A WebGIS Prototype for Visualizing and Monitoring the Spatio-temporal Changes in Seawater Quality

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Abstract. Anthropogenic pressure on the coastal areas triggers a shoreline deep evolution, impacting the marine-coastal ecosystem. A specific fact-finding tool should be developed to detect the potential damages suffered by such an environment both qualitatively and quantitatively. Web Geographical Information Systems (WebGIS), developed to store, and handle geospatial big data, as well as disseminate information generated by processing raw data, appears as an optimal solution to address those needs. Indeed, they allow integrating own data with those ones provided by external sources into a single web application, easily accessible through an interactive and straightforward interface. This may interest several types of target audiences, such as local/national authorities and scientific communities. Therefore, this research is aimed at introducing a WebGIS prototype, developed to analyze and visualize seawater quality data in the Puglia region (Southern Italy). System features and capability was designed considering potential consumers' requirements, and, in accordance with Open Geospatial Consortium and European directive INSPIRE, its infrastructure was developed using Free and Open-Source Software for Geographic information systems. Thus, after defining the end-users and capturing their needs, the platform was built using the three-tier configuration. The levels were devoted to presenting, analyzing, and storing the data, respectively. Additionally, a user-friendly interface, allowing two-dimensional data visualization, was also programmed to help the not-skilled consumers in consulting the stored data. The developed WebGIS allows both multi-temporal and multi-scale analysis to evaluate and monitor seawater quality permitting local authorities to plan the adequate remedial actions.

Keywords: Web mapping; IoT · Water pollution · Geospatial data · FOSS4G

1 Introduction

The natural phenomenon concerning the nutrients accumulation in seawater is generally called eutrophication. It, mainly linked to human pressure in the coastal areas, has been

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getting worse quickly over the last few years because of population growth of about 45% in those zones [1–6]. This has caused a strong deterioration of the coastal-marine ecosystem balance, implying its goods and services degradation [7]. Indeed, as reported by Wurtsbaugh et al., [8] in 2019, an annual loss equal to $1 billion was estimated in Europe. Therefore, various European Directives, such as the Urban Wastewater Directive (UWWD-91/271/EEC), the Water Framework Directive (WFD-2000/60/EC), the Marine Strategy Framework Directive (MSFD-2008/56/EC) [9] were issued to tackle such an environmental question and to improve seawater quality. All those documents suggested the development of specific fact-finding tools aimed at evaluating and monitoring seawater quality. Therefore, the scientific community is totally dedicated on economic and effective approaches detection to meet such a purpose and to support local/national authorities in adopting the optimal management strategies.

Geographical Information System (GIS) appears as the best alternative to handle the large amount of data needed to assess and monitor the seawater quality. Moreover, thanks to the technology advancement and internet coming, GIS can be adopted to disseminate information/data too [10–12]. In fact, the Web Geographic Information System (WebGIS) permits consumers to access data directly, to visualize them both in a two and three-dimension (2D and 3D) and manage them by exploiting cloud potentialities [13].

A client-server structure, based on three-tiers configuration, is commonly selected to implement an intuitive and efficient web platform suitable for handling geospatial big data. Each layer is generally developed as an independent module in order to maximize its performance [13]. Specifically, it consists of i) an attractive easy-to-use interface with the aim of supporting skilled and not-skilled users in getting the desired information [14], ii) a geodatabase, able to store all data types [13–15], and lastly, iii) an application stage, aimed at managing and handling the data [16]. The components of each single tier can be programmed by using both proprietary and open-source software. Those last ones are usually preferred due to their versatility and competitive performance albeit they can be programmed by expert technicians [17, 18]. In addition, Free Open-Source Soft-ware (FOSS) allows also to respect the INfrastructure for Spatial InfoRmation in the European Community (INSPIRE) Directive and Open Geospatial Consortium (OCG) expectations [19].

This work is aimed at presenting the Web application prototype developed to support potential consumers in detecting the optimal eco-compatible management strategies to preserve the coastal-marine ecosystems of Puglia Region (Southern Italy). Thus, after collecting end-users' feedbacks, the external open data sources were analyzed to identify available datasets and to program the field data campaigns needed to fill the lack of information. Such a WebGIS presumes to integrate all required data to assess and monitor the coastal-marine environment. Therefore, its single component was designed properly using FOSS4G software in compliance with OCG and EU Directive INSPIRE.

