EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2024, 25(9), 277–289
https://doi.org/10.12912/27197050/190708
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Received: 2024.06.28
Accepted: 2024.07.10
Published: 2024.08.01

The Oum Er-Rbia Watershed Web Mapping System – A Model for Open-Source Water Quality Dissemination

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ABSTRACT

The Oum Er-Rbia watershed faces a critical challenge in effectively disseminating the results of groundwater and surface water quality assessments to stakeholders and the public. This research aimed to address this challenge by developing a method for synthesizing and visualizing knowledge through web mapping. The methodology followed involved collecting data on surface and groundwater quality, hydrogeology, human impact, and topography. Subsequently, a needs analysis was conducted to identify the requirements of potential users (land managers, water users, researchers) to define system functionalities. Spatial data was organized into thematic layers (e.g., hydrography, geology) with detailed attributes to address user queries and generate maps. Open-source technologies were employed to build a web-based system (SCIEM) allowing users to visualize, analyze, and explore water quality data. Finally, user evaluation confirmed SCIEM's effectiveness in disseminating and analyzing water quality information within the watershed. The developed web mapping system has successfully addressed the challenge of disseminating research results by establishing an online, interactive multi-scale mapping system for groundwater and surface water characterization. This system facilitates the presentation of maps with a simple click, making them accessible to both geospatial experts and non-specialists. As a result, stakeholders such as water managers, land-use planners, and even farmers and citizens can now access a comprehensive view of groundwater and surface water information. Additionally, the utilization of free and open-source software has proven to be a cost-effective and efficient approach. The interactive multi-scale mapping system (IMSMS) provides a valuable tool for disseminating water quality data within the Oum Er-Rbia watershed. Building on this success, future research can explore the potential of adapting the IMSMS framework to other regions facing water quality challenges. Additionally, incorporating new data types beyond water management could provide a more holistic understanding of the interconnected factors influencing water resources.

Keywords: web mapping, water quality, watershed management, knowledge dissemination, geographic information systems, open data, multi-scale web mapping.

INTRODUCTION

The quality of groundwater and surface water is of great importance due to its impact on the environment and human health (Khatri and Tyagi, 2015). These resources are essential to life and the economy, but they are often threatened by pollution and degradation (Adeyemo, 2003). It is therefore crucial to monitor and evaluate their quality in order to prevent health risks and to take appropriate preservation and remediation measures (World Health Organization, 2022). Web mapping offers effective solutions to visualize, analyze and share information related to water quality (Xu et al., 2022), thus allowing a more efficient and sustainable management of these natural resources. It is essential to synthesize and visualize spatial data online to make them more intuitive and accessible to a wide audience (Smith et al., 2013). Nevertheless, the maps, whether in paper or digital version, present limitations as to their distribution to a large number of users. The use of Geographic Information Systems (GIS) is crucial for the effective management of groundwater and surface water (Tsihrintzis et al., 1996). GIS, composed of hardware, software and processes, allow the collection, management, analysis and visualization of spatial data (Fig.1), thus responding to complex planning and management issues (Panagiotopoulou & Stratigea, 2017). Dynamic cartography, in particular, offers an interactive and flexible visualization of geographical information (Dodge, McDerby, et al., 2011; Roth, 2013). Dynamic mapping offers a significant advancement over traditional static maps by providing interactive and flexible visualization of geographic information through real-time user interaction with geospatial data. Its key advantages include real-time interactivity, enabling users to explore geographic data in detail and personalize their experience; zooming and panning capabilities, allowing users to examine specific details or gain a broader overview as needed; and multi-scale navigation, enabling users to seamlessly switch between different scales to suit their specific contexts and needs.

The use of web mapping is proving to be extremely valuable in the assessment and monitoring of groundwater and surface water quality (Brodie et al., 2007; Machiwal et al., 2018). It makes it possible to centralize geospatial and geological data, to analyze temporal variations, to detect anomalies and trends, as well as to visualize the results in the form of thematic maps (Voigt et al., 2016). Thanks to web mapping, it is possible to easily share information with the relevant stakeholders (Giuffrida et al., 2019), improve decision-making, promote collaboration between the actors involved in water management and raise public awareness of the importance of water quality (Kolkman et al., 2005).

