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Using Multispectral Images to Establish Land Categories

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Abstract

At the present stage, the dominant means of obtaining information is space shooting, which is carried out from space carriers with the help of special shooting equipment, and makes it possible to obtain high-quality images covering a significant area of the earth's surface. Methods combining multi-criteria analysis and GIS technologies can be used to make appropriate environmental decisions. At the same time, an important component for all interested parties is obtaining the original information at the lowest cost. In this regard, this publication provides a methodology for constructing maps of land categories, which is based exclusively on a free basis. This methodology includes free and open FOSS software, space images of the Landsat 8 satellite, and multi-criteria analysis of space image processing. The procedure of the methodology includes the creation of a database based on available land management documents, cadastral plans and maps, satellite images, etc.; processing of the database using multi-criteria analysis; analysis of the results and decision-making. The database is created using QGIS software, and PostgreSQL with the PostGIS extension is used for modeling and data storage. MultiSpec software was used to create multispectral images, perform satellite image classification and evaluation. Using a set of the above software products and Landsat 8 satellite images, a pilot project on an area of 615 km2 was carried out to determine the capabilities of this methodology for establishing land categories. It was established that the multispectral image of the combination of 6-5-2 channels best represents land categories. The accuracy of the classification is 96.2%, and the User Accuracy for arable land is almost 100%, for orchards 55%, and for hayfields and pastures 61.3%.

Keywords

Land categories; Space images; Multi-criteria analysis

Introduction

Land resources are characterized by a multifaceted nature of use. They, along with other natural resources, are a component of the environment, means of production, and a source of satisfying human needs. Activities related to the use of land resources are particularly important for economic relations, but have led to a number of environmental and economic problems, the most important of which are inefficient land use, soil deterioration, degradation, water and wind erosion, and so on. Land is a limited natural resource; so human society must manage its national wealth wisely and sparingly. Special attention should be paid to the justification of proposals for the rational use and protection of land, improvement of the conditions, and mechanisms of effective land use (maximum involvement in the economic circulation of all lands and implementation of their effective use).

A quick and high-quality assessment of land resources through a comprehensive analysis of available spatial data will help provide the process of land resource administration with reliable information (Koeva, Bennett and Persello, 2022). In the modern world, these important tasks are solved on the basis of aerospace information and innovative technologies for its processing and use. Space shooting, which is carried out from space carriers with the help of special shooting equipment, makes it possible to obtain high-quality images covering a significant area of the Earth's surface. Space and aerial photography materials are widely used for mapping and solving applied problems in various fields of science and technology: ecology (Young *et al*., 2017; Zhe, Shi and Su, 2022), medicine (Maxwell, 2010), agriculture (Boryan, 2011), (Stupen, Stupen and Stupen, 2018), solar energy (Kereush and Perovych, 2017; Kereush and Perovych, 2019; Sanchez-Lozano *et al*., 2013) and others. Every year, the volume of cartographic and geo-information products increases, new areas of application of space survey data appear. Currently, many algorithms for processing space images have been developed, and satellite monitoring systems of agricultural lands have been created at the global level (Eastman *et al.*, 1995; Tso and Mather, 2009).

In the United States, a number of laws, including the Landsat program, have been adopted to ensure the leading role of the country in obtaining and using remote Earth observation data. Within these documents, at the apex legislative level, the importance of the Landsat operational program of the satellite data obtained within it is described and established. A system that combines multi-criteria analysis and the application of GIS technologies and takes into account the ecology, orography, location and climatic factors can be applied to take appropriate environmental decisions (Aran Carrion *et al*., 2008).

Thus, it can be articulated that the combination of GIS and multi-criteria analysis generates an *analysis tool* that allows creating an extensive cartographic database, which will later be used to make effective decisions. In the land management, a number of important tasks arise in terms of prompt determination of land categories and their registration in the cadastral system. From this point of view, to obtain reliable cadastral information in a short period of time that can be quickly implemented into the cadastral system, it is important factor in the effective administration of land resources. In particular, this applies to determine the combination of spectral channels to form an effective multispectral image of land categories.

The use of these approaches to the definition of land categories allows in the future carrying out constant monitoring of their conditions, which will contribute to the increase in the efficiency of the use of land resources in terms of individual categories and to the reduction of risks related to the deterioration of their condition. At the same time, it becomes possible to optimize the ratio of land categories not only with the aim of minimizing the impact on the environment, but also ensuring the socio-economic development of a certain territory.

This study is devoted to aspects of the possibility of applying this methodology to determine land categories.

