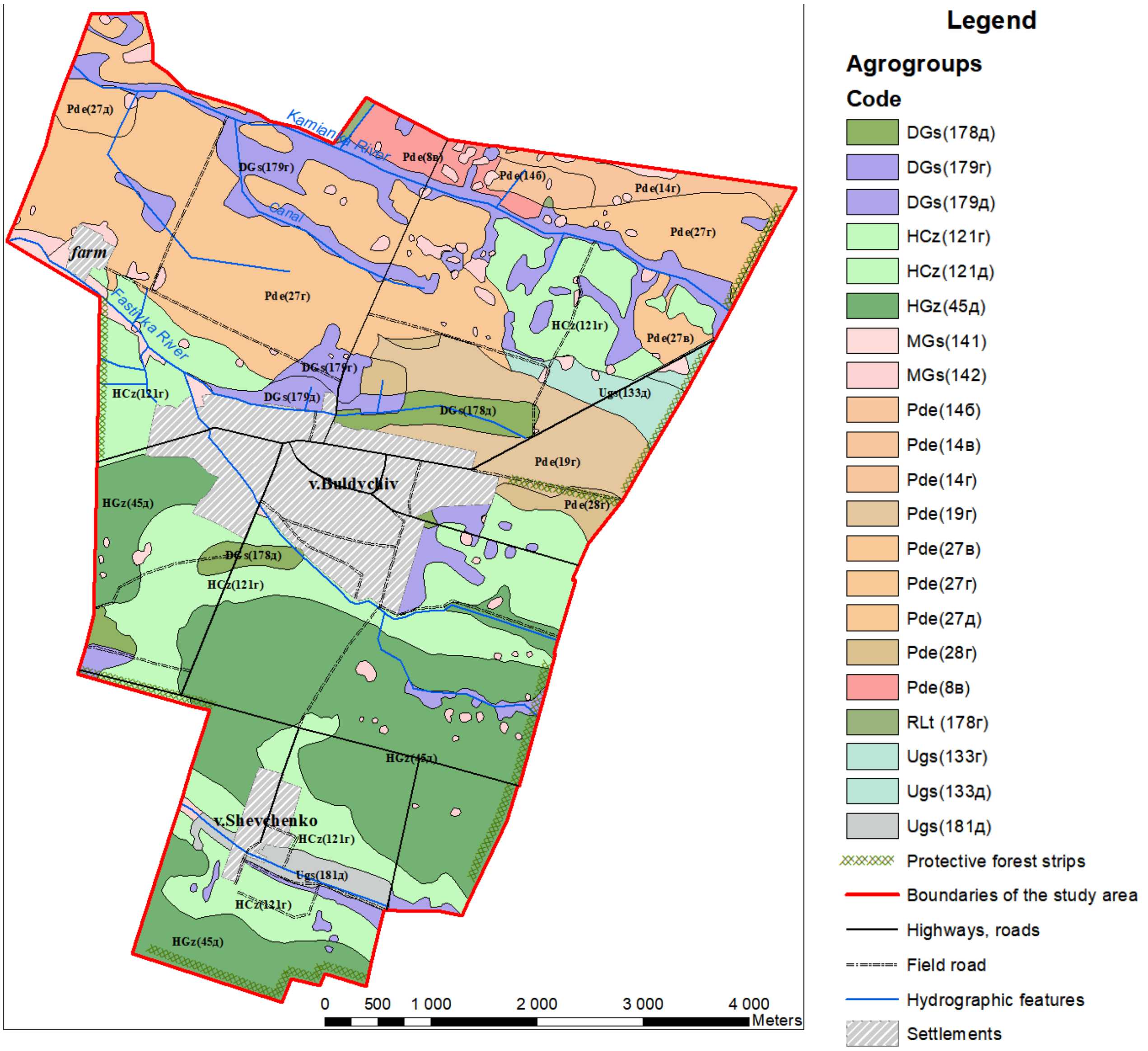


Fig. 2. Soil map of the study area developed according to the WBR international soil classification. The raster of the map of agricultural production groups of soils was used.