This study addresses a real and pressing challenge in the Oum Er-Rbia watershed, namely the difficulty of effectively disseminating the results of groundwater and surface water quality assessments to stakeholders and the public. Dynamic mapping offers an innovative solution to bridge this knowledge gap by providing an interactive and accessible platform for visualizing and exploring water quality data.

This research aims to create an interactive online IMSMS for the characterization of groundwater and surface water in the study area (Abdalla, 2012). This system will be built upon a spatially referenced database containing relevant data on both groundwater and surface water (Bertrand et al., 2012). The underlying hypothesis is that the IMSMS will empower water stakeholders and local managers with a regional perspective on groundwater and surface water knowledge and characteristics (Fraser et al., 2023; Geleta et al., 2023). Specifically, the system will be designed to organize various thematic data on these resources within the spatial reference database, facilitating

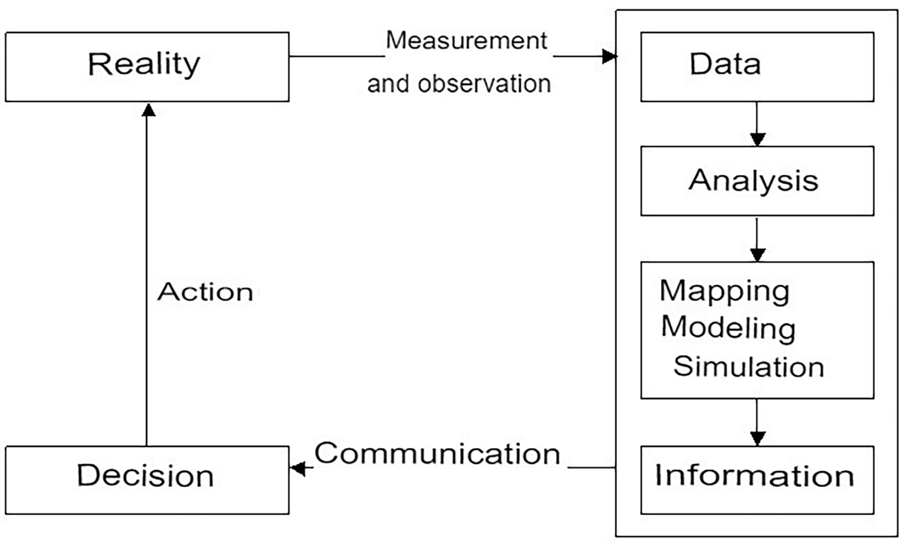

Figure 1. Operation of a Geographic Information System (GIS)

sector-specific analysis and employ a multi-scale approach with user-friendly one-click map display, essentially functioning as a digital atlas accessible even to non-geomatics specialists.

MATERIELS AND METHODOLOGY

Study area

The targeted territory covers an area of 47,032 km² located in the center of Atlantic Morocco, mainly comprising 5 regions (Figure 2). The study area covers the entire watershed of the Oum Er-Rbia River. This study area affects 18 provinces. The Oum Er-Rbia watershed experiences a diverse climate influenced by geography and topography (Aouragh and Essahlaoui, 2018). Coastal regions enjoy a Mediterranean climate with hot, dry summers and mild, humid winters, moderated by the Atlantic Ocean's proximity (Acil, 2016). Moving inland, the climate becomes more continental with harsher seasonal temperature variations. Precipitation is concentrated between November and April, peaking in December and January, with significant regional variations (Nassoh et al., 2023). Coastal areas receive 500–700 mm annually, while mountainous areas can reach 1000 mm. Conversely, inland plains and semi-arid regions receive less than 400 mm. Summer temperatures (June-September) can exceed 35 °C in inland areas, while winters (December-February) vary considerably. Coastal areas average 10–15 °C, whereas mountainous regions experience temperatures below 0 °C with frequent snowfall.

