Development of a Web-based GIS monitoring and environmental assessment system for the Black Sea: application in the Danube Delta area

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Abstract

In this paper, the development of a Web-based GIS system for the monitoring and assessment of the Black Sea is presented. The integrated multi-level system is based on the combination of terrestrial and satellite Earth observation data through the technological assets provided by innovative information tools and facilities. The key component of the system is a unified, easy to update geodatabase including a wide range of appropriately selected environmental parameters. The collection procedure of current and historical data along with the methods employed for their processing in three test areas of the current study are extensively discussed and special attention is given to the overall design and structure of the developed geodatabase. Furthermore, the information system includes a Decision Support Component (DSC) which allows assessment and effective management of a wide range of heterogeneous data and environmental parameters within an appropriately designed and well-tested methodology. The DSC provides simplified and straightforward results based on a classification procedure thus contributing to a monitoring system not only for experts but for auxiliary staff as well. The examples of the system's functionality that are presented highlight its usability as well as the assistance that is provided to the decision maker. The given examples emphasize on the Danube Delta area, however, the information layers of the integrated system can be expanded in the future to cover

other regions, thus contributing to the development of an environmental monitoring system for the entire Black Sea.

Keywords

Environmental Monitoring, Decision Support Component, Geodatabase Development, Satellite Earth Observation Data, Web-based GIS

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1. Introduction

The degradation of natural and semi-natural ecosystems has accelerated over recent decades due to the effect of direct or indirect human pressures (Hassan et al. 2005). At the same time, preserving a good state of ecosystems provides economic, financial, ecological and cultural benefits. The basis for ecosystems' preservation and restoration is environmental monitoring (Burger 2008). Monitoring within the European Water Framework Directive (2000/60/EC) for instance, may be performed as surveillance, operational or investigative, according to various objectives and conditions of water bodies (European Communities 2009). The archiving, secondary analysis and visualization of the results of environmental monitoring are usually performed through an integrated environmental monitoring system (Parr et al. 2002).

The primary utility of these systems is to provide access to information about human pressures and impacts on the environment, as well as its condition, in order to serve decision makers and stakeholders (Lovett et al., 2007). In most cases, no single information system can provide the entire information set needed to generate a comprehensive overview of the environmental state at a given location, as it would require gathering data from multiple sources in a single centralized database. A web-based Geographic Information System (Web-based GIS) could form the basis for a practical approach to an environmental information system, as it has several advantages: display of information in an easy to understand manner, flexibility in combining spatial and temporal dimensions, ability to connect to and extract information from existing databases (Lee et al. 2008).

Previous attempts to use a Web-based GIS system in environmental monitoring include the WaldIS, an Open Source Web-based GIS system that allows for data compilation, visualization and spatial and statistical analyses of forest data in Germany, such as forest condition evaluation, foliar parameters survey and soil condition evaluation (Aden et al. 2010). A Web-based GIS system has also been established for the Miyun reservoir near Beijing in order to model, monitor and manage soil erosion information using two soil erosion models and visual interpretation of Landsat TM images (Huang et al. 2004). Virtual Database is an integrated environmental and landscape Web-based GIS for Switzerland that allows for the retrieval, analysis and visualization of relevant data from various sources, such as biotopes polygons, fauna observations, fungi, moss and lichen occurrences (Frehner and Brandli 2006). Geospatial data and information on Florida's wetlands can be found on the University of Florida Web-based GIS, such as the soils’ physical, chemical, and biological attributes, and land use data (Mathiyalagan et al. 2005). A Web-based GIS has also been developed for the northeast coast of Brazil to analyze and assess areas that are influenced by the oil industry and in need of environmental management, based on spatial queries to identify changes observed in time (De Castro et al. 2011). Another Web-based GIS is used in China to study the landslide hazards in the typhoon affected regions, using predictive models of rainfall intensity that consider geomorphology, geology, vegetation and landslides history (Zhang et al. 2011). An integrated environmental data management system has been created for the Tidal Creek (East Coast, US) to consolidate existing databases, support future data collection efforts, and facilitate data dissemination through Web applications including a Web-based GIS (White et al. 2009).

The use of Web-based GIS is not limited though to stand-alone applications for environmental monitoring as they may be part of a more complex system, e.g., a cyberinfrastructure. Cyberinfrastructures combine distributed computing with information and communication technologies with emphasis in human interaction and focus on multidisciplinary research and applications. An example of a cyberinfrastructure system including a Web-based GIS is the one developed by Iordache et al. (2015) for monitoring air quality in order to protect children with respiratory disorders.

Following the critical environmental problems reported in the Black Sea (Arslan and Okmen 2006), several monitoring projects have been initiated. After long-term monitoring of the hydrological and hydro-chemical parameters in the Bulgarian Black Sea, temporal trends and spatial distribution have been evaluated (Dineva 2005). The phytoplankton community and nutrients of the Western Black Sea have been studied to evaluate the ecosystem functioning and changes (Velikova et al. 2005). Time series of satellite images have been used to monitor several water quality parameters in the Black Sea, such as chlorophyll-a concentration using images from the Medium Resolution Imaging Spectrometer (MERIS) on board the Envisat satellite (Moses et al., 2012), total suspended matter estimated from Sea Viewing Wide Field of View Sensor (SeaWiFS), Moderate resolution imaging spectroradiometer (MODIS) and MERIS satellite images (D'Alimonte et al. 2012), and sea surface temperature derived from nighttime Advanced Very High Resolution Radiometer (AVHRR) images on board the National Oceanic and Atmospheric Administration (NOAA) satellites (Ginzburg et al. 2004). Pollution from oil spills and other urban and industrial point sources has also been monitored using high resolution images from the ERS-2 satellite (European Remote Sensing) and Advanced Synthetic Aperture Radar (ASAR) sensor on board Envisat satellite and in-situ sampling (Ferraro et al. 2009; Ivanov and Zatyagalova 2008; Tuncer et al. 1998). A review of the methods and sensors used in remote sensing for oil spill detection can be found in Topouzelis et al. (2015). Satellite altimetry has also been used to produce time series of Black Sea level in order to study the water circulation (Korotaev et al. 2001).

Consequently, many data regarding the Black Sea environment are available, but rather segmented, disconnected, difficult to access and inconclusive. The aim of this paper is to present an integrated environmental monitoring system for the Black Sea developed in the frame of the ECO-Satellite project, taking advantage of innovative information technologies and various existing data sources. The objectives are: (i) to design a system based on user requirements and environmental legislation, (ii) to create a unified and easily updateable geodatabase and (iii) to develop a Web-based GIS system for dissemination of environmental information facilitating the decision-making process.

