

Application of the Remote Sensing in Environmental Management as the Interdisciplinary Approach

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Abstract—The purpose of this study is to show the interdisciplinary integration of the remotely sensed data and in-situ measurements of different physical and biological nature and various dimensions. The set of methods for monitoring of the environment based on methods and models of the system analysis and their modification which were used in solving the number of problems is proposed. Also the description of the numerical methods of system analysis and their application is given. Approbation of the above methods were done on the variety facilities of Ukraine such as Kyiv city, Dnieper River, Kyiv reservoir, Ukrainian part of Danube River.

Keywords—remotely sensed data, system approach, environmental management, monitoring, Kyiv, Kyiv reservoir, Ukraine

I. INTRODUCTION

The use of remote sensing (RS) makes it possible to provide reliable information on environmental conditions, properties of the spatial structure of natural-territorial complexes, their dynamics and helps in accumulation of data for the development of the system natural resources monitoring [1]. The solution of these problems only through remote sensing is usually impossible without using data from related disciplines. The interdisciplinary approach is moving to the foreground in studying the problems of nature management. Open and self-improvement complex systems become the objects of the interdisciplinary research. Notable place among complex systems occupy a system, which included the man as one of its elements. Solving the problems of the environmental management based on information retrieved from space is a good example of the interdisciplinary scientific approach, the relevance of the use of which is particularly evident when it is necessary to consider many interrelated factors of different physical nature integrating data obtained from various disciplines.

The interdisciplinary research based on the system analysis methods is proposed for the remote aerospace researches in environmental management and defined as the integration of theory, methods and models, information and experimental results from different scientific disciplines.

The most rational mathematical models of the use of remote sensing in solving various thematic problems of natural-territorial complexes assessment, modeling and predicting development of the studied processes are proven by the means of the system analysis.

II. CONCEPT AND METHODS

The methods for monitoring the environmental management are developed due to the use of remote sensing and geographic information (GIS) technology which provide comprehensive monitoring of large areas. The main advantages of using satellite images are: simultaneous coverage of a large area of water area / territory, continuous information content of the image for each image point, high frequency data acquisition for analysis.

The experience of research shows that the main prerequisite for efficient decoding of satellite

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images is the integrated use of in-situ measurements and remotely sensed data. Therefore, the development of integrated methods for assessing the environmental properties is the most urgent task.

Figure 1 represents steps for monitoring the environmental management based on interdisciplinary scientific approach with regard to integration of in-situ measurements and remotely sensed data.