Three main sections can be detected in this paper: i) "Material and methods" (Sect. 2), ii) "Results and discussion" (Sect. 3) and, lastly, iii) "Conclusion" (Sect. 4). The aim of Sect. 2 is to describe the background and the methodology, as well as the data, needed to implement an efficient, effective, and user-friendly web environment aimed

at storing and handling all the available maps and information concerning the coastal-marine ecosystem. On the contrary, Sect. 3 is essentially linked to research outcomes representation and discussion in order to enhance the potentialities and the performance of the implemented Web application prototype. Its results were also compared with the main outcomes obtained by previous works. The last Section, instead, is mainly focused on describing platform strengths and weaknesses as well as outlining future work directions.

2 Material and Methods

The WebGIS application design was based on the workflow suggested by Huxhold and Levinsohm in 1995 [20] which consists of seven essential steps to comply with (Fig. 1). Thus, after detecting potential consumers of such a framework, its main characteristics, and the indispensable data, as well as the optimal architecture to adopt, were defined. That knowledge was the foundation of WebGIS platform design, later converted into a prototype whose effectiveness and efficiency were subsequently assessed. Thus, the implementation phase started by involving three key stages: i) data collection and database construction; ii) interface building and, lastly, iii) data implementation. The final performance of all the above-mentioned phases is iterative and interactive, and they are detailed in the next paragraphs.

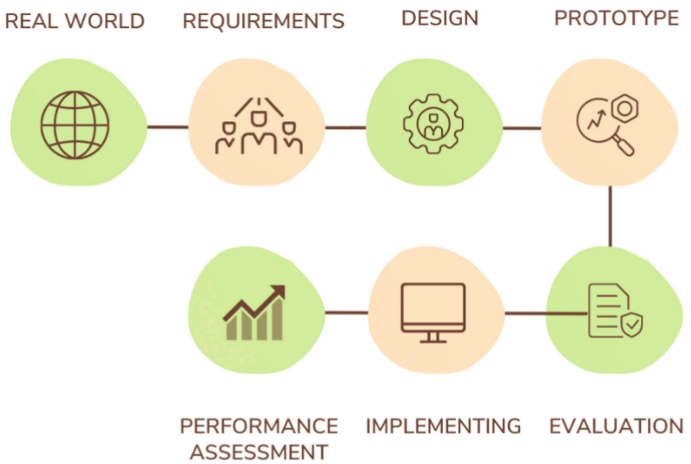

Fig. 1. Operative pipeline applied to develop and implement WebGIS application

2.1 WebGIS Framework Design

Three relevant aspects were considered to design an attractive WebGIS application. Firstly, once potential users were detected, their expectations and requirements were explored and gathered. That information was, thus, used as a substratum to define:

i) the area of interest, ii) the required data and the existing sources to consult or the best practices to acquire the unavailable data, and, lastly, iii) the optimal software and hardware needed to optimize its configuration.

Several target groups, such as the national/regional/local authorities aimed at evaluating and monitoring water quality, as well as the scientific community interested in having a unique database including all the data, may be considered as potential consumers. Individual citizens could benefit from the information provided by the platform too. Indeed, they can access the data directly and, consequently, know the actual water pollution level of the ecosystems where they live. This allows defining which features should be had by the platform and which data should be integrated and handled.

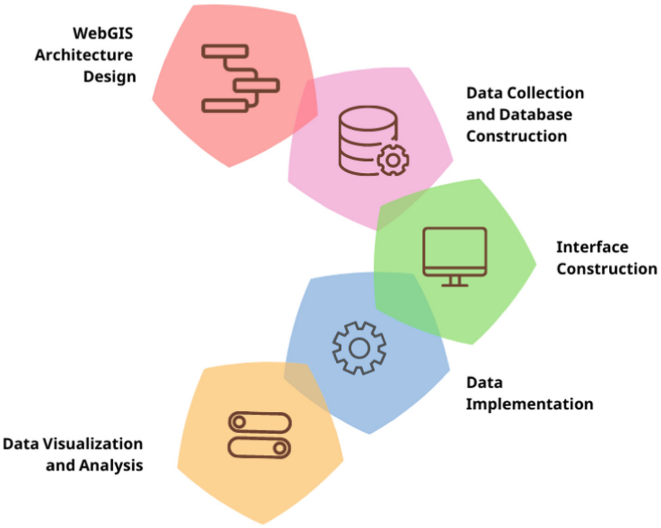

Fig. 2. Architecture operative workflow.

