Development of a WebGIS-based monitoring and environmental protection and preservation system for the Black Sea: The ECO-Satellite project

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(1) Introduction

The ECO-Satellite project has been approved in the frame of the Joint Operational Program "Black Sea Basin 2007-2013" and it is co-financed by the European Union through the European Neighborhood and Partnership Instrument and the Instrument for Pre-Accession Assistance and National Funds. The overall objective of the project is to contribute to the protection and preservation of the water system of the Black Sea, with its main emphasis given to river deltas and protected coastal regions at the seaside. More specifically, it focuses on the creation of an environmental monitoring system targeting the marine, coastal and wetland ecosystems of the Black Sea, thus strengthening the development of common research among the involved partners and increasing the intraregional knowledge for the corresponding coastal zones. This integrated multi-level system is based on the technological assets provided by satellite Earth observation data and Geo-Informatics innovative tools and facilities, as well as on the development of a unified, easy to update geodatabase including a wide range of appropriately selected environmental parameters. Furthermore, a Web-GIS system is under development aiming in principle to support environmental decision and policy making by monitoring the state of marine, coastal and wetland ecosystems of the Black Sea and managing all the aforementioned data sources and derived research results. The system is designed in a way that is easily expandable and adaptable for environmental management in local, regional, national and trans-national level and as such it will increase the capacity of decision makers who are related to Black Sea environmental policy. Therefore, it is expected that administrative authorities, scientifically related institutes and environmental protection bodies, in all eligible areas, will show interest in the results and applications of the information system, since the ECO-Satellite project could serve as a support tool for the environmental monitoring, protection and preservation of the Black Sea system.

In this presentation the design and development of the system architecture along with the innovative technologies for environmental monitoring implemented in the Web-GIS system of the ECO-Satellite project are presented and analyzed. Additionally, the collection and processing of current and historical data and the design and structure of the developed geodatabase are described. Finally, the testing of system components and geodatabase levels in different demonstration sites are also discussed in the frame of a variety of environmentally oriented project applications.

(2) Objectives

- Develop and test a system for monitoring the state of marine, coastal and wetland ecosystems, thus increasing the intraregional knowledge for the coastal zones of Black Sea.
- Create a unified, easy to update geodatabase covering areas of the Black Sea in order to support the design of a common cross-border environmental policy for the entire region.
- Develop a Web-GIS system which will contribute to the environmental protection of the Black Sea ecosystems and facilitate decision making.
- Diffuse the project knowledge and outputs through training, mass media actions, web-portal and e-lessons.
- Increase the capacity of decision makers who are responsible for implementing environmental policy in the Black Sea.

(3) Target Groups

The results and applications of the information system developed are of main importance for administrative authorities, scientifically related institutes and environmental protection bodies, in all eligible areas, since the ECO-satellite action could serve as a support tool for the environmental monitoring, protection and preservation of the Black Sea ecosystem.

The different types of potential users of the ECO-Satellite environmental monitoring system have been grouped in the following categories:

- Decision/policy makers (e.g., Politicians, City and Land Planners, Natural Risk Managers, Environmentalists, Foresters, Environmental Engineers, Marine scientists, Coastal Engineers) and public services/organizations (e.g., Ministries for the Environment, Land Planning and Public Works, Ministries of Agriculture and Forests, Master Plan and Environmental Protection Organizations, Regional Administration, Local Authorities Environmental Organizations, Water Boards, etc.)
- Scientific community (e.g., research and higher education institutions, etc.)
- ECO-Satellite project team members

(4) Study Area

The three test sites of the project are: (A) The protected area of Danube Delta in Romania, (B) the protected area of the Kyliiske Mouth, the northern part of the Danube marine region in Ukraine and the surrounding areas and (C) the protected area of Gallikos estuaries (Axios-Loudias-Aliakmonas) in northern Greece.

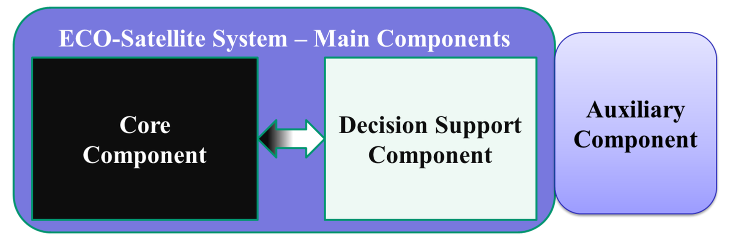
The test areas of the ECO-Satellite project

(5) Structure of the ECO-Satellite Environmental Monitoring System

The ECO-Satellite Environmental Monitoring System (ECO-Satellite System) is a Web-GIS system that provides tools for viewing, analyzing and assessing environmental data stored in the ECO-Satellite geodatabase. More specifically, the ECO-Satellite system is comprised of a geodatabase and a client-server application.