The GIS vector base is tied to the WGS 84 coordinate system. The structure of the geodatabase included: agricultural soil groups, settlements, the boundary of the study area, field protection strips, cultural plantations, water and infrastructure facilities.

To build and verify the model, we laid out test sounding sites on the most common soils using a non-continuous network. Among them, 25 test plots were selected, including for the development of mathematical dependencies between the bonitet scores and the values of the NDVI and NDSI indices.

Based on the principle of a continuous network, 1256 identification points within the remote sensing areas with geographic reference were established on the 15 most significant soils by area (Table 1).

Table 1. Territorial distribution of remote sensing points

Agricultural group number and FAO code	19g(Pde)	179g(DGs)	14g(Pde)	133g (Ugs)	14b(Pde)	27g (Pde)	27v(Pde)	27d(Pde)
Number of points	33	199	24	33	41	315	25	19
Agricultural group number and FAO code	28g(Pde)	8в (pde)	121d(HCz)	121g(HCz)	178d(DGs)	45d(HGz)	179d(DGs)	-
Number of points	18	44	24	291	24	141	25	-

The territorial localization of remote sensing sites for deriving the equation and its verification is shown in Figure 3.

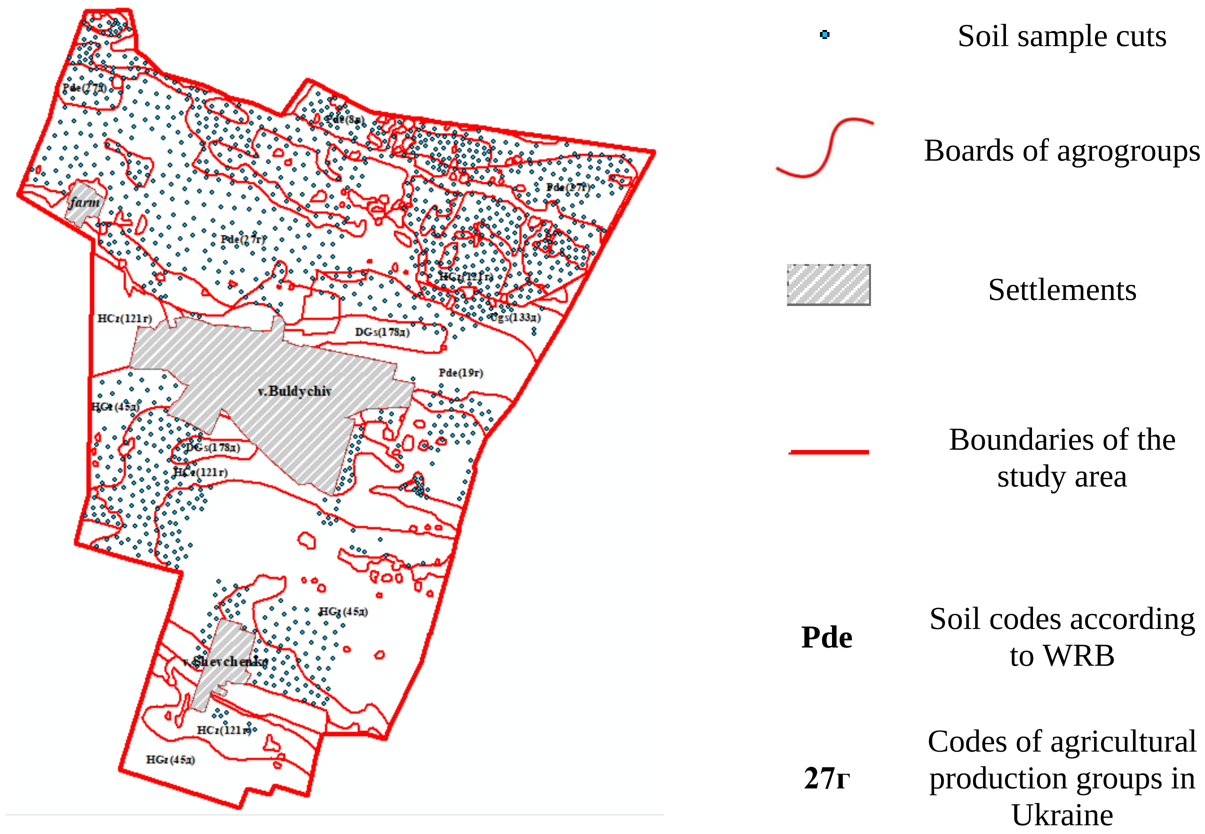


Fig. 3. Locations of remote sensing plots.

The only exceptions were soils localized in areas with NDVI values exceeding > 0.3.

During the geospatial analysis, the kriging function was applied using the Jenks optimization function and the equal interval classification method.

6. Research results

The following soils are widespread on the research area of 3395.3 hectares: dark gray podzolized and podzolized black chernozems gley heavy loamy - 45d/HGz (23.2%), sod-podzolic gley drained light loamy soils - 27g/Pde (21.5%), meadow-chernozem light loamy soils and their slightly saline and slightly saline differences - 121g/HCz (21.3%), soddy gley dried light loamy soils - 179g/DGs (8.1%), sod-podzolic and podzolic-soddy surface-gley light loamy soils - 19g/Pde (5.2%), soddy gley dried medium loamy soils - 179d/DGs (3.4%), soddy deep gley medium loamy soils and their podzolic differences - 178d/DGs (2.5%), meadow-bog, silt-bog and