



**Development of decision support systems for integrated water management in Belarus
Central Europe Initiative-KEP Project (Ref. 1206.006A-09)**



**APPLICATION OF DECISION SUPPORT SYSTEMS FOR INTEGRATED WATER
RESOURCES MANAGEMENT:
OPTIMAL SITE PLANNING FOR PHYTODEPURATION PLANT, NAROCH LAKE,
BELARUS**

CASE STUDY REPORT

1. INTRODUCTION

There are about 10 000 lakes and artificial water bodies with slow water circle within the territory of Belarus which are negatively affected by anthropogenic activity. This requires integrated research for estimating the environmental state of water resources in Belarus, in order to give recommendations and guidelines for the optimal use and protection of inland waters. A complex, integrated research is then needed in order to estimate the environmental state of water resources in Belarus, to give recommendations on optimisation, sustainable use and protection of water resources with slow water circle (lakes, artificial lakes, reservoirs). The research on the water bodies conditions should adopt the integration of decision–support tools and methods to manage information from various sources and to enhance decision-making through modelling and mapping human activities (agricultural activity etc), in particular those related to eutrophication of water ecosystems of Belarus.

The project “Development of decision support systems (DSS) for integrated water management in Belarus” develops and applies the most advanced techniques of environmental analysis, as numerical models, multi-criteria analysis, GIS and remote sensing methods. It adopts the integration of decision–support tools and methods to manage information from various sources and to enhance decision-making through modelling and mapping. The use of decision support systems combining spatial databases, territorial indicators, numerical models, GIS and remote sensing techniques are a viable approach since the generation of DSS and spatial DSS is becoming widely popular in these last years for providing adequate tools of analysis and support to decision-makers.

The main problem in the Integrated water resources management is the lack of institutional structures that match the broad scope and aspirations of integrated management. The main requirement to make integrated water resources management a reality is to build and empower the necessary institutional structures within the overall system of governance. Decision makers need a system that justifies the decisions.

What is important in a DSS is to make the participants in the decision process at any level start to think in a structured way about the problem. A good DSS provides a common language, by making basic elements of the decision making process more explicit: criteria, objectives, constraints. Once they are defined and agreed upon, the mechanisms of trade-off and compromise should become more obvious, even if any “optimal” solution may be as elusive as ever. It is important to realize that the mechanism to arrive at a decision may be more important than the actual outcome.

DSS is designed to make the choice process more open, rational, free of contradictions, eliminate or at least indicate dominated alternatives, make trade-off obvious and thus negotiable, etc. This most critical role however, must be to offer a sufficiently rich set of alternatives to choose from. Like any other formal, simplifying and thus model based method, DSS suffer from uncertainty and error in data, procedures, and interpretation. On the other hand, numerical representation suggests a certain level of precision.

The application of DSS to develop plans for Integrated Water Resources Management should be organised in a clear framework of conceptual and knowledge reference system to policy makers and stakeholders in a social network context. A great potential exists for DSS and related tools in the field of IWRM. DSS is both a process and a tool for solving problems that are too complex for humans alone, but usually too qualitative for only computers. Multiple objectives can complicate the task of decision-making, especially when the objectives conflict. As a process, a DSS is a systematic method of leading decision makers and other stakeholders through the task of considering all objectives and then evaluating options to identify a solution that best solves an explicit problem while satisfying as many objectives as possible to as high a degree as possible.

A *Decision Support Systems* can be viewed as “an integrated, interactive computer system, consisting of analytical tools and information management capabilities, designed to aid decision makers in solving relatively large, unstructured problems”. DSS operate within the spatial-temporal context and permit planners and policy makers to:

- integrate large quantities of existing space-time data,
- use these data as inputs to sophisticated forecasting models for predicting the results of alternative policy choices,

- display the model results in easily understood ways to public officials and private citizens as well as to the scientific community.