Therefore, the design phase was started on the basis of the operative workflow introduced by Caradonna et al., in 2016 [21]. It consists of five main stages, reported in Fig. 2. Initially, the WebGIS capability and, consequently, its structure was defined and constructed ("WebGIS architecture design" phase). Then, the most suitable data, provided by external open sources or collected during proper field data campaigns, were picked up. Due to their heterogeneous formats, the optimal strategies for their treatment and implementation in the platform were outlined too ("Data collection and database construction" step). A 2D user-friendly interface was then built for helping skilled and not-skilled users in consulting the application and getting the desired information ("Interface construction" step). Thus, the collected data were implemented in the specific drop-down menus ("Data implementation" stage) and visualized in the 2D viewer ("Data visualization and analysis" phase).

2.2 Study Area

Puglia, in Southern Italy, was chosen as a pilot site since it is the third region in terms of coastline length at the national level (Fig. 3) [22]. Indeed, as reported by the Regional Coastal Plan of 2011, its shoreline broadens to about 1000 km and it is characterized by a complex morphology, varying from sandy beaches up to river mouths including rocky cliffs too. Marine-coastal ecosystem diversity is mainly due to the influence of anthropogenic activities, such as urban sprawl and increment of population density and infrastructures. To meet the research purpose, five Apulian ports were selected as particular case studies to analyze. Specifically, the harbors of Bari, Mola di Bari, Monopoli, Brindisi, and Otranto were picked up.

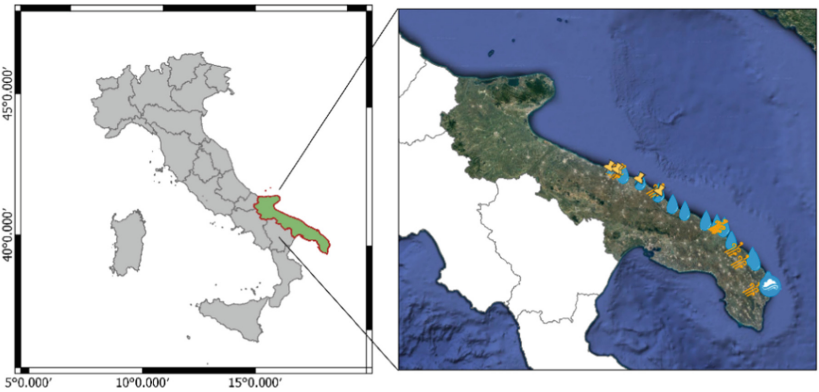

Fig. 3. Study area geographical position (on the left) and stations, devoted to data collection (on the right).

Thanks to its geographical location, the New Port of Bari is considered one of the most relevant multifunctional ports in the Southern Italy as well as the gateway to the countries of Eastern and Middle East Europe. This allows its continuous and dynamic evolution in terms of passengers and freight traffic albeit travelers movement, based on ferry and cruise, is its driving force.

The small port of Mola di Bari is characterized by an internal zone reserved for fishing boats parking and floating docks suitable for hosting recreational boats.

The structure of the Port of Monopoli is protected by two main piers: i) that one of Margherita di Savoia and ii) the Tramontana Dam. The latter, however, is not accessible because of its elbow shape and the presence of an escarpment rocky. Nevertheless, the port is still subjected to some dangers, like the shoal in Punta del Trave, especially in conditions of low tide.

The port of Brindisi is naturally characterized by an internal, medium, and external basin, which corresponds to the tourist, commercial, and industrial port, respectively. The first is delimited by two deep inlets that enclose the historic center of Brindisi. The second comprises the stretch of sea, located close to the Pigonati canal. On the north, the basin forms the "Bocche di Puglia". Lastly, the third one is delimited by the mainland on the south, the Pedagne islands on the east, Sant'Andrea island and the Costa Morena pier on the west, and the Punta Riso dam on the north.

The development of the port of Otranto is mainly linked to its touristic relevance, indeed, this small gulf is a significant point for welcoming visitors' boats. It can accommodate up to 390 berths with a maximum length of 20 m.

2.3 Data Collection and Geodatabase Building

Preserving the marine-coastal ecosystem and guaranteeing the implementation of eco-friendly actions may be ensured by a timely monitoring program aimed at assessing and controlling both natural and anthropogenic pressure factors. Therefore, in compliance with the Government Decree n. 152/2006, the most suitable parameters for meeting research purposes were identified and collected by consulting open and own data sources.