peaty-bog dried soils - 142/MGs (1.7%), meadow-chernozem medium loamy soils and their slightly saline and slightly saline differences - 121d/HCz (1.6%), sod-podzolic gley sandy loamy soils on sandy loam deposits - 8v/Pde (1.6%), meadow medium loamy soils and their slightly saline and slightly saline differences - 133d/Ugs (1.5%), sod-podzolic and podzolic-sod gley loamy light loamy soils - 14g/Pde (1.5%), Sod-podzolic surface-ash dried light loamy soils - 28g/Pde (1.3%), Sod gley carbonate medium loamy soils - 181d/Ugs (1.3%), Meadow-bog, silty-bog and peaty-bog undrained soils - 141/MGs (1.2%), Sod-podzolic clayey drained medium loamy soils - 27d/Pde (0.9%), Sod-podzolic and podzolic-soddy clayey clay-sandy soils - 14b/Pde (0.9%), Sod-podzolic clayey drained sandy loamy soils - 27c/Pde (0.9%), Meadow soils and their slightly saline and slightly saline light loamy soils - 133g/Ugs (0.3%), Deep soddy gley light loamy soils and their podzolic soils - 178g/RLt (0.2%) and Sod-podzolic and podzolic-soddy gley sandy loamy soils - 14c/Pde (0.1%).

The construction of the model for remote determination of soil bonitet scores involved the use of remote sensing data, in particular, the use of the most commonly used vegetation indices NDSI and NDVI.

The indices were calculated according to standard formulas using the "float" function, which minimized the influence of other objects on the results of index calculations (f. 1 and 2):

$$NDVI = float\,(\frac{B8-B4}{B8+B4}) \quad (1)$$

where B8 (NIR) is the value of the near-infrared zone reflection;
B4 (Red) - the value of the red zone reflection.

$$NDSI = float\,(\frac{B4-B5}{B4+B5}) \quad (2)$$

where B4 (Red) is the value of the red zone display;
B5 (NIR) is the value of the near-infrared zone display.

It is well known that NDVI values for agricultural landscapes range from -1 to +1, while NDSI values range from 0 to -1.

Differentiation of the soil cover by the value of the NDVI and NDSI indices is shown in Figure 4.

Taking into account the characteristics of soil and vegetation cover, in this study, the information-significant intervals of the calculated indices should be considered from 0 to 0.3 for NDVI, while for NDSI - the entire negative range.

