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A WebGIS-BASED MONITORING AND DECISION SUPPORT TOOL FOR THE ENVIRONMENTAL PROTECTION AND PRESERVATION OF THE BLACK SEA: THE ECO-SATELLITE PROJECT

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ABSTRACT

The ECO-Satellite project is being financed by the Joint Operational Programme "BLACK SEA 2007-2013". The main objective of the project is the creation of an environmental monitoring system mainly oriented to the marine, coastal and wetland ecosystems of the Black Sea that will increase the intraregional knowledge for the corresponding coastal zones. This integrated multi-level system will make use of technological assets provided by Geomatics as well as satellite Earth Observation data, along with the creation of geo-databases including the appropriate environmental parameters. Furthermore, a WebGIS system is being under development that will contribute to the management of environmental data and the protection of the Black Sea ecosystems as it will raise awareness through the presentation of the study results and facilitate decision making, with the use of a decision support module.

In this paper, the system architecture design and the basic structure of the geo-database are being described along with the presentation of the first version and capabilities of the ECO-Satellite system.

Keywords
Black Sea, WebGIS, satellite Earth observation systems, environmental monitoring.

1. INTRODUCTION

The protection from pollution of the environment and especially the aquatic environment and the water resources is one of the top priorities set worldwide. One important large marine ecosystem that is threatened by pollution is the Black Sea ecosystem. The Black Sea is surrounded by six countries and about one third of continental Europe drains into this semi-enclosed sea through major rivers like the Danube, Dnieper, Dniester, Don and Kuban. Hence, there is a necessity for a common intraregional and transnational approach for managing and preventing the environmental pollution by sharing environmental data and information as well as adopting common policies and strategies. This may be achieved through the use of an integrated geo-database along with appropriate environmental monitoring and decision making systems that adhere to predefined standards and specifications and follow local/national and regional legislation under a common framework. The web-based Geographical Information Systems (WebGIS) serve as the most appropriate platform for developing such systems as they provide all the necessary functionality and capabilities for presenting, analysing and retrieving spatial and descriptive data over the Internet (Schmidt and Lösewitz, 2005). Such a web-based GIS environmental monitoring system with decision making capabilities is the ECO-Satellite system.

The ECO-Satellite environmental monitoring system is developed in the frame of the "Development of a common intraregional monitoring system for the environmental protection and preservation of the Black Sea – ECO-Satellite" project of the Joint Operational Programme "Black Sea 2007-2013" funded by the European Union through the European Neighbourhood and Partnership Instrument (ENPI) and co-financed by the states taking part in the Programme (web-site: www.eco-satellite.eu, Figure 1).

Figure 1. The Home page of the Eco-Satellite project web-site (www.eco-satellite.eu).

The partners of the project are the Decentralized Administration of Macedonia and Thrace (Greece), the Aristotle University of Thessaloniki (Greece), the Balkan Environment Centre (Greece), the Odessa Branch Institute of Biology of Southern Seas (Ukraine), the Danube Delta Institute for Research and Development (Romania) and the District Administration of Varna (Bulgaria). Through the development of the ECO-Satellite system, the project will contribute to the efforts of strengthening the joint knowledge and information base needed for the environmental protection and preservation of the Black Sea ecosystem, the promotion of stronger integration and development of research between the involved partners and the exchange of scientific data and know-how in the fields of monitoring and protection of marine, coastal and wetland systems in the Black Sea Basin. The ECO-Satellite system incorporates a geo-database that includes cartographic and environmental data along with the environmental monitoring system and its decision support component. In the following sections, a detailed description of the geo-database and the design of the ECO-Satellite environmental monitoring system is provided.

2. GEO-DATABASE

The ECO-Satellite geo-database is the basis for the ECO-Satellite system. The geo-database developed in the frame of the ECO-Satellite project includes basic cartographic and environmental data originating from terrestrial and satellite sources, e.g., in-situ measurements, measurements from permanent monitoring stations, remote sensing data etc., as it is typical in WebGIS applications (Doukas et al., 2007). The data included refer mostly to the three test sites of the project. These are the protected area of Danube Delta in Romania, the protected area of the Kyliiske Mouth and the northern part of the Danube marine region in Ukraine and the protected area of Galikos estuaries (Axios-Loudias-Aliakmonas) in northern Greece.