Methods and Materials

In order to provide an opportunity for all interested investors, entrepreneurs and executive authorities to create their own land structure map for free. A technology for processing space images of the Earth's surface using FOSS software with freely available data sources is proposed. Free access to the archive of satellite images taken over different periods of time and by different imaging systems (including data from the Landsat, Sentinel-2, NOAA CDR, eMODIS LST missions) is available on the website of the United States Geological Survey. Appropriate images were selected for research using the navigation functions of the Earth Explorer data request tool (https://earthexplorer.usgs.gov). It provides an opportunity to customize the data request by selecting the type of satellite, the level of processing of the space image, the coordinates of the studied area, the date of obtaining the image and the percentage of cloud cover.

Creation of the proposed database is implemented exclusively using FOSS (free and open source software). It is suggested to use PostgreSQL database with PostGIS extension. The main advantage of PostGIS is that it is free and it combines the SQL programming language with spatial operators and functions. In addition to simple data storage, PostGIS allows to perform all kinds of operations on data, and also has a strong connection with QGIS Software. For this purpose, PostgreSQL Open Source Database with PostGIS extension, QGIS and MultiSpec software were used. PostgreSQL Open Source Database with PostGIS extension is used for modeling and data storage. QGIS is for uploading, managing, sharing, analyzing and visualizing the data. Therefore, the application of FOSS software consisted of PostgreSQL Open Source Database with PostGIS extension, QGIS and MultiSpec software.

To determine the land cover, it is necessary to classify the satellite image. The classification of satellite images involves the grouping of pixels into meaningful classes to represent land cover features. Automated satellite image classification methods use algorithms that group pixels into meaningful categories (classes). For this study, it is proposed to use the method of maximum likelihood and controlled classification of satellite images due to its better accuracy and quality of presentation of results. Maximum likelihood method is a statistically controlled approach for pattern recognition (Tso and Mather, 2009). It separates pixels into appropriate classes based on the likely values of the pixels. The maximum likelihood method is an efficient common method for classifying satellite image pixels. An important element of this methodology is the creation of a multispectral image based on combinations of individual spectral channels. From the list of combinations of spectral channels, the best can be chosen to contribute to solving the task at hand. For that, the MultiSpec software was used. Supervised classification consisted of analyzing pixels within each reference polygon and creating spectral signatures for each land cover type. Image classification was performed by comparing the spectral values of pixels with the generated signatures (training samples). Actually, the accuracy of the method largely depends on the accuracy of the definition of the training sample. So, the training samples consisted of two types, one of which was used for classification and the other for checking the accuracy of the classification. For this purpose, the accuracy of the manufacturer and the accuracy of the user and the reliability coefficient of the classification were determined. It created an accuracy matrix representing the distribution of pixels. Producer Accuracy shows the percentage of a certain basic class that is correctly classified. User Accuracy is an indicator of classification efficiency. It indicates the percentage of probability that the class to which a pixel is classified actually represents that class in the area (Story and Congalton, 1986). The classification reliability indicator was determined by the k coefficient (Cohen, 1960).

The procedure for implementing the methodology involved the analysis of the structure of land resources under the research, collection of raw data, creating a database, data processing, and, at the final stage, analysis of the received map of land categories with verification of its reliability and appropriate decision making. One of the most important problems of land management is obtaining reliable geospatial information with accuracy of geometric parameters of land plots and land. This aspect is absent in this methodology, which calls for additional research to address this issue. The use of this methodology to determine the categories of land covered by different types of vegetation definitely has some limitations. To eliminate the limitations, the identification of land plots was conducted by their direct survey on the ground.

Results

The implementation of this technology was carried out in an area of 615 km^2, which is covered by one satellite image. The Landsat 8 OLI / TIRS Collection 1 satellite image received on 19 August 2016, the data of which is presented in DN units, is geometrically corrected the processes of georeferencing and orthorectification (correction of effects due to the influence of the terrain). The Landsat 8 satellite has two sensors: the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). Wavelengths and spatial resolution of each spectral channel of Landsat 8 OLI/TIRS (US Geological Survey, Landsat 8 Imagery) are presented in the table 1.

Multispectral images were created for satellite image classification. At the same time, it is important to find such a combination of spectral channels, which can best identify different types of land categories. Creation of multispectral images was performed in the MultiSpec software environment. For this, all necessary spectral channels were imported into it, and the procedure for combining separate files of spectral channels into a single multispectral image file (Combining Separate Image Files into a Single Multispectral Image File) was performed. Particular attention was attached to defining the category of agricultural land with the allocation of certain types of land (arable land, pastures and hayfields, perennial plantations - gardens), stony land and land of forest and water areas. In other words, most attention was given to the dominant land categories in the project area.

