Using remote sensing and GIS to monitor of land cover change in the Middle Volga region during 1985-2014

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Abstract. Study of land cover change is one of the most significant fields in sustainable development in forestry and prevention of ecological degradation in the Middle Volga region. Land use change can directly transform wide landscapes, impact on the biodiversity and eco-productivity. Due to these remote sensing technologies, take an important place in such research. GIS techniques are widely used for land cover change monitoring under climate change and human impact but the lack of reliable information on land use changes remains a major challenge of today. The research covers the assessment of land cover change caused by different types of natural and human disturbance in the Middle Volga region of the Russian Federation. This paper argues the method of monitoring of land cover change using satellite information and assessing land cover that can be beneficial for the further research affecting changes over different space and time scales.

1. Introduction

Modern approaches to studying the land use change are largely based on long-term monitoring and spatio-temporal analysis of the dynamics of land cover [1-7]. The role of using satellite images and software for obtaining information and creating up-to-date methods for monitoring global changes in land cover [8-11] is increasing with the development of information technologies. The created GIS databases provide the necessary platform for analysing a large amount of data, updating and forecasting the results of thematic mapping [12-15]. Landsat satellite images are the most widely used for land cover assessment [16-18].

Analysis of modern research in the field of land cover assessment has shown that there is a great practical interest in using the spatio-temporal analysis of land cover dynamics. Scientific teams around the world (countries near and far abroad, Australia, China, Japan, Europe, Canada and the USA) are developing different approaches to solving the problem of accuracy of assessment land cover dynamics caused by global climate changes and human activities. This process is facilitated by the rapid development of modern technologies for remote sensing (RS) and geoinformation systems (GIS).

Most of the work on assessment of changes in land cover is based on the study of two main natural processes: disturbance (decreasing of land cover) and regeneration (increasing of land cover) [19]. Both these phenomena, which affect the accumulation of phytomass and the global cycle of carbon, are the main theme of modern remote monitoring of land cover. Analytical review of scientific literature is shown that the most research in this area are based on combining methods of thematic mapping of land cover using the satellite images of different spatial resolution and assessment of land cover changes. For example, more advanced data of land cover dynamics based on comparison of
Sentinel satellite images of high spatial resolution and medium global images Landsat. At the same time, assessment the accuracy of the obtained thematic maps is important in those studies that are being conducting by comparing the results with independent ground-based data. Good results that improve the accuracy of thematic maps show methods for post-classification processing of satellite images.

Many researches with the use of different satellite images to prognosis changes and determine the main factors affecting the dynamics of land cover are conducted [20]. For a large-scale spatial assessment of territories modelling of land cover change by the methods of geostatistics and multifactorial regression analysis are used [21]. In such models, the following factors such that the socio-economic conditions of the region, the intensity of land use, the development of urban infrastructure and other indicators are used.

The objective of this article is monitoring of land cover change using RS and GIS techniques. The focus is the use of method "cellular automata" using Landsat satellite in the research region. Created database for land cover changes will be important indicator for solving issues in sustainable development and promoting public well-being in the future. Furthermore, it will be necessary for building forecasting models of the dynamics of ecological situation in the studied region. Assessment of land use change dynamic will provide a broad-scale evaluation of available land cover, an assessment of human impact in particular on local scale and for international comparisons as well.

2. Methods and Materials

2.1. Data and research materials

Study territory for monitoring of land cover changes is the Middle Volga region within the satellite image scene. The southern part of territory is mainly forest land; the northern part is agricultural land.

A test site is a series of three Landsat-resolution images (1985, 2001, and 2014) on the territory of the Middle Volga region of the Russian Federation, which cover full Landsat scenes (180 x 180 km minimum). Several types of ground data used as reference data for land cover mapping including forest inventory maps and database of surveys, plot measurements and transects.

2.2. Research methods

The Tasseled Cap transformation [22] for Landsat images has been used for the equation of different spectral signatures of vegetation changes during shooting images.

This algorithm represents empirical equalization of spectral channels and linear transformation of bands to three indices: Brightness, Greenness, and Wetness. Brightness is associated with bare or partially covered lands, greenness - with green vegetation, and the last component, wetness, is associated with moisture, water and other moist features. Images after Tasseled Cap transformation (BGW) were used in the study of land cover for interpretation of objects.

For the data processing follow methods were used:
- Thematic mapping of satellite images;
- Accuracy assessment;
- The method of “cellular automata”;
- Land covers change monitoring.