The ECO-Satellite geo-database is being developed in four stages. The first stage involved the design of the geo-database. The design refers to the definition of the data that will be incorporated into the geo-database, their types and relationships. The basis for the design was set by legislative documents, data availability and the local characteristics of the project test areas. With regard to the legislative documents, the following ones provided a common framework for defining the necessary data and their specifications: the Ramsar Convention, the Habitats Directive (Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora), the Water Framework Directive (Directive 2000/60/EC of the European Parliament and the Council establishing a framework for the Community action in the field of water policy) and the Marine Strategy Framework Directive (Directive 2008/56/EC of the European Parliament and the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy). On the other hand, data availability was assessed by the project partners by looking for existing data in their own and in non-commercial databases.

Having defined the data requirements, the second stage involved the collection of current and historical data for the test-sites and the broader region. The collection of historical data is of major importance in environmental applications. Historical data assist in detecting and safely evaluate changes in monitored values and indicators, especially when the evaluation results are dependent on variability over time (Irvine, 2004). The data collected may be classified into four categories: the in-situ environmental data, the remote sensing data, the Mean Sea Level (MSL) and bathymetry data and the basic cartographic data. Regarding the basic cartographic data, they supplement with special local features the free ArcGIS Online Map and Image services of ESRI that were decided to be used for the basic cartographic breadboard.

The third stage of developing the geo-database dealt with the processing of the collected data including their transformation to a common coordinate reference system, i.e., the World Geodetic Reference System 1984 (WGS84). The processing resulted in various types of data, i.e., vector, raster and table data. Some of the available raster datasets represent environmental parameters with respect to specific time epochs. In order to facilitate the exploitation of these data, due to their great amount (332 raster datasets), auxiliary tables were created for indexing the available data series for each parameter. An additional auxiliary table was added for holding threshold values for environmental parameters in order to allow the ECO-Satellite system to classify the stored values throughout the system requests. A list of the processed groups of data is provided in Table 1.

Table 1. List of the available groups of data in the ECO-Satellite geodatabase.

Datasets	Test areas	
	Galikos estuaries	**Danube Delta**
Biological parameters (e.g., macrophytes, phytoplankton, invertebrates)	■	■
Biological Parameters (fish species, macrozoobenthos, bivalves population, meiobenthos, zooplankton)		■
Land cover maps	■	
Habitats map	■	
In-situ vegetation identification	■	
Mean Sea Level Models	■	■
Mussel farms	■	
Natura 2000 (v28) areas	■	
Physico-chemical parameters (e.g. N total, disolved oxygen, temperature, salinity, etc.)	■	■
Ramsar areas	■	■
Surface water extents and level changes	■	
Terrain and bathymetry models	■	■
Tide gauge stations	■	■
Water quality permanent monitoring stations	■	

The fourth and final stage involved the integration of all the available data into the geo-database. The geo-database resides in Microsoft SQL-Server 2008 and was developed using tools from ESRI ArcMap v10 and the ESRI ArcSDE v10 data sources communication layer. The ESRI ArcCatalog was used to internally define the geo-database metadata. Regarding the sharing of the metadata to the end-users, it was decided to share the metadata in a descriptive form rather than follow a standard form in order to retain a user-friendly and comprehensive system for non-scientists and non-expert users. The ECO-Satellite geo-database has all the standard functionality of an ESRI geo-database and the functionality provided by the Microsoft SQL Server, including the ability to perform attribute and spatial queries. The geo-database is open to new types of data and may be easily updated. A noticeable characteristic of the ECO-Satellite geo-database is related to the approach that was followed to define tables with respect to the peculiarities of each area.

The process of environmental monitoring may present significant differences from area to area in terms of the parameters measured or observed. This led the ECO-Satellite project team to reorganize the geo-database structure by area rather than integrate all the parameters under a common layer/table that would include all areas. By this decision, the geo-database allows the inclusion of data from areas with different characteristics, while the management of the data under a common frame is left to be done programmatically through the ECO-Satellite system. Although this would be thought to cause difficulties in managing the data, the fact that for each area a subset of all the possible monitored parameters is selected eases the representation of the data to the end-users.

Another characteristic of the geodatabase, as mentioned above, is the significant amount of raster images representing different environmental parameters over different time epochs. These raster images were prepared in order to eliminate the production time that would be required by the server. The images will be cached hence allowing the end-user to experience a faster connection to the server while maintaining the server resources requirements at a low level. Since the number of raster images is significant, it was decided that it is necessary to be served to the end-user on-demand through the ECO-Satellite system, as it is described next.