Table 1: Wavelengths and spatial resolution of Landsat 8 OLI/TIRS spectral channels

Spectral channel Wavelengths	*Spatial resolution (size 1 pixel), μm*	*OLI ranges, m*
Channel 1 Coastal / Aerosol, New Deep Blue	0.433 - 0.453	30
Channel 2 – Blue	0.450 - 0.515	30
Channel 3 – Green	0.525 - 0.600	30
Channel 4 – Red	0.630 - 0.680	30
Channel 5 – Near Infrared	0.845 - 0.885	30
Channel 6 - Short Wavelength Infrared, SWIR 1	1.560 - 1.660	30
Channel 7 Short Wavelength Infrared, SWIR 2	2.100 – 2.300	100
Channel 8 – Panchromatic, PAN	0.500 - 0.680	15
Channel 9 – Cirrus	1.360 - 1.390	30
Channel 10 - Long Wavelength Infrared (TIR1)	10.30 – 11.30	100
Channel 11 - Long Wavelength Infrared (TIR2	11.50 - 12.50	100

As a result, five multispectral images were obtained with a spatial resolution of 30 m. The analysis of multispectral images showed that the multispectral image "channels 6- 5- 2" best represents land categories (Figure 1).

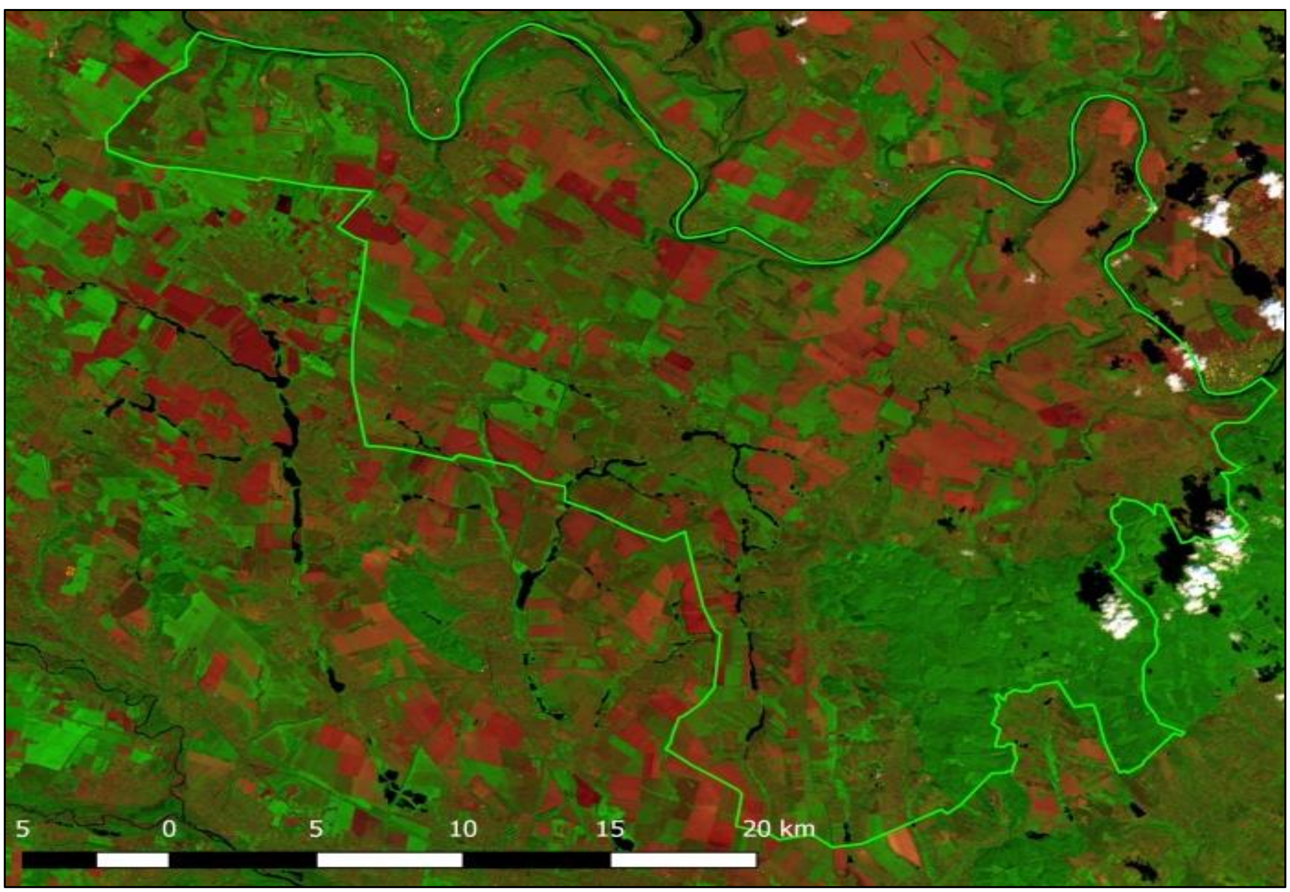

Figure 1: Multispectral image of the Earth's surface

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On this multispectral image (Figure 1), arable land with green vegetation is displayed in bright green colors; arable land with dry vegetation (in burgundy color); arable land with open soil appears in pink; hayfields and pastures in green-brown color; forest in green and dark green colors; and stony lands in light pink color. The method of maximum likelihood was used for the controlled classification of the satellite image. For this, the multispectral image "channels 6-5-2" was imported into the MultiSpec software in order to create training samples (regions of interest) according to the land category. Supervised classification was used to identify classes and to calculate their signatures. In the research process, the following 11 training samples were created with the appropriate signature sizes:

1. Water bodie - 108 pixels;
2. Forest – 4,871 pixels;
3. Gardens – 300 pixels;
4. Rocky lands - 10 pixels;
5. Hayfields and pastures - 780 pixels;
6. Arable lands with open soil – 4,338 pixels;
7. Arable lands with dry vegetation – 3,104 pixels;