Basic to the use of the DSS is the ability to examine various "what if" situations within the operational context of the spatial or temporal problem. Building a spatial or spatial-temporal DSS generally involves four major activities:

- data acquisition and evaluation,
- database design and construction,
- construction and testing of analytic space-time forecast models,
- primary data and end-product visualization.

Geographic Information System (GIS) technologies have been extensively used for decision-making alongside DSS models. In recent times, Spatial Decision Support Systems technologies have been widely built and marketed by all the big names in the field of GIS which is a powerful tool, wherein complicated operations can be performed with greater ease and better quality information gleaned.

By integrating GIS and decision support systems, decision makers may become active participants in a planning analysis, rather than selectors among a few, pre-planned alternatives. The integration of GIS and DSS model designs may bring about the following advantages:

- a GIS serves as a basic platform from which a DSS may be developed;
- the system integration provides an effective functional coupling of spatial data, spatial simulation and optimization models;
- it supports various analysis techniques for solving spatial conflicts of different objectives, and for spatial decision making.

Geographical Information System and remote sensing are increasingly employed for IWRM studies. In large part, this has been due to the increased accessibility over the past decade of spatial datasets and the profusion of remote sensing and GIS products with enhanced integration and querying capabilities (Lowry, 2006).

The use of **remote sensing tools**, either aerial or based on satellite, multi- and hyperspectral, permits the gathering of all kinds of territorial information, and the investigation of territorial aspects that are very difficult to monitor (Altobelli *et al.*, 2007; Altobelli & Ortolan, 2007).

Satellite technology has had profound impacts on science-based management of water resources. The use of satellite remote sensing is a cost-effective way to gather the information needed for regional water quality assessments and understanding of the physical, chemical and biological characteristics. The digitized satellite data makes it possible to evaluate and model natural phenomena.

The integration of multisource georeferenced spatial data within a GIS database allows a synergistic processing of a considerable amount of information, the standardisation of data and the elaboration of digital maps which could be an input for further decision making. The ability of GIS to integrate and overlay multiple layers of data over an area of interest which could be modelled, queried and analysed provides a particularly powerful tool to environmental managers.

2. CASE STUDY OBJECTIVES

The general aim of this case study is to develop an example of DSS application for Integrate Water Resources Management within the Naroch lake area. The optimal site for the phytodepuration plant construction has to be found.

In this context the objectives of the research are:

- to acquire the data sets available (the basic data sets / parameters and information selected by partners: spatial information (maps, satellite imagery) concerning the geographical and physical characteristics of the area (physical/administrative boundaries, digital terrain model, land cover and land use, water bodies network, infrastructures, etc.), environmental parameters (water characteristics), ecological components (vegetation and animal communities), human components (demography, economic activities, etc.);
- to create a DSS / SDSS;
- to rank the options;
- to develop a suitability map for the optimal site of the phytodepuration plant.

3. STUDY AREA

A highland from the northeast to the southwest divides the country into two water catchment areas; the northern one drains to the Baltic Sea and the southern one to the Black Sea. The largest of the thousands of Belorussian lakes is Lake Naroch (80 square km) in the northwest which is a National Park unique by biodiversity. At the same time, this zone is of high importance for recreation for Belarussian population. The main environmental issues within the area are rehabilitation of the lake, biological and human contamination (mainly tourism and agriculture), water quality improvement, recreation zones management, water protection from nutrient pollution.



Fig.1 - Naroch lakes system watershed designed by Belarussian scientists (the base is the LANDSAT 245, fragment)