3. SYSTEM DESIGN

The ECO-Satellite environmental monitoring system aims to provide a common intraregional environmental monitoring system for the area of the Black Sea basin and a useful tool for stakeholders interested in environmental policies and decision making. Hence, the system will include tools for presenting and analysing data as well as decision support tools for stakeholders, while at the same it will retain a user-friendly interface. The system will be composed of two components: The first is the *core component* and the second is the *decision support component*.

The core component is the main platform of the system. Its role is to provide to the end-users the ability to visualize and analyse the available data by using appropriately designed tools. It is the basis for any further development and extension of the system. The visualization includes the abilities to browse through a map, identify elements on a map and display or hide layers of information (Figure 2). On the other hand the analysis features include the ability to display graphs and table data as well as perform attribute and spatial queries. The visualization and analysis functionality and processes are considered as common among WebGIS systems (Grigoriadis et al., 2008).

The decision support component is a specialized component of the system that will make use of the core component for producing results that lead to decision and policy making. The reason for separating the decision support component from the core component is because any changes in policies may require the restructuring and redevelopment of the algorithms pertaining to decision and policy making. Hence, by keeping separate the decision support part any future changes will not affect the system as a whole and will require the minimum amount of work for implementation. Regarding the decision making model, the component will follow the most commonly used model, that is the semi-structured, and the structured model in profound cases. This means that the system will analyse all the data and factors and either it will require human judgment in order to lead to a decision or its results will be the requested decision.

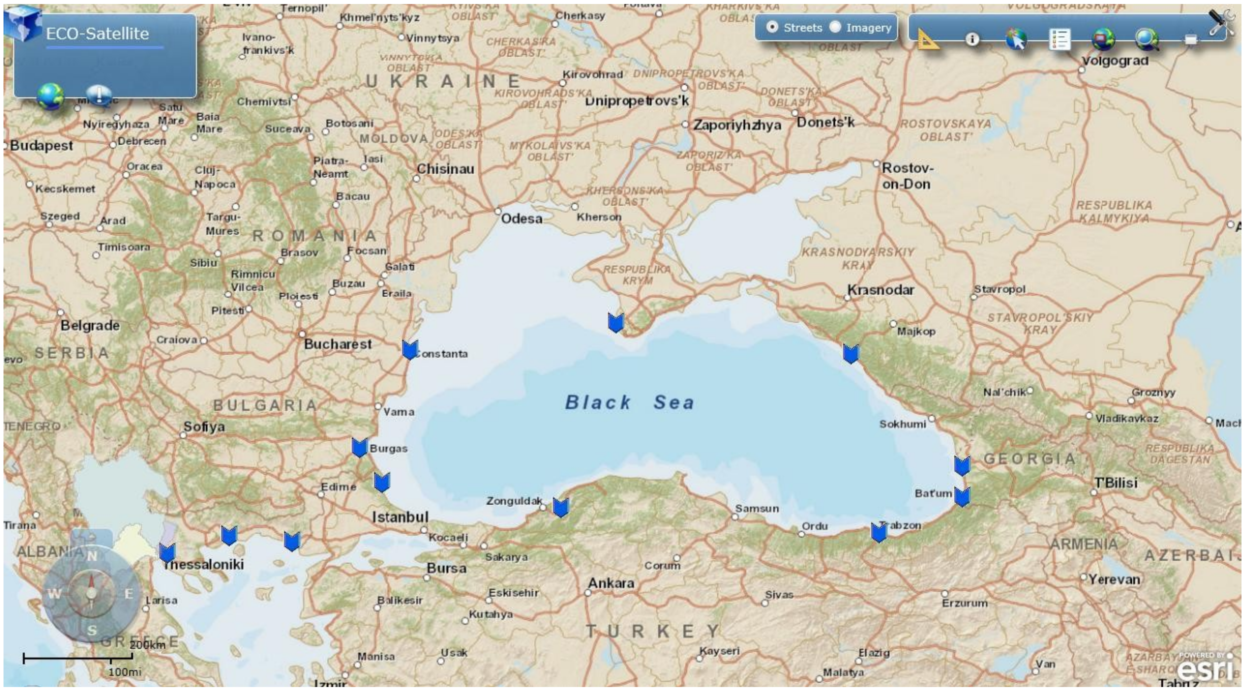

Figure 2. The user interface of the core component of the Eco-Satellite system that provides to the end-users the ability to visualize and analyse the available data in the area under investigation.

