Multifunctional landscape assessment

Sandlerskiy R.B., Stefanov S.V., Puzachenko Y.G., Puzachenko M.Y.
A.N. Severtsov Institute of Ecology and Evolution RAS, 33 Leninskij prosp., 119071, Moscow, RUSSIA, *srobert_landy@mail.ru*

Abstract

This report concerns to application of complex approach named «multifunctional landscape assessment» for specific task of developing a procedure of monitoring of Reserve. «Multifunctional landscape assessment» is a direction of researches which concerns complex assessment of landscape, its features and functions based on modern view on complex systems, newest measurement means and information processing (Puzachenko 2007). Using field measurements and digital elevation models, remote sensing connected with hypothesis which come from non-equilibrium thermodynamics, theory of non-linear dynamic systems, synergetic and modern methods of quantitative analysis. «Multifunctional landscape assessment» gives methodological and technological basis for surveying landscape as a system which reflects reality and targeted to obtaining new knowledge, verification of existing knowledge and synthesis of new examined hypotheses and models.

Development of monitoring procedure of «Yamskaya steppe» cluster of state nature biosphere reserve «Belogorie» in scale 1:10000 needed versatile assessment of landscapes and their dynamics. Potentially as basic danger factor we accounted tailings dam of Lebedinsky Mining-Concentration Complex and their possible influence to hydrology of the Reserve. To assess this factor a detail analysis of relief was needed before and after dam creation. All this tasks were solved basing on «Multifunctional landscape assessment».

Key Words: landscape assessment, monitoring, remote sensing

Introduction

Cluster «Yamskaya steppe» of state nature biosphere reserve «Belogorie» lies close to Lebedinsky Mining-Concentration Complex – leading producer of raw iron ore in Russia. Its share is 21% of inner market. From middle ninetieth the tailings dams were organized on the territory lies closely to reserve. Potentially they influence landscapes of the Reserve via changing the level of ground water. We tried to confirm or to contradict this hypothesis by four independent sources of information: digital elevation model, satellite multispectral imagery for various years, field measurements of soil moisture, seismic profile sampling data. The landscape map also been created during research.

Materials

Survey territory - cluster «Yamskaya steppe» of state nature biosphere reserve «Belogorie», geographic coordinates 51°11’N, 37°38’E. Cluster area is 6 square km. Closest locality – Stary Oskol, lies 15 km from cluster. «Yamskaya steppe» - the only residual of forest-steppe landscape in European part of Russia. Reserve is situated in moderately cold climate, moderate precipitation. Annual precipitation (570 mm)

exceed annual evaporation (408 mm). Reserve lies within Voronezh crystalline shield. Most ancient bedrocks which lie close to surface – are deposits of Upper Cretaceous, presented by malmrocks and chalk-stones. Bedrocks are covered by continuous mantle of loess loam sedimented by Dnieper glaciation outwash. Relief of the Reserve is typical erosion type. All its territory is strongly cut and drained by deep narrows with numerous branches. Elevation – 190-230 above sea level. «Yamskaya steppe» is the southern variant of meadow steppe. Special value of the Reserve is its soils. Black soils have the most abundant with nutrition elements (depth of humus layer reaches 1 m and more).

There are following data and materials have been used for the analysis:

- temperature and precipitation monthly average data since 1901 till 2001 years (project CRU2.0, Mitchell T. 2006) – for the analysis of climate dynamics;
-NDVI data since 1981 till 2001 (NASS, 2007) – for the analysis of productivity dynamics;
- multispectral imagery Landsat TM and ETM with resolution 30 meters per pixel, 7 summer scenes since 1988 till 2007 years – for the analysis of landscape energy characteristics and it's dynamics estimation;
- QuickBird satellite scene with resolution 2 meters per pixel – for the accurate georeference other materials;
- digital elevation model (DEM) with resolution 30 meters per pixel, based on topographic maps of scale 1:10 000, and DEM SRTM, based on radar images with resolution 90x90 meters – relief structure analysis and comparison original (from the topographic maps) and modern anthropogenic relief (SRTM);
- vegetation (300) and soil (200) field descriptions – interpretation of soil and vegetation types based on DEM and remote sensing data;
- seismic profile shooting data with 5 meters step for 2 transects (2800 and 3200 meters length) – vertical profile moisture estimation and determination of high-moisture layers;
- soil moisture field measurements at a top 15 sm soil layer with 20 meters lateral step using TDR-100 sensor – estimation a spatial variation of top-layer-soil moisture.