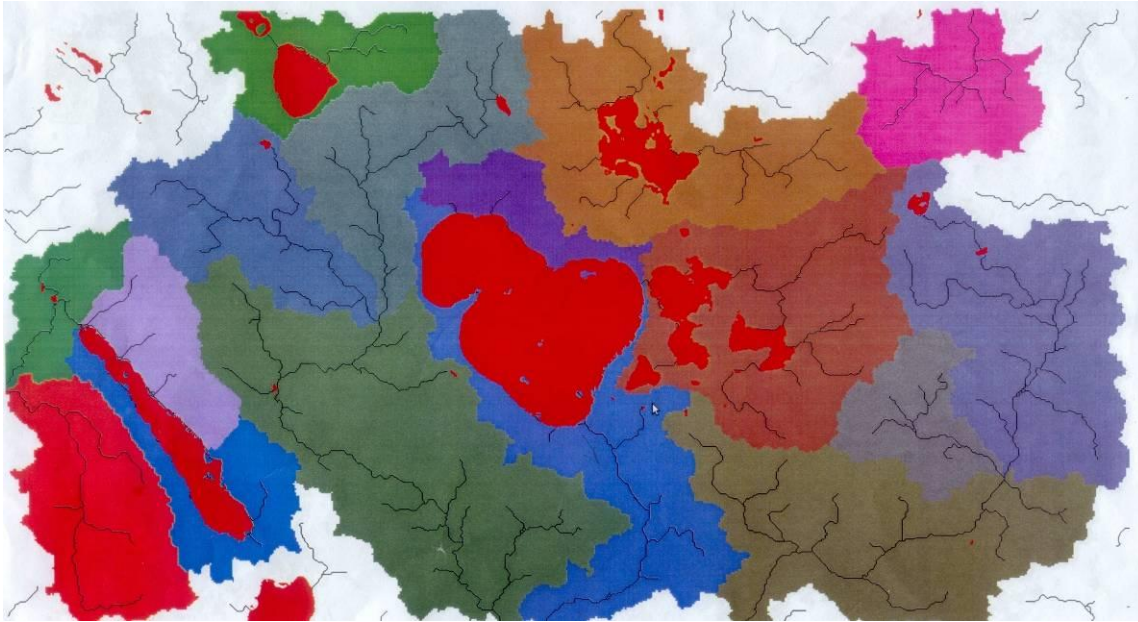


Fig.2 - *Naroch lakes system watersheds derived automatically from the DEM (SRTM 90). The Naroch watershed should also include partly the steam Pron'ca because of the amelioration construction. The river Narochanka watershed should be excluded from the Naroch watershed.*

It is of high priority for Belarus to keep the environmental state of the lakes, to improve their environmental quality and to avoid environmental degradation due to the increasing tourism.

4. MATERIALS AND METHODS

4.1 Dataset description

The following digital spatial data such as discrete object types of data (vector), continuous forms of data (raster), and ancillary data were integrated into GIS for further elaborations.

Collected Data Description	Source	Spatial coverage	Time coverage	Format
LANDSAT TM <i>(Landsat Thematic Mapper)</i> satellite imagery	U.S. Geological Survey LANDSAT mission http:// landsat.usgs.gov/	Lake Naroch watershed	2009	Raster (.geotiff)
Sampling results on chemical parameters	The Belorussian State University (contact person Dr Boris Vlasov)	Lake Naroch watershed	1999	Ancillary (.excl)
Digital Elevation Model SRTM 90m Digital Elevation Data	The CGIAR Consortium for Spatial Information http://srtm.csi.cgiar.org/	Belarus	2008	Raster (.tif)
GIS layers: - administrative areas (boundaries); - inland water; - roads; - railroads; - elevation; - land cover.	Free geographic (GIS) data http://www.diva-gis.org/	Belarus area	2006	Vector (.shp), Grid
MODIS 12Q1 Land Cover Type 1 The Moderate Resolution Imaging Spectroradiometer	Warehouse Inventory Search Tool (WIST) - earth science data products from NASA and affiliated centers https://wist.echo.nasa.gov/wist-bin/api/ims.cgi?mode=MAINSRCH&JS=1	Belarus area	2010	Raster (.hdf)
Map of the coastal zone lake Mjastro and Batorino	The Belorussian State University (contact person Dr Boris Vlasov) Scale- 1: 25 000	coastal zone lake Mjastro and Batorino	2000	Raster, jpg
Map of the coastal zone lake Naroch	The Belorussian State University (contact person Dr Boris Vlasov) Scale- 1: 25 000	coastal zone lake Naroch	2000	Raster jpg
Sampling points within the Naroch watershed	The Belorussian State University (contact person Dr Boris Vlasov)	Lake Naroch watershed	1999	Raster, jpg
The list and description of the major land use within the protected Naroch area	The Belorussian State University (contact person Dr Boris Vlasov)	Lake Naroch protected area		Text (. Word)
The list and discription of the key indicators of streams flowing into the lake Naroch	The Belorussian State University (contact person Dr Boris Vlasov)	Lake Naroch watershed	1997 -2008	Text (. Word)