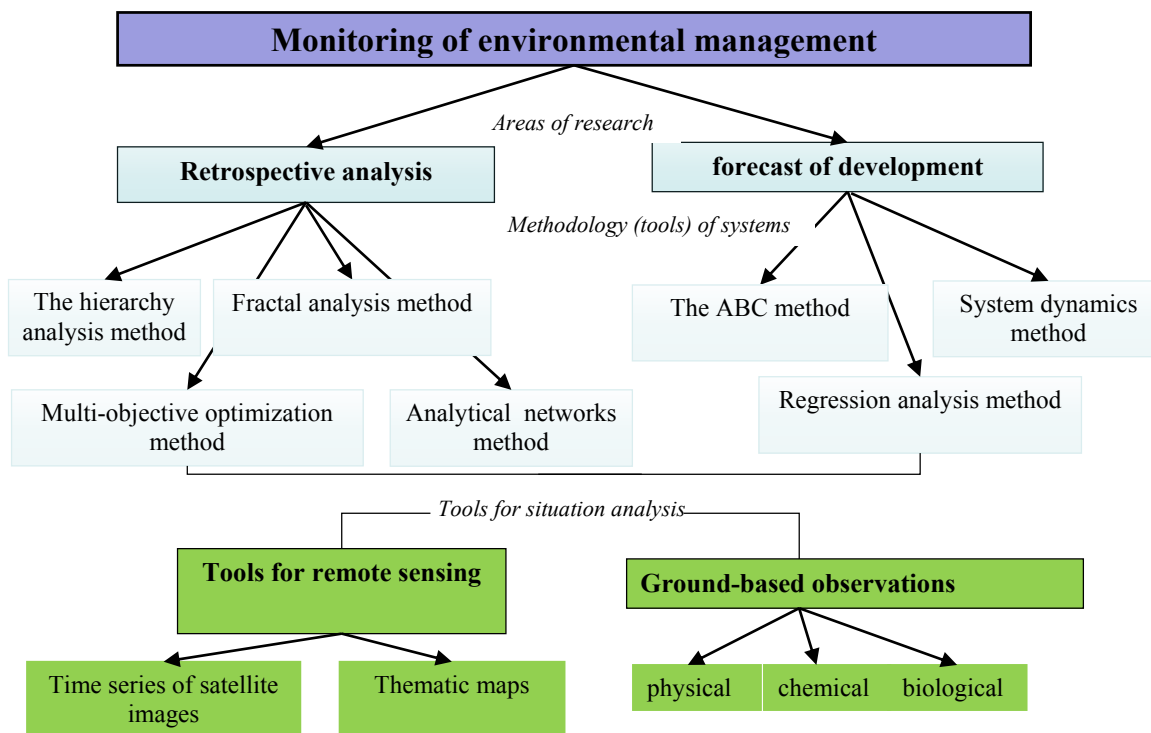


Fig. 1. Schematic representation of the stages of monitoring natural resources.

A. Pre-processing

The interdisciplinary approach to the study of nature management is presented by two different examples: urban landscapes of Kyiv as anthropogenically altered object and the top of the Kyiv reservoir, as natural water bodies of Dnieper River, which has undergone radical changes as a result of human activities. Block "tools for situation analysis" in both cases is the same material of remote sensing and ground data, but in each case it has its own features. Satellite images are chosen for the season when the selected features are better represented. For example, urban landscapes are better represented at the beginning of summer when trees are covered with leaves, but aquatic landscapes are better presented late summer, when the aquatic vegetation is at the peak of the growing season. Ground-based measurement are differ in the same way. For example, for urban landscapes - the concentration of harmful substances in the air, or the state of water pollution within the city, and for the water bodies - indicators of water quality, such as stability indices of hydrobiological organisms to organic pollution (saprobic index) or hydrophysical, such as flow rate, and water exchange rate.

Ground-based observations appear as the coherent set of characteristics. Therefore, the first stage is the examination, classification and processing of all possible ground statistics. Figure 2 shows the location of the observation points of the ecological state. Kyiv (a) and the scheme of ground structured data (b).