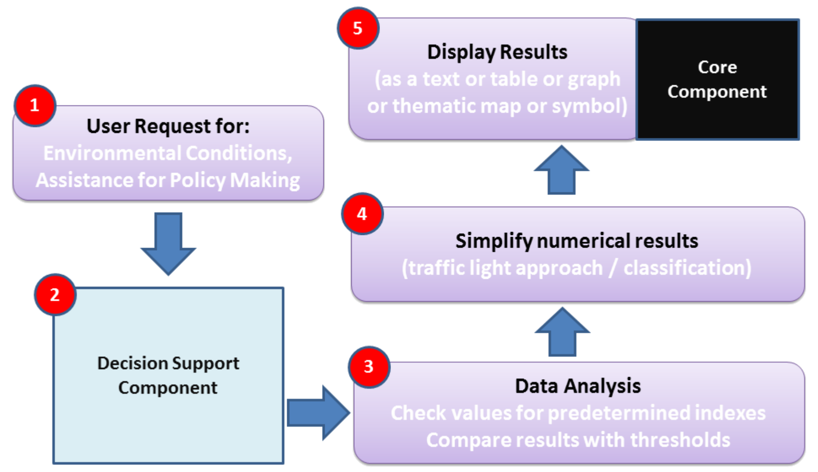
The geodatabase contains both raster and vector data originating from freely available data sources as well as data collected and/or processed by the project partners. The data sets, both terrestrial and satellite, stored in the geodatabase may be categorized as: a) in-situ Environmental, b) Remote Sensing Environmental, c) Mean Sea Level and Bathymetry and d) Basic Cartographic. The ECO-Satellite geodatabase uses Microsoft SQL-Server.

The client-server application, i.e., the Web-GIS application, is based on the ESRI ArcGIS Server and ESRI ArcGIS Silverlight API. The client side is a Microsoft Silverlight Application that utilizes services provided by the ECO-Satellite server. In overall, the Web-GIS is composed of the following components: a) Core Component, b) Decision Support Component and c) Auxiliary Component.



The ECO-Satellite System Components

The purpose of the Core Component is to display all kinds of data (layers, tables, raster images, charts, etc.) and provide map navigation and analysis tools to the end-user. On the other hand, the purpose of the Decision Support Component is to assist in policy/decision making by providing specific tasks that lead to the estimation of the quality of water bodies. The results obtained are presented in a simplified manner either by using the traffic light approach or by displaying a pass/fail statement.



The Decision Support Component flowchart

The last component of the ECO-Satellite system, i.e., the Auxiliary Component, provides to the administrators of the system the abilities to: a) Manage the users of the system and their rights and b) update the geodatabase with processed raster datasets of environmental parameters (e.g., chlorophyll-α concentration, total suspended matter concentration, etc.).

(6) ECO-Satellite geodatabase

The ECO-Satellite geodatabase is the basis for the ECO-Satellite system. It includes basic cartographic and environmental data originating from terrestrial and satellite sources. In-situ measurements as well as imagery from satellite remote sensing are the two key sources of environmental data in the ECO-Satellite geodatabase, while both current and historical data were collected and processed. The data included refer mainly to the study areas of the project. The structure of the geodatabase, though, allows for the easy incorporation of additional data, while the online update tool that was developed allows the insertion of newly processed satellite images, thus keeping the geodatabase up-to-date.

The process of environmental monitoring may present significant differences from one area to another regarding the parameters measured or observed. This led the ECO-Satellite project team to reorganize the structure of the tables in the geodatabase by area rather than by parameters. By this decision, the geodatabase 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 it would be thought that this will cause difficulties in managing the data, the fact that for each area a subset of all the possible parameters monitored is selected, eases the representation of the data to the end-users.

