Environ Monit Assess (2015) 187: 574
DOI 10.1007/s10661-015-4786-x

A WebGIS platform to monitor environmental conditions in ports and their surroundings in South Eastern Europe

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Received: 27 February 2015 / Accepted: 5 August 2015 / Published online: 15 August 2015

Abstract The scope of this work is to describe the design and development of a web-based Geographic Information System (GIS) application and highlight its usefulness regarding monitoring and evaluating environmental conditions in several ports and their surroundings in the greater South East Europe (SEE). The system receives inputs and handles two kinds of data that are processed and illustrated through maps and graphs at various temporal and spatial scales in this informational platform. The aforementioned data consists of point measurements from stations operating in the area of SEE ports as well as satellite date sets derived monthly for a period of 10 to 12 years, in terms of sea surface temperature, chlorophyll *a*, and colored dissolved organic matter (CDOM). The WebGIS platform is based on the client–server model and uses Google Maps API services for data plotting. Advanced designing and development tools and methodologies are used. The available valuable data render the application into a trustful and accurate provider of visual environmental interest information regarding the main ports of southeastern Europe and their surroundings that would operate as a guide for an environmentally sustainable future of ports and sea corridors in SEE.

Keywords WebGIS · Remote sensing data · Monitoring · Environmental conditions · Seaport · Southeastern Europe

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Introduction

Nowadays, seaports and port-related activities—more than ever—are considered key components for the socioeconomic development of cities and countries around the world (Becker et al. 2012; Ng and Liu 2014; Quynh et al. 2011), constituting in parallel, an additional and significant factor that may contribute to the integrated coastal zone management (Le Gentil and Mongruel 2015) as well as in marine and coastal spatial planning and development (Douvere and Ehler 2009). Moreover, sea transport sector has major environmental impacts, among all the other forms of transport, globally (Marinski et al. 2015).

The contiguous increase in the international trade and the new tendencies in the transportation (using modern, larger, and safer ships) highlight ports as major key players for the growth of cities, regions, and countries (Ng et al. 2014). Additionally, the advances in the information and communications technology (ICT) help further the propulsion of sea ports to become significant commercial and economic hubs, globally. More specifically, this is achieved through the adoption and the operational use of applications and informational systems like port community systems (PCS), "Single Window" approaches, and WebGIS applications (e.g., UNECE 2003; EPCSA 2011; Koh Tat Tsen 2011; Guojun et al. 2005; Ivanov et al. 2008) that improve significantly many port operations, contribute to safety and the information exchange, and simultaneously save time and operational costs. Having as a driven force the contribution of ICT for a sustainable future of seaports as well as the neighbor atmospheric and marine environment, this study describes a web-based GIS application that provides visually valuable information about environmental conditions, possible sources of pollution, and spatial and temporal distributions of various parameters, concerning sea water and air quality. Characteristically, the provision of graphical representations about concentration levels of air and/or water pollutants at different spatial and temporal scales provides a visual, easy, and quick evaluation of any possible abnormal situation and alarms the excess of the maximum allowed levels. This contributes to increase the awareness and so to the deterioration of possible sources of pollutant and, finally, to the protection of environment.

The port-related activities and the explosion of the maritime commerce through intermodal and unimodal transportation have great and serious impacts to the quality of port marine and air environment (e.g., Dinwoodie et al. 2012; Grifoll et al. 2011; Gupta et al. 2005; Bailey and Solomon 2004; Edoho 2008; Eyring et al. 2010). Such affections may have significant consequences on the health and the quality of life for the population that lives close to ports as well as in the natural environment (Eyring et al. 2010; WHO 2000). These consequences are intensified considering the fact that ports attract, nowadays, more and more amounts of ship traffic, influencing ecosystems nearby port areas. Such ecosystems are considered as highly vulnerable areas (Urquhart et al. 2013) and include estuaries, surrounding coastal waters, and protected natural zones [such as Sites of (European) Community Importance (SCI) and Special Protected Areas (SPA) in terms of their biodiversity]. As a result, ICT applications that collect data and provide information and evaluation about environmental conditions of ports and their greater areas can be a valuable tool not only for port authorities and the relative stakeholders but also for general public and any other authority.

Moreover, it is noteworthy to point out that there is close relation between seaports and their natural environment. More specifically, the port areas as well as maritime shipping and sea commerce corridors are highly sensitive in extreme weather conditions and phenomena, and so, the environmental and climate changes have serious impacts to any port-related activities (Becker et al. 2012; Nursey–Bray et al. 2013). Additionally, the extreme weather events are expected to be increased in terms of their frequency and intensity, because of the rapidly changing climate worldwide (IPCC 2014). If such scenarios are confirmed, among others, many port areas and the relative infrastructure would be vulnerable and many port-related activities would have to be redesigned in order to lead to a sustainable and environmental friendly future of ports and maritime transportation (e.g., Watson 2012; Geels 2012).

A well-known and widely applied practice contributing, nowadays, to the environmentally sustainable perspectives of ports that are operating under highly competitive conditions is the adoption of environmental management systems (EMS), the use of performance indicators (EPI), and the implementation of international common practices defined by audit schemes (e.g., Puig et al. 2014, Donnelly et al. 2007; Quynh et al. 2011; PPRISM 2012). Toward this, the role of satellite data products is crucial for improving many port-related activities, providing contiguous and accurate information in regard to environmental monitoring. More specifically, many satellite missions have, as an exclusive scope, the collection of various datasets using instrumentation on board of their satellite platforms. Modern satellite instruments are able to provide accurate remote sensed data and products, covering wide areas where would be impossible to be monitored contiguously from other instrumentation and technologies.

At this point, it is worth mentioning that the last decade has been an extensive use of spatial analysis techniques and there is a contiguous development of GIS applications dealing with either the marine or the land environment (e.g., Saranya et al. 2014; Gowri et al. 2008; Fustes et al. 2014; Ivanov et al. 2008; Merrifield et al. 2013). Such applications not only are focusing in spatial analysis, decision making, and future planning using the wide range of GIS capabilities, but also provide integrated web-based applications to end users and public about the final results of scientific efforts via visual maps and graphs by the tools and methods of a GIS (e.g., Fustes et al. 2014; Merrifield et al. 2013; Kulkarni et al. 2014; Hilde and Paterson 2014). These computer-based applications are very significant for the modern visual representation of environmental issues through the monitoring of spatial and temporal changes even in remote areas, helping planners and stakeholders to design and envision in medium- to long-term scales, an environmentally sustainable future (Portman 2014). It is noteworthy to mention also that WebGIS platforms are considered, nowadays, integral part of the management action plans and the improvement of the seaport environmental policies (Marinski et al. 2015). Furthermore, a WebGIS can play a basic role in the community-based monitoring and information provision (Kebo and Bunch 2013) through many modern capabilities that are offered by such applications in terms of searching and visualizing data in time and space.