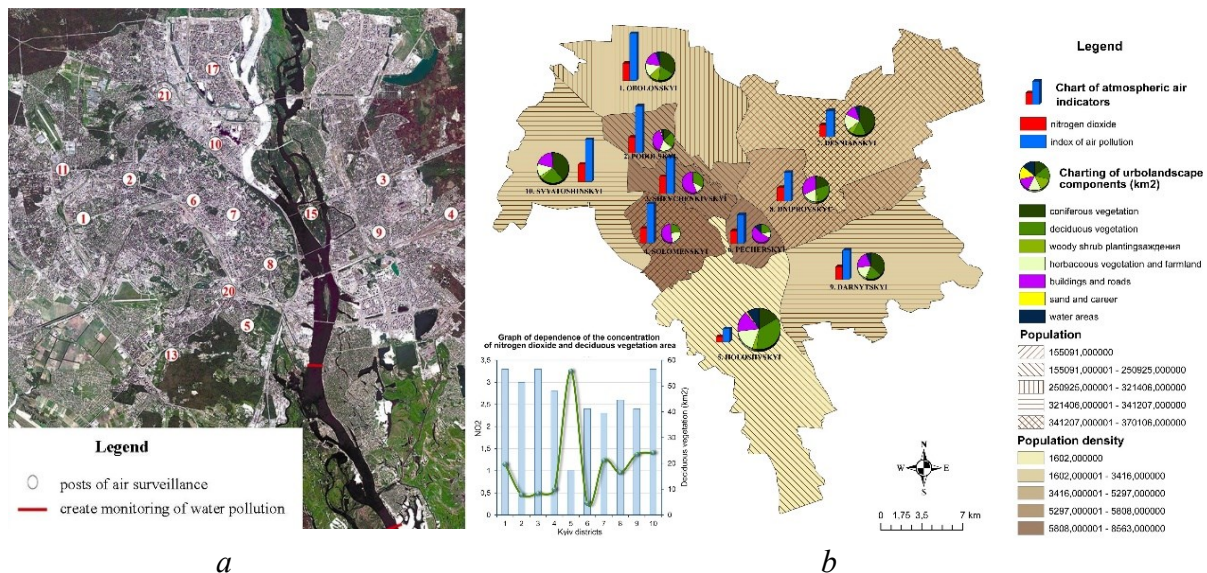


Fig. 2. Ground-based statistics for environmental assessment of Kyiv.

The next step is systematization of satellite images and their decoding for changes in the territory, such as the assessment of vegetation, areas under buildings, geological structures, surface temperature, etc. (Fig. 3, 4).

Results from decoding of satellite images and maps (topographic maps and depth maps) are used for retrospective analysis. The procedure for thematic processing of the remotely sensed data and ground-based data that are built on isolating certain combinations of objects with similar spectral characteristics related to common structural nature and uniformity of propagation conditions is developed. Maps of natural-territorial complexes are the results of such procedure. Next two ways of decoding and classification of satellite images for the following studies are developed:

- Pixel-oriented classification using neural networks to highlight biotopes on satellite images of medium spatial resolution (Landsat).
- Object-oriented classification of remotely sensed data (feature extraction) to highlight biotopes on satellite images of high spatial resolution (QuickBird).

The results of processing and interpretation of satellite images are:

- The set of thematic maps of the environment state (biotopes, vegetation and water indexes, surface temperature, parameters of landscape diversity) high and medium spatial fragmentation.
- Statistical tables with values of components from ground-based observations.