In Figure 3, the flowchart for the decision support component of the ECO-Satellite system is given. The decision support procedure will be as following: The end-user requests from the system information on environmental conditions for a specific area/site. The system transfers the request to the decision support component where the required analysis takes place. The analysis is based on predefined algorithms, indicators, threshold values and standards (e.g., Directive on Environmental Quality Standards - 2008/105/EC). At this stage it will also be taken into account the different spatial and temporal scales of the examined features and data as these may significantly affect the outcome of the analysis (Atauri Mezquida et al., 2005). After the decision support component computes the results of the analysis these are simplified in order to be easily understandable by non-scientists/non-experts. The simplification is carried out using various approaches like the traffic light method or another classification method. Then, the simplified results can be displayed to the end-user in various forms (Figure 4). More specifically, results may be displayed in descriptive form (Figure 5), as graphs (Figure 6), as thematic maps (Figures 7&8), etc. with the aid of the core component. Since the aforementioned process will assist policy making, it is necessary to provide safe results with low chance of false estimates. Thus, in the analysis phase, only variables/indicators/parameters that their efficiency has been demonstrated in adequate studies will be used (Vos et al., 2000).

The system is being developed using the ESRI ArcGIS Application Programming Interface (API) for Microsoft Silverlight and will exploit the ECO-Satellite geo-database through services provided by the ESRI ArcGIS Server v10. The system will reside on Microsoft Windows 2008 Server operating system, while the system security will be developed using the Microsoft ASP.NET membership provider for the Microsoft SQL Server. Regarding security, there are four categories of potential users, the ECO-Satellite project partners, scientists, decision and policy makers and the general public. Each category will have its own user rights.