This work has as scope to provide a modern, easy, and efficient way for presenting different kinds of environmental information so that to contribute to the environmental port management through an operational use of a web-based GIS application. The WebGIS platform provides and visualizes useful information about monitoring environmental issues concerning a network of ports in southeastern Europe, using information from satellite datasets as well as measurements from environmental ground stations, operating in the port areas.

The paper is divided into five sections. The first section briefly provides some technical details on how the WebGIS platform has been designed and developed. "Design and development of WebGIS platform" section presents the data as well as the information collected and visualized through the WebGIS platform. In the following section, the user interface and the monitoring capabilities of the system are presented. In the last section, the main conclusions and future perspectives of the WebGIS application are provided.

Design and development of WebGIS platform

Most of the WebGIS applications follow the client–server model. The client communicates with the server through a web browser, and then, the server responds to client requests, sending back information on web page format. The main structure of the WebGIS platform consists of the presentation tier (web browser), application logic tier (web server), and the storage tier (database). The main benefit of this structure is the subdivision of the application into different tiers where every tier is independent of the others. Thus, any update and change on the system can be handled much easier and even failures are managed easily. The information flow between a request and the corresponding response of the WebGIS system is provided schematically in Fig. 1.

The presentation tier comprises the user interface, and it is accessed directly by internet users. On the other side, it communicates with the application logic tier (web server), forwarding any client request and displaying the data/information that responds to the client's request in the form of web page appearance. All web pages of the application tier have been developed based on HTML and JavaScript format. The application logic tier has its own layer, controls all the application's functionalities, and processes the client requests; its layer is based on an Apache HTTP Server. Apache is a freely available web server that runs on most of the operating systems (UNIX-based or not), and it is the most widely used than any other web server. The web interaction language is the PHP, which is a scripting language widely used for web development and as a general-purpose programming language. The third tier, the storage tier, includes the data persistence mechanisms, consisting of the database server where there are stored files and there is a data access layer that encapsulates the persistence mechanisms and exposes the data. The data access layer provides an application programming interface (API) interacting with the application tier so that to expose methods of managing the stored data without causing dependencies on the data storage mechanism. In this layer, a MySQL database server is used and configured properly to handle the data.

An overall view of the WebGIS application components, the user requests, and the interactions among system components is shown in Fig. 2, which presents the user interactions through the web browser to the WebGIS. More analytically, the web browser makes requests (driven by the user) to the Apache server using the HTTP protocol. The Apache server forwards the request and accesses data at the MySQL server, and then, it returns the requested information through generating back web pages serving as a response to user's requests. Web browser renders the response from the Apache server, and the results are appearing on a user's screen.

The whole WebGIS application consists of a software framework that integrates software modules providing generic functionality along with specific written code to

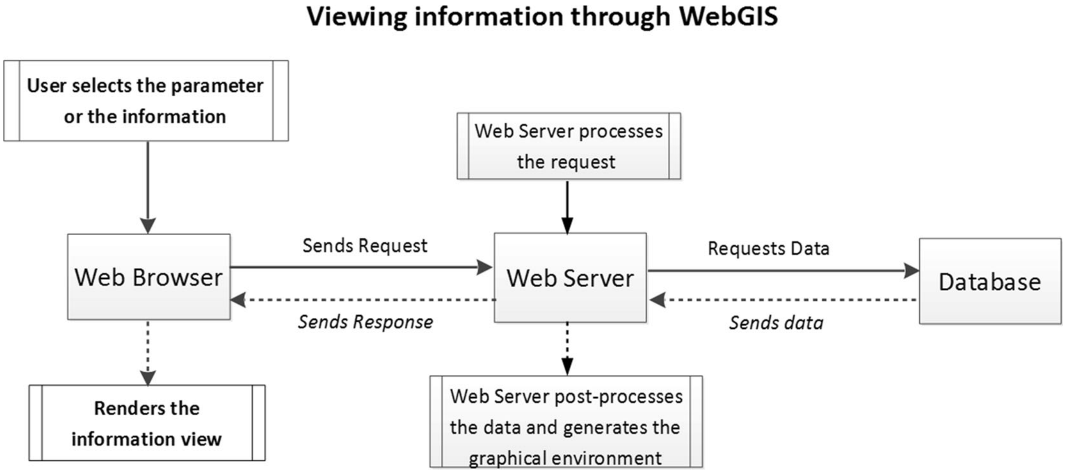


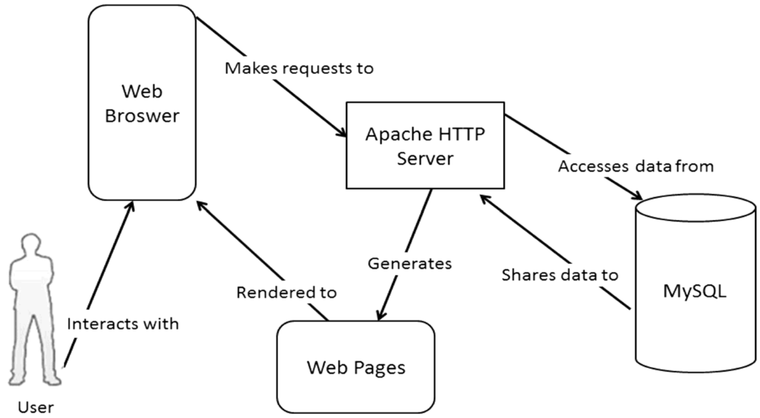
Fig. 1 Information flow in the WebGIS system

achieve the system requirements. The WebGIS platform utilizes various open-source frameworks and libraries to success a professional level of development and maintenance. More specifically, the following are used: "Codeigniter PHP Model–View–Controller (MVC)" Framework, the "Twitter Bootstrap CSS" Framework, the "jQuery JavaScript" Library, the "jQuery UI JavaScript GUI" Library, and the Google Maps API (version 3) web mapping service.

More analytically, the MVC is used as a software architectural pattern for implementing user interfaces. It divides a given software application into three interconnected parts in order to separate internal representations of information from the way that information is presented to or accepted from the user. The central component (the model) consists of the application data, business rules, logic, and functions. Multiple views of the same information are possible (e.g., a menu bar or various options about navigation or other operations). The third part is the controller, which accepts inputs and converts them to commands to the model (managing the data of the application) or different views (presenting of data). In addition to dividing the application into three kinds of components, the MCV design defines the interactions among them.