In order to identify and distinguish between vegetation-free (unshielded) areas of soil cover and areas partially shielded by vegetation, a range of NDVI values ranging from 0 to 0.3 was used. In these areas, the degree of transformation of the spectral image of individual pixels due to the vegetation of crops belonging to separate soil ranges will be minimal.

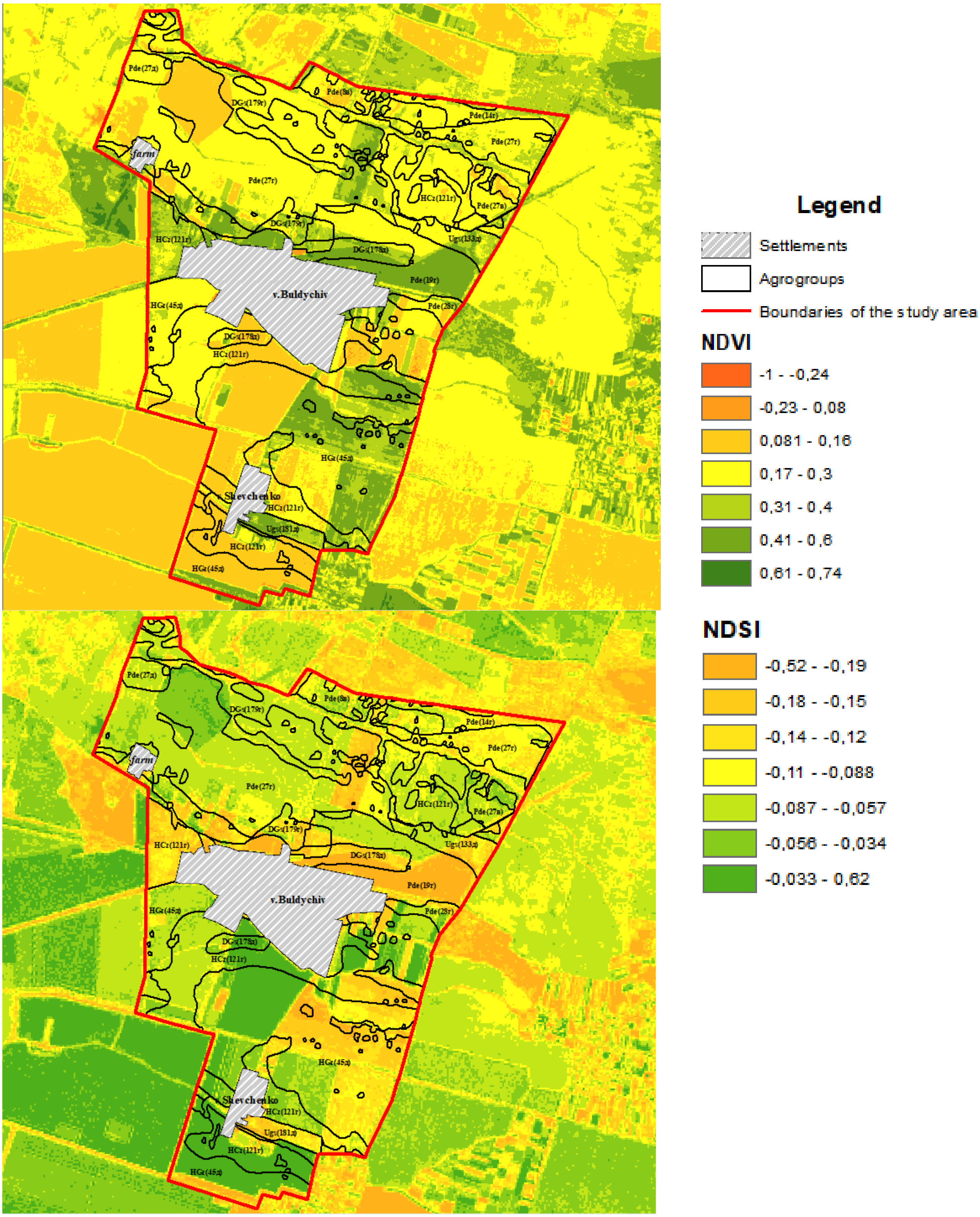


Fig. 4. Differentiation of soil cover of the study area by NDVI and NDSI values.

