Integrated GIS as a Tool for Sustainable Land Study

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1. Abstract

The large volumes of heterogeneous information needed for planning of sustainable land management requires collection, processing and analysis of many data. For the most rational tool is Integrated GIS which includes data banks consisting of cartographic and remotely sensed data as raster and vector layers. Remotely sensed data is often indispensable because they allows to fix simultaneously landscape state as a whole or its separated components over large areas and it allows comparison of images acquired at different times to observe dynamics. The importance of digital multi-spectral images, especially with high spatial resolution is increasing. The required set and scale of cartographic materials depends on the properties of the investigated objects.

For example, for the study of soils the following large scale maps are used: geological, map of Quaternary sediments, relief, geochemical, hydrogeological, topographical and others. However, fieldwork is also needed. The results of ground observations are entered into the data bank as separate blocks and used for further integrated analysis aimed at sustainable land management. One way of control of sustainable land use is monitoring by systematic and special interpretation of remotely sensed data and limited ground observations with compilation of thematic maps.

Such works were executed for some Russian regions with the aim to study the state and long term changes of landscapes; changes of agricultural areas (structure and quality), including recultivated land in mining districts. The result of such work is included in recommendations for sustainable land management.

2. Introduction

High intensity anthropogenic forces exerted on the natural environment cause global changes. For estimation and prediction of these changes it is necessary to carry out longtime observations at different levels (regional, local and others) and operative analysis of the data and their generalization. Spatial environmental monitoring which includes recurrent observations based on remotely sensed data was elaborated at VNIIKAM. The main monitoring purpose is observation of environmental state and its changes under the influence of natural and technogenic factors. Remote sensing provides operative information on environmental changes which allows to take timely measures and to predict unfavourable processes.

The most important and available source of ecological information is multi-spectral satellite data: RESURS, LANDSAT, SPOT, JERS and RADARSAT.

They are the basis of Integrated Geographical Information Systems (GIS) which allows operating and analyzing various types of information using ARC-INFO, ERDAS and others. GIS is an effective tool for ecological investigations because it allows analyzing many satellite images and maps at the same time. The map compiled on the basis of satellite images with geological and landscape data is the main form to register the environmental state. Comparison of images reflecting the state of the objects at different times is conducted to study the dynamics. The earliest state is considered as initial and the map reflecting this state is called the base map. The base map is compared with others. In ideal cases base maps reflect the natural state before anthropogenic disturbance. But in the North-West of Russia such areas were practically not retained. Therefore, the maps of anthropogenic disturbance compiled in the first stage of dynamic observation are considered as base maps. Such maps are classified as inventory maps. The natural complexes with anthropogenic changes and technogenic objects and processes are registered on them. Objectivity and quality of map making are stipulated both with regard to estimation of natural environment state and reliability of forecast changes, i.e. the main task of monitoring. These requirements may be satisfied by means of new types of remote sensing and by using contemporary technologies of data processing and interpretation.

3. Remotely Sensed Data

In accordance with the large variety of technogenic influence forms and types, it is important to define the requirements to remotely sensed Data (RSD). The requirements include type of data acquisition (photographic, multi-spectral, radar, infrared), ground resolution, scale, season, time, hydrometeorologic conditions and route direction. RSD impartially reflects the Earth surface structure for the time when the survey was done according to wavelength of electromagnetic spectrum. The satellite images contain the information on landscape, relief, hydrography, vegetation, soils, geological features and technogenic objects. RSD allows recording and analyzing the types of intensity, relationships of different influences on the environment with accuracy and speed over large areas. The analysis of satellite images collected at different times gives the possibility to trace dynamics and predict trends of environment components development. The selection of RSD is defined by the environmental monitoring system - the regulated system of remotely sensed observations of all environment components (Ecosystems) and their changes caused by natural and technogenic processes. RSD is a basis for a system approach to environmental monitoring of ecosystems and their parts. The scale width of RSD allows studying ecosystems at diverse levels. Multi-spectral satellite data acquired by RESURS, KOSMOS-1939 (MSU-SK), are used for investigations at the global level; KOSMOS-1939 MSU-E), SPOT, LANDSAT (MSS and TM), JERS-1 (OPS)- for regional and local levels and aerial photography with high resolution acquired by KFA-1000, KVR-1000, TK-350 - for detailed levels. Field investigation data and knowledge of relationships between different natural objects broaden the possibilities of remotely sensed images interpretation.