The MVC can send commands to the model to update the model's state (e.g., editing a publication document). It can also send commands to its associated views to change the view's presentation of the model (e.g., viewing all the details of a publication document). A model notifies its associated views and controllers when there has been a change in its state. This notification produces updated output views, and the controllers change the available set of commands. In some cases, a MVC implementation might be "passive" so that other components must poll the model for updates rather than being notified. The Codeigniter PHP MVC framework that is used for the development of the WebGIS platfrom is an open-source MVC framework written in PHP.

Fig. 2 Schematic diagram of the WebGIS application components and their interactions



The Cascading Style Sheets (CSS) framework is considered as a library of CSS files that are used to develop standard-based XHTML and CSS Web pages. The CSS framework offers different tools and capabilities for styling tooltips, buttons, elements of forms, and many others. The "Twitter Bootstrap" is an open-source CSS framework compatible with the latest versions of all major browsers. The jQuery is a cross-platform JavaScript library designed to simplify the client-side scripting of HTML. The "jQuery UI" is a collection of GUI widgets, animated visual effects, and themes implemented with jQuery, CSS, and HTML. The Google Maps API is a service (launched by Google at 2005) to allow developers to integrate Google Maps into their websites; it is based on JavaScript and is widely used worldwide.

Datasets

Firstly, there were discussed and defined the main environmental issues and there were investigated the potential needs of port authorities and all the related stakeholders (other responsible authorities, institutions, port users, and experts) that could provide data within the framework of "Transnational ENhancement of ECOPORT8 (TEN ECOPORT)" project (http://www.tenecoport.eu/) and take advantage of the results. During this requirement analysis procedure, there was an official exchange of information, documentation, and a provision of specific questionnaires to record and identify the main categories of the port-related environmental issues. The summary results of this procedure are provided in Tables 1 and 2 (TEN ECOPORT 2013). Table 1 gathers all the types of the main environmental issues that the participated port authorities face regarding the quality of air and marine environment. Table 2 presents the second types of issues that could be considered either occasionally or indirectly environmental sensitive with quite significant importance for ports. According to both tables, the air pollution, the effluent contaminants by surface runoff, and the energy consumption issues are highlighted as the most frequent and important among all others. It is mentioned that similar results regarding the major environmental issues for some other 26 European Union (EU) ports are also concluded at the "PEARL" Project that summarized the study of Darbra et al. (2009).

Based on these results as well as taking into consideration the availability, the validity, and the overall quality of different kinds of data, two basic general datasets were finally selected. Satellite derived data and point environmental measurements at the stations in port areas. The environmental offices of port authorities also identified the exact locations and the areas of specific environmental interest, so that to place in the right point the "eco-map" symbols as well as the relative polygons at GIS platform.

The use of satellite products is suitable to present and highlights short-term mean spatial changes of basic sea parameters at a monthly basis. This approach provides a clear and accurate depiction of areas that are environmentally sensitive, and it operates as a valuable informational background for any interested agency, organization, or company (at a local, national, and European level) that may need to detect spatial patterns of high sea surface temperature (SST) and chlorophyll *a* values. Thus, it supports inferring conclusions and decisions, examining solutions and new strategies or legislations for a sustainable future of sea environment and the protection of coastal areas, especially around ports.

More specifically, three basic parameters were chosen to be depicted that cover the above-mentioned aspects. The SST (in °C), the chlorophyll *a* (in mg/m^3), and the colored dissolved organic matter (CDOM) (unitless). The original satellite datasets come from NASA's MODerate resolution Imaging Spectroradiometer (MODIS) instrument on board of Terra and Aqua satellite platforms, and they are widely used in a great variety of studies (e.g., Shang et al. 2011; Urquhart et al. 2013; Li et al. 2013; Brewin et al. 2013). These parameters are key factors for the water quality, and such information can be very useful especially in broad geographical areas like South East Europe (SEE) that include many places with eutrophic problems and that are been affected—among other—by many human activities, sea commerce, and tourist activities (e.g., Karydis and Kitsiou 2012; Stylios et al. 2015).

Regarding SST, which represents the temperature of the water at the topmost layer of the water surface, the data was selected on a monthly basis for a period between 2000 and 2013 (168 files in total) at a spatial resolution of 9 km. The data products of chlorophyll *a* and CDOM were selected on a monthly basis for a period between 2003 and 2013 (132 files in total) at a spatial resolution of 4 km. Chlorophyll *a* is a data product generated by the NASA Ocean Biogeochemical Model (NOBM) based on data assimilation of remotely sensed chlorophyll *a*.

Table 1 The major environmental issues regarding air and water reported by 12 port authorities

Ports	Environmental issues				
	Air pollution		Water pollution		
	Emissions of gases	Dust and particle emissions	Effluent contaminants by surface runoff	Ship waste	Eutrophication of sea water
Bari	✓		✓		
Barletta	✓		✓		
Monopoli			✓		
Brindisi	✓	✓	✓		
Igoumenitsa	✓	✓	✓		
Patras	✓				
Burgas		✓	✓		
Varna	✓	✓	✓		
Constanta		✓	✓	✓	
Bar		✓	✓		
Dubrovnik	✓		✓		
Durres		✓			✓

This type of chlorophyll is the most common and predominant in all oxygen-evolving photosynthetic organisms, and it is strictly connected with the phenomenon of eutrophication.

Regarding colored (also called chromophoric) dissolved organic matter (CDOM) which absorbs light, most strongly in the blue to UV range, the CDOM diminishes light as it penetrates the water. This can inhibit the growth of phytoplankton populations, which form the basis of sea food chain and constitute a primary source of atmospheric oxygen. The CDOM also absorbs harmful UVA/B radiation, protecting organisms from DNA damage.

For each of the three selected parameters, mean monthly values (per pixel) for the whole period of the relative datasets were calculated. Figure 3 provides a schematic representation regarding the calculation of the mean values (per pixel). The mean values per pixel are used to generate mapping representations for the spatial distributions of the mean values for every parameter.

Table 2 List of secondary types of pollution and environmental issues reported by 12 port authorities

Ports	Secondary types of pollution and environmental issues					
	Waste management	Soil pollution	Energy consumption	Natural resources consumption	Noise pollution	Accidental pollution
Bari	✓	✓	✓			✓
Barletta		✓	✓			✓
Monopoli		✓	✓			✓
Brindisi	✓		✓			✓
Igoumenitsa				✓		
Patras			✓	✓		✓
Burgas						
Varna						
Constanta		✓	✓	✓	✓	✓
Bar						
Dubrovnik						
Durres	✓		✓			