Preliminary results of the ECO-Satellite system on its development considerations, objectives and data analysis were presented in several publications (e.g., Savvaidis et al. 2012, Alexandridis et al. 2013, and Tziavos et al. 2013). This paper presents the ECO-Satellite system in its full operational mode emphasizing on (a) the structure and flexibility of the developed geodatabase towards the incorporation of additional, environmentally related data sources and (b) the Decision Support Component (DSC) that provides reliable results following a simplified and well-tested methodology. The latter is primarily based on the evaluation of specific indexes and parameters being in line with policies and existing legislative framework.

2. Study areas

The selection of test sites was carried out based on an evaluation of their environmental significance, specifically with regard to their roles in maintaining the biological biodiversity and sustaining of human life. Therefore, three Ramsar sites (Ramsar Convention Secretariat 2013) meeting these criteria were selected, which are described as follows.

The first study area is the Danube Delta, one of the biggest deltas in Europe, covering 4800 km^2. The Danube has a catchment area of 817000 km^2 and its course flows through 17 countries, and thus drains sediment and waste, both human and natural, from a huge basin inhabited by 76 million people (Alexandrov 1998). Half of the fresh water flow into the Black Sea comes from northwestern rivers, while about 36% is accounted for by the Danube's contribution (Nikolenko and Reshetnikov 1991).Approximately 80% of the surface is still in its natural condition, with 500 km^2 being under a strictly protected regime, via the Danube Delta Biosphere Reserve (DDBR). The diversity of the habitats supported and encouraged in DDBR is sustained by consistent assessments, interventions and protection and varies greatly in terms of the communities of flora and fauna it hosts. At any given time, it encompasses 30 types of ecosystems, 2383 plant and 4029 animal species according to the DDBR (2016). It has long been recognized that the Danube Delta natural capacity comprises unique aspects of biodiversity in the region and is an area of incomparable resources for both human subsistence, and plant and animal life. Thus, the efforts to preserve its ecosystems began in 1938, when Letea Forest was declared a protected area by the Romanian Academy. UNESCO recognized the wider value of the Delta in 1990, when it was included in its 'Man and Biosphere' program (MAB), which is the international network of biosphere reserves. Further realization and recognition of the area's global importance include the listing of the DDBR under the Ramsar Convention in 1991, when it was included as a wetland of international importance, with particular emphasis on its waterfowl habitat. Moreover, in 1990, the World Cultural and Natural Heritage Convention recognized the universal natural heritage value of the reserve with its inclusion on the World Heritage List. This recognition signifies that the value of the area is not only environmental, but also economic, historical and culturally relevant with the sustainable use of water, fauna and flora by local populations for thousands of years.

Over time and with human development and expansion, intrusion in the ecosystem by human habitation and activity has put pressure on the natural resources. In 1862, the first large-scale works began in the Danube Delta, when corrections of the Sulina branch were made to assure large-vessel navigation for ameliorating transport, trade and economic growth (Gastescu and Stiuca 2008). Traditional activities in the area, such as fishing, farming, and hunting were significantly affected by reed development and use, fishponds and large-scale agricultural plans, during and before the 1960s. In 1960, around 750 km^2 were converted from natural habitats into economically productive areas, leading to a multitude of environmental issues, including water pollution, coastal erosion, flooding, over-fishing, illegal fishing, uncontrolled tourism and illegal construction.

The second study area is the protected region of the Kyliiske Mouth (Ramsar Site No. 113), which comprises the northern part of the Danube marine region in Ukraine and the surrounding areas.

Covering an area of 1240 km^2, the Ukrainian part of the Danube delta is made up of about 20% wetlands (Zhmud 1999) and is characterized by a diverse landscape including reed beds, water channels, numerous lakes, flooded forests, meadows, marshes, sand and patches of steppes. In 1998, the Danube Biosphere Reserve of Ukraine was established, encompassing the "Dunaiski Plavni" National Reserve. It was awarded for World Heritage status as a joint Romanian-Ukrainian site. A diverse set of habitats can be found at this site, including coastal shallows, and it is located in the maritime zone of the secondary Delta of the Kilia Branch of the Danube River. The Danube Biosphere Reserve of Ukraine covers approximately 500 km^2, while the marine coastal zone of the Reserve is 66 km^2. Hosting a unique and diverse range of flora (1557 species of plants), the Reserve has 26 of these species listed in the Red Data Book of Ukraine (RDB) and 10 of them on the European Red List. The fauna is rich, with 106 species of fish (26 in the RDB), 276 bird-species (60 in the RDB) and 43 identified mammal species (19 in the RDB) according to the data held by the Danube Biosphere Reserve (DBR 2016). More information about the Danube marine region in Ukraine can be found in the literature (IUCN 1992; Zhmud 1999).

The third study site is another Ramsar Site (No. 59) and is the protected area of the delta of the Axios, Loudias, and Aliakmonas Rivers (Axios-Loudias-Aliakmonas) in northern Greece. Comprising a complex deltaic system, the three rivers flow into the Thermaikos bay through numerous branches from the main rivers' courses. Due to this, the rivers' diverse habitats are made up of small interwoven patches of high biodiversity. Previous work (Alexandridis et al. 2009) has mapped a number of important habitats for rare and endangered species in this area. Upstream of the delta, the floodplain is one of the most productive agricultural areas of Greece. As early as the 1930's, extensive irrigation projects and reclamation work have been implemented. Aquaculture is an additional human activity in the area with high economic importance, currently accounting for 88% of the national mussel production (Alexandridis et al. 2008; Askew 1987; NCRM, 2001). Industrial development, led by both economic and population growth, has led to the expansion of the industrial zone of Thessaloniki up to the north-eastern boundary of the study site. Human activity in the area and its upstream part have resulted in a variety of environmental problems, such as dams and irrigation networks, drainage works, pollution of surface waters, over-fishing, and extensive aquacultures. Some particular environmental issues were determined by mussel farming, hunting, overgrazing, illegal sand extraction, construction of illegal settlements on the coastline, and poor management of water resources (Zalidis et al. 1997; Armenakis et al. 2014).