This approach ultimately allowed us to minimize the direct impact of vegetation on the spectral characteristics of soils and to obtain more accurate dependence equations for building geospatial models of the distribution of the bonus score (Table 2).

Table 2. Values of the NDVI and NDSI indices

Codes of agricultural groups and WRB	Interval of NDVI values	Average value of NDVI	Interval of NDSI values	Average value of NDSI
121д (HCz)	0.104 - 0.291	0.170	-0.090 – -0.006	-0.058
121г (HCz)	0.123 - 0.288	0.199	-0.131 – -0.024	-0.069
45д (HGz)	0.121 - 0.292	0.180	-0.173 – -0.020	-0.063
179г (DGs)	0.127 - 0.293	0.212	-0.124 – -0.012	-0.074
133д (Ugs)	0.157 - 0.290	0.203	-0.108 – -0.055	-0.072
27д (Pde)	0.134 - 0.248	0.199	-0.092 – -0.042	-0.071
27г (Pde)	0.122 - 0.292	0.213	-0.128 – -0.030	-0.078
8в (Pde)	0.132 - 0.274	0.185	-0.126 – -0.046	-0.079
14г (Pde)	0.148 - 0.262	0.219	-0.112 – -0.058	-0.092
14б (Pde)	0.132 - 0.276	0.210	-0.123 – -0.058	-0.091

According to the above data, the NDVI value for the studied soils ranges from 0.104 to 0.148, while the NDSI value ranges from -0.173 to -0.006. Given the much wider range of NDSI values, as well as the significant differentiation of the studied soils by type, particle size distribution and, as a result, fertility level, the data presented here are quite informative. The data on the values of the two most commonly used indices indicate that the NDSI index has a higher identification capacity for taking into account the level of soil fertility.

An additional argument in favor of the latter statement is the data on the correspondence of the average values of the NDSI index to the values of soil fertility expressed in the total points of soil bonitet in the research area (Table 3).

Table 3. Correlation of NDSI values and grade points

Codes of soil agro groups and WRB	Area, ha	Percentage of the area of the soil agro group	Average value of NDSI	Bonitas scores
121д (HCz)	54.2	1.6	-0.058	84
121г (HCz)	721.5	21.3	-0.069	82
45д (HGz)	786.1	23.2	-0.063	74
179г (DGs)	274.8	8.1	-0.074	73
133д (Ugs)	52.5	1.5	-0.072	63
27д (Pde)	30.9	0.9	-0.071	55
27г (Pde)	731.3	21.5	-0.078	55
8в (Pde)	54.0	1.6	-0.079	49
14г (Pde)	51.0	1.5	-0.092	39
14б (Pde)	29.3	0.9	-0.091	33

In general, the data show a gradual decrease in the index values with a decrease in the soil bonitet score.

The data from the analysis of variance and regression, as well as the results of statistical data processing, indicate a fairly high degree of correlation between the two variables and its quality (Tables 4-6).

Table 4. Results of statistical analysis

No. of items	Indicators	Value
1.	Even R	0.91
2.	R-squared	0.83
3.	Normalized R-squared	0.81
4.	Standard error	7.67
5.	Observations	10

Table 5. Results of dispersion analysis

Indicators	df	SS	MS	F	Significance F
Regression	1	2299.308427	2299.308	39.07136	0.00024552
Residual	8	470.7915732	58.84895		
Total	9	2770.1			

Table 6. Results of the regression analysis

Indicators	Ratios	Standard error	t-statistics	P-value	Confidence intervals, 95%	
					lower	upper
Y-section	169,91	17, 64	9,63	0,00001	129,23	210,59
Average value of NDSI	1462, 782	234.02	6,25	0,00025	923,13	2002,43

These results indicate that the NDSI index and the soil grade score have a high and statistically significant correlation, which indicates that changes in the NDSI index values depend on changes in the soil grade score ($r = 0.91$, $F = 39.07136$, $p < 0.05$). the results of the analysis confirm the high reliability of the obtained regression with a t-statistic value of less than 0.05 (0.0002).