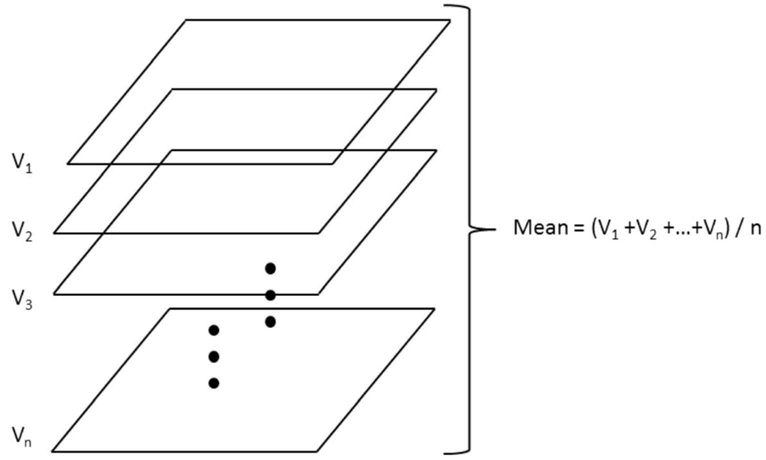


Fig. 3 Schematic diagram for the calculation of the mean values (per pixel) regarding the three selected parameters (sea surface temperature, chlorophyll *a*, colored dissolved organic matter). The "V_i" represents the mean value of the month "i" for a specific pixel

Referring to the point measurements, there are 12 ports taking part in this project. Seven out of 12 ports operate local stations that measure environmental parameters in terms of the sea and/or air quality. Many of the recorded measurements are provided and presented through the WebGIS platform, where a menu plots the temporal evolution of the studying parameters and it is capable to include any possible future update and to provide relative graphs in real-time basis. The current version of the WebGIS platform presents graphs for the sample datasets (archive data) regarding the parameters and the ports that are referred in Table 3.

The WebGIS platform has been developed within the framework of the "TEN ECOPORT network" project (http://www.tenecoport.eu/WebGIS/), and Fig. 4 presents a schematic diagram of the main data and information included. The sustenance of a steadily operation and maintenance of the WebGIS platform are continuously preserved by adding and updating relative official information and validated measurements that port authorities provide regularly. Characteristic example is the port authority of Burgas, which provide inputs in the system with monthly measurements concerning port water quality, although TEN ECOPORT project concluded at December 2014. This information is added in the platform, contributing to its sustainability and increasing its usefulness. In addition to this, WebGIS platform is able to gather and present real-time-based measurements and other kind of environmental information. The developed tools and the source code of the platform fully support the visualization of real-time-based information. Such potential capability is ready for usage by any interested port agency or institution that wants to use a web-based application and share information in real-time basis.

It is noteworthily mentioned that internal evaluation was conducted to assess the stability of the WebGIS platform in the case of a huge number of parallel requests and to ensure the response time considering the data volume that can be retrieved from the internal database to the web browser. The response speed during the operational (real-time) use of the WebGIS platform is immediate in any user request. The portability of the platform was tested in a variety of mobile devices like smartphones and tablets.

Table 3 List of measured parameters displayed at WebGIS provided by the environmental stations installed in the network of ports at the Southeast Europe

n/n	Station location	Country	Parameters
1	Port of Bari	Italy	PM_1, $PM_{2.5}$, PM_4, PM_{10}, PST
2	Port of Barletta	Italy	PM_1, $PM_{2.5}$, PM_4, PM_{10}, PST
3	Port of Igoumenitsa	Greece	CO, NO_2, SO_2, O_3
4	Port of Patras	Greece	PM_1, $PM_{2.5}$, PM_{10}
5	Port of Burgas	Bulgaria	Turbidity, PH, salinity, chlorophyll, temperature
6	Port of Constanta	Romania	Wind (direction and speed), relative humidity, air temperature
7	Port of Bar	Montenegro	SST, BOD, salinity, chlorophyll *a*

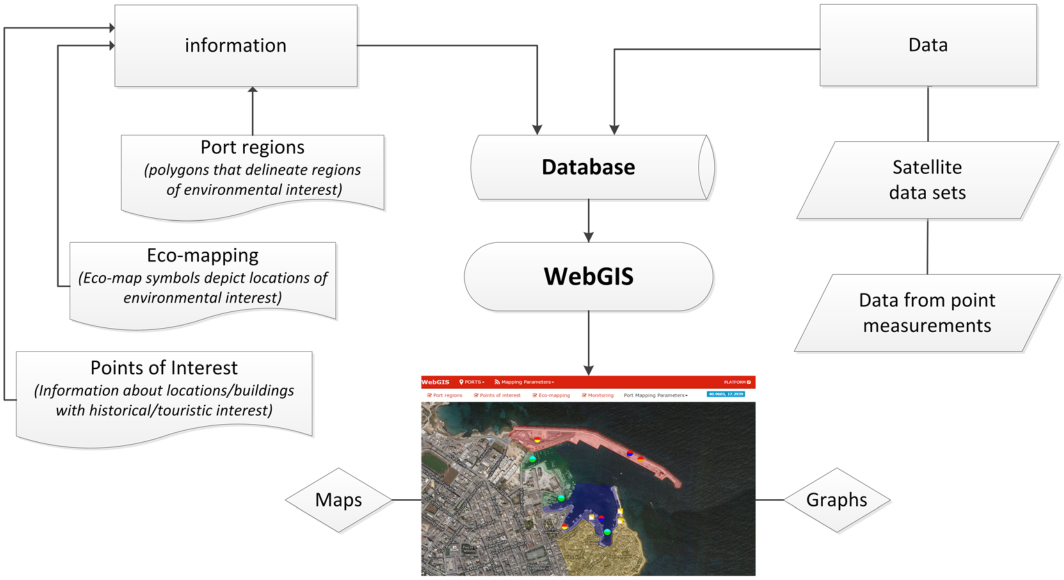


Fig. 4 A diagram of the data and the information flows seen through the WebGIS platform

WebGIS presents the main parameters (Table 3) that meet the needs of the ports (Tables 1 and 2) that were discussed at project meetings after communication of the port environmental agencies along with analysis of the project deliverables (TEN ECOPORT 2013). On the other hand, the quality of the satellite datasets was checked, compared, and validated with available in situ measurements. More specifically, there performed a comparison of SST and the chlorophyll *a* values from satellite data and ground measurements from point stations, and it was concluded a satisfactory accuracy of monthly satellite datasets in comparison with the relative point measurements (Kolios and Stylios 2015).

Description of the WebGIS platform and its menus

The WebGIS platform has two basic menus ("Ports" and "Mapping Parameters") in its central interface. Figure 5 presents a schematic diagram of these menus as well as their submenus. The main menu named ports provides interesting information to port stakeholders, port authorities, touristic and transportation stakeholders, and the general public. The user may choose the port of his interest and then one (or more) of the following submenus: "Port regions," "Points of interest," "Eco-mapping," "Monitoring," and "Port Mapping Parameters."

The submenu Port regions depicts main areas of interest in port territory. Polygons with different colors represent specific locations of ports ("Mercantile areas," "commercial areas," "touristic areas," "historical locations," "old industrial areas"). Different colored polygons stand for different areas of interest (Fig. 6).