Fig. 1. Test areas of the ECO-Satellite project: a) Danube Delta, b) Kyliiske Mouth and c) delta of rivers Axios-Loudias-Aliakmonas and the main interface of the ECO-Satellite system

The locations of the test sites are presented in Fig. 1. Although the ECO-Satellite system focuses on the area of the Black Sea, the third test site was selected in order to carry out comparative studies and validation of the methodologies used throughout the project as well as to demonstrate the ability of the ECO-Satellite system to expand in other areas of interest. Although each site is characterized by specific conditions and its environmental monitoring may be governed by different legislation, the geodatabase design and user interface allow easy expansion to cover these particularities. Thus, the system is adapted to focus on the specific characteristics of each study area rather than on a common set for all areas.

3. Data sources and geodatabase development

The ECO-Satellite geodatabase includes all the relevant terrestrial and satellite-derived data for the three test sites as well as a wider region. Apart from the background map, both current and historical environmental data are stored in the geodatabase. These data sets were selected from in-situ measurements as well as from the processing of satellite images. In more detail, regarding the environmental data for the first two test-sites stored in the geodatabase, these refer to biological parameters (e.g., macrophytes, phytoplankton, invertebrates, macrozoobenthos, bivalves population, meiobenthos, zooplankton and fish species) and physicochemical parameters (e.g., dissolved oxygen, temperature, salinity, etc.). Even though the zooplankton community is not listed as a quality element in the Water Framework Directive it can be easily integrated into the classification schemes, being an important component of water quality. In Danube Delta, zooplankton community is clearly dominated by the copepods in Danube arms and rotifers and cladocerans in the shallow lakes (Tudor et al. 2014).

For the third test site, i.e., the delta of Axios-Loudias-Aliakmonas Rivers, the additional data include a habitat map, mussel farms, in-situ vegetation identification and water quality data from permanent monitoring stations. For the morphology of the wider region and the sea level state, a digital terrain and bathymetry model (Becker et al. 2009), a Mean Sea Surface (MSS) model (Andersen 2010; Andersen and Knudsen 1998) as well as tide gauge data (Holgate et al. 2013; PSMSL 2012) were incorporated in the geodatabase. The land topography and bathymetry model was based on SRTM30 Plus (Becker et al. 2009), being based on the 3 arcsec resolution SRTM data for continental areas and a hybrid bathymetry model from the combination of echo-soundings and re-tracked altimetry. The MSS model is based on the DTU2010 model derived from the combination of sea surface heights based on multi-mission re-tracked altimetry (Andersen 2010).

Table 1 – Summary list of the geodatabase contents of the ECO-Satellite system

Data source	Data description
Remote sensing images	For land: maps of land cover, land cover change, habitats, habitats change For water surface: Chlorophyll-a, total suspended matter, sea surface temperature
Remote sensing altimetry	Mean Sea Surface (DTU2010) model, sea surface heights over the geoid with 1 arcmin and 5 arcmin resolutions
Terrain/Bathymetry	Land topography and sea bathymetry from the SRTM30 Plus model at 30 arcsec, 1 arcmin and 5 arcmin resolutions
Water body typology	Typology for riverine, deltaic, and transitional water bodies

In-situ measurements of water quality	Hydrochemistry, phytoplankton, zooplankton, meiobenthos, macrozoobenthos, mollusks, and makrophytes at sampling stations
Water quality from telemetric monitoring stations	Time series of water temperature, specific conductivity, salinity, dissolved oxygen, oxidation reduction potential, turbidity, pH, total dissolved solids, Chlorophyll-a, NO_3^-
Water quality assessment	Map of water quality characterization per water body according to the Water Framework Directive using a five-color scale

The final geodatabase is an ESRI ArcSDE Enterprise Geodatabase hosted by the Microsoft SQL-Server. The use of a Relation Database Management System (RDBMS) in combination with a multi-user geodatabase provides enhanced security and data integrity. A summarized list of the data used in the geodatabase is given in Table 1. In addition to the data stored in the ECO-Satellite geodatabase, further data were included in the ECO-Satellite system by using a Web Map Service (WMS) provided by a server located in the Danube Delta National Institute of Romania. The additional data contain the processed chemical values from the monitoring of water quality in the Danube Delta. The data processing involved also the application of an inverse distance weighting interpolation method (Fisher et al. 1987) to obtain gridded raster datasets.

During the design phase of the monitoring system, the available environmental parameters for the first two study areas were analyzed and examined. This examination revealed significant differences regarding the selection of the necessary parameters due to the particular conditions and environmental risks affecting each area. This conclusion was further strengthened by the fact that each area has its own peculiarities and threats and therefore the appropriate monitoring parameters and indexes have to be selected accordingly. Thus, it was decided to restructure the geodatabase, store the available information on a per area basis, and leave the necessary unified management of the data to be done programmatically through the system. Consequently, special attention was given to keep the geodatabase easily updateable and consequently to guarantee and facilitate the extensibility of the ECO-Satellite system. The online update tool that was developed for accommodating the update of the geodatabase demonstrates the latter. This tool is used for incorporating environmental data from newly processed satellite images, thus keeping the geodatabase up-to-date. Currently, the tool provides the ability to include data only for existing parameters and for the test areas described in the previous section. More details regarding the online update tool are provided in the following section.

The primary focus of the ECO-Satellite system is not to be used in real-time monitoring but mainly to provide validated and reliable information for decision and policymaking processes. Hence, all data, prior to being stored in the geodatabase, were processed (e.g., homogenized - refer to the same coordinate reference system, use the same Unit System etc.) and checked for outliers and logical errors. This procedure was also set as a rule regarding the usage of the online update tool of the system. More specifically, the available data were validated against in-situ measurements, which were carried out for this reason, as well as data derived from recently processed satellite images. Regarding the validation of the bathymetry models and the topography of the surrounding land regions, in-situ echo-soundings were carried out and GPS/leveling observations were conducted in the wider area of the delta of the rivers Axios-Loudias-Aliakmonas, respectively. As far as the environmental data sets are concerned, additional in-situ measurements were carried out in the Axios-Loudias-Aliakmonas test area for assessing the available data recorded by the automated environmental monitoring stations. This was achieved by using time series analysis, such as data cleaning and filtering. In the second test area of the project, i.e., the wider region of the Danube Delta, similar comparisons were made for assessing specific environmental parameters following also time series analysis and conducting comparisons between in-situ measurements and data based on the processing of satellite images (e.g., the average accuracy for Chlorophyll-a concentration is < 5 mg/m^3 and for Sea Surface Temperature is < 1.5 °C) (Alexandridis et al. 2013).