The regression equation is as follows (f. 3):

$$y = 1462.8 \cdot x + 169.91 \quad (3)$$

where y is the score of the soil grade;

x - the value of the NDSI index.

The scatter plot of the NDSI and the score is linear, which, despite the high diversity of the soil cover, is quite relevant (Fig. 5).

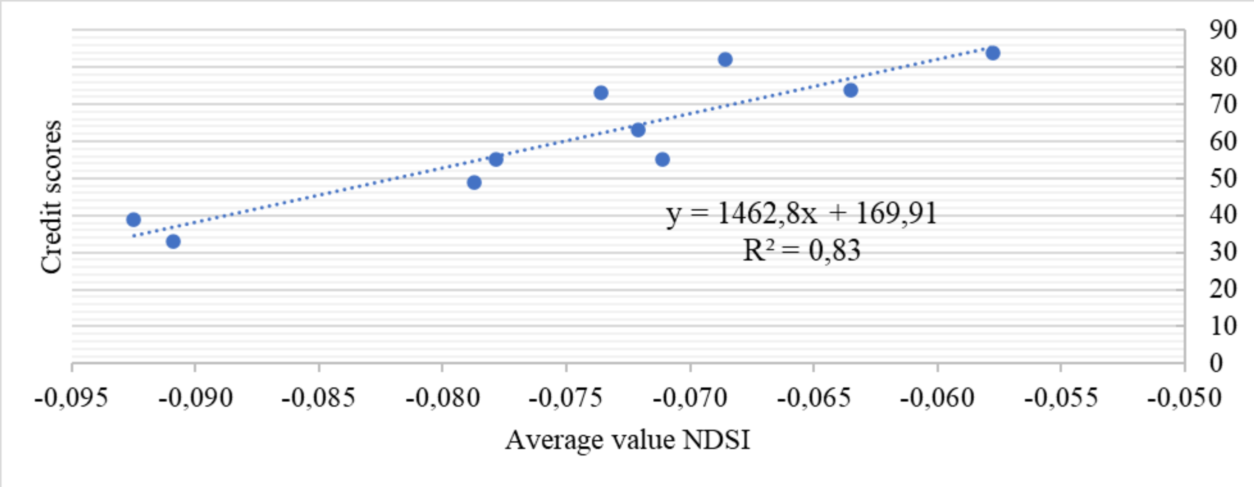


Fig. 5. Correlation between the score and the NDSI index.

The linear regression model is appropriate for data analysis and can be used to determine the score of a certain agricultural production group in the research area. At the same time, the NDVI index plays an important auxiliary role in the construction of the equation for the geospatial distribution of NDSI values.

To enter the resulting regression equation into the ArcMap 10.4 environment, we used the "raster calculator" function.

The expression has the following form (f. 4):

$$float\ (NDSI) \cdot 1462.8 + 169.91 \tag{4}$$

where - float NDSI - formatted numeric values of NDSI in decimal format with a floating point;
1462.8 - the average NDSI value;
169.91 - Y-section.

