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Cartographic Modeling of Pipeline Routes in the Arctic Zone of Siberia

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Abstract—This paper presents the scientific-methodological approaches to cartographic GIS-based modeling of pipelines with geoecological restrictions which essentially imply a spatial multiparametric analysis of the natural potential of the study territory in order to explore its possibilities of consistently performing the socioeconomic functions as pre-assigned without disturbing the life-support (environment and resource reproduction) functions. The suggested technique is illustrated by the example of selecting the route for the laying of the pipeline system on the model territory in the arctic zone of Siberia. Critical principles are applied to the technique of cartographic modeling of the pipeline route, i.e. the principles of systemacy, ecological security, priority of estimated indicators, unity of assessment and economic expediency. The following investigation methods were used in implementing the technique: ranking of the properties of natural landscapes according to their influence on the suitability of the territory, qualimetric assessments for the suitability classes of lands of natural systems, and graph theory for determining the optimal pipeline route on the basis of Dijkstra's algorithm. The table of unnormalized and normalized weight factors is compiled, which are taken in consideration for assessing the suitability of natural landscape components and their characteristic properties. Archival and published reference data are used to calculate the reference values of the indicators used in an integral assessment of the suitability of the territory for the laying of the pipeline route.

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INTRODUCTION

For informational support of efforts related to governance of nature management in the arctic zone of Siberia, the system of cartographic-space monitoring is being developed, which is intended for real-time collection of geospatial data on natural and anthropogenic processes and phenomena, and for their assessment, forecasting, visualization and supply to customers. Monitoring of this type incorporates processing technologies of Earth's remote sensing data (ERSD), digital cartography and geoinformation support [1–3].

One of the most challenging problems to be dealt with by the system of cartographic-space monitoring involves an integrated assessment of the territory suitability for anthropogenic impacts which is implemented by using the methodology of cartographic GIS-based modeling. This is considered to mean the spatial multiparametric analysis of the natural potential of a territory in order to determine its ability to steadily perform the socioeconomic functions assigned to it, without disturbing the life-support functions (environment and resource reproduction). The complexity of solving this problem is caused by an inadequate level of the algorithms for conversion geospatial data in accordance with requests of customers, except for the solution of Cartometric problems.

METHODS OF CARTOGRAPHIC MODELING

It is appropriate to use, as the basis of cartographic modeling, the geosystem concept of nature management realized in terms of the basin-landscape approach [4–6]. Its main statements are:

– the landscape geosphere has a basin-landscape hierarchy;

– basin geosystems are characterized by the landscape organization;

– within basin-landscape geosystems, the natural conditions and economic activity are closely interrelated;

– basin-landscape geosystems are optimal territorial units for control over the state of natural environment, and

– a combined use of cartographic and simulation modeling of basin-landscape geosystems in terms of GIS provides the basis for an optimization of nature management.

The technique thus developed relies on the following principles [7–11].

1. The principle of systemacy. Determination of the territory suitability for anthropogenic development must be based on the theory of system analysis. In terms of this principle, it is possible to consider each characteristic involved in cartographic modeling not in isolation but in the form of one of the elements of the natural-technical object created.

2. The principle of ecological security. Cartographic modeling must take into account anthropogenic loads resulting from the construction of the object of anthropogenic development and from its exploitation.

3. The principle of priority of estimated indicators. When determining the territory suitability for the location of a facility, it is necessary to take into account the degree of influence of each characteristic on the resistance of the natural environment to anthropogenic impact, i.e. the assessment criteria must be ranked according to their influence on ecological security of the natural-engineering system created.

4. The principle of unity of assessment. A cartographic modeling within the whole of the study territory must be carried out according to identical attributes (their form and number) having common assessment (qualimetric, axiometric) scales (assessment gradations) as well as with identical priorities (weights) which are taken into account when convolving the indicators. In this case, the number of classes and gradations is selected so that the reliability of modeling results was achieved.

5. The principle of economic expediency. The facility created must be located on the model territory having regard to a minimization of expenditures connected with its construction and operation.

The technique thus developed consists of eleven main steps.

Step 1. *Information support of cartographic modeling of the territory suitability for the laying of the pipeline route.* This step includes determining the list of the properties of natural landscapes influencing the territory suitability for the laying of the pipeline route. To deal with this problem, it is necessary to formalize, at the level of general presentation, the content of the application area to be referred to as the conceptual information model. The process of constructing the conceptual information model involves justifiably breaking down the application area into a number of local tracts, obtaining local models and combining them by abstracting into the generalized model.

Step 2. *Constructing the tree of properties implementing the conceptual information model.* The tree of properties represents a hierarchical structure in which the properties of the higher levels are associated with the properties of the lower, primary levels [12]. The lowest, zero level of the tree of properties is a complex property characterizing the degree of territory suitability for the laying of the pipeline route. The properties are subdivided until there arises the level containing elementary properties which cannot be subdivided further or quasi-elementary properties and there is no point in subdividing them further.

The tree of properties is constructed by the following principles:

– the subdivision within each individual group is carried out according to a common attribute, i.e. to the equal basis;

– each complex property must be subdivided at the nearest high-lying level into such properties, the number and character of which correspond to the requirements of necessity and sufficiency;

– generic and species properties cannot reside within a group simultaneously;

– the number of levels in the tree of properties must be such that each group contains a minimum number of properties (ideally two), and

– the properties are subdivided until the highest level is reached, which contains elementary and quasi-elementary properties.

Step 3. *Ranking of the properties of natural landscapes according to their influence on the territory suitability for the laying of the pipeline route.* The ranking process of the properties includes two stages: 1) determining the unnormalized factors of weight (importance) of the properties of natural landscapes from their influence on the territory suitability for the laying of the route, and 2) calculating the normalized weight (importance, priority) factors.

The unnormalized factors are determined for all the properties involved in the assessment. To accomplish this uses the expert method of paired comparisons described in detail in [10]. Its selection is dictated by ease of expert examination, and by reliable results of expert analysis. In using this method, the experts are sequentially offered the pairs of alternatives to be selected the most preferred out of each of them. Such an expert examination is followed by a calculation