Table 1 - The list of spatial data and parameters available

4.2 Spatial Decision Support Systems

SDSS are meant to optimally locate in space human activities (e.g. cropping, logging, selling, etc.) and structures (buildings, infrastructures, phytodepuration plant etc.). The application of SDSS should follow a decision making process and the following definitions for (Decision Support System) DSS and SDSS should be adopted:

- DSS is a combination of information, technology and tools designed to rank possible alternatives in order to choose the most suitable ones.
- SDSS is a combination of information, technology and tools designed to optimally locate the alternatives chosen with the help of a DSS.

The concept of suitability is very important for DSS and SDSS applications. According to this concept, the choice done is not the best in absolute terms, but just the best in the relative context in which DSS and SDSS are applied. For this reason, the ultimate objective of a computer based decision support system is merely to improve the decision making processes by providing useful and scientifically based information to the actors involved in these processes, and tools that can flexibly and easily deal with such information in an iterative and recursive way. DSS and SDSS belong to the “domain of decision making” that is given by a network of stakeholders whose main nodes are: decision and policy makers, investors, entrepreneurs, the “general public” and the scientific/ technical institutions that can offer knowledge and tools to support the decision making.

According to Fedra and Feoli (1998) in this network where “problem owners and various actors in the decision making process have a central role; supporting their respective tasks, requires man-machine interfaces that are easy to use and easy to understand: the paradigm of the thematic map offered by GIS is a powerful tool for this purpose...” an effective decision support system must first of all provide a common, shared information basis, framework and language for dialogue and negotiation. The network requires that information provided by SDSS is adequate for and acceptable to the broad range of users “needs” involved in the respective assessment and decision making processes. Fedra and Feoli (1998) stated also that “an information system that can cater to these needs must be based on more than good science and solid engineering”. It should consider the problems related to the complexity of the environmental systems such as the availability and quality of data, uncertainty of data and models and the limits of predictability inherent in the study of complex systems.

The decision support systems must address and communicate this uncertainty to make it a useful component of decision *making strategy rather than a problem*. The information technology acts as the necessary assessment tool in handling environmental and resource management problems.

The main elements of a decision include the design of promising, feasible alternatives and the subsequent selection of a solution (alternative) from a set of alternatives thus generated or identified. This decision process is based on:

1. a set of *Alternatives*, which can be discrete and pre-existing, or generated on demand;
2. a set of *Criteria* describing each of the alternatives; criteria can be qualitative or quantitative, cardinal, ordinal or nominal;
3. *Constraints* describing acceptable lower or upper bounds on any one of the criteria; only a solution that meets all constraints is deemed a feasible alternative and subsequently considered;
4. *Objectives* or objective function(s), expressed in terms of the criteria that should be minimized or maximized by the selection;
5. A *Preference Structure* that defines the relative importance of different criteria in contributing to the objective function, and the different importance of different objectives in an overall evaluation.

4.3 Definition of alternatives

The word “alternative” is the key word in the domain of decision-making. A decision may be defined as a choice between alternatives. The alternatives may represent different options of action following different hypotheses among which a choice is desirable based on some specific criteria. Establishing alternatives is the first step in a decision making process.