Types of data stored in the ECO-Satellite geodatabase

Datasets	Study areas	
	Gallikos estuaries	Danube Delta
Biological parameters (e.g., macrophyes, 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, dissolved oxygen, temperature, salinity, etc.)	■	■
Ramsar sites	■	■
Surface water extents and level changes	■	
Terrain and bathymetry models	■	■
Tide gauge stations	■	■
Water quality permanent monitoring stations	■	

Since the ECO-Satellite system does not intend to be a real-time monitoring system but rather a system that provides reliable assistance in decision and policy making, the data stored in the geodatabase should be first processed and checked for possible errors and blunders before inserted in the geodatabase. Therefore, only data that have been validated, when possible, have been included in the geodatabase.

It should be noticed that the selection of data was made also in accordance to certain legislative documents, i.e., the Ramsar Convention, the Habitats Directive (Council Directive 92/43/EEC - conservation of natural habitats and of wild fauna and flora), the Water Framework Directive (Directive 2000/60/EC - water policy) and the Marine Strategy Framework Directive (Directive 2008/56/EC - marine environmental policy). The aforementioned legislative documents were also used in designing the decision support component of the ECO-Satellite system.

(7) ECO-Satellite geodatabase validation

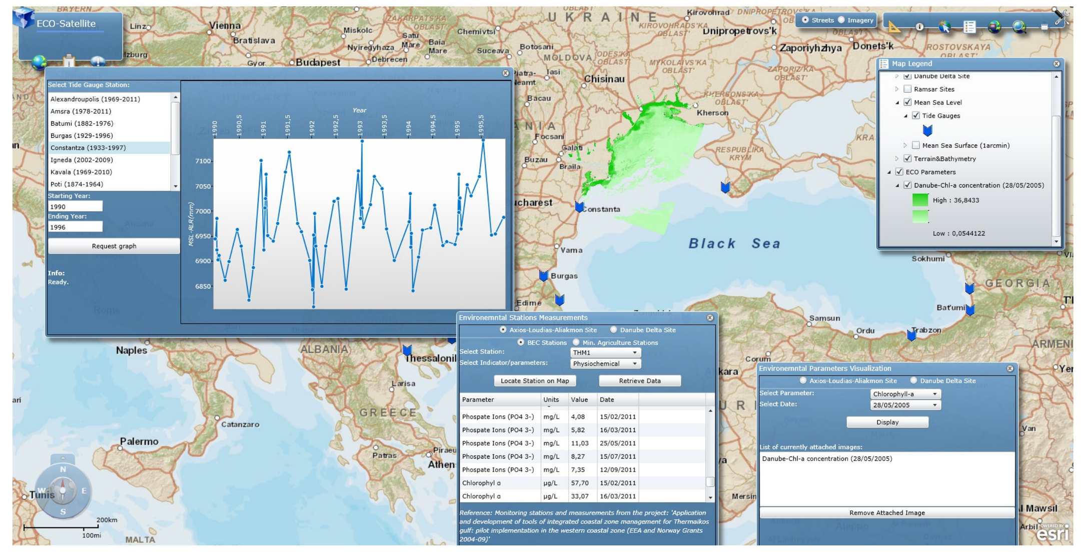
The data stored in the ECO-Satellite geodatabase were validated in the study areas of the project using newly collected data from in-situ measurements and satellite remote sensing imagery. Echo-sounding and GPS leveling measurements where carried out in the wider area of the Gallikos estuaries in order to validate the topography of the surrounding land regions and the bathymetry models. Additionally, in-situ measurements were carried out in Gallikos test area in order to assess the data from permanent environmental monitoring stations through a time series analysis. On the other hand, in the wider region of the Danube Delta comparative studies were carried out for specific environmental parameters either through a time series analysis or by comparing in-situ measurements with data derived from satellite remote sensing images (e.g., Chlorophyll-α concentration, Total Suspended Matter concentration).

(7) ECO-Satellite geodatabase validation (continued)

The aforementioned comparisons showed that the data sets finally stored in the ECO-Satellite geodatabase are reliable, while whenever no direct comparison was possible, the data compatibility was investigated by a time series analysis. From this validation, conclusions were also drawn with respect to the limitation of satellite derived data. In the case of imagery from satellite remote sensing, cloud coverage was identified as a major problem. Similarly, satellite altimetry data sets, from which the bathymetry model is derived, has also accuracy problems near the coastal areas. In overall though, these problems may be addressed with the optimal combination of satellite and terrestrial data, wherever is possible.