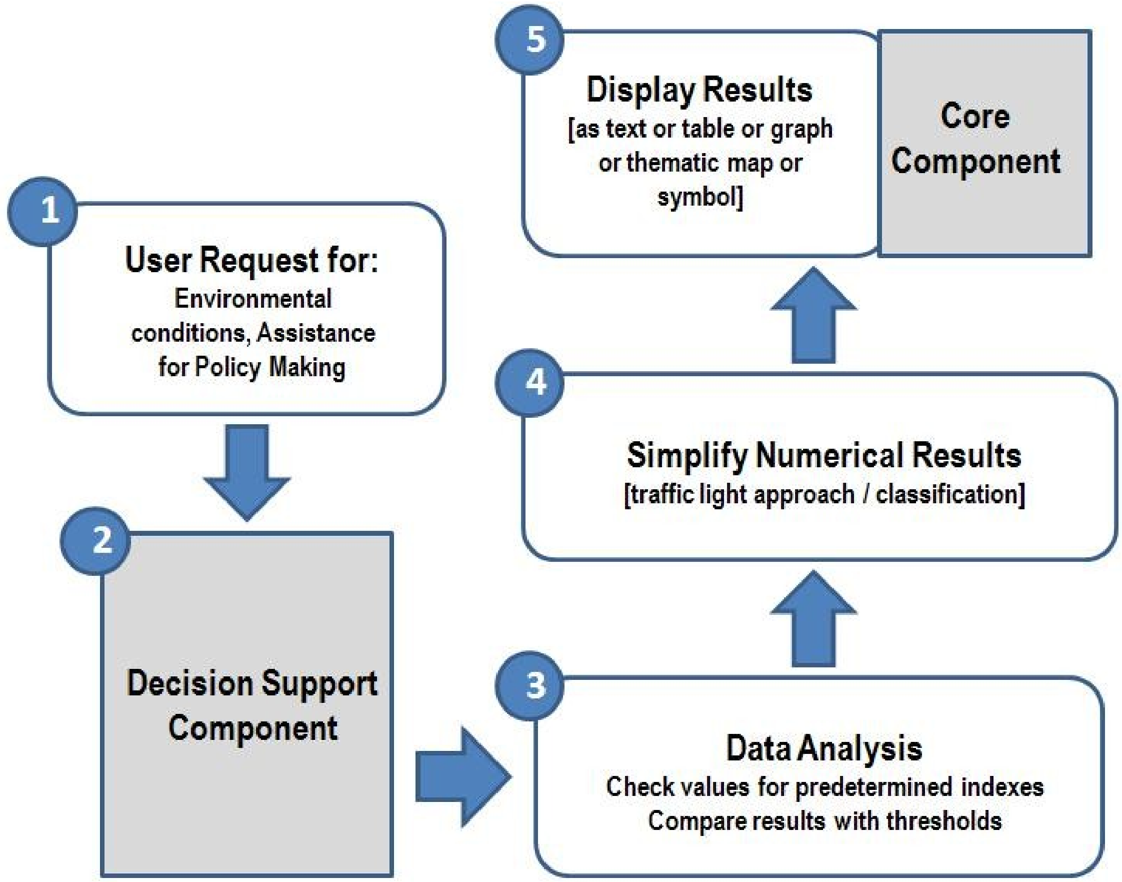

Figure 3. Flowchart of the decision support component of the ECO-Satellite system.

It should be noted that the ECO-Satellite system does not aim in processing raw data nor serve as a real-time monitoring system. Although WebGIS offer the ability to implement such functionality, processing requires a significant amount of hardware and network resources. Additionally, a server-based processing scheme is not possible to achieve the performance and the features provided by a desktop computer. On the other hand, real-time monitoring or near-real-time requires a significant budget for deploying and maintaining wireless networks. The ECO-Satellite system will offer an interface for trusted users in order to upload processed data and update the geo-database but will also allow the near real-time update through the use of web services. By this way, the manual update may be used in cases where: a) it is not possible to cover the cost for maintaining automated collection and processing systems; b) there are data from in-situ measurements; and c) there are historical data that may not yet be in digital form.

Last, the ECO-Satellite system will also benefit from public participation. As it has been shown (e.g., Tsou, 2004; Gouveia and Fonseca, 2008), the public may provide useful information that may also assist in the decision and policy making process. Especially with the availability of smart-phones that integrate GPS antennas, users have also the ability to report location in terms of geographical coordinates. A two-step procedure will be followed for the public participation. Users will have the ability to use an on-line form to provide their information. This information will then be validated by the system administrators/scientific experts and accordingly be integrated into the system.

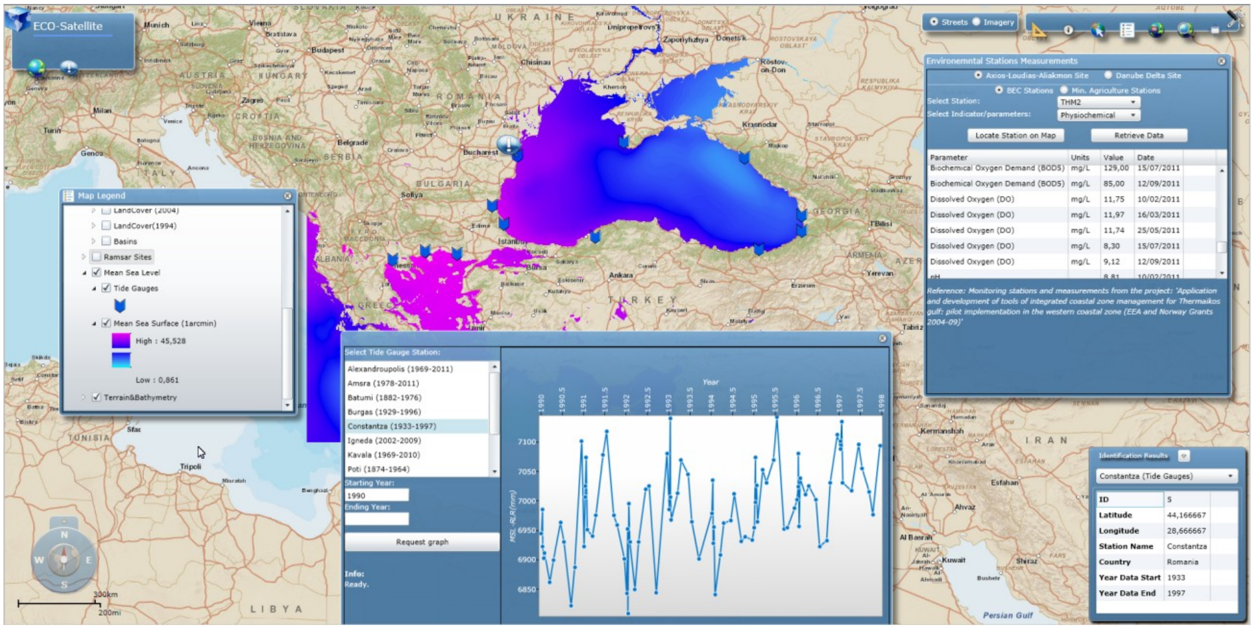

Figure 4. The ECO-Satellite system data representation capabilities.