Another important informational field of the WebGIS platform is included in the submenu Eco-mapping. This submenu highlights environmental sensitive locations of high interest in the port area. More precisely, the Eco-

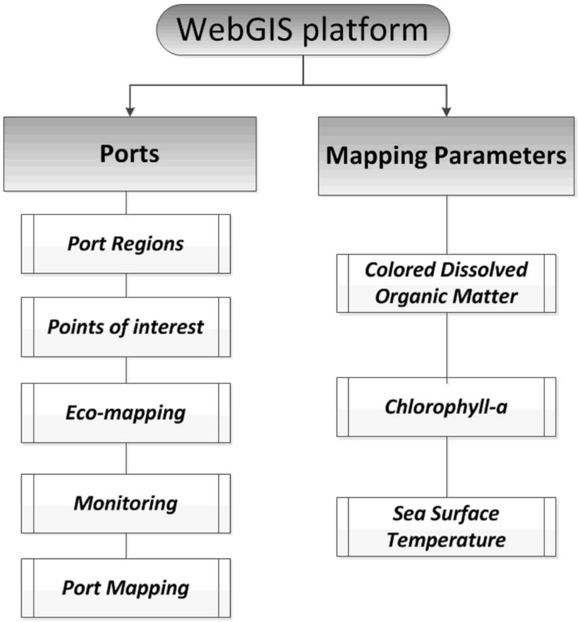


Fig. 5 Main menus ("Ports" and "Mapping Parameters") and submenus of the WebGIS platform

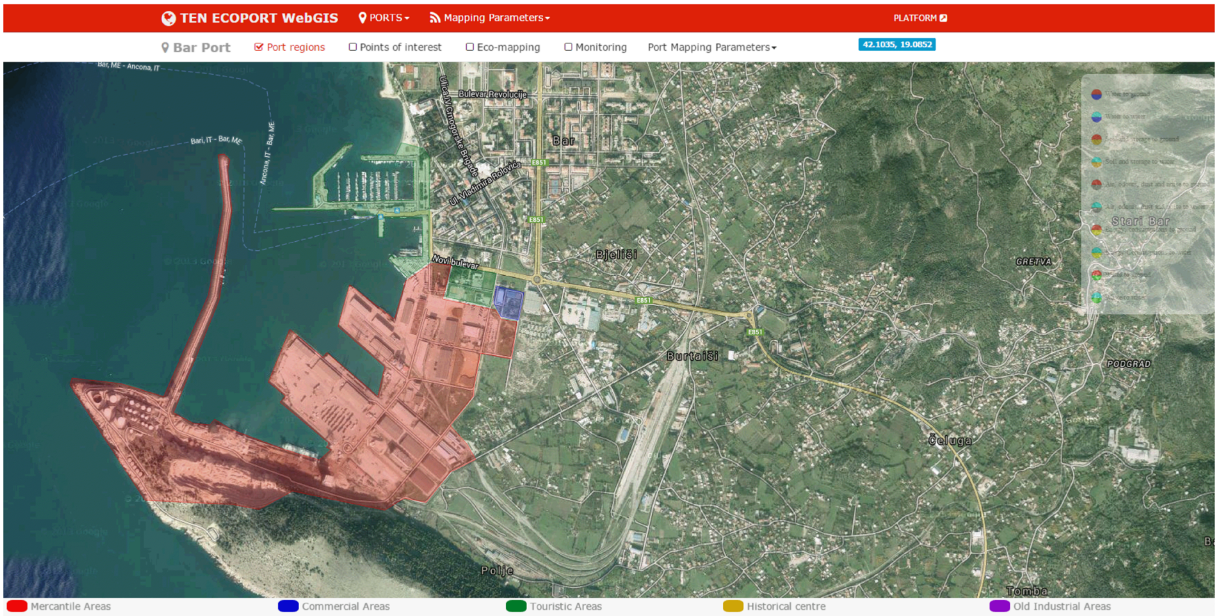


Fig. 6 The outcome of submenu "Port regions" in the menu "PORTS." *Colored polygons* represent different areas of interest inside port territories

mapping section was designed and introduced as an original and simple tool to support implementing environmental management policies using determined symbols to depict locations of high environmental importance in port area. The Eco-mapping comprises a first step toward port environmental management and aims to be an inventory of good practices and interest points along with a systematic method of conducting on-site environmental review, as well as a tool that encourages stakeholder involvement and participation. The Eco-mapping symbols have determined to cover the main environmental needs of the ports covering all discipline perspectives related to water, energy, soil, and waste management issues. For every port, the main and critical environmental issues along with their exact locations are included in their master environmental plan, and so, the corresponding relative Eco-mapping" symbols are placed on these points as it is seen in Fig. 7. Along with the circular environmental (Eco-mapping) symbols, there are also shown rectangular yellow symbols (submenu Points of interest) that highlight buildings and infrastructure of historical interest in the port area (Fig. 7). By clicking on a yellow rectangle symbol, relative information about the specific location is appeared. Figure 8 presents the Eco-mapping symbols along with their meanings. When a user clicks on a symbol, detailed environment-related information about the specific location is presented.

It is mentioned that the color of the upper part of the circle indicates the source of the possible pollution and the color of the lower part of the circle indicates the issue. Besides, every color in the circular symbols of Fig. 8 has a different meaning. More specifically, for the upper part of the circle, the red color represents ground pollution and the light blue (cyan) is for water pollution. Regarding the colors for the lower part of the circular symbol; the blue color represents water surfaces; the brown is for soil and storage; the gray color is for air, odors, dust, and noise; the yellow color is for energy/consumption; and the green represents waste. For example, the circular symbol with the red-colored upper part and the blue-colored lower part (circle in the upper left part of Fig. 8 is placed in locations of sea areas where, nearby, there are discharges from the mainland.