Methods

Data processing has been realized using Statistica 8.0 software. All data was combined into a database using MS Access and GIS MapInfo. Processing time series (dynamics of precipitation, temperature, NDVI) has been realized using spectral analysis. Analysis included the following tasks: evidence of non-random fluctuations or trend (autocorrelation); allocation of periodic components (spectral analysis); determine of dynamics components (filtration using Fourier method); assessment of the possible impact of the dynamics on hydrological regime and ecosystem processes.

There was made a calculation of energy variables based on 7 scenes of multispectral Landsat imagery. Remote sensing allows estimating the energetic condition of a terrestrial surface and features of solar energy transformation in ecosystems at the surveying moment. Satellite measurements in the different spectral zone of the reflected solar energy in comparison to a solar constant permit to calculate absorbed solar radiation on unit of a surface, albedo. The image of thermal channel shows the spatial heterogeneity of land cover temperatures.

Have been calculated: coming solar energy (Wt/m^2), the reflected solar energy (Wt/m^2), albedo, the absorbed energy (Wt/m^2), Kullback's entropy (nit) - measure of distinction of two compared distributions, and it is the important physical parameter of the open no equilibrium thermodynamic systems, exergy of absorbed solar radiation (Wt/m^2) – energy expenses for evapotranspiration (Jorgensen, Svirezhev, 2004), an increment of internal energy (Wt/m^2), flow of heat (Wt/m^2), temperature of a surface (ºC), a share of the absorbed energy spent for manufacture of biological production (Wt/m^2). All energy characteristics have been analyzed using factor analysis with allocation of base variables, generalizing all variables for all periods of Landsat image boards. Also dynamics of main base variables for 20 years was estimated.

Target of DEM analysis is determination parameters of relief, estimation its current state, relief typology mapping, allocation of river basins and characteristic structures as a basis for designing a monitoring system of groundwater and atmospheric transitions. In addition, parameters of landforms on different hierarchical levels considered as factors, that redistribute atmospheric moisture, mass transfer, solar radiation and, relatively, potentially determines the state of soil and vegetation, and as a result landscape structure of territory.

Analysis of the hierarchical organization of the relief produced by two-dimensional Fourier spectrum. According to the scheme Turcotte (Turcotte, 1997), two-dimensional spectrum collapses into one-dimensional, then the trend removed from this spectrum and analyze the residuals. Those present in the spectra of periodic components, are associated with hierarchical levels. For each hierarchical level is calculated morphometric characteristics: the absolute elevation, slope, surface shape (convexity, concavity - Laplacian).

Analysis of landscape structure and making the landscape map is based on the consistent integration of properties through diskriminant analysis. The analysis included soil type, soil depth, type of soil-forming process, the degree of gley, the depth of effervescence carbonates, the depth of bedrock, a class of plant communities and a group of associations. Discrimination is based on the characteristics of a relief for the four spatial levels, reflecting the steepness and shape of the surface and channel location Landsat.

Results

Analysis of precipitation ant temperature for 100 years and NDVI dynamics for 20 years shows that regional climate can be recognized as significantly stationary. Observed warming during last 40 years is significant but revealed as a general tendency with small input into total variance. On separate intervals for example 1981-2001 it is not expressed. Ecosystem dynamics seem to be quasi-periodical with productivity change first as a function of temperature oscillation. Precipitation in general is constant respectively the hydrological regime determined by climate is also stationary. Formally the stationarity of processes in time allows to believe stationarity of hydrological regime relatively to relief and geological conditions which transform outflow.