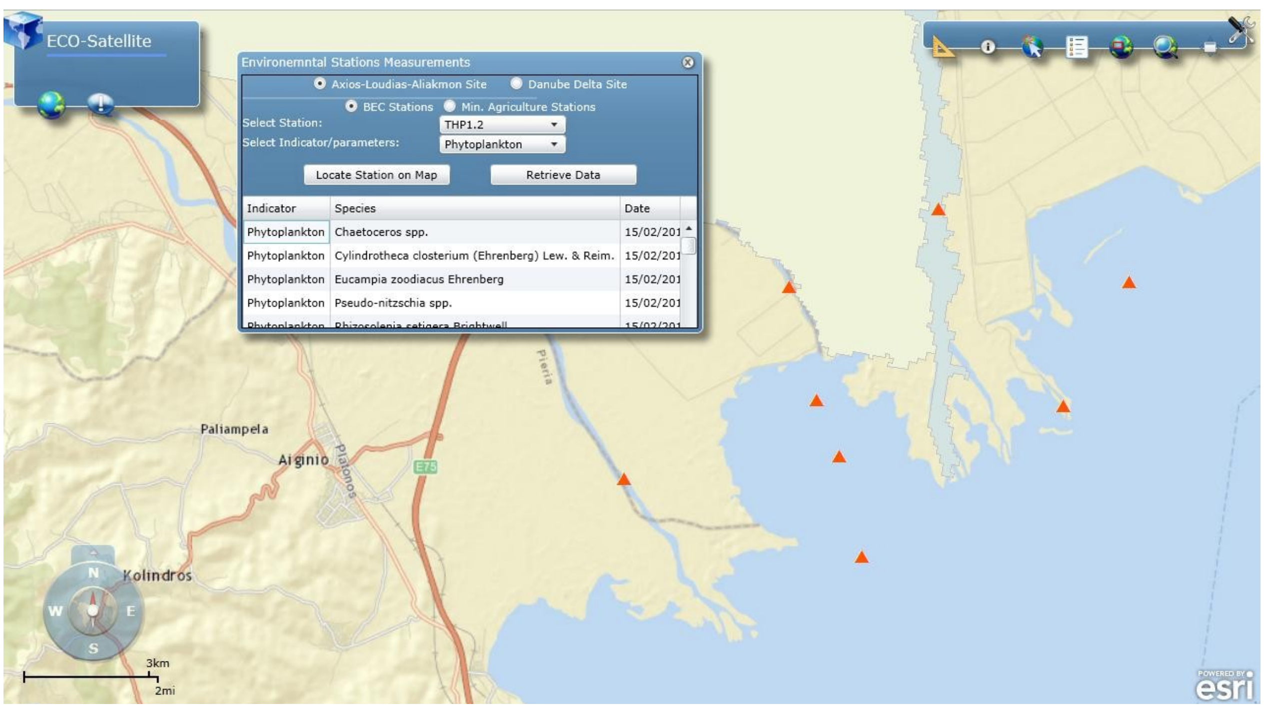

Figure 5. The ECO-Satellite system data representation in descriptive form: Categories of environmental data and values of observed parameters at monitoring stations in the area of Axios-Loudias-Aliakmon test site. The red triangles show the location of the monitoring stations.