The Middle Atlas Mountains significantly affect the watershed's climate, influencing precipitation patterns and creating diverse microclimates. The western slopes receive more rain due to prevailing westerly winds. Semi-arid areas, like the Tadla Plains, experience limited rainfall and high evapotranspiration. This varied climate significantly influences the

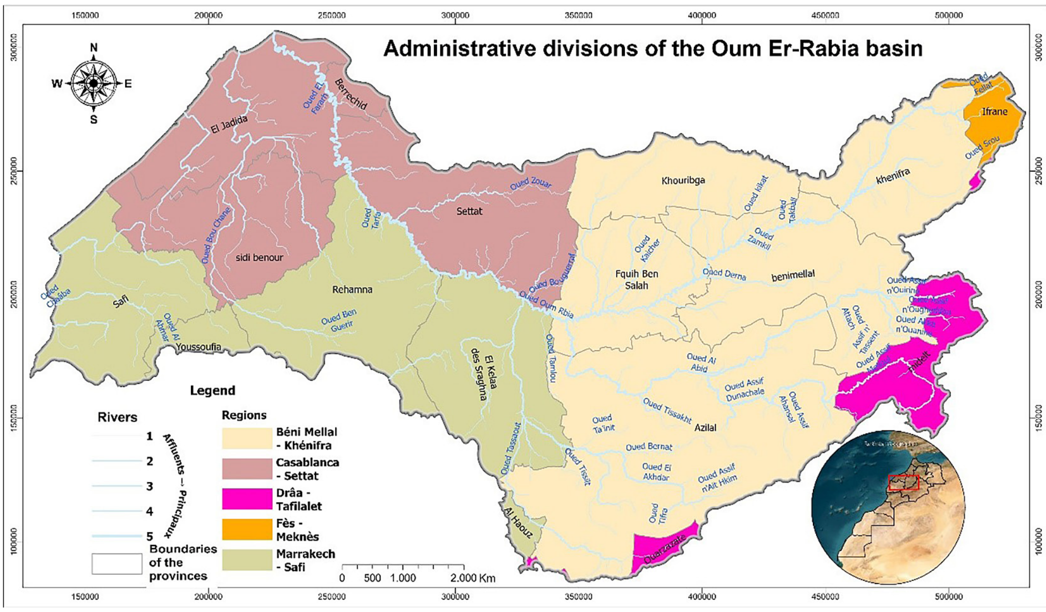

Figure 2. Administrative boundaries of the Oum Er-Rbia basin

Table 1. Region, area and population of the studied territory

Region	Total area of the region (km²)	Area in the targeted territory (km²)	Population in the target territory (inhabitants)
Béni Mellal - Khénifra	27 498	21 486	2 520 776
Casablanca - Settat	20 064	11 254	2 357 866
Drâa - Tafilalet	86 587	2 088	289 337
Fès - Meknès	39 156	617	155 221
Marrakech - Safi	38 979	11 541	1 796 491
Total	212 284	46 986	7 119 691

region's water resources. Seasonal variations in rainfall and temperature affect streamflow, aquifer recharge, and water availability for irrigation and other uses. Frequent summer droughts pose significant challenges for water resource management.

METHODOLOGY AND ANALYSIS TECHNIQUES

A five-stage methodology is employed for this research, detailed in Figure 3. It begins with data acquisition, followed by user needs analysis and system modeling. A robust database is then built, before application modules for data visualization and analysis are developed. Finally, the system is deployed and results are analyzed.

Data acquisition

The data used come from the results of the research "Modeling of the water quality of the oued Oum Er-Rbia" and are detailed in Tables 2 and 3. Due to data availability, all research maps were generated at a 1:100,000 scale. Data sources included various Moroccan agencies (Hydraulic Basin Agency, Ministry of Equipment and Water, Geological Database), along with international resources (USGS EarthExplorer) and the national topographic database.

Needs analysis

An interactive, multi-scale mapping system was developed to address two key needs: local water user access to groundwater and surface water data, and a comprehensive view of these resources for territorial managers. The results of the research provide very useful information on the indicators of water quality in the study area (Fig. 4). However, these results are more visual if they are presented in multi-scale cartographic form to have a global vision of the groundwater and surface water resource.