4.3 Geographic Information System structure

GIS is a powerful set of tools for gathering, storing, retrieving, transforming, analysing and visualizing spatial data from the real world for a particular set of purposes (Burrough, 1991). A generic approach for linking vector, raster and ancillary data and statistical information has been developed. The unique integration capabilities of a GIS allow disparate data sets to be brought together to create a complete picture of a situation. GIS technology illustrates relationships, connections, and patterns that are not necessarily obvious in any one data set (ESRI, 2003).

4.4 Remote sensing techniques

Remote Sensing – the science, technology, and art of obtaining information about objects from a distance – allows us to collect information over regions too costly, or too remote for human observers to directly assess. Remote sensing offers important advantages over other methods of data collection that have led to its use in a wide range of applications (Aronoff, 2005). Remote sensing is one of the most efficient methods for environmental monitoring.

4.5 Phytodepuration

Phytodepuration is a purification technique characterised by biological type treatments, in which plants growing in water-saturated soil develop a key role for direct action of the bacteria that colonize the root system and rootstock. These treatments are seen both as alternatives as well as support to traditional systems based on biological processes and chemical and physical reactions.

The European legislation concerning the protection of water resources has established the Directives 91/271/EEC and 91/676/EEC (wastewater treatment) and claims the importance of using natural techniques as an alternative to traditional systems for the treatment of wastewater.

5. RESULTS

The general aim of this case study is to develop an example of DSS application for Integrated Water Resources Management within the Naroch lake area (an optimal site planning for phytodepuration plant). It is important to note, that all the constraints, factors and limitations might be incorrect or excessive, since the case study is just an example of DSS application. The constraints, limits and standards are purely indicative for study purpose. The distance will always depend on regional or national law, stakeholders decision and other parameters. In case of future operative project, the proposed method should be applied according to the local standards.

5.1 Definition of criteria for the DSS

In any DSS application criteria are the factors that act positively or negatively in favour of a specific alternative. The ranking of alternatives is conditioned by the choice of criteria and by the weight given to them. For that reason the participatory approach is necessary to ensure the democratic discussion and the respect of the equity principle. It is obvious that the criteria are determined on the basis of the objectives to be achieved. In theory, there is no limit for the choice of the criteria. In terms of the DPSIR model the criteria are based on the State – Impact indicators. They are always determined by experts who act on the basis of their experience with or without the analysis of available data and/or modelling and in consultation with stakeholders and interested public. Also the choice of the criteria is always based on cost-benefit considerations and has always a strong component of subjectivity.

In SDSS the criteria are not “effects” but just factors that act in favour of the suitability of a given OGU to host the selected “land use” and constraints that deny the suitability. The most important key-word in SDSS is *suitability* and the most important tool is the *suitability map*. The GIS component of SDSS is essential to produce suitability maps. Criteria on which to rank the OGUs are spatial variables: topographical, geomorphological, geographical, ecological etc., and they are expressed by values of distances (e.g. distance by the rivers, by the roads, by urban areas etc.), degrees of inclination of slopes, aspect, by meters above the sea level etc. or by the quality of the position (e.g. within a valley, on the top of a mountain etc.), or by measures of risks of various (soil erosion, water flooding, fire, etc.).

Each SDSS variable (criterion) should be spatially defined and GIS mapped (territorial indicators). Let us consider just for showing the use of SDSS the following maps of a GIS:

- DEM;
- rivers network and waterbodies;
- settlements,
- tourist structures,
- forests,
- wetlands,
- limits of protected areas.

Besides the spatial variables factors have been defined also as space availability, cost for building, time to build, environmental state of the lake, rivers and streams (19/08/1999 - sampling data available).