The previously described validation procedure ensured that the data stored in the ECO-Satellite geodatabase are reliable. In cases where no other sources of data were available and thus validation by comparison was not possible, it was decided to examine the datasets using time series analysis along with a thorough examination for possible discrepancies in their spatial distribution as well as in their statistics (e.g., mean value, standard deviation, range etc.). The validation procedure led to certain conclusions especially for the satellite data used. For satellite imagery, the cloud cover, the low accuracy of certain parameters and the issue of continuity of satellite missions to ensure long time series were the main problems identified according to this analysis. For the satellite altimetry derived products, i.e., the digital bathymetry models employed for the test areas, it was concluded that the well-known accuracy problems near the coastal regions still exist, although significant progress has been reported towards the minimization of the respective effects following different techniques, e.g., re-tracking (Andersen 2010). A more efficient procedure to overcome this drawback of satellite altimetry would be the optimal combination of the satellite altimetry derived data sets with terrestrial ones when the latter are available with a high accuracy and resolution.

Different alternatives regarding the data visualization were examined and made available in the ECO-Satellite system. More specifically, the descriptive and spatial information stored in the geodatabase is made available to the end-user with the aid of graphs for displaying variations over time, data tables for viewing raw data (e.g., measured quantities and vector and raster entities), etc. In order to minimize the outgoing traffic of the server hosting the system, the above-mentioned information is made available only upon request (on-demand) by the end-user. This requirement was set especially for the raster images stored in the geodatabase, whose number by the time the system was completed exceeded two hundred. Additionally, the on-demand sharing of information was also necessary for the minimization of the loading time and for keeping the list of available layers structured and well organized. This was achieved through properly designed forms placed inside the ECO-Satellite system. These forms allow the user to select a specific date and parameter and subsequently load the selected raster images and add them to the map-legend, i.e., the list of layers.

4. Structure of the Environmental Monitoring System

The ECO-Satellite Environmental Monitoring System (ECO-Satellite System) is a Web-based GIS system that provides tools for viewing, analyzing and assessing environmental data stored in the ECO-

Satellite geodatabase (Tziavos et al. 2013). The system contains a geodatabase, which was described in the previous section, and a client-server application (see Fig. 2), which is the Web-based GIS application. The server side of the application is based on the ESRI ArcGIS Server, while the client part was programmed using the ESRI ArcGIS Silverlight Application Programming Interface (API). On the server's side, a Microsoft Internet Information Services (IIS) Web server hosts ASP.NET web pages and the GIS and Windows Communication Foundation (WCF) services, while on the client's side a Microsoft Silverlight cross-platform compatible (Microsoft Windows, Mac OS X and Linux) application is used for utilizing the services offered by the server. The GIS services are utilized for retrieving information from the ArcSDE geodatabase, primarily spatial data, while the WCF services are used for exchanging descriptive data with the end-user and for the online update tool. The selection of the aforementioned software and API was solely based upon their functionality, their widespread acceptance and the experience of the authors. In overall, the ECO-Satellite system has the following three components: a) the Core Component, b) the Decision Support Component (DSC) and c) the User Login/Administrative Component.

Fig. 2. ECO-Satellite system diagram

The Core Component provides all the required functionality for the visualization of information stored in the geodatabase, includes tools for handling map browsing and facilitates the identification of elements on the map, the management of layers (display/hide) as well as the display of graphs and tables. Furthermore, the extensibility of the ECO-Satellite system mainly relies on this component. The main interface provided by the Core Component to the end-user of the system is shown in Fig. 1. The interface includes the main toolbar, which provides basic tools that are commonly used in GIS environments, as well as two menus. The first menu, i.e., Data Viewing menu, provides the ability to the end-user to retrieve the measured values stored in the geodatabase for each available environmental monitoring station. Additionally, from the same menu, the end-user has the ability to select from a list and add as layer on-demand (as described in the previous section) raster images of environmental parameters that are either stored in the ECO-Satellite geodatabase or provided by a different server. The second menu option provides access to the Decision Support (DS) tasks of the system.

Fig. 3. Operation flowchart for decision support requests

The DSC provides end-user with tasks that allow him to assess the quality of water bodies and consequently assist him in the decision making process. This is achieved by implementing the DSC as a rule-based structure that relies on existing legislating documents, scientific research results and previous experience (see, e.g., Dunea et al. 2014). The DSC makes use of the core component for producing results. The reason for the separation of the DSC from the core component is because, in the long-term, scientific progress along with adjustments made in policies may require significant changes to the ECO-Satellite system and specifically to the parts of the system related to decision making process. Therefore, by separating the decision support part from the rest of the system we ensure that the implementation cost and time for any required changes will be kept at minimum (Savvaidis et al. 2012). Fig. 3 presents the flowchart of the DSC component. Initially, the end-user will request information for environmental conditions in a specific area. The system will transfer the request to the DSC, where the available data will be analyzed and the computations (e.g., the computation of the trophic index), if necessary, will be made. Then, the numerical results will be simplified and converted into an easily understandable form by classifying it using decision trees. Finally, the core component will present the results to the end-user. In the whole process, the end-user interacts only with the core component, which is responsible for transferring requests and retrieving results from the DSC. The results obtained are displayed following the traffic light approach (red-orange-green for bad-medium-good, respectively) or by simply showing a pass/fail statement. Therefore, the results are presented to the end-user in a simplified and easily understandable way.

The DSC enables tasks to be carried out based on environmental indicator values, which the system compares to reference values (environmental standards whose values are extracted from the environmental regulations or deduced values from scientific research). This comparison leads to results in the form of an assessment of the environment that is eventually useful for decision-making and environmental policy planning.

The final component of the ECO-Satellite system, i.e., the User Login/Administrative Component, provides the user verification and introductory web pages to the end-users of the system. Additionally, users belonging to the administrator group may select the following tasks: a) User and rights management and b) geodatabase update through the web. Regarding the user management, this feature allows the administrator to add, update and delete users from the system as well as to set different roles. On the other hand, the update of the geodatabase is an important task, since it keeps the system up to date. During the update, processed raster datasets of environmental parameters are imported in the geodatabase by taking the system offline only for a short time. In Fig. 4, the operations flowchart for the online update tool is presented. The user initially provides input regarding the dataset files to be uploaded. Then, the user selects the date and area location and the environmental parameter (e.g., chlorophyll-a concentration, total suspended matter concentration, etc.) they refer to. The system validates the input and upon success, the files are uploaded to the server. Then, the GIS services are stopped and the data are imported into the geodatabase while the related indexes and map documents are updated. Finally, after updating the map cache and clearing the ArcGIS Server REST cache, the GIS services are restarted and the system is again operational. Since during the update of the geodatabase all services of the system are not available temporarily, the tool is not meant for carrying out bulk updating operations. On the other hand, after the update is over, any users that were connected and were working with the system may take up their work from where they had left off.