On the WebGIS platform (in the menu Ports), there is also a checkbox named Monitoring, which gives the user, via a "popup" window, the option to select and create his own graphs, by selecting the parameter and the corresponding period of interest (Fig. 9). The available datasets are archive measurements provided by the seven ports participating in the SEE network (Table 3). In these ports, local stations to measure environmental parameters about the sea and/or air quality are operating. By this menu, user selects plotting the temporal evolution of the different parameters relative to the environmental quality

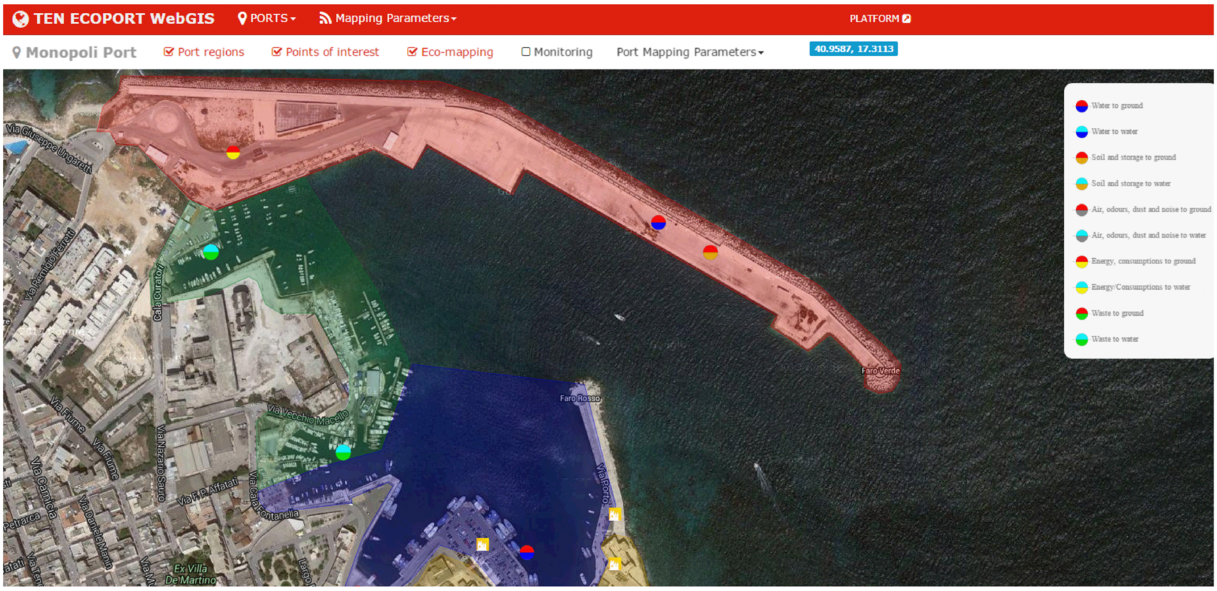
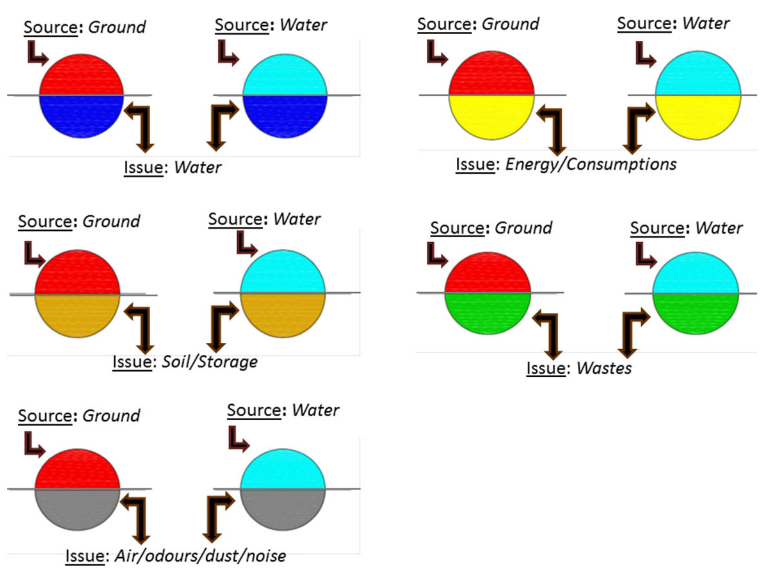


Fig. 7 The visualization of port area when the submenus "Point of interest" and "Eco-mapping" in the menu "PORTS" of the WebGIS platform are selected

of a port and there also options for possible future updates to provide relative graphs in real-time basis.

The WebGIS platform plots also the mean monthly spatial distribution of the three previously mentioned marine parameters in the greater port area, by selecting them at the Port Mapping parameters menu (Fig. 10). The user may choose the parameter and the month of interest, and then, the mean monthly spatial distribution of the corresponding parameter is depicted (Fig. 9). This menu comprises part of the main menu Mapping Parameters, which provides spatial distribution of mean values of parameters in the whole southeastern Mediterranean Sea. The menu Port Mapping parameters is created to focus only on the main sea area of a port. It is mentioned that the smooth color changes are owed to the spatial resolution of the satellite data (4 to 9 km). This means that there are no abrupt changes in values for small sea areas and the color changes are smoothed for better visualization. Nevertheless, the actual pixel values are

Fig. 8 The "Eco-mapping" environmental symbols and their meanings. The *upper parts* define the source of pollution, and the *lower parts of the circles* define the issue



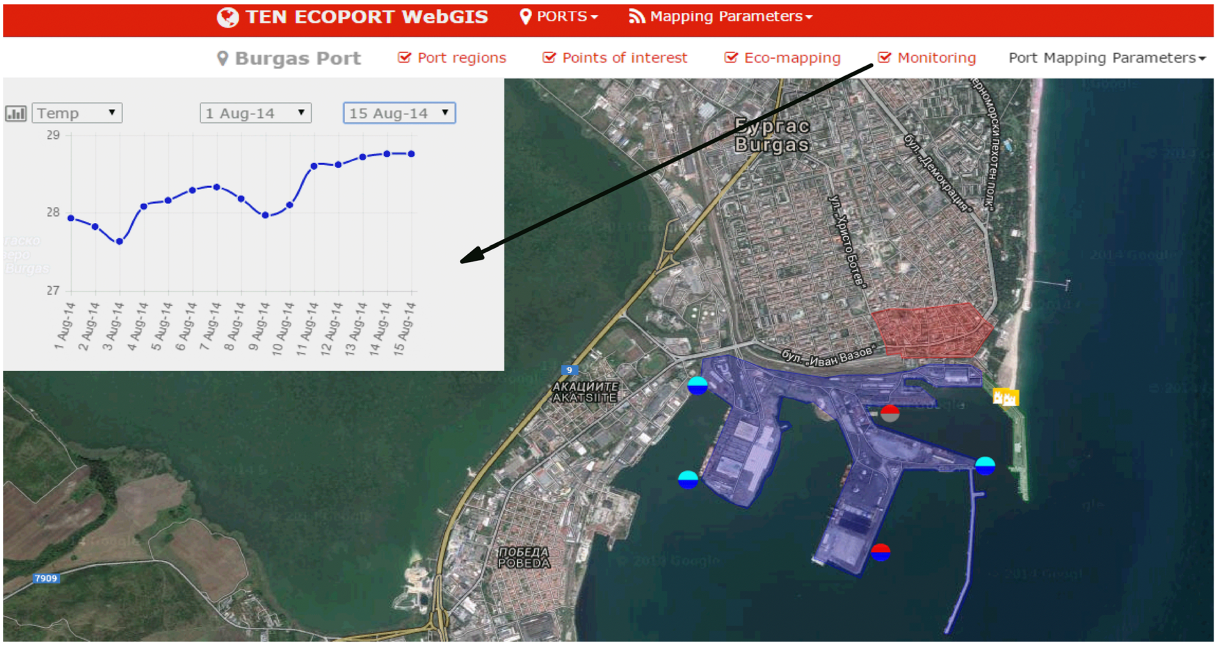


Fig. 9 The output of selecting a parameter and a period of interest at submenu "Monitoring" in the menu "PORTS" of the WebGIS platform

not affected. If the user clicks on any point of the map (Fig. 10), the actual values are provided along with the distance from the nearest pixel center (percentage value below the parameter value).