The criteria chosen as factors and the related constraints imposed for suitability are presented in the table below:

<i>Factors</i>	<i>Constrains</i>
Distance from human settlements	> 200 m
Distance from water sources, rivers, streams, aqueducts etc.	< 50 m
Distance to roads	> 100 m
Slope	< 5 %

Distance from protected areas, wetlands etc. (forbidden areas)	> 500 m
Forests	Excluded
<i>Other criteria to be taken in consideration (no data available)</i>	
Hydrogeological risk	
Soil permeability	
Groundwater's depth	
Areas reserved to other land-use matters (agriculture, industry)	

Table 2 - The list of factors and constrains

5.2 Image processing. Unsupervised classification and Supervised classification

In order to derive information on waterbodies and rivers network, the unsupervised classification ISODATA (Iterative Self-Organizing Data Analysis Techniques) algorithm (Dermanis & Biagi, 2002) was carried out (fig. 2,3).

The ISODATA algorithm has some further refinements by splitting and merging of clusters. Clusters are merged if either the number of members (pixel) in a cluster is less than a certain threshold or if the centres of two clusters are closer than a certain threshold. Clusters are split into two different clusters if the cluster standard deviation exceeds a predefined value and the number of members (pixels) is twice the threshold for the minimum number of members. The algorithm ISODATA has been already successfully applied to map.

Similar to the unsupervised classification, the supervised classification technique is also a computer-assisted interpretation of the data but in this case the classification processor was trained to look for the surface features with similar reflectance characteristics into a set of training sites of known interpretation within the image. Using Image Processing/Hard Classifiers/ MAXLIKE ENVI procedure, a maximum likelihood classification was undertaken to categorize the ASTER satellite imagery based on the information contained in a set of signature files. According to Peddle (1993), the Maximum Likelihood classification is based on the probability density function associated with a particular training site signature. Pixels were assigned to the most likely class based on a comparison of the posterior probability that it belongs to each of the signatures being considered. This technique was also known as a Bayesian classifier.



Fig.3 - Unsupervised classification result (LANDSAT image band composite 245, fragment)



Fig.4 - Waterbodies derived from the LANDSAT image classification

GIS represents a considerable change in environmental data management, as it connects territorial information to different databases, allowing for the “integration” of the territory, adding and producing new information. Within this context, geographically referenced information was integrated into a GIS-based system using various set of software packages. In this case GIS is not an isolated technology but part of an integrated methodology of analysis and renders legible and decipherable a considerable amount of data sets which are difficult to understand at a glance.

Areas that have a slope $> 5\%$ are considered not suitable (value 0) for the phytodepuration plant construction.