The thematic mapping of land cover for the study area was formed by the method of multiple unsupervised classification by the IsoData method (Iterative Self-Organizing Data Analysis Technique - iterative self-organizing method of data analysis). This method is based on the assessment of criteria for the proximity of points in a feature space. Identification of the changes in land cover associated with anthropogenic activities and natural phenomena is one of the important elements of the work in the classification of satellite images. The spectral characteristics of disturbed areas have similar indicators with other classes of land cover: shrubs and young forest. They are almost indistinguishable from Landsat satellite images. For such
tasks, spectral transformation or detailed mapping of satellite images is usually carried out in order to improve the accuracy of interpretation.

Assessment accuracy of the created thematic map was carried out by the method of post-classification data processing, including:

- Comparison with ground data (reference sites);
- Construction of a “matrix of inaccuracies” (Confusion Matrix);
- Overall accuracy and Kappa coefficient.

A set of ground data of field research and visual observation of land cover is carried out. Forest inventory, afforestation plans, satellite images of high resolution (Canopus-B, Resource-P) and Internet-resources as additional materials is used.

The algorithm for identification the changes in land cover based on the methodology “cellular automata” model (simulation models), which includes spatio-temporal changes in land cover.

The method introduces maps overlay by using package Spatial Analyst in software ArcGIS. At the first stage, the construction of binary digital maps takes place. The main focus on the following classes: forest land and agricultural land. The most important factor in overlay is the assignment code to each class. In our case, the three classes in maps of 1985, 2001 and 2014 have been reclassified: forest land, agricultural land and boundary (other land). For example, raster data of class “forest” in 2001 and 2014 contain the cells with value “10” and “20” respectively; raster data of class “agricultural” - “11” and “12”. In the result, each cell in the land cover layer has a value reflecting the type of land cover. Further, the direct superposition of raster datasets and getting a map of the dynamics of land cover. The output map represents maps overlay using the algorithm «map algebra» (figure 1).

![Figure 1. Maps overlay.](image)

3. Results and Discussion

In this article, we used the integrated technique of RS and GIS to update data of the land cover change for 1985-2014 in the Middle Volga region and further examine the roles played by natural and human impact factors in driving the change.

The result of multiple unsupervised classification of satellite image Landsat data were thematic maps reflecting the spatial distribution of forest and agricultural land cover. Flora of studied region is including the border of southern taiga and mixed forest cover (coniferous and deciduous). Agricultural land is including the cultivated and non-cultivated (abandoned) fields.

In the result of the unsupervised classification of Landsat TM (ETM +) satellite images, thematic maps on the studied territory of the Middle Volga region was created. On each thematic map, the main forest and non-forest classes (strata) covering the study area are presented. The overall classification accuracy of thematic map in 2018 was 84% with a Kappa coefficient of 0.82.

Major changes in forest cover associated with timber harvesting, clear cutting, forest fires and drying of spruce stands are the result of drought 2010. Mostly disturbed forest objects are represented by separate plots (cuttings that dry up tree stands) or large areas (burned in 2010). Significant areas of disturbances in the 1980s are more often the result of conducting intensive logging work. Due to the
increasing role of climate change forest fires become a main disaster. Also, during the dry season wetland (peat land, land with abundant moisture) are more dangerous from the point of view of forest fire. This is explained by the decrease areas of these classes during the research period.

Major changes in agricultural land cover associated with reforestation on abandoned agricultural lands. Such changes in land cover linked to the influence of human factor. The problem is that many rural people moved to the city, comes urbanization, agricultural lands are abandoned.

Land cover changes and its border monitoring in time and space is a fundamental research [23-26]. The results presented in article can be used for the spatio-temporal analysis of land use change with influence factors.

This paper represents the approach of the monitoring of land cover change. The methodology based on assessment of change detection in time and space. Data analysis allows identifying changes in land cover (when and where change is going on). The presented methodology will help to track the changes which taken place, to plan activities for forest planning, improve the forecasts of forest landscapes. In addition, the developed method will improve the efficiency of research work and activities of forest enterprises for estimation the changes of forest management and improve the quality of thematic mapping. Influence of social-economic aspects is also important in these researches. Timely and accurate change detection is an important indicator in decision-making of sustainable forest management. Practical use of the developed method can be useful in assessment of changes in agriculture and forestry. Also, research has important for decision of issues under climate change and the role of forests in the global carbon cycle.

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