4. Integrated GIS

For study and evaluation of the compounded impact of technogenic factors on the environment and prediction of changes, much and heterogeneous information is needed. Collection, processing and analysis of ecologically relevant data are required. Above mentioned tasks may be most efficiently solved by means of Integrated GIS, which allows to use large volumes of vector, raster and statistic data.

- These are firstly materials from airborne and satellite surveys, which allow to record the environmental state simultaneously over considerable areas. Comparison of images obtaining at different times permits to observe the dynamics of the environment.
- The second type of necessary information are cartographic materials included as vector layers such as geological, geomorphological, mineral resources (ores, hydrocarbons, building materials), Quaternary deposits, soils, vegetation, topographic, landscape, economic, medical-biological and others maps.
- The third type of information is statistic data on environment, economy, natural resources, infrastructure etc.

These three types of data are the basis of Integrated GIS. An important problem is the elaboration of a data organizing structure which could provide their easy input, saving accuracy and informative content, as well as provide rapid and efficient spatial data processing.

The GIS systems Geo Draw 2.0 and Geo Graph under Windows (version 1), elaborated by the Centre of Geoinformative Research of the Russian Academy of Sciences were used.

5. Technogenic Processes

All technogenic objects and processes are in one way or another negative influence on natural environment components: atmosphere, relief, vegetation, soils, surface and ground waters.

Deterioration of the air within a region as well as outside is caused by waste products of mining and metallurgical, pulp and paper and other plants and is a serious problem. Heavy metals, sulphur, arsenic, bromine, cadmium, strontium and others get to the Earth - surface from the atmosphere.

Degradation of forest and depletion of timber resources are observed. Intensive logging is carried out over large areas. The rate of logging far exceeds the rate of forest rehabilitation. Reduction of rehabilitated forest areas has led to a decrease of the numbers of birds and animals.

The soils of region are subject to significant change, including soil disturbance (due to mining works), erosion, formation of marshly, drying, impoverishment, chemical pollution and others. They lead to a reduction of the soil's fertility.

Upper groundwater is polluted with heavy metals, nitrates, phenols, chemical fertilizers and others.

All these factors create critical ecological situations in some ecosystems in the North-West of Russia.

The investigations of economical and ecological characteristics carried out by the Geography Institute of the Russian Academy of Sciences allow classifying this region as an area with the highest level of technogenic disturbance of natural environment.

To understand the processes of regional environment changes it is necessary to study the influence of natural and anthropogenic factors. So we will consider these factors in more detail with reference to different test sites in the investigated area.

6. Stages of work

After determination of the GIS project aims and tasks the work was realized in several stages.

- I stage. Planning and creation of the data base involve the following operations:
  - input of spatial cartographic and remotely sensed data;
  - editing and creation of topology;
  - input of attribute data;
  - preliminary data processing including transformation to certain cartographic projection.
- II stage. Interpretation of remotely sensed data and compilation of preliminary thematic maps.
- III stage. Analysis and preparation of cartographic data and execution of spatial operations, estimation of acquired results.
- IV stage. Presentation of results as graphic documents - maps; schemes, compile recommendations on organization of aerial and space environmental monitoring and recommendations to planning and project works.

7. Ecological situation of the test sites

The investigations were carried out in the North-West of the European part of Russia. The area of investigations includes the Kola peninsula, Kareliya, and the Leningradian, Novgorodian and Pskovian regions. This area is of great significance for the Russian economy and characterized by a great number of industrial, agricultural plants and large populated areas in this region. The largest lakes of Europe-Ladoga and Onega are in this region. They are of great significance for the supply of drinking water.

7.1 Kola peninsula

The western part of the Kola peninsula is subject to intensive technogenic influences. There are large integrated mining and metallurgical plants (Nickel, Monchegorsk, Apatity, Zapolyarny and others) and the Kirovsk power-station is situated in this region.

On the satellite images we can see the deserts formed around industrial centers. For example, in the Monchegorsk region the vegetation is destroyed over an area of nearby 300 square kilometers.

