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COMPREHENSIVE TECHNIQUE FOR SOIL CONSTITUTION ESTIMATION BASED ON SATELLITE OBSERVATION METHODS

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Abstract. *A strong correlation between spectral brightness (red, green and blue channels) of Landsat 8 OLI image and actual humus content index has been obtained for the monitored areas of the Transcarpathian region. The normalized difference vegetation index has been determined. The value of humus content in each pixel of the image has been calculated using spectral characteristics in the red channel. The non-linear mathematical model of the increasing the efficiency of soil fertility has been developed. The model is based on the spectral parameters of the calculated humus content.*

Keywords: aerospace methods; correlation; humus content; linear and non-linear dependence; remote sensing of the Earth; soils; spectral characteristics.

1. Introduction

Ukraine has favorable natural conditions for agricultural development. The territory of Ukraine is 60,335 thousand hectares, almost 95% of the territory is plains, mountain systems of Carpathians and Crimea occupy 5%, and forests are 16%. As of January 1, 2014, 70.3% of Ukrainian lands or 42,766 thousand hectares are agricultural (0.8% of the world agricultural lands) [1]. During recent years the trend of deterioration of the soil has been determined on all territory of our country.

Table 1. Agro-chemical indicators of the soils in the context of natural climatic zones

Natural climatic zone	Average for 2010 to 2013, mg/kg				
	N	**P_2O_5**	**K_2O**	**G, %**	**pH**
Low land	65.1	147.3	188.1	2.4	5.7
Foothills	94.8	98.68	102.3	2.9	5.8
Mountainous	97.5	124.7	103.3	3.2	5.1

Ukraine, the second largest country in Europe, is known as a breadbasket thanks to its black “chernozem” soil, which is highly fertile and rich in organic matter called humus. Despite the favorable condition, however, a major challenge for our country is soil erosion. Over the decades, “chernozem” soil across the country was increasingly degraded by poor land management and subsequent soil erosion. It is estimated that over 500 million tones of soil are eroded annually from arable land in Ukraine, resulting in a loss of fertility in over 32 million hectares of soil [2]. The fertility of Ukrainian “chernozems” is lost due to moldboard tilling and the excessive application of chemical fertilizers and plant-protecting substances. The biodynamic system of the fertile soil layer with a pH of 5.5 and organic content at 2.5 percent does not function, because the land is bled dry. Soil’s ‘favorite food’ is organic matter that has undergone fermentation, i.e., humus. The application of raw waste and manure is harmful because they contain many disease agents and the seeds of weeds. Degradation of the soils is a global problem of agriculture. Therefore to overcome this problem, it is required to implement a system of monitoring soil cover that will be based on methods of remote sensing. Monitoring the occurrence of soil degradation will be an important component of successful land management. Remote sensing, with its unique ability to measure across space and time, will be an increasingly indispensible tool for assessing degradation. Remote sensing systems, particularly those deployed on satellites, provide a repetitive and consistent view of earth that is invaluable to monitoring short-term and long-term changes and the impact of human activities. To meet the needs of different data users, many remote sensing systems have been developed, offering a wide range of spatial, spectral, and temporal parameters. Some of important applications of remote sensing technologies are:

– Environmental assessment and monitoring (urban growth, hazardous waste);

– Global change detection and monitoring (atmospheric ozone depletion, deforestation, global warming);

– Agriculture (crop condition, yield prediction, soil erosion);

– Nonrenewable resource exploration (minerals, oil, natural gas);

– Meteorology (atmosphere dynamics, weather prediction);

– Mapping (topography, land use, civil engineering);

– Military surveillance and reconnaissance (strategic policy, tactical assessment) [3].

The remote-sensing determination of the extent, frequency, and rates of soil degradation is based on spectral contrast of reflectance values measured from the upper few millimeters of soil surfaces. The chemical, physical and morphological properties that develop at soil surfaces as a result of soil degradation and detectable by remote sensing instruments are, but not limited to, organic matter, iron oxide, moisture content, texture and roughness. Remote sensing techniques can be distinguished between laboratory field approaches which normally consist of the measurements and interpretation of the form of reflectance curves and satellite-based approaches which deal with the analysis and interpretation of radiance and digital images [4].