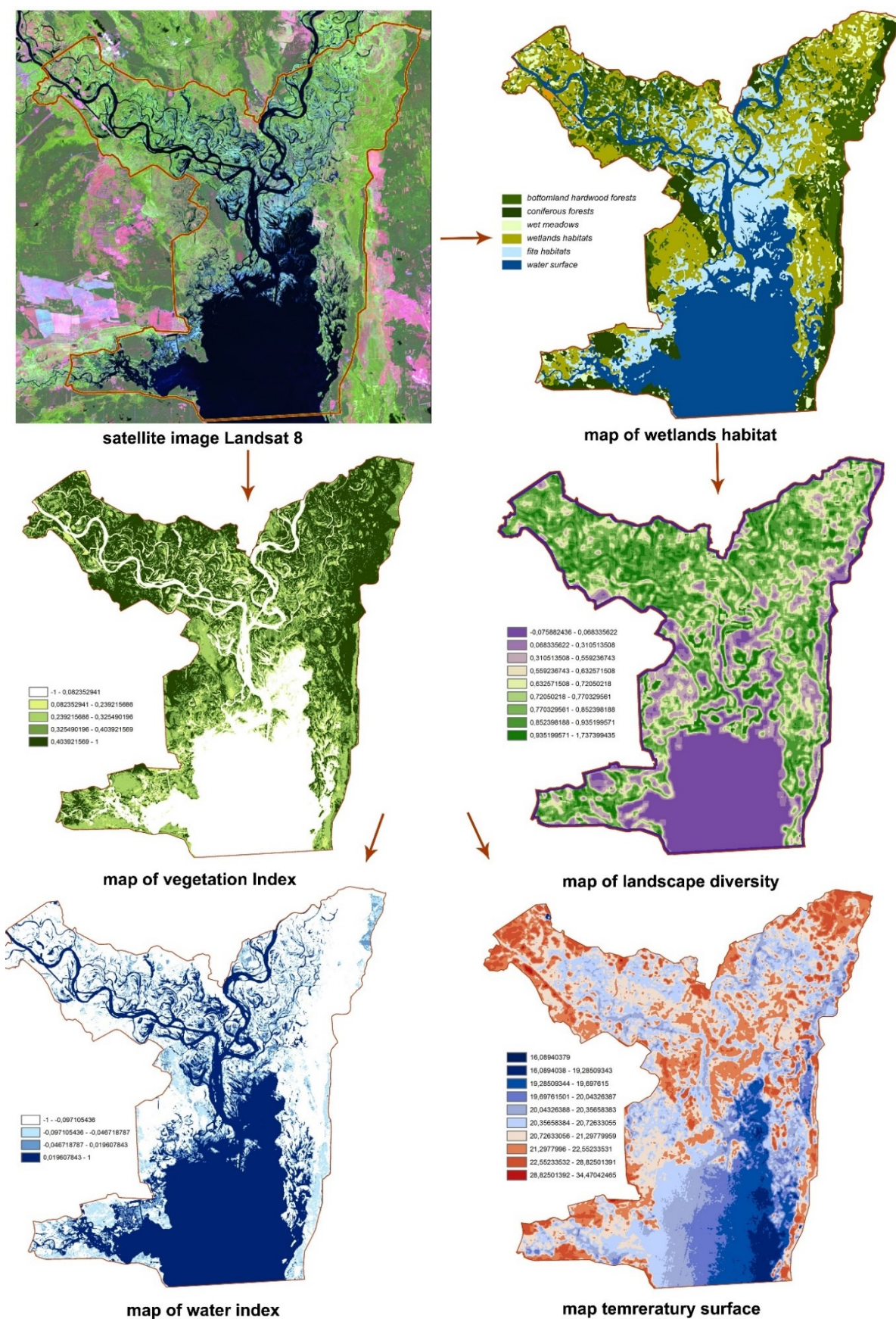


Fig. 3. Decoding of satellite images and mapping biotopes of the top of Kyiv reservoir.