(8) ECO-Satellite Data Representation

Different alternatives regarding the data representation are available through the ECO-Satellite system. Graphs, data tables, vector and raster entities are the available ways to display descriptive and spatial information. All information is retrieved from the server by the end-user on demand. This is necessary mainly for the raster images, whose number exceeds two hundred. In this case the user selects a specific date and parameter and the images are added to the map legend thus minimizing the loading time and keeping the legend well organised.

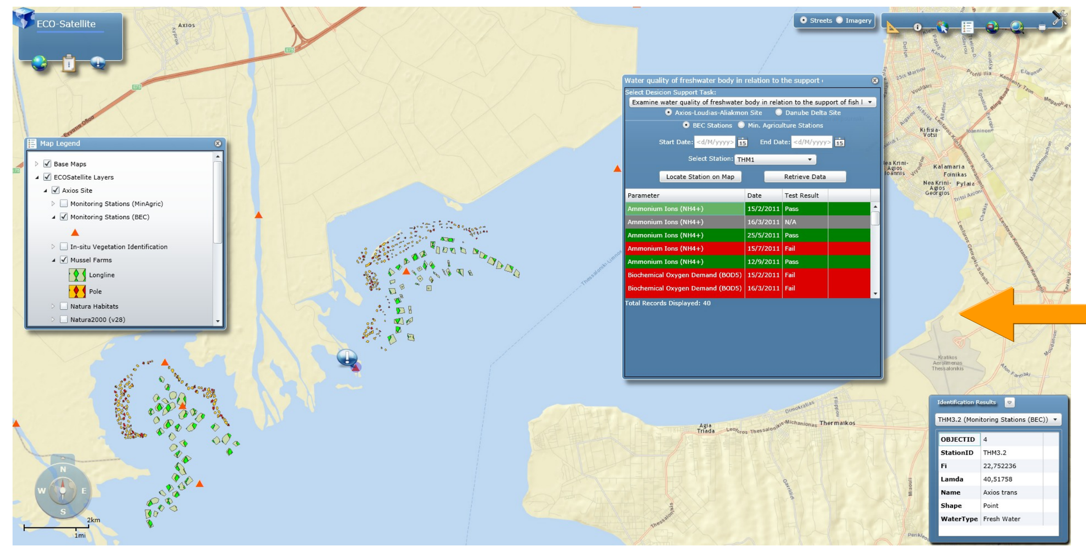


Data representation capabilities of the ECO-Satellite system

(9) ECO-Satellite Decision Support

The Decision Support component is the most important part of the system. It aims to support policy and decision makers that are not necessarily scientists but are actively involved in environmental protection and monitoring. Hence, the component was designed under the principle that its results should be simplified in order to be easily understandable but without affecting their credibility and reliability. Regarding the decision making model, the component follows the most commonly used model, that is the *semi-structured*, and the *structured* model in profound cases. In other words, 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.

Taking into account that each environmental parameter has not necessarily a straightforward interpretation regarding the water quality of an ecosystem, the ECO-Satellite team decided to avoid such parameters and include in the decision support only those tasks that may be considered as safe and reliable to use. Finally, thirteen tasks have been included in the Decision Support component.



ECO-Satellite Decision Support component— Examining the water quality in support of fish life using a Pass/Fail analysis for a specific environmental monitoring station

(9) ECO-Satellite Decision Support (continued)

The listed tasks offered by the system are based on specific environmental parameters and/or their combination. Hence, in order to provide to the end-user, through the tasks, results for a specific period of time, data for these parameters should be available. This is one of the most critical problems faced in a decision support system, since if even one parameter is missing either the result cannot be obtained or the end-user is supplied with incomplete result. Therefore, it was decided to include tasks in the ECO-Satellite system that depend on various data types (e.g., zooplankton indexes, phytoplankton indexes, physiochemical parameters, etc.). By this way, the ECO-Satellite system provides different ways to evaluate water quality by exploiting, as much as possible, different types of parameters.