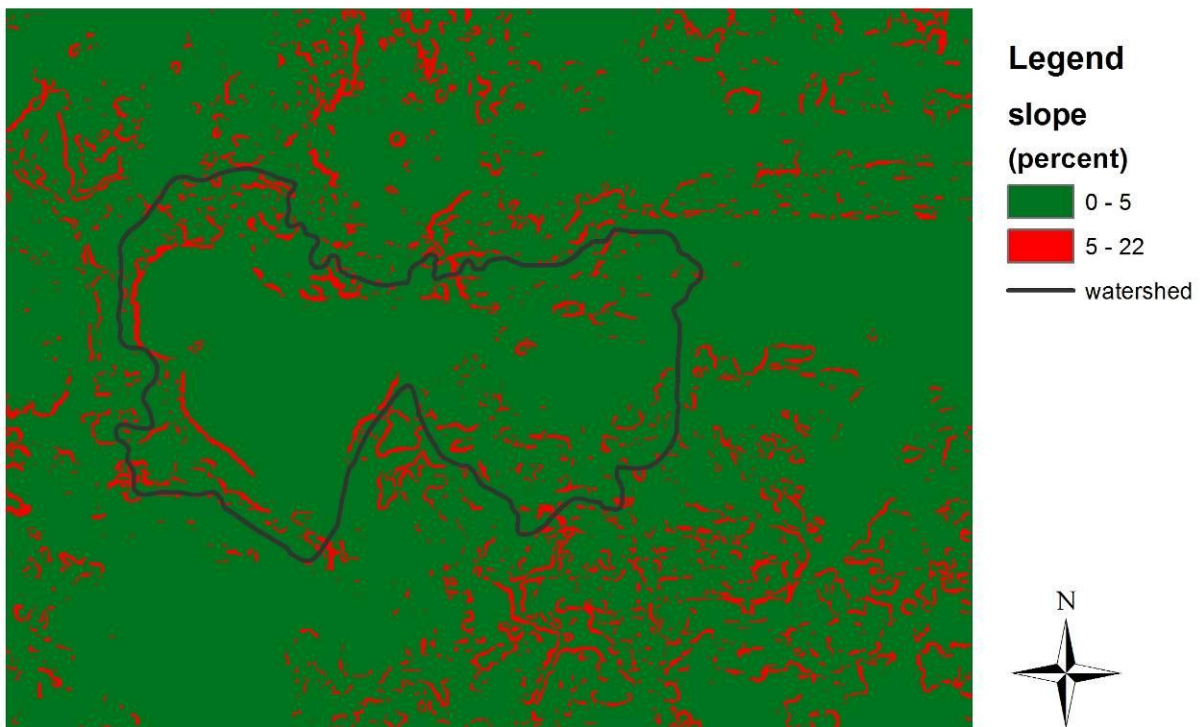


Fig.5 - Naroch lakes system watershed created automatically using the DEM (SRTM 90)

If the distance from the settlements and tourist infrastructure is less than 200 m, there is no possibility to build a phytodepuration plant. If the distance from settlements is more than 200 m the area is suitable for construction (value 1).

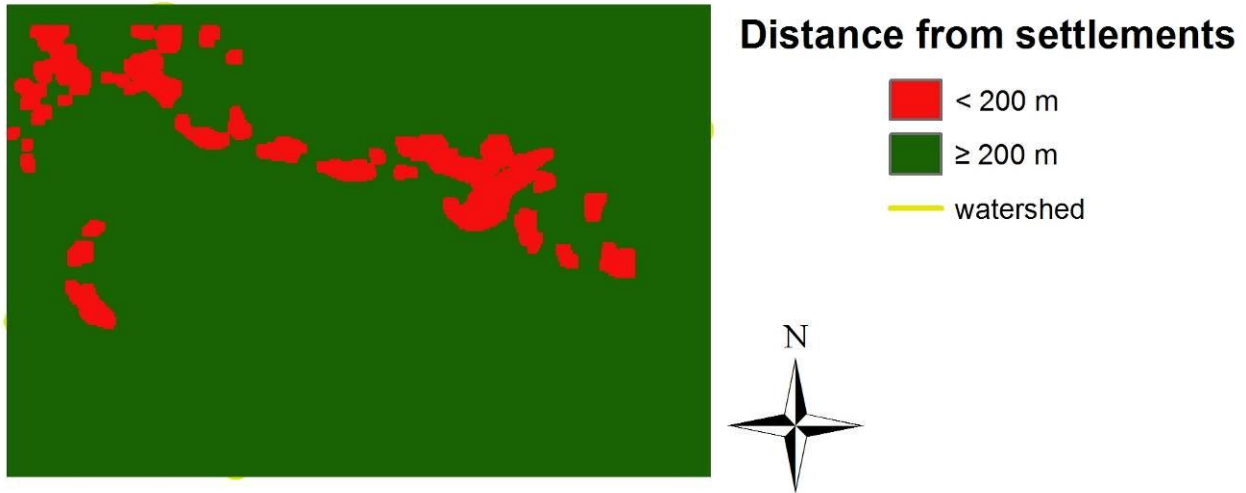


Fig.6 - Naroch lakes system watershed created automatically using the DEM (SRTM 90)

If the distance from rivers (or waterbodies) is more than 50 m it isn't possible to build a phytodepuration plant (suitability is 0); if the distance is less than 50 m the site is suitable for construction (suitability is 1). Within the forest area it is impossible to build. The map of forests has been reclassified in order to assign value 0 within the forest area (no suitability) and value 1 outside the forest (area suitable for phytodepuration plant).