The National Geoportal [23] and Territorial Information System of Apulian Region (SIT Puglia [24]) provided the basic cartography. Conversely, the Regional Agency for Environmental Prevention and Protection (ARPA Puglia) [25], and the Italian Institute for Environmental Protection and Research (ISPRA) [26] supplied water and air quality data while the free website VesselFinder [27] gave details about the real-time maritime traffic. Additionally, to extend the information concerning the quality of seawater, sediment, and air, the dataset gathered within the AI SMART project [28], was uploaded too.

After importing those data into PostGreSQL using PostGIS extension and storing them together with style and Uniform Resource Locator (URL), their reference systems were transformed into WGS84 UTM 33N (EPSG: 32633). Each data was uploaded in the most adequate menu.

2.4 WebGIS Structure Implementation and Interface Construction

The WebGIS was structured by adopting the three tiers configuration, as depicted in Fig. 4. Thus, a specific independent module was developed for each of them, and, specifically, for i) the presentation tier (interface), aimed at visualizing the data, ii) the application layer, devoted to handling the data and producing information, and iii) the database level, dedicated to storing the data.

As outlined in Fig. 4, web browsers, session pools, static files, and rendered maps were the main tools combined to build the first level. Conversely, web servers, additional libraries, and model generation tools were adopted to construct the second tier and, lastly, an open DataBase Management System (DBMS) was, instead, applied to define the structure of the third layer.

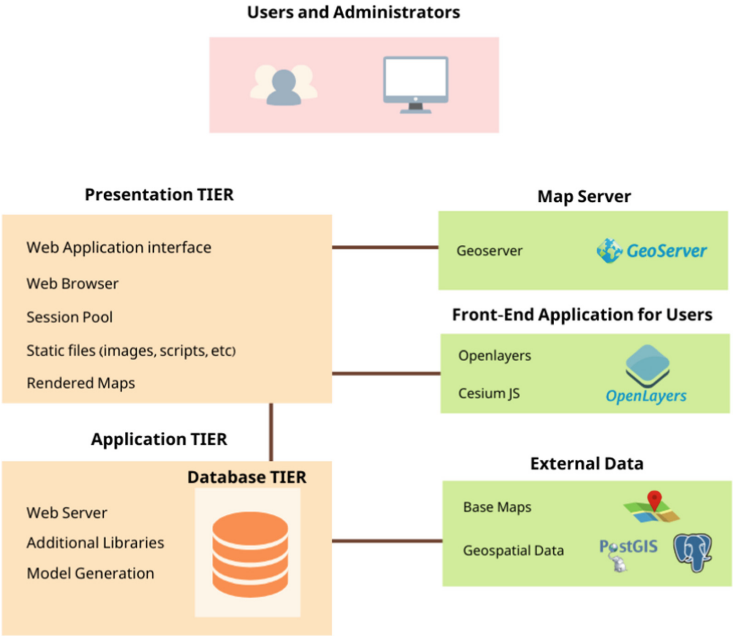

Fig. 4. Three-tiers configuration of the develop WebGIS application

Web browsers had the role of client front-end allowing web page access and consumers' queries transferee to the webserver and map server. The former, aimed at running the web scripts and forwarding the query to the implemented geodatabase, was constructed using version 9.0.39 of the open-source HTTP Apache Tomcat Server [29], realized by the Apache Software Foundation (Forest Hill, MD, USA) [14, 30]. On the contrary, the latter was mainly devoted to data treatment in the 2D viewer as well as the integration of web services available from external sources, provided in the following formats: Web Map Service (WMS), Web Feature Service (WFS); Web Coverage Service (WCS); Web Processing Service (WPS); Web Map Tile Service (WMTS) [14, 30]. Version 2.15.1 of the open-source Java-script Map server Geoserver (Boundless Spatial, GeoSolutions, Refractions Research, St. Louis, MO, USA [31]) was adopted to set the Map server. The DBMS, instead, was designed by applying version 12.0 of the PostGre Structured Query Language (PostGreSQL) database system (PostgreSQL Global Development Group [32]). Lastly, additional libraries, like, for instance, version 6.4.3 of OSGEO of OpenLayers (Boundless Spatial, GeoSolutions, Refractions Research, St. Louis, MO, USA [33]), were introduced to improve data analysis and presentation.