2. Some of spectral characteristics of soil surfaces.

The spatial resolution of satellite remote-sensing systems is too low to identify many objects by their shape or spatial detail. In some cases, it is possible to identify such objects by spectral measurements. There has, therefore, been great interest in measuring the spectral signatures of surface materials, such as vegetation, soil, and rock, over the spectral range. The spectral signature of a material may be defined in the solar-reflective region by its reflectance as a function of wavelength, measured at an appropriate spectral resolution [3].

The spectral reflectance characteristics of soil are a function of their chemical, physical, and mineralogical composition. Much of studies have been conducted using laboratory, ground, and aircraft instruments to differentiate soils based on their reflectance values. These studies identified diagnostic absorption bands and portions of the electromagnetic spectrum that are most sensitive in detecting the differences in soil properties which are important to soil mapping. In general terms, the reflectance of soils was found to be low but increasing with wavelength in the visible and near infrared spectrum. The most important soil variables, which are used to indicate soil degradation at the soil surfaces and that have diagnostic absorption features detectable by remote-sensing systems, are organic matter, soil moisture, texture, and iron oxide. Other soil parameters relevant to soil degradation determinations are roughness and crusting. Although spectral measurements of these parameters provide information in some cases, their effect is often masked by soil organic matter like humus and moisture content. The existence of spectrally detectable differences in these soil constituents appears to be the basis for distinguishing stage by remote sensing techniques [4].

For the spectral analysis we use the spectral radiance factor $\rho(\lambda)$:

$$\rho(\lambda) = B(\lambda)/B_0$$

where $B(\lambda)$ is the surface spectral brightness at given illumination/observation geometry, and B_0 is the brightness of the perfectly-reflecting Lambertian surface with the normal oriented to the light source [7]. Let us assume that all studied areas was measured in the same illumination/observation geometry ($B_0 = const$). Then we can use relative distribution of the surface brightness $B(\lambda)$ instead of the distribution of the radiance factor $\rho(\lambda)$.

3. Problem statement

The aim and task of this article is development of comprehensive technique for soil constitution estimation that is based on geospatial data of remote sensing and will be an effective toolkit for informational support of management solutions concerning the monitoring of soil. The use of such techniques will allow us to take agro-technical measures to improve soil fertility. Using of the developed technique gives a possibility of the precise obtaining of the information about the state of soils at the concrete areas.

4. The solution of the stated task

Experimental studies was performed using the Erdas Imagine 2014 software for radiometric calibration and atmospheric image correction, and also for determination of spectral signatures and spectral channels data for further determination of correlation and mapping of humus content in each pixel of the image. With assistance of the ArcGis software the schematic map of the investigated territory has been created. The used nonlinear mathematical model of improving of soil fertility is based on statistical information such as: the amount of sown areas, the amount of crop yields, and the amount of gross harvest and of soil fertility index.

5. Results

A strong correlation between spectral brightness in the red (R^2=0.70), green (R^2= 0.63) and blue (R^2= 0.69) channels (R^2 is the coefficient of determination) of Landsat 8 OLI (9 April 2013) image and actual humus content index ($G_{average}$ = 2.12 for 2013) has been obtained for the monitored areas of the Transcarpathian region (Fig. 1).

We used areas for which the normalized difference vegetation index was determined as *NDVI < 0.12,* where vegetation is nearly absent.

The highest degree of correlation was detected in red spectral channel:

$$B(red) = -285{,}07 \times G_{act} + 9097{,}57\,, \qquad (1)$$

where *B(red)* – relative brightness in the red spectral channel; G_{act} – average of actual humus content index.

The value of humus in each pixel of image has been calculated using formula (1) according to spectral characteristics in the red channel (Table 2). Accuracy of the results has been estimated using the discrepancy of points in Fig. 1.

Thus, for instance, for monitoring area Rakoshino with number 14 with actual humus content index 3,17 (as of year 2013), humus content was estimated to range from 1,299 to 3,025 with average value G_p=2,104 and uncertainty ΔG =- 1,07, that shows significant decrease of soil fertility index in 2013 (Fig.2).