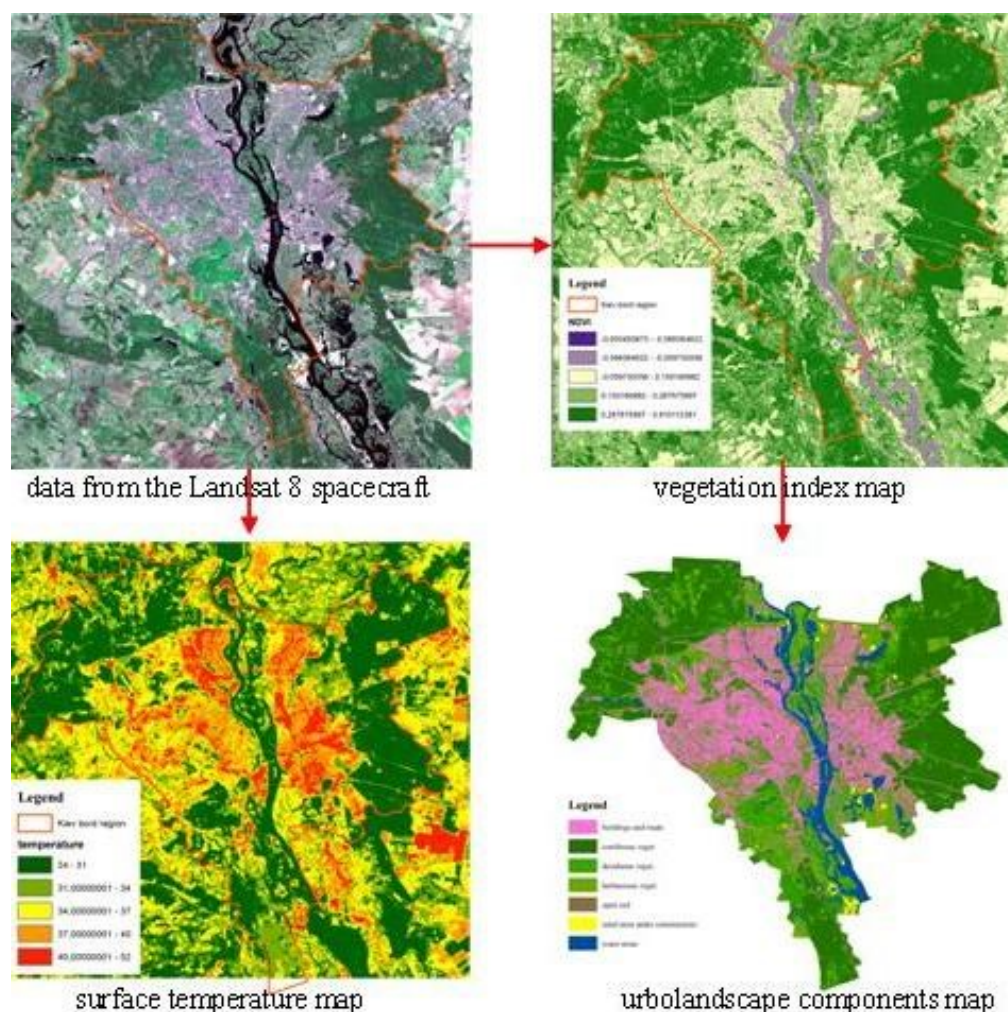


Fig. 4. Decoding of satellite images and mapping components of urban landscapes of Kyiv.

B. Methods of system analysis

The methods of system analysis is used on the next step for the obtained arrays of the statistical and remotely sensed data.

The system approach is the set of methods for decision-making system based on the comprehensive analysis and modeling of the relationships between components of processes in complex systems, including the technological, environmental, economic, and social conditions subsystems under the conditions of a large amount of information of different physical nature [2].

Different thematic environmental and ecological problems were solved in the Scientific Centre for Aerospace Research of the Earth using satellite imagery and the systems analysis methods. The theoretical basis of the system analysis methods that have been modified and adapted for monitoring and assessment of the anthropogenic facilities (for example, Kyiv city) and natural facilities (for example Svitjaz Lake, Pripjat River, Dnieper River, Danube River, Kyiv reservoir, etc.) are presented in this section.

When solving problems that need to simultaneously take into account values of many individual criteria, each of which describes one side of the problem, the *method of multi-objective optimization (MOO)* is used [3,4]. It is often necessary to find a compromise version of the studied system, when the process of selecting is done with a single generalized criterion. The MOO method consists of the following stages: introduction of proximity functions for the values and being compared, calculating values for the proximity function - S , and the membership function F (generalized criterion). The method is adapted for the specific purpose

of environmental protection by forming the corresponding generalized criterion F and choosing the functions: proximity – S and the trade off function f , which are determined by the nature of the problem.

For obtaining regularized, uniformly distributed data with a specified step in a predetermined coordinate system, the *Kolmogorov spatial interpolation technique* is used [5]. This complex of these methods is called downscaling or "reducing dimensions." Using them one can transform unevenly distributed low-resolution data into regularized datasets that fit the simulation requirements and allow minimizing errors present in monitoring systems.

Fractal analysis [6,7,8] gives the possibilities for obtaining objective geodynamic information based on real data, provides an estimation of the structure and configuration of the test process or object, the frequency of distribution of geometrical, physical and other characteristics. Introducing multifractal parameters allows evaluating the system's degree of order and resistance to external influences, which is impossible to determine by other regular statistical methods.

The fractal dimension of Renyi – D_q , which shows how tight and uniform set of items fill Euclidean space is used as a quantitative measure that describes the structure of the composite objects. The value D_q - invariant to the size of the sample area, scale.