As above-mentioned, in compliance with the Open Geospatial Consortium (OGC) and EU directive INSPIRE, free and Open-Source Software for Geospatial Applications (FOSS4G) were adopted for every single module [34–38].

Moreover, the interface was made more attractive thanks to the adoption of version 4.5.0 and 4.7.0 of the Bootstrap [39] and version 4 of W3 [40] libraries. Additionally, a CSS style file, programmed using the HTML and JS languages, was integrated with the previously mentioned libraries, into a unique script [41]. This combination allows setting adequate menus where the data were collocated properly.

3 Results and Discussion

A web application was developed to geo-visualize and monitor air/seawater quality and sediment in the most relevant ports of the Puglia region. To meet such a purpose, the working plan comprised three basic phases: i) potential end-users needs exploration, and, thus, definition of case studies and data to collect, ii) web application design, iii) data collection and web tool implementation.

To carry out each phase, the operative workflow proposed by Huxhold and Levinsohm in 1995 [20] (Fig. 1) was adopted. Thus, potential stakeholders and users were detected, and their feedbacks were gathered. WebGIS platform was designed and calibrated on the basis of their needs through the operative workflow described in Fig. 2. After completing such a stage, the required data were collected from available external sources and AI-SMART project, and then, stored in the geo-database developed using an open-source DBMS, PostGreSQL (version 12.0) [32]. Simultaneously, the other two tiers were implemented to complete the WebGIS configuration: an attractive interface, aimed at helping users in consulting the platform, and the application layer, devoted to handling the data. All tiers were developed independently through FOSS4G in accordance with OCG and EU directive INSPIRE.

The interface, depicted in Fig. 5, is characterized by three main factors: Table of Content (ToC) and printer panel on the left, and the 2D viewer on the right. ToC groups together all the data into the most adequate menu, such as base layers (Fig. 5A), water quality monitoring, air quality monitoring, seawater surface temperature, humidity parameter, wind condition, hydrometric level, real-time maritime traffic (Fig. 5B e Fig. 5C). Each drop-down menu includes layers bringing similar information. The printer panel is located on the bottom of the ToC and it allows downloading the data by selecting the most suitable format (Fig. 5D). On the contrary, the 2D window is located on the right. Beyond the visualization of the active maps, it includes other tools too. Specifically, the navigation toolbar, comprising zoom in, zoom out, slide zoom, zoom to layer extension and full screen, is arranged on the top-left (Fig. 5E), the overview map (Fig. 5F) and the scale bar (Fig. 5G) are at the bottom-left while, lastly, the coordinates of the mouse pointer are displayed on the top-right (Fig. 5I) and the information tool is on the bottom-right (Fig. 5L).