Fig. 4. Flowchart of the online update tool operations

5. Applications of the system

The specialized fields of application of the ECO-Satellite environmental monitoring system are directly related to the different needs of its potential users. Therefore a categorized list of users was prepared and used as a reference throughout the development of the system. The list is provided in Table 2 where the potential users are grouped in five categories. There are users (group members) who are actively involved in environmental protection and monitoring but are not necessarily scientists. This was the main reason for the simplification of the results provided by the DSC along with the introduction of a classification step, which was previously described. This simplification does not affect the credibility and reliability of the results.

A critical point during the implementation of the ECO-Satellite system was the selection of environmental parameters for the DSC. It was decided to exclude any parameters that do not provide a straightforward interpretation in the process of assessing the quality of a water body. Therefore, the tasks that were included in the DSC were based only on parameters, which may be considered safe and reliable to assess. Thirteen (13) tasks are available in total to the end-user of the system (Table 3). The results though provided to the end-user by the DSC for a specific time-period depend on the availability of data for the parameters involved. This is a an inherent problem existing in any system that facilitates decision making, since if even one parameter is missing either the results cannot be obtained or the end-user is supplied with incomplete results. In order to overcome this limitation, tasks depending on different kinds of data (e.g., zooplankton indexes, phytoplankton indexes, physiochemical parameters, etc.) were included in the DSC in order to reduce the possibility of not receiving results at all, while different approaches are provided at the same time regarding the assessment of water quality (Tziavos et al. 2013).

Table 2 – Users and user groups of the ECO-Satellite system*

Group Name	Group Members
Decision/policy makers	City and Land Planners, Natural Risk Managers, Coastal Engineers, Foresters, Environmentalists, Marine scientists, Environmental Engineers
Decision/policy makers (Public Bodies)	Ministries for the Environment, Land Planning and Public Works, Ministries of Agriculture and Forests, Master Plan and Environmental Protection Organizations, Regional Administration, Emergency Planning and Protection Organizations, Local Authority Organizations
Scientists	Researchers / Members of Higher Education Institutions
ECO-Satellite project team	Members of the ECO-Satellite project team
Public	All other users

* A modified version of this table was published in Tziavos et al (2013).

In the ECO-Satellite geodatabase, there are environmental datasets stored belonging to various collection methods and parameters. These collection methods may vary according to the spatial coverage (e.g., data measured by permanent monitoring stations or random point values), repetition regularity (e.g., daily/monthly/yearly measurements) and the spatial density of the data collected. Therefore, data obtained from a permanent station on a daily basis require a different approach with respect to data collected from random in-situ measurements. Similarly, data having a wide spatial coverage and possibly available in a gridded form need to be presented differently than data referring to point values. Based on these characteristics, the available tasks provided by the DSC were grouped further into five categories (see Table 3) according to the type of input data used and the way the results obtained are presented to the end-user. These categories are presented as follows:

A) Tasks that provide the ecological status of surface waters based on specific parameters, according to the Water Framework Directive, and have as output thematic maps (5 classes-colors). It should be noted that in this group the input data are available as a grid covering a wide area. The available parameters are: dissolved oxygen, biochemical oxygen demand (5 days), chloride, calcium, nitrites, nitrates, phosphates, arsenic, cadmium, lead and ammonium.

B) Tasks that compare measured physiochemical parameters at permanent environmental monitoring stations against user-defined threshold values. These tasks aim to demonstrate the usefulness of such a tool in studying the effect of threshold values in the results obtained from DSC. The available parameters are: dissolved oxygen, pH, temperature, salinity, chlorophyll a and turbidity.

C) Tasks that assess water quality for various uses and result in pass/fail values for the selected indicators per water use and for the user-defined dates/periods. The results of these tasks are presented in a table format where each measured parameter is assigned a pass, fail or not available value (N/A), respectively. Uses/quality of water options include support of fish in freshwaters, support of shellfish in saltwater, quality of water for bathing and chemical quality of surface waters.

D) Tasks that assess the water quality status from measurements carried out at randomly selected point stations in order to determine the biological indicators. The results of these tasks produce classification point-maps (5 classes-colors) for each indicator-specific measured parameter and for a user-defined time-period. The biological indicators are: trophic index (TRIX), phytoplankton, zooplankton, macrophytes, meiobenthos and meiozoobenthos.

E) Tasks that assess the quality status of 1 species of mussel settlements (*Mytilus galloprovincialis*) and 2 species of mollusk settlements, (*Mya arenaria*, *Anadara inaequivalvis*) for a specific user-defined date/period.

Table 3 – List of available tasks provided by the Decision Support Component*

Group	Task
A	Evaluate the ecological status of a water body
B	Compare measured values at environmental stations against user-defined threshold values
C	Examine water quality of freshwater body in relation to the support of fish life

	Examine water quality of saltwater body in relation to the growth and reproduction of shellfish
	Examine quality of water for bathing
	Examine water quality of surface body in relation to specific pollutants and physiochemical parameters
D	Evaluate water quality based on the trophic index
	Evaluate the water quality and trophic conditions using phytoplankton indexes
	Evaluate the water quality and trophic conditions using zooplankton indexes
	Assessment of the Ecological Class using macrophyte's morphofunctional indexes
	Evaluate the water quality and trophic conditions using meiobenthos indexes
	Evaluate the water quality and trophic conditions using macrozoobenthos indexes
E	Evaluate water quality from the mussel settlements

* Source: Tziavos et al (2013), with modifications

The threshold values used for assessing the various environmental parameters and the general guidelines that were followed for the development of the DSC were based on the following legislative documents:

- The Ramsar Convention
- The Habitats Directive (92/43/EEC)
- The Water Framework Directive (2000/60/EC)
- The Marine Strategy Framework Directive (2008/56/EC)
- The Freshwater Fish Directives (78/659/EEC and 2006/44/EC)
- The Shellfish Waters Directives (79/923/EEC and 2006/113/EC)
- The Bathing Water Directive (76/160/EEC and 2006/7/EC)

Fig. 5. Using the Decision Support Component for the assessment of water quality of freshwater body in relation to the support of fish life and consumer health