Multidimensional analysis of relief and its forms typing gives a map which can be used as by designing of ecological monitoring as by complex ecological research grounding. Important functional properties of relief are revealed through analysis: asymmetry and crucially different structure of opposite watershed slopes, layout of potential hydrologic relations of watershed surfaces, combes and narrows,

localization of karst forms. Simple comparison of initial and anthropogenic relief allows to measure potential area and level of anthropogenic change of hydrology of Reserve. Thus, analysis of relief allowed to create basis for designing landscape map and to reveal important basements for conception of hydrologic and hydro-geologic monitoring, which include prove of slope asymmetry and most probable direction of underground flow by flat northern and east-northern slopes, pointing out of holes which connected with heads of hollows and being suitable points of ground water control on various depth. Also – Distinct allocation of thalwegs and basins as relatively autonomous hydrologic and hydro-geologic objects, determination of approximate field of ground water change as a result of man-induced change of flow basis. Comparison shows that flow basis in northern and western part of Reserve increased for 30 m, eastern - for 60 m.

Analysis of energy characteristics for seven terms shows that there are two independent basic variables (principal components): first integrates temperature, NDVI and variables connected with entropy. Second – exergy (heat input for evapotranspiration). At that, the higher the production, the higher Kulbak entropy as measure of system non-stationarity and the lower heat flow and bound energy. Thus, first component reflects production process, second one – heat absorbtion and evaporation heat expenses. Maps of relative productivity and relative evaporation can be designed as well as land facies can be detached. Analysis of energy characteristics would be limited by exergy and productivity. Energy expenses for evapotranspiration increased from 1988 till 2007. Exergy and respectively soil moisture on the watershed changed insignificantly. North-eastern part has significantly «dried». Southern sloped moistened well especially narrow bottoms as well as north-eastern slope turned to Mining-Concentration Complex. This distinct configuration of changes forces to accept the only hypothesis: changes observed are determined by increase of ground water level foremost at depth of 30 m and as a result of moistening increase mainly in narrows less on the slopes. Thus we can accept the fact the changes of hydrologic regime from 1988 till now. It has only one explanation confirmed with other independent measurements.

Seismic profile sampling. Basing on this measurements we can say that tailing dam increases ground water level on depth 45-70 m in eastern part of Reserve and 28-37 m in western part. In center of the Reserve ground water level seem to stay the same. Analysis of moisture measurements in 15 cm depth on transects shown that there is hydraulic connection between all layers of hydrologic basin and surface even on watersheds on highest parts of territory. Peaks of soil moisture in the highest part of transect force to suppose artesian water inflow into upper layers of soil-forming rocks.

Analysis of landscape structure revealed that properties and components of landscape are relatively independent and in general landscape is characterized by 15 basic independent variables – factors, main six of them are presented on fig. 1. First factor reflects influence of macrorelief (fig. 1.a), second one – change of black soil depth (fig. 1.b), third one – moisture (fig. 1.c), fourth one – erosion network combined with drainage (bottoms of valleys are more drained than the slopes) (fig. 1.d), fifth one – elements of land use (fig. 1.e), sixth one – biological productivity (fig. 1.f).