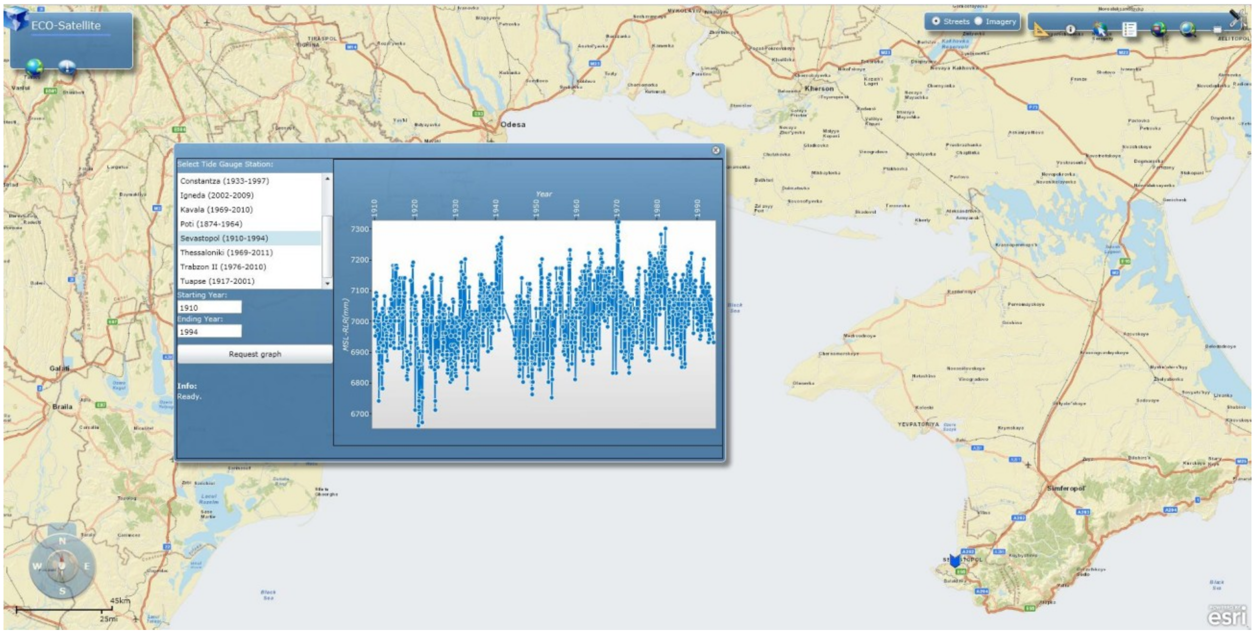

Figure 6. The ECO-Satellite system data representation as graphs: Mean Sea Level variation at Sevastopol gauge site with time.