An example is described as follows focusing on the assessment of water quality in relation to the support of fish life and consumer health. First, the end-user selects the corresponding task from the decision support menu of the system as well as the area of interest. Only three study areas are available. Then, the user selects the station of interest from a list of available stations monitoring water quality parameters, while a choice of narrowing the requested results by specifying a time window (stand and end date) is also offered. The user's request is transmitted to the server where the system processes it and returns the results. The specific task's results are displayed in the form of a Table (Fig. 5), where the possible values are Pass, Fail and N/A. Different colors are used for the latter values, which are green, red and gray, respectively. The results are classified by the corresponding parameter and sorted by date and thus the detection of any trends over time is provided. Furthermore, the ability to copy the results to the clipboard to process them in a spreadsheet or other compatible software is provided. In that example and following the "Fail" result, local authorities responsible for shell fish control (Veterinary Directorate of the Regional Authority) could issue an alarm and intensify their monitoring activities (or undertake site-specific "investigative" monitoring actions) for the detection of possible blooms of toxic phytoplankton, while at the same time prevent the mussel farmers from harvesting (Nikolaidis et al. 2005). Thus with the help of the ECO-Satellite system, the mussel farms' management could become more effective at the local level.

Fig. 6. Using the Decision Support Component for the assessment of water quality with user-defined threshold values

Another example of using the ECO-Satellite DSC is provided in Fig. 6. In this case, the end-user selects the threshold values for assessing water quality. More specifically, the end-user selects a permanent monitoring station, for example in the Danube Delta area. The system then enables the available parameters that may be defined while at the same time disables the parameters for which there are no data available. Then, the user employing the available sliders selects a value as well as the operator for comparison ("equal" or "greater than"). After completing the selection of values, the user retrieves the results in a table format where they are classified in a same manner with those previously described (Pass, Fail, N/A). The classification involves all available parameters (displayed in the columns). Even if just one of the parameters does not meet the criteria set by the end-user, then the overall result will be Fail (red row background). If all parameters pass the test then the overall result will be Pass (green row background). This example can find application in the classification of surface water bodies according to their status, and assist the manager/decision maker to issue regulations for specific physicochemical parameters in order for the water body to achieve good quality status, as required by the Danube River Basin Management Plan (ICPDR 2009) in accordance to the Water Framework Directive.

Fig. 7. Using the Decision Support Component for evaluating water quality and trophic conditions using zooplankton indexes

The last example of the use of the DSC of the ECO-Satellite system is presented in Fig. 7. The DSC is used for evaluating water quality and trophic conditions using zooplankton indexes for all available data since 1 January 2010. This task is based on data obtained from non-permanent stations and the results are classified in five categories (high, good, moderate, poor and bad quality). The user may then select tools provided by the system in order to identify and retrieve data and information for the station of interest to study further the results. In this example, the majority of the monitoring stations of the coastal water body are characterized as "bad quality". Using the ECO-Satellite system, the user can seek spatial or temporal patterns in the parameters that are related to the bad quality, and identify the source of the problem, which for zooplankton could be the upstream pollutants, local environmental conditions or other aspects.

The ECO-Satellite environmental monitoring system may be accessed from the ECO-Satellite project website (http://www.eco-satellite.eu/) or directly by visiting the system's URL: http://ecosatellite.topo.auth.gr. A user account and acceptance of usage terms are mandatory for using the system, while credentials for a new account are provided by the ECO-Satellite project team upon request. Currently, there are five types of users (see Table 2). Policy/decision makers (including public body users) and groups of scientists may use the DSC, while the public users do not have access to DSC. Finally, the system administration may be carried out only by the project partners. Administrative tasks, such as user management and the use of the online geodatabase update tool are carried out through the User Login/Administrative component.

6. Conclusions

In this study, the development and features of the ECO-Satellite environmental monitoring system were presented along with its abilities to provide assistance for policy and decision-making processes. ECO-Satellite is based on the collocated use of Web-based GIS technology and a properly structured geodatabase in order to provide a common framework for the analysis and visualization of environmental data thus enhancing transnational and cross-border cooperation. A significant number of end-users within the wider limits of the areas under study, e.g., public services and state authorities, environmental protection bodies, universities, research institutes and private companies, can benefit from the results achieved and the applications and tools developed. The latter are of main importance to environmental monitoring and assessment of the various marine, coastal and wetland ecosystems of the northwestern part of Black Sea.

The integrated and multi-level nature of the ECO-Satellite system takes advantages from the technological assets provided nowadays from satellite Earth observation data and innovative Geo-information tools. This efficient combination is strongly supported by the structured geodatabase, which contains a wide range of environmental parameters and facilitates the management of heterogeneous geo-data sets. The aforementioned database, and consequently the system itself, can be easily updated, modified and extended in order to be used in other, environmentally oriented applications (e.g., management of natural hazards) in local, regional, national or transnational scales. All data files incorporated into the geodatabase have been validated, wherever possible, while the system offers an on-line tool for the addition of new datasets and the update of the current ones. Several tools for the visualization of the available data through graphs, data tables and vector or raster entities are also available within the system, while the data transmission over the internet was kept at a low level by implementing an on-demand approach.

The ECO-Satellite system contributes to the decision and policy making by the developed Decision Support Component. The design of DSC was implemented according to current legislation and scientific experience taking into account that the results should be simple, reliable and safe to use. This particular component offers a variety of tasks to end-users enabling them to assess the water quality conditions of the studied areas. Each task handles different types of data and therefore the results are summarized and displayed. The flexibility in handling various types of data facilitates the extension of the capabilities of the system, while innovative parts, such as the ability of the end-user to define the specific threshold values for assessing water quality conditions, provide different evaluation procedures.

The ECO-Satellite system may be further developed in order to include data for more regions of the Black Sea keeping the geodatabase up to date. Future improvements will also focus on the extension of its functionality towards the assessment of various environmental problems instead of being limited to their detection and/or monitoring. Additionally, the system may be further improved by offering forecasting capabilities concerning the early-detection of environmental risks that threat the public health and economic stability.

References

Aden, C., Schmidt, G., Schonrock, S., & Schroder, W. (2010). Data analyses with the WebGIS WaldIS. *European Journal of Forest Research*, 129(3), 489-497.

Alexandridis, T.K., Topaloglou, C.A., Lazaridou, E., & Zalidis, G.C. (2008). The performance of satellite images in mapping aquacultures. *Ocean and Coastal Management*, 51(8-9), 638-644.