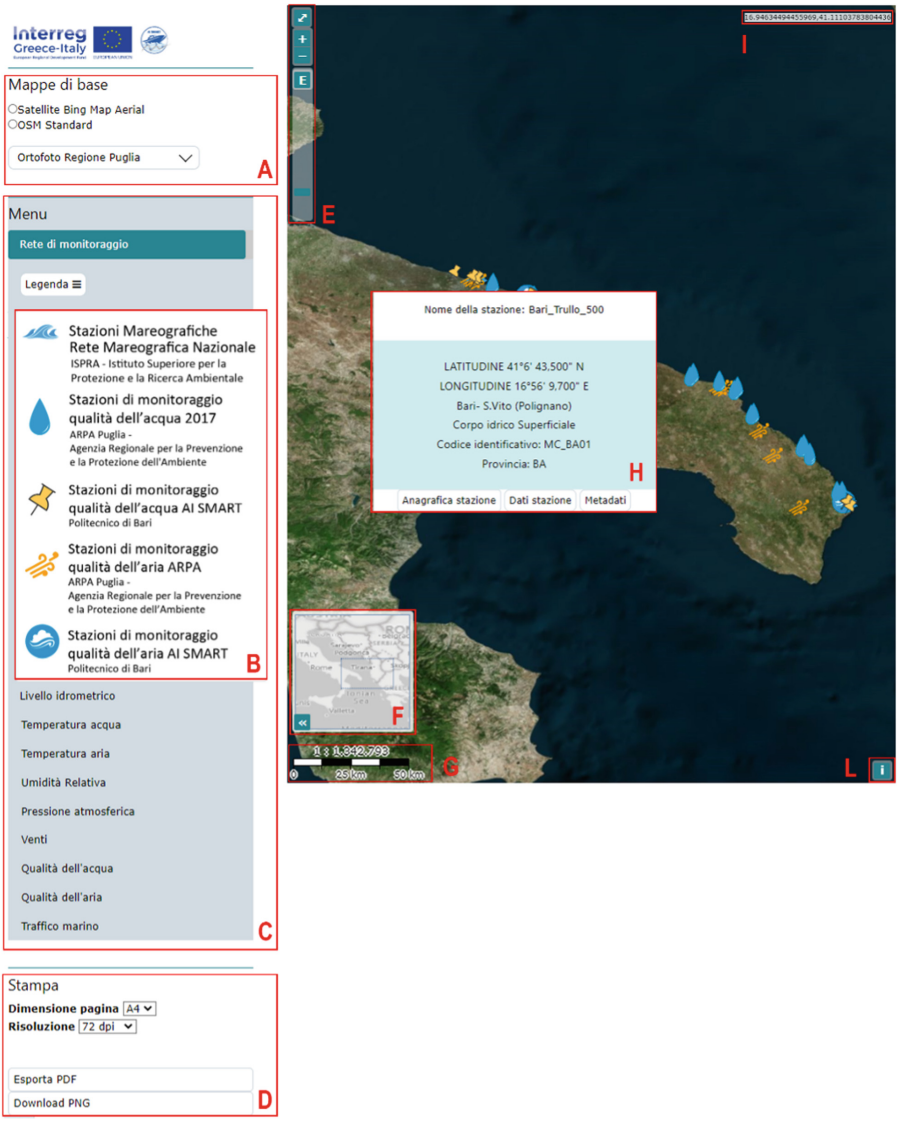

Fig. 5. 2D viewer interface: A) baseline maps; B) Sampling points; C) Table of Content (ToC); D) export tools; E) zoom in/zoom out widgets; F) frame visualization; G) scale and H) metadata panel; I) Pointer coordinates; L) information.

When active, the layer overlaps the base map and, just clinking on the corresponding panel, the users can select the information to display. Indeed, he/she can choose among the station registry panel, displayed in Fig. 5H, the data window, depicted in Figs. 6, 7, and the metadata panel.



		PORTO DI BARI				DM 173/2016	
Nome stazione		Bianco			Bianco	Livelli chimici di riferimento nazionali	
Sigla		BlankN_S	BlankN_F		BlankN		
Data campionamento		Giugno 2021	Giugno 2021		Giugno 2021		
Fase		Ante operam	Ante operam		Ante operam	L1	L2
PARAMETRI CHIMICO-FISICI	**U.M.**			**U.M.**			
pH	u. pH	8,10	8,23	u. pH	8,78	-	-
Pot. Redox				mV	-83,9	-	-
Umidità a 105 °C				%	21,61	-	-
Frazione < 2mm				% s.s.	100,0	-	-
METALLI							
Arsenico	mg/l	< 0.01	< 0.01	mg/kg s.s.	6,51	12	20
Berillio	mg/l	< 0.01	< 0.01	mg/kg s.s.	0,03	-	-
Cadmio	mg/l	< 0.01	< 0.01	mg/kg s.s.	0,07	0,3	0,8
Cobalto	mg/l	< 0.01	< 0.01	mg/kg s.s.	1,75	-	-
Cromo totale	mg/l	< 0.01	< 0.01	mg/kg s.s.	9,52	50	150
Mercurio	mg/l	< 0.01	< 0.01	mg/kg s.s.	< 0.01	0,3	0,8
Nichel	mg/l	< 0.01	< 0.01	mg/kg s.s.	3,05	30	75
Piombo	mg/l	< 0.01	< 0.01	mg/kg s.s.	46,17	30	70
Rame	mg/l	< 0.01	< 0.01	mg/kg s.s.	7,92	40	52
Selenio	mg/l	< 0.01	< 0.01	mg/kg s.s.	< 0.01	-	-
Tallio	mg/l	< 0.01	< 0.01	mg/kg s.s.	< 0.01	-	-
Vanadio	mg/l	< 0.01	< 0.01	mg/kg s.s.	15,62	-	-
Zinco	mg/l	< 0.01	< 0.01	mg/kg s.s.	13,01	100	150
IDROCARBURI POLICICLICI AROMATICI (IPA)							
Naftalene	µg/l	< 5	< 5	µg/kg s.s.	< 20	35	391
Fluorantene	µg/l	< 5	< 5	µg/kg s.s.	< 20	110	1494
Antracene	µg/l	< 5	< 5	µg/kg s.s.	< 20	24	245
Acenaftene	µg/l	< 5	< 5	µg/kg s.s.	< 20	-	-
Acenaftilene	µg/l	< 5	< 5	µg/kg s.s.	< 20	-	-
Fluorene	µg/l	< 5	< 5	µg/kg s.s.	< 20	21	144
Fenantrene	µg/l	< 5	< 5	µg/kg s.s.	< 20	87	544
Pirene	µg/l	< 5	< 5	µg/kg s.s.	< 21	153	1398
Crisene	µg/l	< 5	< 5	µg/kg s.s.	< 20	108	846
Benzo[a]antracene	µg/l	< 5	< 5	µg/kg s.s.	< 20	75	500
Benzo[a]pirene	µg/l	< 5	< 5	µg/kg s.s.	< 20	30	100
Benzo[k,j]fluorantene	µg/l	< 5	< 5	µg/kg s.s.	< 20	20	500
Benzo[b]fluorantene	µg/l	< 5	< 5	µg/kg s.s.	< 20	40	500
Benzo[g,h,i]perilene	µg/l	< 5	< 5	µg/kg s.s.	< 20	55	100
Dibenzo[a,h]antracene	µg/l	< 5	< 5	µg/kg s.s.	< 20	-	-
Indeno[1,2,3-a,b]pirene	µg/l	< 5	< 5	µg/kg s.s.	< 20	-	-
∑ IPA	µg/l	< 5	< 5	µg/kg s.s.	< 21	900	4000