8. Arable lands with green vegetation – 1,940 pixels;
9. Arable lands with semi-dry vegetation – 2,502 pixels.

After creating the samples, the procedure of controlled classification was performed using the method of maximum likelihood. As a result of the procedure, a table of the results of the "Training Class Performance" classification (accuracy matrix for each class) was created along with the coefficient k (Cohen's kappa). Producer Accuracy and User Accuracy were also determined for each class. At the final stage, a resulting map of land categories was created in GeoTIFF format (Figure 2).

As a result of the processing of the initial data, the coefficient κ equal to 0.962 was determined, which indicates the high accuracy of the performed classification - 96.2%. User Accuracy - almost 100% - was achieved for most reference areas, with the exception of gardens (55%) and hayfields and pastures (61.3%). From the "garden" class, 135 pixels were classified into the "Forest" class, because they have very similar spectral brightness values of the classes. The same problem arose during the classification of hayfields and pastures. The spectral brightness values of this class and the "arable land with semi-arid vegetation" class are also similar; so, out of the total number of 780 pixels of the "hayland and pasture" class, 286 pixels were classified into the "arable land with semi-dry vegetation" class. In this case, it is proposed to evaluate each set of pixels of the "arable land with semi-arid vegetation" class for visual determination of the real type of the Earth's surface, according to Google Satellite Map data.

Thus, as a result of the implementation of the proposed methodology, the resulting land map was obtained, which includes the lands of water and forest lands, stony lands, as well as such agricultural lands as hayfields and pastures, arable lands covered and not covered with vegetation. Experience shows that, for the reliable identification of land plots covered with high vegetation (gardens, forests), as well as of the same type (pastures, hayfields), it is advisable to make field surveys in advance.