Alexandridis, T.K., Lazaridou, E., Tsirika, A., & Zalidis, G.C. (2009). Using Earth Observation to update a Natura 2000 habitat map for a wetland in Greece. *Journal of Environmental Management*, 90(7), 2243-2251.

Alexandridis, T.K., Aleksandrov, B.G., Monachou, S., Kalogeropoulos, C., Strati, S., Vorobyova, L., Bogatova, Y., Grigoriadis, V.N., Vergos, G.S., & Topaloglou, C. (2013). Monitoring water quality parameters in the marine area of Danube Delta using satellite remote sensing: preliminary results. In: D.G. Hadjimitsis, K. Themistocleous, S. Michaelides, G. Papadavid (Eds), *First International Conference on Remote Sensing and Geoinformation of Environments*, SPIE 8795, 87950P-8, doi: 10.1117/12.2027210.

Alexandrov, B.G. (1998). The function of wetlands. In: S. Hobson, L.-D. Mee, S., Morgan (Eds.) *The Black Sea in Crisis* (pp. 84-89), World Scientific.

Andersen, O.B. (2010). The DTU10 Global Gravity field and mean sea surface. Presented at the *Second international symposium of the gravity field of the Earth* (IGFS2010), Fairbanks, Alaska.

Andersen O.B., & Knudsen, P. (1998). Global marine gravity field from the ERS1 and Geosat geodetic mission. *Journal of Geophysical Research*, 103, 8129-8137.

Armenakis, C., Nirupama, N., Zalidis, G., & Alexandridis, T.K. (2014). Degradation of Coastal Wetlands using Examples from Greece and Canada: A Review. *International Journal of Ecology & Development*, 29(3), 87-109.

Arslan, N.T., & Okmen, M. (2006). The economical and international dimensions of the environmental problems in the Black Sea region and the role of the voluntary organizations. *Building and Environment*, 41(8), 1040-1049.

Askew, C. (1987). *Shellfish Cultivation in Greece. Field Document No 6.* Food and Agriculture Organization of the United Nations, Rome.

Becker, J.J., Sandwell, D.T., Smith, W.H.F., Braud, J., Binder, B., Depner, J., Fabre, D., Factor, J., Ingalls, S., Kim, S-H., Ladner, R., Marks, K., Nelson, S., Pharaoh, A., Trimmer, R., Von Rosenberg, J., Wallace, G., & Weatherall, P. (2009). Global Bathymetry and Elevation Data at 30 Arc Seconds Resolution: SRTM30_PLUS. *Marine Geodesy*, 32(4), 355-371.

Burger, J. (2008). Environmental management: Integrating ecological evaluation, remediation, restoration, natural resource damage assessment and long-term stewardship on contaminated lands. *The Science of the Total Environment*, 400(0), 6-19.

D'Alimonte, D., Zibordi, G., Berthon, J.F., Canuti, E., & Kajiyama, T. (2012). Performance and applicability of bio-optical algorithms in different European seas. *Remote Sensing of Environment*, 124, 402-412.

DBR (2016). Danube Biosphere Reserve (DBR). http://dbr.org.ua/en/home. Accessed on 17/06/2016.

DDBR (2016). Danube Delta Biosphere Reserve (DDBR). Short history of the nature's protection in the Danube Delta. http://www.ddbra.ro/en/danube-delta-biosphere-reserve/danube-delta/biodiversity/short-history-of-the-nature-s-protection-in-the-danube-delta-a916. Accessed on 17/06/2016.

De Castro, A.F., Amaro, V.E., Grigio, A.M., & Cavalcante, R.G. (2011). Modeling and development of a WebGIS for environmental monitoring of coastal areas that are influenced by the oil industry. *Journal of Coastal Research*, Special Issue, 64, 1643-1647.

Dineva, S. (2005). Long-term evolution and trends of the hydrological and hydrochemical parameters in Bulgarian Black Sea waters during the period 1992-2000. *Water Science and Technology*, 51(11), 19-26.

Dunea, D., Iordache, S., Pohoata, A., & Neagu Frasin, L.B. (2014). Investigation and Selection of Remediation Technologies for Petroleum-Contaminated Soils Using a Decision Support System. *Water Air & Soil Pollution*, 225:2035.

European Communities (2009). *Common implementation strategy for the Water Framework Directive (2000/60/EC)*. WFD CIS Guidance Document No7, Luxemburg: European Communities.

Ferraro, G., Meyer-Roux, S., Muellenhoff, O., Pavliha, M., Svetak, J., Tarchi, D., & Topouzelis, K. (2009). Long term monitoring of oil spills in European seas. *International Journal of Remote Sensing*, 30(3), 627-645.

Fisher, N.I., Lewis, T., & Embleton, B.J.J. (1987). *Statistical analysis of spherical data*. Cambridge: University Press.

Frehner, M., & Brandli, M. (2006). Virtual database: Spatial analysis in a Web-based data management system for distributed ecological data. *Environmental Modelling and Software*, 21(11), 1544-1554.

Gastescu, P., & Stiuca, R. (2008). *Delta Dunarii: rezervatie a biosferei*. Bucharest: CD Press (in Romanian).

Ginzburg, A.I., Kostianoy, A.G., & Sheremet, N.A. (2004). Seasonal and interannual variability of the Black Sea surface temperature as revealed from satellite data (1982-2000). *Journal of Marine Systems*, 52(1-4), 33-50.

Hassan, R., Scholes, R., & Ash, N. (2005). *Ecosystems and Human Well-being: Current State and Trends, Volume 1*. Findings of the Condition and Trends Working Group of the Millennium Ecosystem Assessment. Washington, DC: Island Press.

Holgate, S.J., Matthews, A., Woodworth, P.L., Rickards, L.J., Tamisiea, M.E., Bradshaw, E., Foden, P.R., Gordon, K.M., Jevrejeva, S., & Pugh, J. (2013). New Data Systems and Products at the Permanent Service for Mean Sea Level. *Journal of Coastal Research*, 29 (3), 493-504.

Huang, J., Wu, B., Xu, W., Zhou, Y., Tian, Y., & Huang, W. (2004). WebGIS for monitoring soil erosion in Miyun reservoir area. In: *Proceedings of the International Geoscience and Remote Sensing Symposium*, 2004 (pp. 4843-4845), IEEE.

International Commission for the Protection of the Danube River (ICPDR) (2009). *Danube River Basin District Management Plan*. Vienna: ICPDR.