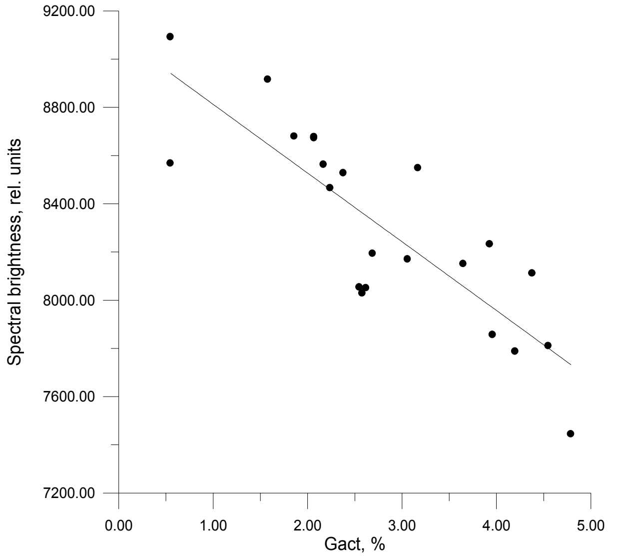

Fig. 1. Dependence of the spectral brightness in the red spectral channel on actual humus content index

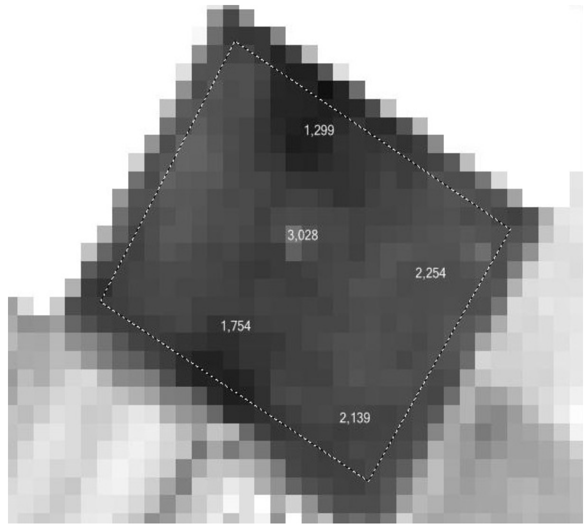

Fig. 2. The field with a minimum and the maximum index of humus content (14.Rakoshino)

Mean-squared deviation of calculated humus content index from actual one is:

$$\sigma = \sqrt{\frac{\sum (G_{act} - G_p)^2}{n-2}} = \sqrt{\frac{12{,}57}{20}} = 0{,}79$$

$$\sigma = 0{,}79$$

Let us use 2σ = 1.58 as an error of humus content index estimation with the level of significance of 0.05 (Fig.3).

Table 2. The assessment of accuracy of the results obtained.

Number and name of monitoring field	G_{act}*, %	G_p**, %	ΔG***
20. V.Dobron	0,55	0,02	-0,53
21. Hust	0,55	1,86	1,31
7. Vinogradiv	1,58	0,64	-0,94
19. Solomonovo	1,86	1,46	-0,40
3. Bovtrad	2,07	1,49	-0,58
18. Seredne	2,07	1,47	-0,60
11.Dovge	2,17	1,88	-0,29
1. Astey	2,24	2,22	-0,02
6. V. Kopana	2,38	2,00	-0,38
4. Ujok	2,55	3,66	1,11
2. Mujievo	2,58	3,75	1,17
12. Vuchkove	2,62	3,67	1,05
15. Turiya Remeta	2,69	3,17	0,48
17. Polyana	3,06	3,25	0,19
14. Rakoshino	3,17	2,10	-1,07
22. Gatj	3,65	3,32	-0,33
16. Golubino	3,93	3,03	-0,90
9. V.Grabivnica	3,96	4,35	0,39
5. Volosanka	4,2	4,59	0,39
10. Kuchnica	4,38	3,46	-0,92
8. V.Vorota	4,55	4,51	-0,04
13. Podobovec	4,79	5,80	1,01

G_{act}*, % - average of actual humus content index

G_p**, % - average of the value of humus in each pixel of image has been built in the red channel.

ΔG –residual, value of assessment of accuracy of the results obtained.