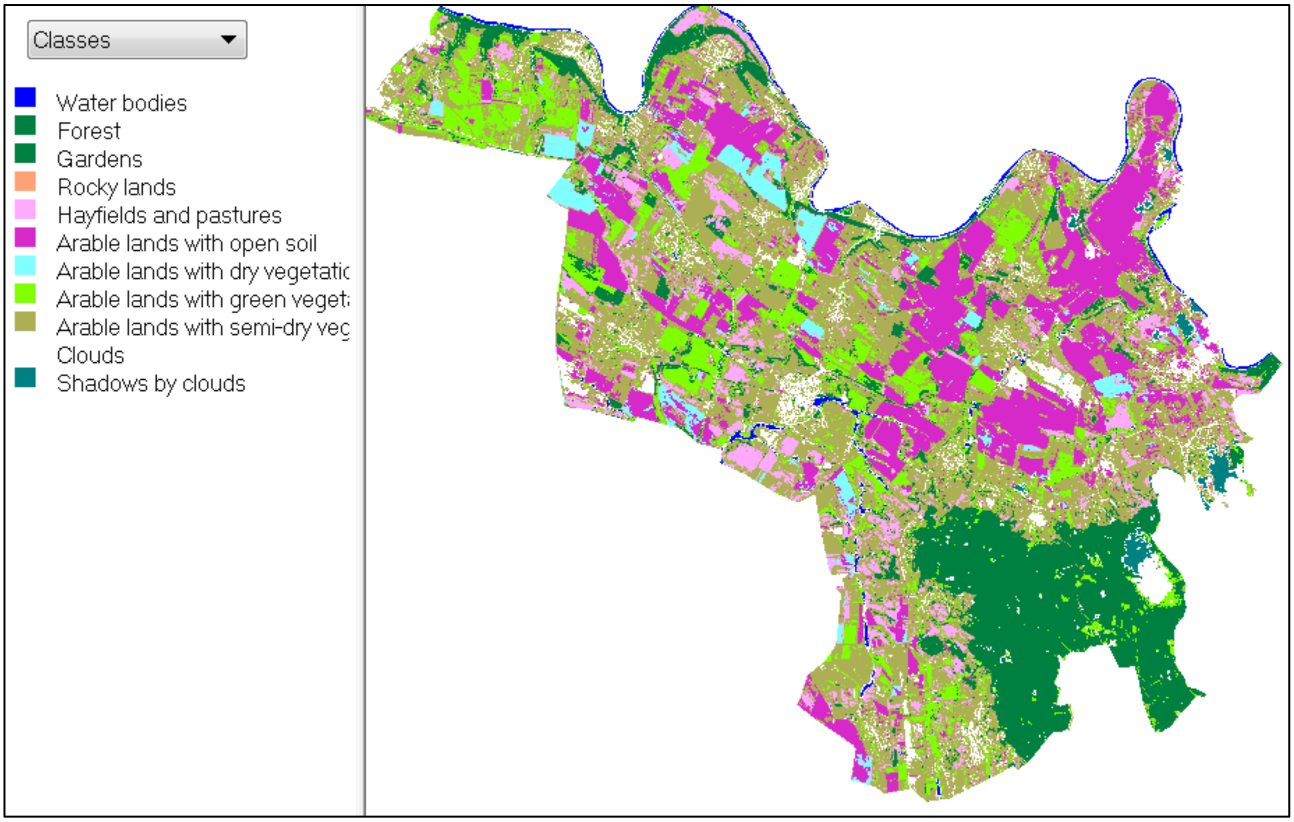

Figure 2: Map of land categories

Conclusion

The structure of land resources is an important factor in determining development of territories. To this end, the possibility of applying the methodology for determining land categories on a free-of-charge basis was investigated. This methodology provides for a holistically theoretically grounded mechanism for determining land categories. It involves the use of LANDSAT 8 OLI/TIRS satellite imagery and freely available QGIS, PostgreSQL, PostGIS and MultiSpec software products and the selection of a combination of spectral channels to build a multispectral image that would meet the task of mapping land categories, evaluating the results, and making the decisions.

In the process of implementing this methodology, it was found that the multispectral image of the 6-5-2 spectral channel combination best represents land categories. User Accuracy for most of the reference plots (arable, water and stone) is almost 100%, which indicates the correct classification of pixels. However, for the land plots covered with tall vegetation, in particular, for gardens, hayfields and pastures, this figure is 55% and 61%, respectively. This allows us to conclude that this methodology is effective in determining the categories of open land, and that field surveys should be carried out beforehand to identify closed land.

The application of this methodology in land management at different epochs will lead to an improvement in the result of its use, as it will allow for operational control over the state and dynamics of changes in the structure of land categories, which in turn will facilitate the adoption of informed decisions on their land protection and use. In the future, the results of the research can be used primarily by specialists of the agro-industrial complex, investors and private entrepreneurs to monitor the state of the structure of land resources and determine the feasibility of their use for the intended purpose, as well as by a wide range of specialists in the field of land management in the course of land inventory and cadastre registration, etc.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	*Author 1*	*Author 2*	*Author 3*	*Author 4*
Conceived and designed the research or analysis	Yes	Yes	Yes	Yes
Collected the data	Yes	Yes	No	No
Contributed to data analysis & interpretation	Yes	Yes	Yes	Yes
Wrote the article/paper	Yes	No	No	No
Critical revision of the article/paper	Yes	Yes	Yes	Yes
Editing of the article/paper	Yes	Yes	Yes	Yes
Supervision	Yes	No	No	No
Project Administration	Yes	No	Yes	No
Funding Acquisition	No	No	No	No
Overall Contribution Proportion (%)	50	20	20	10

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Research involving human bodies or organs or tissues (Helsinki Declaration)
The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

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The author(s) has/have NOT complied with PRISMA standards. It is not relevant in case of this study or written work.

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