Fig.7 - Naroch lakes system watershed created automatically using the DEM (SRTM 90)

In order to create an example suitability map for optimal site planning for phytodepuration plant an attempt was made to insert interactive effects of several contributing **factors** and **constraints** (delineated in a set of raster and vector maps) that may contribute in enhancing or decreasing the susceptibility of change for each pixel. The suitable areas are the product of factor map and constrains map combination . Suitability map is

showing the most "suitable" allocations for the phytodepuration plant taking in consideration all the criteria's discussed before.

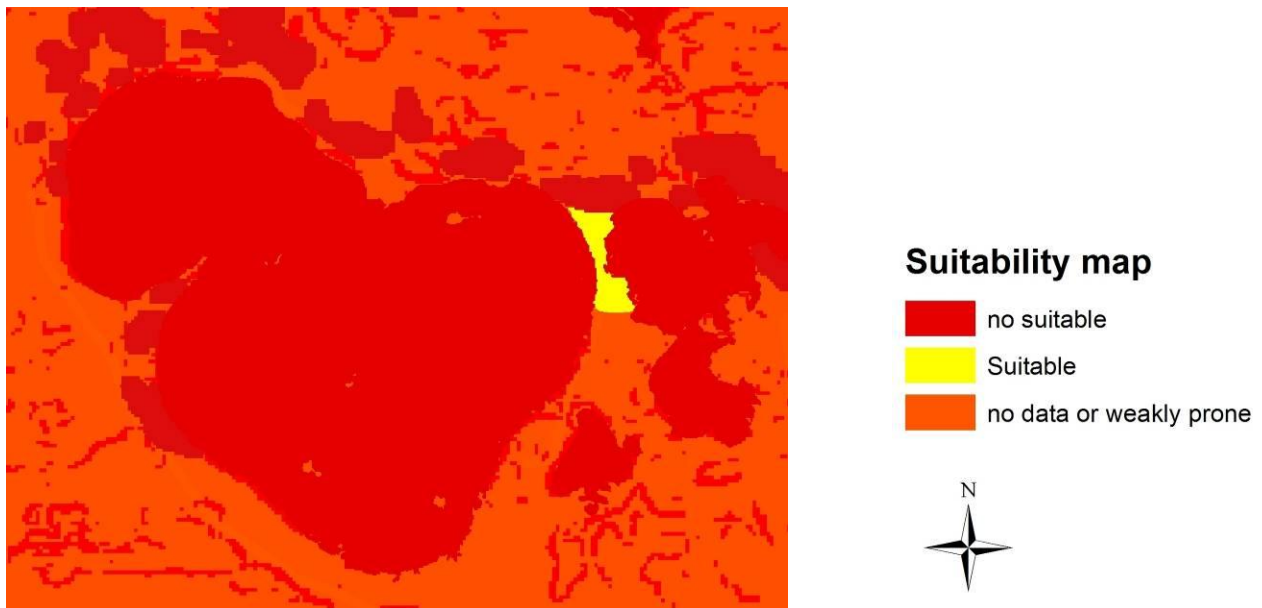


Fig.8 - Suitability map (one of the suitable sites for phytodepuration plant corresponds to the stream Schema)

6. CONCLUSIONS

It is important to note that all the constraints, factors and limitations might be incorrect or excessive, since the case study is just an example of DSS application. The constraints, limits and standards are purely indicative for study purpose. The distance will always depend on regional or national law, stakeholders decision and other parameters. In case of future operative project, the proposed method should be applied according to the local standards.

In the most outstanding examples of DSS, the development is due to academic community or national/international research projects, and the link with and the follow-up to the stakeholders, namely land and water administrators, is broadly to be enforced. DSS is a systematic method of leading decision makers and other stakeholders through the task of considering all objectives and then evaluating options to identify a solution that best solves an explicit problem. DSS output act as an "input" for decision making process.

7. REFERENCES

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