As a result of the calculations, a geospatial model of the quality of the soil cover of the territory by the total score of the bonus was obtained (Fig. 6):

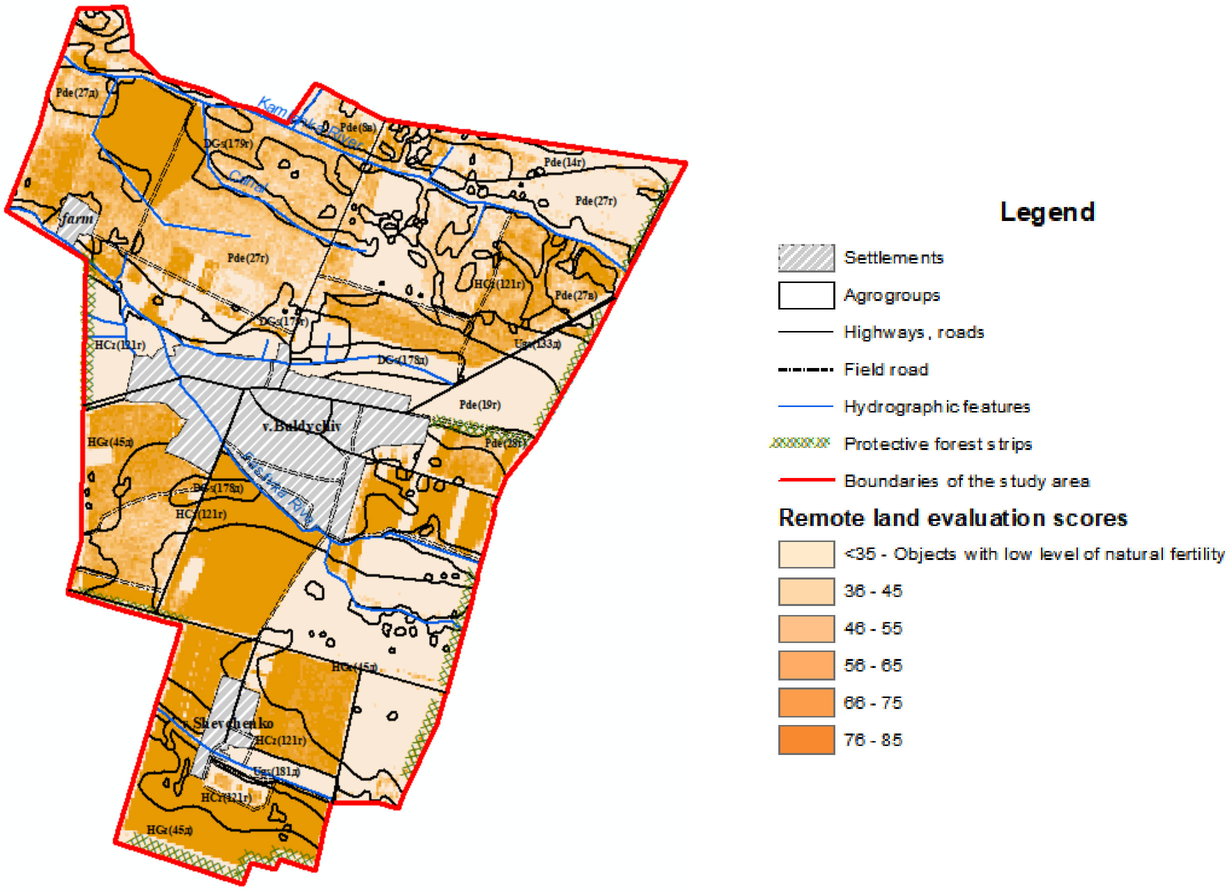


Fig. 6. Geospatial model of land cover differentiation by the score of the NDSI index.

In order to determine the level of correctness of the obtained equation of geospatial differentiation of soil cover by the value of the bonus score, its verification was carried out. The solution to this problem involved comparing officially calculated and remotely obtained bonita scores. To this end, the values of the bonus score were remotely determined on the test verification plots of soils and compared with the calculated scores according to the current bonus methodology (Table 7).

Table 7. Results of verification of geospatial analysis data by the score of the bonus

Code	Average value of NDSI	Bonitet points		Score error, Δ
		calculated*, %.	obtained from the model	
121д	-0.058	84	85	1
121г	-0.069	82	70	-12
45д	-0.063	74	77	3
179г	-0.074	73	62	-11
133д	-0.072	63	65	2
27д	-0.071	55	66	11
27г	-0.078	55	56	1
8в	-0.079	49	55	6
14г	-0.092	39	35	-4
14б	-0.091	33	37	4

Notes. *calculated - scores obtained from the rating scales.