The WebGIS platform includes another environmentally important menu with the title Mapping Parameters that is addressing mainly to the scientific community and the policy makers. This menu presents maps with the spatial distribution of monthly satellite-derived products (SST, chlorophyll *a*, and CDOM) for the whole southeastern Europe. Examples of such visualization regarding these parameters are seen in Fig. 11.

The user can select the mean monthly distribution of any of the three previously mentioned sea parameters, and then, the spatial distribution (mean monthly values for a 10- to 12-year period) regarding the selected parameter for the whole eastern Mediterranean Sea is provided (Fig. 11).

Such spatial information is very useful because it highlights sea regions and sea corridors that have high or low values regarding the above-mentioned parameters. These specific areas could be further studied in detail, and the corresponding agencies are able to adapt environmental friendly policies in order to achieve a sustainable future of the marine and coastal environment in harmonization with the sea transportation corridors and the commerce needs.

Conclusions

This study presents a WebGIS platform that has been developed to provide visually useful environmental information for a network of ports in the SEE. Satellite remote sensing data as well as in situ measurements from port stations are used and plotted through the WebGIS platform. Furthermore, official information from the port environmental departments regarding points and areas of environmental interest inside port territories led to the provision of eco-map symbols. These symbols are displayed at the WebGIS platform (along with relative short descriptions) informing about specific locations where environmentally friendly port activities and quality controls have to be applied in order to decrease the pollution levels. It is noteworthy pointing out that the eco-map symbols comprise an innovative categorization approach that could be used in other relative applications and procedures.

From the technical point of view, modern tools and methodologies have been implemented to develop the WebGIS platform, following the criteria of portability, flexibility, user-friendly menus, and update capabilities.

The web-based GIS platform provides useful and high-quality information in terms of sea corridors for the whole southeastern Europe. This is achieved by visualizing mean monthly spatial distributions of three

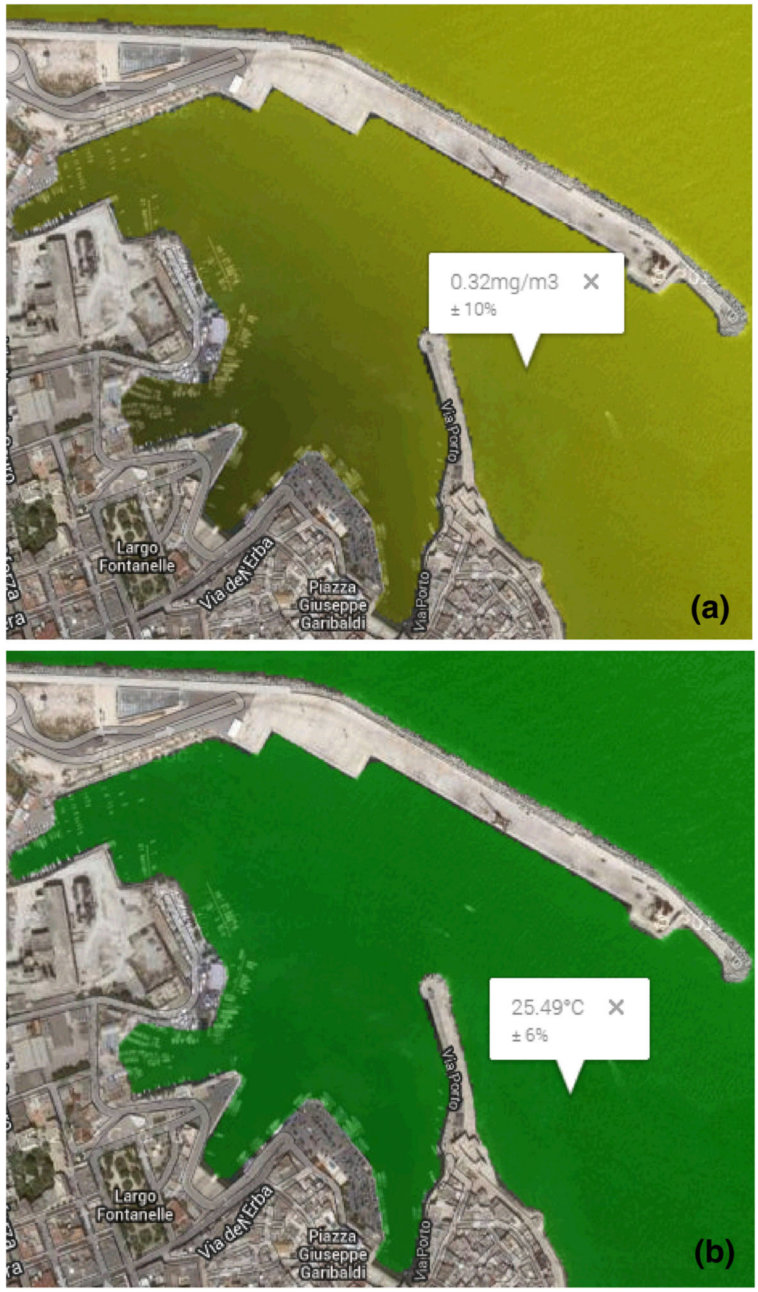


Fig. 10 **a** Illustration of the spatial distribution of the mean monthly (July) chlorophyll *a* for the period 2003–2012 in the greater sea area of the port of Monopoli. **b** Illustration of the spatial distribution of the mean monthly (July) SST for the period 2000–2013 in the greater sea area of the port of Monopoli (Italy)

essential marine parameters (SST, chlorophyll *a*, and CDOM) that are provided through the menu Mapping Parameters. The visualization of the corresponding datasets can be used as informational background and as an initial guide to study and adopt new legislation and environmental friendly policies to protect the air and marine environment, taking simultaneously into consideration the increasing tendencies of sea transportation and sea commerce sector (Huang and Chang 2003; Darbra et al. 2009; Gonzalez Del Campo 2012; Bunch et al. 2012; Tziavos et al. 2012; Goodchild 2009).