Decision Support Tasks provided by the ECO-Satellite system

Decision Support Task	Result
Evaluate the ecological status of a water body	traffic light approach
Examine water quality of freshwater body in relation to the support of fish life	pass/fail
Examine water quality of saltwater body in relation to the growth and reproduction of shellfish	pass/fail
Examine quality of water for bathing	pass/fail
Examine water quality of surface body in relation to specific pollutants and physiochemical parameters	pass/fail
Compare measured values at environmental stations against user-defined threshold values	pass/fail
Evaluate water quality based on the trophic index	traffic light approach
Evaluate the water quality and trophic conditions using phytoplankton indexes	traffic light approach
Evaluate the water quality and trophic conditions using zooplankton indexes	traffic light approach
Assessment of the Ecological Class using macrophyte's morpho-functional indexes	traffic light approach
Evaluate the water quality and trophic conditions using meiobenthos indexes	traffic light approach
Evaluate the water quality and trophic conditions using macrozoobenthos indexes	traffic light approach
Evaluate water quality from mussel settlements	traffic light approach

A Decision Support Task Example

In this section an example is provided analytically towards the assessment of the water quality of freshwater in relation to the support of fish life. Then, the user of the ECO-Satellite system selects the task from the respective list and then he selects through an option the area of interest (currently only the test areas of the project are available). Then, the user selects from a list the station of interest, which monitors fresh water, while there is also the ability to narrow the time window of request by specifying start and end dates. In the next step, the user sends the request to the server that after processing returns the results, which are presented in a table. Pass, Fail and Not Available are the possible resulting values, which are colored green, red and gray respectively. The results are classified by parameter and ordered by date. By this way trends over time may be detected, while, the user may have an overall view of the water quality at the station in a particular date by narrowing the results to a specific date.

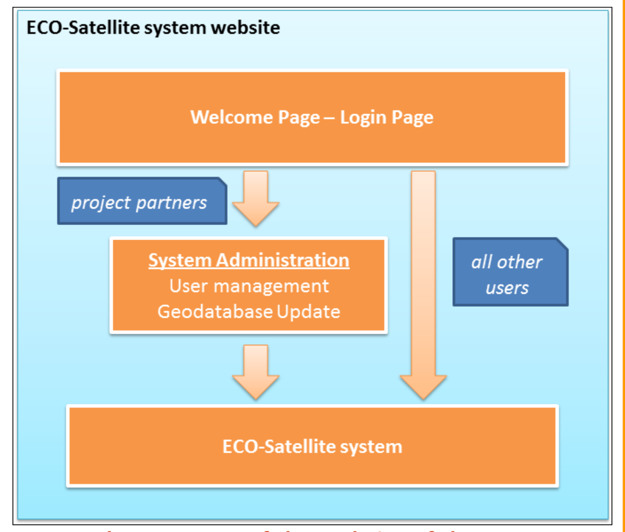
Threshold values for assessing the "Quality of freshwater for the support of fish life" according to the Council Directive 78/659/EEC "On the quality of fresh waters needing protection or improvement in order to support fish life (Freshwater Fish Directive)"

Parameter		Value	Units
Ammonia	<	0,025	mg/l
Ammonium	<	1	mg/l
Biological Oxygen Demand	<	3	mg/l
Chlorine	<	0,005	mg/l
Dissolved Oxygen	>	8	mg/l
Nitrite	<	0,01	mg/l
pH		6-9	-
Suspended Solids	<	25	mg/l

(10) ECO-Satellite System Website

The ECO-Satellite environmental monitoring system may be accessed from the ECO-Satellite project website (http://www.eco-satellite.eu). In order to use the system, a user account is required, which may be provided by the ECO-Satellite project team upon request and after accepting the usage terms. Users that belong to the project/decision makers and groups of scientists may use also the Decision Support component.

The system administration is carried out only by the project partners through the auxiliary component of the system. Hence, the project partners may additionally manage the end-users of the system or update the geodatabase through the online raster data update tool.



The structure of the website of the ECO-Satellite system

(11) Conclusions and future work

The ECO-Satellite environmental monitoring system enhances transnational cooperation and allows the use of a common tool for decision and policy making.

Based on the Web-GIS technology, the system provides a common framework for analyzing environmental data through an appropriately designed and easily updated geodatabase.

The ECO-Satellite geodatabase contains current and historical data for environmental parameters from terrestrial and satellite data sources. The coexistence of both sources of data improves data availability and provides different means for the verification of the decision support results.

Data representations, analysis and decision making are key features of the ECO-Satellite system.

Its design was based on legislative documents, local area characteristics, temporal variations and data availability.

Future work involves the completion of the decision support component's development and the evaluation of the completed ECO-Satellite system in the test-sites of the project in order to assess its usefulness, efficiency and credibility.

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