The study revealed that the error of the bonitet scores in the studied soil groups varies from 1 to 12 points. Given the exceptional diversity of the soil cover, the discrepancy in the values of the soil rating scores indicates the relevance of the obtained equation and, as a result, a completely acceptable result.

The calculated regression equation model is an effective tool for determining the soil grade at a distance, as demonstrated in the test plots.

Therefore, we can conclude that the goal of the work was achieved, and the model can be used to determine the bonus points remotely.

7. Prospects for further research development

Given the high degree of differentiation of soil cover in Ukraine and other countries of the world and the significant amount of work involved in traditional soil grading, remote sensing of soil grades may prove to be quite promising. Even if we assume that the scope of application of remotely obtained soil bonitet scores, compared to the officially calculated ones, will be somewhat limited, the efficiency of obtaining their values can compensate for a certain decrease in the level of reliability.

We believe that the developed methodology is quite promising if it is necessary to obtain preliminary information on the level of soil fertility in the case of determining the suitability of land for growing various crops and selecting arable land for them (potential farmers, tenants).

The remote sensing approaches and models developed in this paper need to be verified in similar areas under similar survey conditions, as well as extended to other soil and climatic conditions.

8. Conclusions

In this study, we developed a methodology for the remote determination of the value of the arable soil quality indicator in the form of a bonita score using Sentinel 2A high-resolution spectral images.

1. To achieve this goal, several stages were implemented, including: the formation of methodological approaches to research, the development of a GIS database, the construction of a model for geospatial analysis of the soil surface based on remote sensing data, which allowed to determine the values of soil bonitas scores in the study area.

2. In order to identify and spatially delineate vegetation-free (unshielded) areas of soil cover and areas partially occupied by vegetation, we used NDVI values that ranged from 0 to 0.3. Taking into account the relatively lower degree of distortion of the reflected spectral characteristics of the studied soils, the best conditions were provided for obtaining a model of the geospatial distribution of soil quality, in particular, the soil quality score.

3. The calculation of the vegetation index of the unshielded (free of vegetation) and partially shielded soil cover based on the Sentinel 2A image allowed us to determine the high degree of informativeness of the NDSI vegetation index in determining the value of the arable soil bonitas score.

4. Statistical and correlation-regression analysis of the data allowed us to state the satisfactory quality of the statistical sample of remote sensing results, as well as a high degree of correlation between the values of the calculated and remotely determined soil bonitas scores and its significance ($r = 0.91$; $F = 39.0714$; 0.00025 for $p < 0.05$)

5. It was found that the NDVI values for the studied soils under conditions of minimal shielding by vegetation are in the range from 0.104 to 0.148, while the NDSI values are from -0.173 to -0.006. Therefore, in the case of remote determination of the areas of individual soil distinctive features, the identification capacity of the NDSI index is higher.

6. The values of the NDSI index are in good agreement with the values of the bonitet score of individual soils, which indicates its high ability to determine the level of soil fertility. The results of comparing the values of the bonitas scores of agricultural production groups of soils allowed us to establish a low discrepancy between the calculated and remotely determined values of the scores (1<

Δ <12). At the same time, it is advisable to use NDVI as an important auxiliary index, which plays an important auxiliary function and allows to geographically distinguish areas of soil cover with minimal shielding by vegetation.

The NDSI index has proven to be a reliable tool for determining the level of productivity of agricultural arable land based on the bonus score calculated using the main indicators of soil fertility.

Taking into account the conducted research, it should be noted that the NDSI index should be used for qualitative soil assessment. In general, NDSI is a promising tool for assessing the current state of the territory and making informed decisions on its use and management. By providing accurate and reliable data, the NDSI can facilitate effective decision-making on the use and management of natural resources.

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