IUCN (1992). East European programme. *Environmental status reports, Volume Four. Conservation status of the Danube Delta*. Cambridge: IUCN Publications Unit.

Iordache, S., Dunea, D., Lungu, E., Predescu, & L. Dumitru, D. (2015). A Cyberinfrastructure for Air Quality Monitoring and Early Warnings to protect Children with Respiratory Disorders. In: I. Dumitrache, A.M. Florea, F. Pop, A. Dumitrascu (Eds.), *Proceedings of the 2015 20th International Conference on Control Systems and Computer Science*, (pp. 789-796), IEEE.

Ivanov, A.Y., & Zatyagalova, V.V. (2008). A GIS approach to mapping oil spills in a marine environment. *International Journal of Remote Sensing*, 29(21), 6297-6313.

Korotaev, G.K., Saenko, O.A., & Koblinsky, C.J. (2001). Satellite altimetry observations of the Black Sea level. *Journal of Geophysical Research C: Oceans*, 106(C1), 917-933.

Lee, H.II., Reusser, D.A., Olden, J.D., Smith, S.S., Graham, J., Burkett, V., Dukes, J.S., Piorkowski, R.J., & McPhedran, J. (2008). Integrated monitoring and information systems for managing aquatic invasive species in a changing climate. *Conservation Biology*, 22(3), 575-584.

Lovett, G. M., Burns, D. A., Driscoll, C. T., Jenkins, J. C., Mitchell, M. J., Rustad, L., Shanley, J.B., Likens, G.E. and Haeuber, R. (2007). Who needs environmental monitoring? *Frontiers in Ecology and the Environment*, 5(5), 253-260.

Mathiyalagan, V., Grunwald, S., Reddy, K.R., & Bloom, S.A. (2005). A WebGIS and geodatabase for Florida's wetlands. *Computers and Electronics in Agriculture*, 47(1), 69-75.

Moses, W. J., Gitelson, A. A., Berdnikov, S., Saprygin, V., & Povazhnyi, V. (2012). Operational MERIS-based NIR-red algorithms for estimating chlorophyll-a concentrations in coastal waters—The Azov Sea case study. *Remote Sensing of Environment*, 121, 118-124.

NCRM (2001). *Management Study of Mussel Growing Zones in Thessaloniki and Thermaikos bays.* National Center for Marine Research, Institute of Oceanography, Athens.

Nikolaidis, G., Koukaras, K., Aligizaki, K., Heracleous, A., Kalopesa, E., Moschandreou, K., Tsolaki, E., & Mantoudis, A. (2005). Harmful microalgal episodes in Greek coastal waters. *Journal of Biological Research*, 3, 77-85.

Nikolenko, A.V., & Reshetnikov, V.I. (1991). Investigation of long-term changes of the freshwater balance in the Black Sea. *Vodnie resursi*, 1, 20-28 (in Russian).

Parr, T., Ferretti, M., Simpson, I., Forsius, M., & Kovacs-Lang, E. (2002). Towards a long-term integrated monitoring programme in Europe: network design in theory and practice. *Environmental monitoring and assessment*, 78(3), 253-290.

Permanent Service for Mean Sea Level (PSMSL) (2012). Tide Gauge Data. http://www.psmsl.org/data/obtaining/. Accessed 09 May 2012.

Ramsar Convention Secretariat (2013). *The Ramsar Convention Manual: a guide to the Convention on Wetlands* (Ramsar, Iran, 1971), 6th ed. Gland, Switzerland: Ramsar Convention Secretariat.

Savvaidis, P., Tziavos, I.N., Grigoriadis, V.N., Vergos, G.S., Papadopoulou, I.D., & Stergioudis, A. (2012). A WebGIS-based monitoring and decision support tool for the environmental protection and preservation of the Black Sea: The ECO-Satellite project. In: e-Proceedings of the conference *Modern technologies, education and professional practice in geodesy and related fields*, 20th International Symposium, 08 - 09 November, Sofia, 2012.

Topouzelis, K., Tarchi, D., Vespe, M., Posada, M., Muellenhoff, O., & Ferraro, G. (2015). Detection, Tracking, and Remote Sensing: Satellites and Image Processing (Spaceborne Oil Spill Detection). In: Fingas, M. (Ed.), *Handbook of Oil Spill Science and Technology* (pp. 357-384). John Wiley & Sons.

Tudor, I. M., Tudor, M., Ibram, O., Alexandrov, B., & Racovet N. (2014). The evolution of zooplankton community structure in Danube delta region. *Journal of Environmental Protection and Ecology*, 15(2), 506-516.

Tuncer, G., Karakas, T., Balkas, T.I., Gokcay, C.F., Aygnn, S., Yurteri, C., & Tuncel, G. (1998). Land-based sources of pollution along the Black Sea coast of Turkey: Concentrations and annual loads to the Black Sea. *Marine Pollution Bulletin*, 36(6), 409-423.

Tziavos, I.N., et al. (2013). Development of a WebGIS-based monitoring and environmental protection and preservation system for the Black Sea: The ECO-Satellite project. Presented at the 2013 EGU General Assembly, Session OS2.2 *Advances in understanding of the multi-disciplinary dynamics of the Southern European Seas (Mediterranean and Black Sea)*, April 7th-12th, Vienna, Austria.

Velikova, V., Cociasu, A., Popa, L., Boicenco, L., & Petrova, D. (2005). Phytoplankton community and hydrochemical characteristics of the Western Black Sea. *Water Science and Technology*, 9-18.

White, D.L., Wolf, D., Porter, D.E., Sanger, D.M., Riekerk, G.H., DiDonato, G., Holland, A.F., & Dabney, D. (2009). Development of a data management framework in support of southeastern tidal creek research. *Environmental monitoring and assessment*, 150(1-4), 323-331.

Zalidis, G.C., Mantzavelas, A.L., & Gourvelou, E. (1997) Environmental impacts on Greek wetlands. *Wetlands*, 17, 339-345.

Zhang, G., Chen, L., & Dong, Z. (2011). Real-time warning system of regional landslides supported by WEBGIS and its application in Zhejiang province, China. *Procedia Earth and Planetary Science*, 2, 247-254.

Zhmud, M.Ye. (1999). The present-day conditions of the wetlands in the Ukrainian Danube Delta. In: H.J. Nijland (Ed.), *Dealing with Nature in Deltas* (pp. 143-156), Institute for Inland Water Management and Wastewater Treatment RIZA, The Netherlands.