The ability to use fractal analysis for comparison purposes of the variability of the components of the studied object establishes verification of two conditions: first, the power dependence of the growth components of the partition Z_q of the sample size N and, secondly, not growing range of features views of the generalized dimensions D_q , dynamics changes which characterize the patterns of growth and evolution process.

$$Z_q(N, q) = \sum_{i=1}^n p_i^q, p_i = \frac{N_i}{N}, \sum_{i=1}^n p_i = 1 \quad (1)$$

$$D_q = \frac{\tau(q)}{1-q} \Big|_{q \neq 1}, \tau(q) = \frac{\log \sum_{i=1}^n p_i^q}{\log N} \quad (2)$$

For simulating integrated ecosystem processes and evaluating potential resources I. Timchenko and Y. Igumnova proposed the *method of adaptive balance of causes (ABC)*, which by using basic principles of the system dynamics method is free from these limitations [9]. The ABC method allows to model and predict the development of complex systems and perform computing functions, taking into account the interaction of all the modules, each of which is in a state of dynamic balance. The balance is maintained by influence functions that relate the module with other modules of the system. The mode of dynamic balance is maintained inside the system under control of external influences on the system.

The *System dynamics method* was proposed by J. Forrester for quantitative analysis of complex systems with multiple internal connections between the elements (modules) of the system [10]. With this method, a conceptual model was elaborated and a mathematical model was formed that consists of mathematical equations describing the balance of influence in the system, based on the cause-and-effect relationships in the system. Four types of tasks are resolved by this: analysis and assimilation of information, forecasting, and planning. With the help of these models state functions are calculated, which characterize the behavior of the system in space and time. Formally, the system's levels are mathematically described by a coupled system of nonlinear first order differential equations of the following form:

$$d\mathbf{x} / dt = F(\mathbf{x}(t), \mathbf{p}(t), t), \rightarrow \mathbf{x}(t_0) = \mathbf{x}_0 \quad (3)$$

where: $\mathbf{x}(t)$ - vector – equation function (shifting states);

$\mathbf{p}(t)$ - vector – function of the system parameter;

$F(\mathbf{x}(t), \mathbf{p}(t), t)$ - nonlinear, in general time-dependent vector function, which in most cases is the difference between the rates (flow, velocity) of the positive and negative feedbacks

$$F(\mathbf{x}(t), \mathbf{p}(t), t) = f^+(\mathbf{x}(t), \mathbf{p}(t), t) - f^-(\mathbf{x}(t), \mathbf{p}(t), t) \quad (4)$$

where: $f^+(\mathbf{x}(t), \mathbf{p}(t), t)$ - rate of positive feedbacks, which include all the factors that cause the growth of the variable x ; $f^-(\mathbf{x}(t), \mathbf{p}(t), t)$ - rate of negative feedbacks, which includes all the factors that cause a decrease in the variable x .

Multiple regression method [11]. Its general purpose (the term was first used by Pearson in 1908) to analyze the relationship between several independent variables (also called covariates or predictors) and the dependent variable. The term "multiple" refers to the presence of several covariates or predictors, which are used in the model.

The *method of spectral autocorrelation* [12] is based on the statistical relationship between the values of the spectral intervals of the same spectrogram taken with a shift along the wavelength. If one consider the spectrogram as an implementation of a process with unknown characteristics along the wavelength axis of the emission spectrum, then it is advisable to use the autocorrelation function, which is the second-order correlation moment of one process, to determine the informativity of the spectral ranges.

When the evaluation of a particular process is associated with such concepts as a practical necessity, technological opportunity, economic feasibility, which are not possible to measure by direct measurements and calculations, the *Analytic Hierarchy Process* is used, proposed by T. Saaty (USA) on the basis of the linguistic approach and expert data [13]. It allows to form the desired objective function and hold rating alternatives based on expert judgments. The main problem of the method consists in a sequential decomposition of the objective function into simpler criterial components - indicators that are combined in appropriate hierarchical levels. The most important stage is the construction of a hierarchy of judgments between the first and last levels.

$$F = \sum K_l^1 \sum K_m^2 \sum K_r^3 \sum K_p^4 \cdot x_p^s \quad (5)$$

Where the top index of the criteria priority K_j notes the hierarchy level; x_p^s - coefficient of the advantage of option s by the indicator p , F - generalized criterion.