Fig. 6. Visualization of chemical-physical features measured by the station located in Mola di Bari Port

WebGIS platform efficiency and effectiveness were assessed too. All software, selected to implement each element of the three tiers, showed a performance in line with the literature. Indeed, as already registered by [42–45], up to 10 s and 2.4 s are required by PostGreSQL and PostgreSQL/PostGIS and Geoserver to run 12 million



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Vanadio	mg/l	< 0.01	< 0.01	mg/kg s.s.	15,62	-	-
Zinco	mg/l	< 0.01	< 0.01	mg/kg s.s.	13,01	100	150

Fig. 7. Visualization of hydrocarbon measured by the station located in Mola di Bari Port

records and to answer a query, respectively. Lastly, to increase the application performance, the main page was divided into various JS files. This allows speeding up the procedure as well as reducing programming errors.

4 Conclusion

The developed application provides a strategic instrument for the evaluation and dissemination of seawater quality data maps concerning the Puglia region in Southern Italy. Such data may be interesting for two types of target audiences particularly: local/regional/national authorities and scientific communities. The former, indeed, can exploit platform information to make the best decision to preserve the marine-coastal ecosystem while the latter can benefit from the fact that all data are concentrated in a unique database. Additionally, the scientific community can download both raw and processed data to apply for their own research purposes. Therefore, the WebGIS provides an easy-to-use environment for the geo-visualization of free open data available

on external sources as well as data and maps produced within the AI-SMART project. Both skilled and not-skilled users can access the data and visualize or download those they are interested in.

As shown in Figs. 5, 6, the application comprises several independent modules to facilitate its consultation, such as panels concerning metadata, acquisition instrument, and data acquisition point, and, lastly, ToC. Then, the consumers can select the water/air quality parameters maps or data from the ToC and overlaid them on the base maps, such as, for instance, satellite images or historical orthophotos. Moreover, they can explore maps proprieties from the metadata panel as well as the applied techniques and instruments from the stations and tools registers, respectively.

Most of the implemented data are time series, and, consequently, they allow monitoring the seawater and air quality as well as sediment both spatially and temporally. This helps the consumers to understand the actual situation and its evolution so as to predict its future development.

To achieve the research aim and to produce an easy, efficient and effective platform, a big effort was made in selecting the optimal hardware and software tool. In compliance with the OGC and EU directive INSPIRE, FOSS4G was picked up to implement every single module, guaranteeing that all browsers may access them. Nevertheless, the application still shows some limitations, such as, e.g., i) the number of contact points that can simultaneously access the database, ii) the opportunity to customize the data treatment, and, lastly, iii) the possibility to upload consumers' maps. Therefore, in the next future, the web application will be modified to face such issues.

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