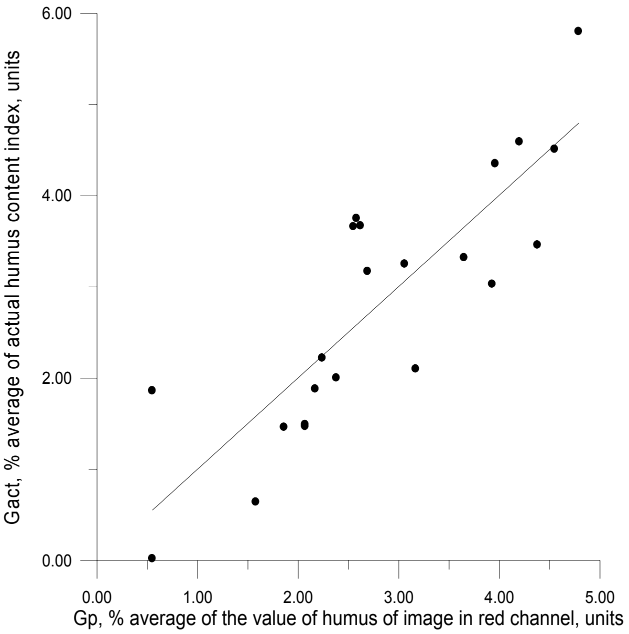

Fig. 3. Dependence of average of actual humus content index on average of the value of humus in each pixel of the red-channel.

The next stage of research it is to build a nonlinear mathematical model of the effectiveness of assessment of fertility of agricultural lands. The model is based on geospatial analysis of the statistical data about crop area, of productivity, gross yield of basic crops within the limits of the administrative districts of Transcarpathian region. The basic component of the model is a coefficient the humus content, that obtained based on linear regression:

$$R_i = S_i I_i Q_i G_i$$
$$P_i = R_i - C_i \quad (2)$$

i is the index of an area, S_i is the sown area; I_i is the market price of agricultural crop; Q_i is the crop yield per unit area and per unit of humus content; G_i is the average humus content index of the area; R_i is the revenue from the yield; P_i is the profit from cultivation; C_i is the calculation of expenses for agrotechnical steps.

Formula (2) shows that there is a direct dependence between the humus content and the crop yield profit. Therefore, the proposed remote-sensing method of humus content estimation is very important for global planning of crops sowing in a region.

5. Conclusion

It has been confirmed that soil in Ukraine in general and in some regions (the Transcarpathian Region) is susceptible to degradation, and it is rapidly losing its nutritional value, especially that of humus. Such a tendency leads the lands to become unfit for agricultural use and to the decay of Agro-industrial sector of the country in whole.

Use of on-the-ground techniques to monitor the state of crops is clearly effective, but time-consuming and costly. The comprehensive technique for soil constitution assessment based on global positioning satellite observation is a swift and proved tool when making managing decisions regarding efficient running of agriculture.

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Мета даної статті полягає в аналізі чіткої кореляції між спектральною яскравістю (червоного, зеленого і синього каналів) супутникового зображення Landsat 8 OLI і фактичного індексу вмісту гумусу, що був отриманий для моніторингових ділянок Закарпатської області. Визначено нормалізовано-вегетаційний індекс рослинності. Розраховано значення вмісту гумусу в кожному пікселі зображення з використанням спектральних характеристик в червоному каналі. Розроблена нелінійна математична модель підвищення ефективності родючості ґрунту, що заснована на спектральних параметрах розрахунку вмісту гумусу.

Ключові слова: аерокосмічні методи; дистанційне зондування Землі; ґрунти; кореляція; показник гумусу; лінійна та нелінійна залежність; спектральні характеристики

Л.В. Гебрин[1], О.А. Железняк[2], Ю.И. Великодский[3], Ю.Ю. Бандурович[4]. Комплексная методика оценки состояния почв на основании методов спутникового наблюдения.

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Цель данной статьи заключается в анализе четкой корреляции между спектральной яркостью (красного, зеленого и синего каналов) спутникового изображения Landsat 8 OLI и фактического индекса содержания гумуса, который был получен для мониторинговых участков Закарпатской области. Определен нормализировано-вегетационный индекс растительности. Рассчитано значение содержания гумуса в каждом пикселе изображения с использованием спектральных характеристик в красном канале. Разработана нелинейная математическая модель повышения эффективности плодородия почвы, основанная на спектральных параметрах расчета содержания гумуса.

Ключевые слова: аэрокосмические методы; дистанционное зондирование Земли; линейные и нелинейные зависимости; корреляция; показатель гумуса; почвы; спектральные характеристики

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