$$K_1 = a_1 / \sum_i a_i; \dots; K_n = a_n / \sum_i a_i, a_1 = \left(\prod_{j=1}^n a_{1j} \right)^{1/n}; \dots; a_n = \left(\prod_{j=1}^n a_{nj} \right)^{1/n} \quad (6)$$

During this, the objective function is decomposed into simpler indicators, which are combined in appropriate levels of a hierarchical scheme. To formalize the expert procedure we construct a set of matrices of pairwise comparisons for each level and for each component of the hierarchical level. Their normalization is held and priority vectors K_j are rated in terms of their effect on the components of the previous level. The matrix processing, for example, of four equations makes it possible to calculate the priority vectors of the respective equations K^1 , K^2 , K^3 and K^4 - components determining their priorities from the expert viewpoint. The meanings F allow establishing the advantage of one or the other alternative states of the system along the totality of the factors considered.

III. RESULTS AND DISCUSSION

In CASRE IGS NAS of Ukraine next thematic problems in nature management have been solved on the basis of satellite imagery and system methods:

- evaluation and improvement of water quality Dnieper River estuary and analysis of anthropogenic impact on water resources and aquatic vegetation classification of areas

and the quality of water in the Pripyat River mouth area [14];

- comprehensive assessment of the ecological state of water bodies (for example Lake Svitiaz) [15];
- study of wetlands (for example, the top of the Kyiv reservoir) [16].
- assessment and forecast of urban areas on the example of Kyiv [17];
- the study of changes in coastal marine areas; [18];
- monitoring of aquatic landscapes Kiliya delta of the Danube River [19].

The following conclusions were made using a multidisciplinary approach on Kyiv reservoir:

- Creation of integrated criterion for evaluation of water quality based on remote sensing data including indicators that have positive and negative effects set the change of state of the Kyiv reservoir towards a slight deterioration in the quality of water for consumption purposes.
- The developed hierarchical model of expert assessment of the ecological functions of Upper Kyiv reservoir proved that the analysis of ecosystem value of waters should be based on an assessment of the capacity of the operation of two of its main components: the maintenance and production and implementation of three directions of reservoir purpose such as: maintaining biotic diversity, water supply and electricity.
- The distinct relationship have been found between the dynamics of changes in the structure and condition of wetlands reservoir. This relation is the priority for operational control of the reservoir ecosystem. The developed ABC model confirmed the direct relation between water quality and the degree of the overgrown shallow biotopes.
- Predictive estimation of wetland of the top of the Kyiv reservoir up to 2023 is done based on various factors. This showed a clear tendency for further transformation of major biotope types in the direction of growth that will further improve water quality and enhance the potential of biological resources reservoir.

The following conclusions were made during assessing and forecasting of the ecological state of the environment in Kyiv:

- The relationship between the dynamics of changes in the structure of components of the urban landscape and environmental condition of the city was established. This confirmed the feasibility of space monitoring for operational control of the environment of the urban area.
- The complex criteria for environmental assessment of urban areas based on remote monitoring was developed. This also includes indicators that have positive and negative effects on the ecological state of the city. The change of state toward deterioration by reducing the amount of green space and increased density in the central built-up area boroughs was found.
- A multifractal model of the city was made. It allowed describing components of urban landscapes using fractal analysis and conducting a study of variability of components of the urban area.
- Modification of Graham-Forrester dynamics system model of city, allowed to conduct integrated environmental assessment of urban areas based on information obtained from remotely sensed data and ground-based environmental and socio-economic statistics and get the estimation of the environment of Kyiv up to 2025. This showed clear trends in further deterioration of the ecological state of the city by increasing the density of the built-up part of town and destruction of adjacent green plantations.

IV. CONCLUSION

The suggested approaches make it possible to monitor the condition of the explored territory

at a qualitatively new level, to predict the change in the environmental situation with minor errors and to develop a balanced management and action plan for public services.

Further development is seen in increasing the efficiency of remote research in environmental management by extending functionality through the development of methodological base such as interdisciplinary scientific direction: integration of knowledge from different disciplines and areas of information and different physical parameters of various dimensions.

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