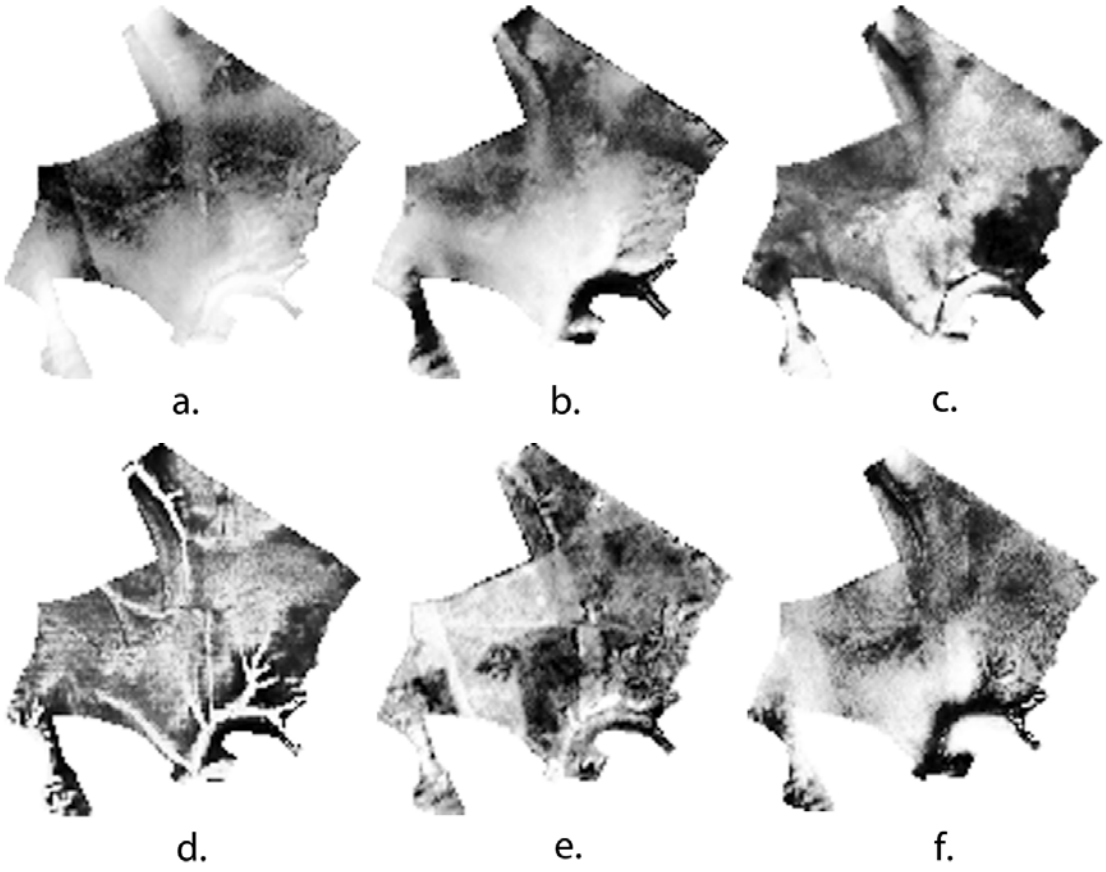

Fig.1. Leading factors of Yamskaya Steppe landscapes differentiation
(the lighter -the higher the value)

a. - influence of macrorelief
b. - change of black soil depth
c. - moisture
d. - erosion network combined with drainage
e. - elements of land use
f. - biological productivity

Dichotomic classification realized upon integral landscape factors on 4-th level reflects landscape structure on a stow level, 6-th level – land facie level. To understand semantics, landscape classes using statistical methods are compared with features of vegetation, soils, relief and energy characteristics. Vegetation and soil maps using DEM and remote sensing data, through interpolation of field sampling.

Conclusion

This report concerns all stages of landscape analysis of territory based on field sampling, digital elevation model and remote sensing information. For managing its territory and monitoring organization it would be useful not only to know spatial structure of landscape but also to have concept of its functioning.

Spatial structure and functioning of forest steppe landscape is determined by activity of many factors (dimension up to 15) which follows to strong uncertainty of landscape components in space and time. High dimension is determined by diversity of soil-forming rocks and mainly complex influence of various relief properties on various hierarchical levels onto soil and vegetation properties. Under simple spatial macro-structure, we see diverse micro-structure.

After series of independent measurements from various positions we confirm hypothesis of tailing dams influence to hydrological regime of Reserve territory. Based on work performed we propose layout of multifunctional monitoring of Reserve's territory.

We have shown that approach of ecological monitoring design based on spatial multidimensional landscape analysis can be considered as prospective one and decreasing non-certainty of selection of observation objects. Basing on it we can minimize labour expences for data collection under their high informativeness.

Acknowledgements

The work was financially supported by the Russian Foundation for Basic Research (grants no. 07-05-12021-ofi, 10-05-00039-a, 09-05-00292-a).

We are gratefully to state nature biosphere reserve «Belogorie» administration. In gathering and data processing took part N. A. Krenke (Institute of Geography RAS, Moscow), A. A. Nemikin, I. P. Kotlov (A.N. Severtsov Institute of Ecology and Evolution RAS Moscow).

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