Important environmental information regarding port areas is also included in the WebGIS platform. More specifically, information about regions (menu Port regions) and locations inside port areas with specific environmental interest (menu Eco-mapping) is easily illustrated, through the respective submenus. Additionally, graphs with the temporal evolution of

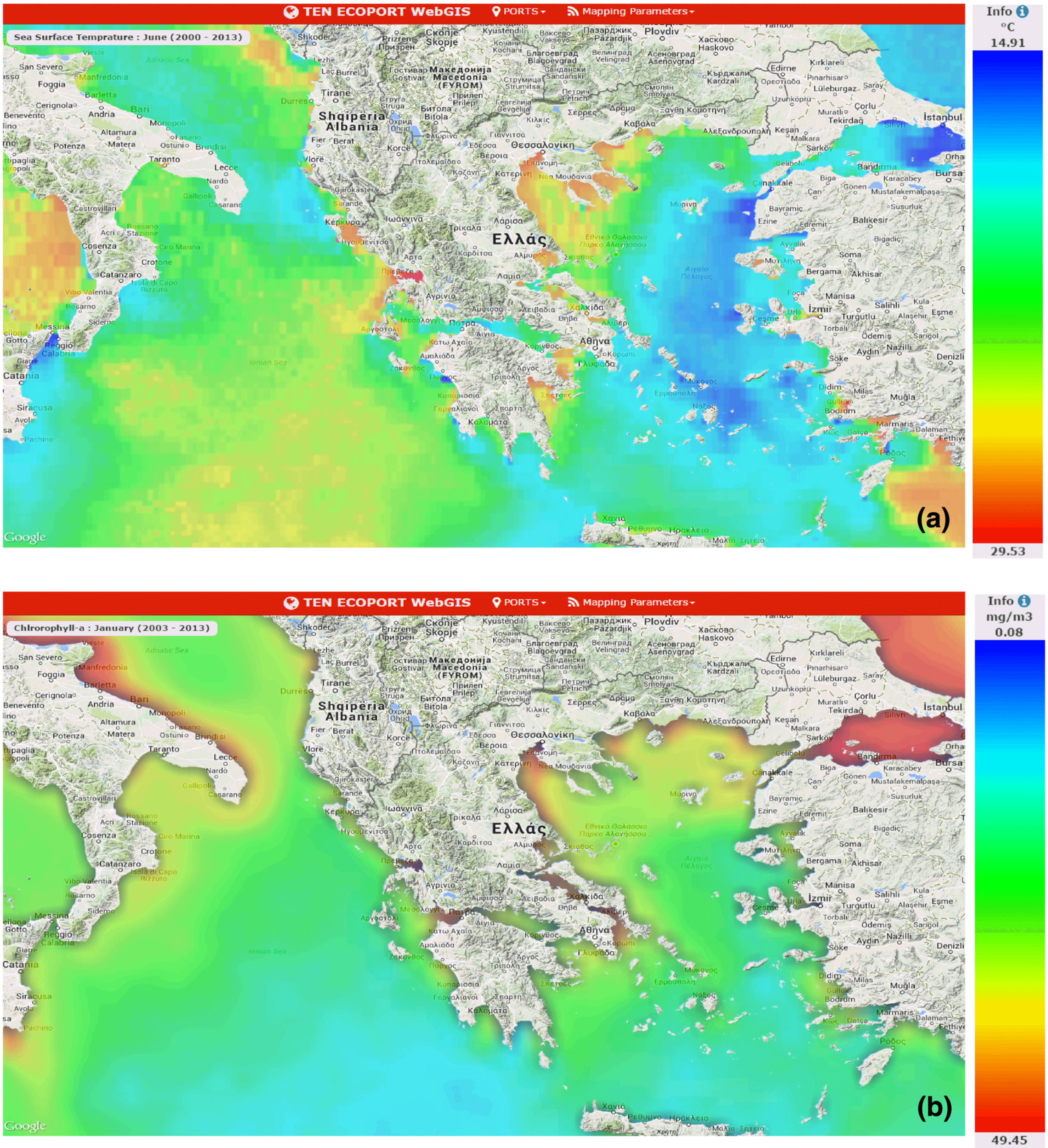


Fig. 11 **a** Illustration of the spatial distribution of the mean monthly (June) SST for the period 2000–2013 in Southeast Europe. **b** Illustration of the spatial distribution of the mean monthly (January) chlorophyll *a* for the period 2003–2013 in Southeast Europe

marine/air pollution parameters are provided together with the mean spatial distribution of selected marine parameters in small sea areas around ports (menu “Mapping”).

It is pointed out that during the design and the development of this web-based application, the four general monitoring guidelines proposed in the study of Ferreira et al. (2007) are as follows. Firstly, there were defined the current and potential needs and requirements as well as the environmental objectives after communication and documentation exchange with all involved partners (port authorities, institutions, and experts) within the framework of TEN ECOPORT project. Secondly, the priorities and the optimum solutions not only from a technical but also from an environmental point of view were set. Finally, all the appropriate datasets and the relative informational material were selected and internal quality controls (where it was necessary) were implemented (e.g., Kolios and Stylios 2015). The assessment of the application in terms of functionality, portability, and the satisfaction of the initially defined needs was—at first stage—accomplished during the final project meetings and the finalization of the relative technical reports.

In conclusion, the developed WebGIS application can be considered as a valuable system that has been designed to operate and visualize spatiotemporal information in order to cover the environmental needs of ports. It is a modern, web-based GIS application that provides in time and space environmental information for a network of seaports covering the whole southeastern Europe. The portability of the WebGIS platform (easily accessed from mobile devices such as tablets and smartphones) makes this platform, not only very informative regarding environmental issues of SEE ports and their sea corridors, but also easy to use. The central aims of this application are to collect and illustrate important information from a network of sea ports around SEE and operate as an environmental guide in order to highlight "hot spots" in port territories and their greater sea area, supporting them toward the adoption of new practices and policies for a sustainable and environmental friendly port future.

Improvements and future perspectives of this platform would include monitoring capabilities in real-time basis, spatial analysis capabilities at the coastal parts of port areas, and regular updates of the existing information so that to cover the continuous changes in port environment and their sea corridors.

Acknowledgments This work is supported by the "Transnational ENhancement of ECOPORT8 network" (TEN ECOPORT) project with code SEE/D/0189/2.2/X, co-financed by the EU within the South East Europe Transnational Cooperation Program. The authors would like to thank all the partners of the TEN ECOPORT project for the provision of data and all their valuable information and advice.

The authors would also like to especially thank NASA, for the provision to the scientific community, free of charge, of a wide range of high-quality satellite data and products through its official sites and relative web-based applications.

Authors would like to thank the anonymous reviewers for their comments and suggestions who helped to improve the clarity and the overall quality of the paper.

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