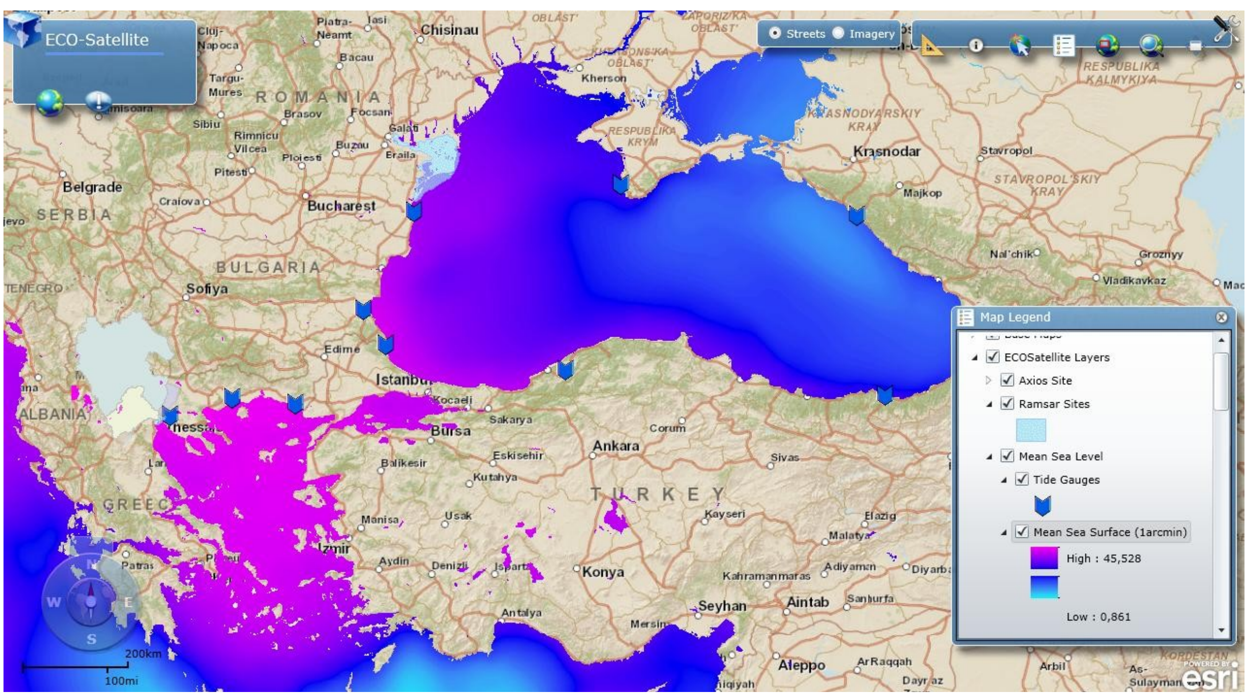

Figure 7. The ECO-Satellite system data representation as thematic maps: Mean Sea Level Model of the area under consideration. The location of tide gauges is also shown as well as Ramsar sites.

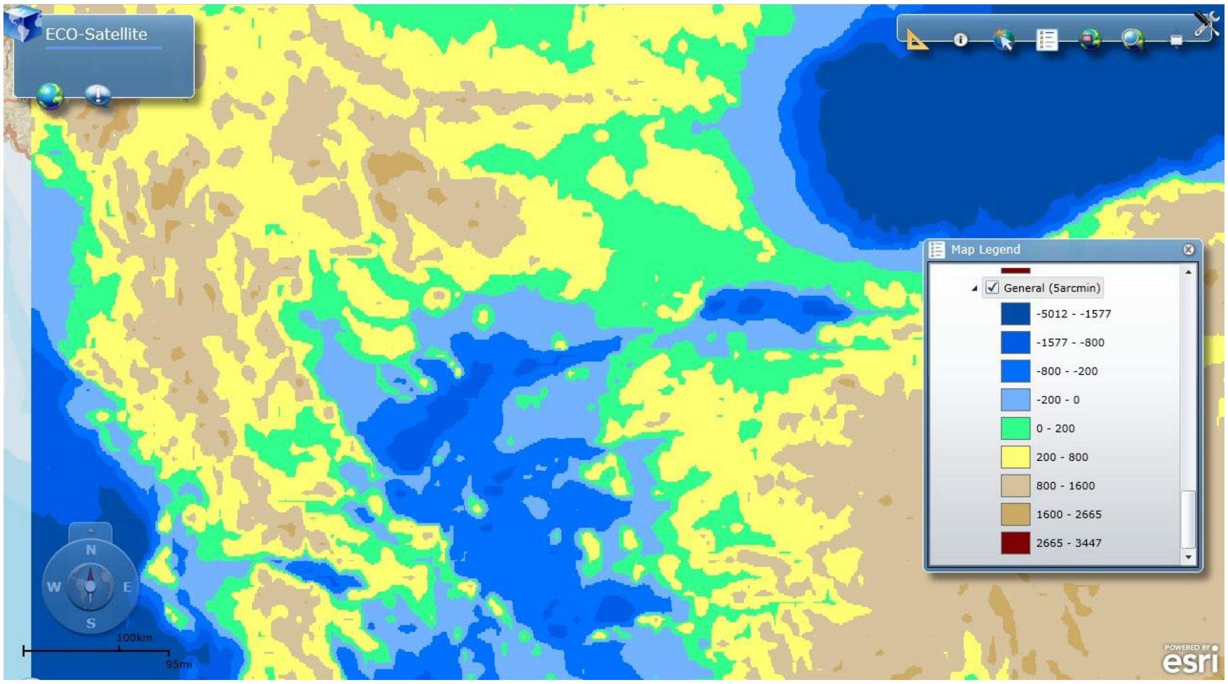

Figure 8. The ECO-Satellite system data representation as thematic maps: Terrain and bathymetry model of the area under consideration.

4. CONCLUSION AND FUTURE WORK

The ECO-Satellite environmental monitoring system enhances cross-border cooperation and allows the use of a common tool by many countries and stakeholders for decision and policy making. Based on the WebGIS technology, the system minimizes data redundancy and provides a common framework for analysing environmental data through an appropriately designed and easily updated geodatabase. Data representation, analysis and decision making are key-features of the ECO-Satellite system whose design was based on legislative documents, local area characteristics, temporal variations and data availability. Future work involves the development of the decision support component and the evaluation of the completed system in the test-sites of the project in order to assess its usefulness, efficiency and credibility.

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