Near the city of Nickel the desert aggregates of the rate of 1-2 km each year. The plants of Kirovsk and Apatity throw out near 180 million cubic meters of waste, the main part gets into the Imandra lake - the largest lake of the Kola peninsula. The formation of gigantic dumps, deep quarries, reservoirs, storage of slags and other constructions is the result of the exploitation of mineral deposits. The area of these constructions is increasing and they are the sources of dust transferred by wind over a large distance. Satellite images of high resolution (to 10 meters) or aerial photography are used to study these objects. The dynamics maps for the mining areas are compiled on the basis of these images.

Other sources of air pollution are eruptions of sulfur gas that affect soils and vegetation. Their influence is spreading to the Kola peninsula as well as to Northern Europe.

In the Laplandian preserve, which is situated to the south of the "SeveroNickel" plant, the influence of this plant is spreading over a distance of 60 km. There is increased acidity in the lakes of Laplandiya due to acid rains. In the Inary area (North Finland) an increased concentration of heavy metals is observed in the moss. During the past three years the ecological situation of the Kola peninsula became worse due to the changes of the economic mechanism and the decrease of technological discipline that led to increased eruption of polluted substances to atmosphere and water reservoirs. Disturbances of the vegetation cover are clearly visible on satellite images as changes of spectral characteristics.

A considerable part of the Kola peninsula is situated in the taiga and characterized by intensive logging that brought about a significant decrease of the forest areas.

Comparison of the images obtained in different years have allowed to trace the dynamics of environmental changes on the Kola peninsula (Western part).

7.2 The Kareliya

Kareliya is situated in the taiga and characterized by intensive logging and development of the timber industry. The main ecological problem is connected with the significant decrease of the pine forests that is clearly observed on satellite images.

The industrial objects: mining, metallurgical, pulp and paper plants and thermal power stations are concentrated mainly in the southern part of Kareliya. Eruptions of harmful substances affected the vegetation and soils over large distances.

Stockbreeding farms situated near rivers and lakes do a great harm. Pollution from the farms is spreading over a large distance along rivers and lakes.

To study and estimate the combined influence of industrial and agricultural emission points, the maps of the sources, and migration of harmful substances are compiled on the basis of satellite images and after the determination of impact zones is conducted.

7.3 Leningradian region

The Leningradian region is situated in the taiga. This area is characterized by complex and intensive technogenic activity. There are many plants of heavy mechanical engineering, energetic and electromechanical engineering, aluminum, chemical, pulp and paper, mining and timber industry as well as many agricultural objects (pig breeding, cattle-breeding and poultry farms, pastures and crop areas). All these plants and farms directly or indirectly influence the natural environment and cause pollution:

- gas and dust substances in the atmosphere;
- toxic matter in surface and ground waters;
- heavy metals and chemical poisons in soils;
- eruptions of industrial plants and others, affect the vegetation.

The interpretation of satellite images collected at different moments shows that a decrease of forest area is observed in the Leningradian region particularly in its northern part, where a National park will be created.

The industrial centers particularly St.Petersburg are characterized by high water consumption and disposal of sewage into rivers, lakes and the gulf causing pollution by suspended matter, oil products, factory wastes and other harmful substances, sometimes toxic.

This pollution is of a regional character because all surface waters are included in the system - Ladoga Lake - Neva river - Finland Gulf - Baltic Sea. The application of remotely sensed data has permitted to estimate the natural environment state of the region. For the fulfillment of this task, observations on deforestation due to logging have been conducted, maps of pollution sources, trends of migration and areas of pollution and maps of anthropogenic disturbances and landuse have been made. The changes in the hydrodynamics of the Finland Gulf caused by dam construction have been traced.

8. Conclusions

Application of GIS to study the state and human-induced changes of the environment allows solving the following task:

- identification of pollution sources and of technogenic influences on the environment and appraisal of its character and affected zones;
- estimation of the contemporary state and dynamics of the environment, and prediction of its changes in mining, peat oil and gas exploitation regions;
- control of felled areas and overgrown felled areas;
- control of soil erosion in agricultural regions;
- land use control.

The results of the investigations are presented as various thematic maps composed by using GeoDraw and GeoGraph software for example:

- maps of the environment (state and dynamics) in mining/industrial regions of North-West of Russia;
- zoning maps of areas with different types and degree of technogenic load;
- prediction maps of environmental changes, etc.

These maps are used for execution of ecological monitoring of territories and to support ecological expert opinion for planning and project works of industrial and agricultural enterprises.