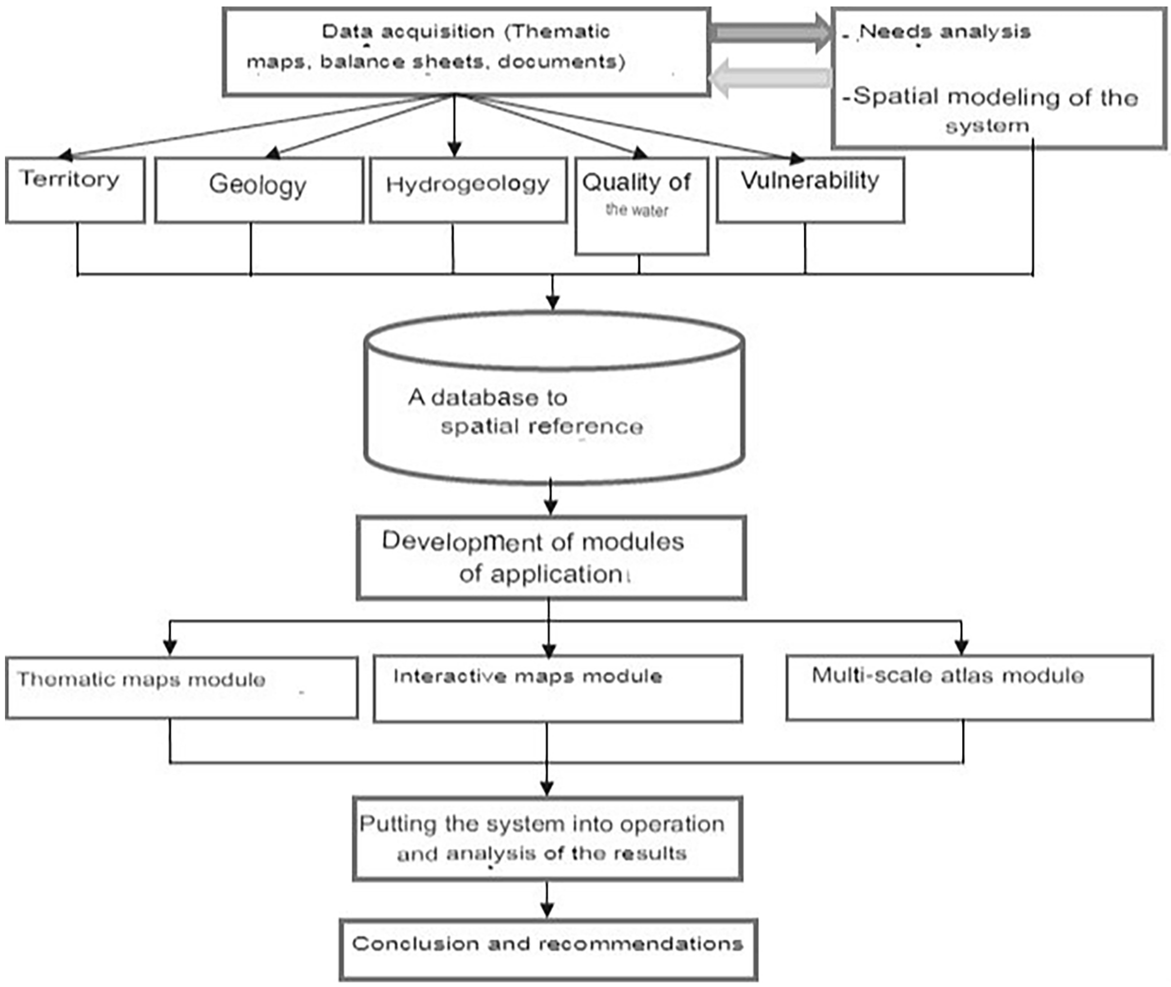

Figure 3. The five-stage methodology employed for this research

Table 2. Surface water quality according to the WQI index

WQI class	Quality	Number of sample	The stations	Rates (%)
0–25	Excellent quality	11	D5-D6-D7- D10-D11-PS8- PS10-SS9-SS12-SS14-SS17	27.5
25–50	Good quality	15	D3-D4-D8-D9-PS1-PS2-PS3-PS4-PS5-SS6-SS7-SS10-SS16-SS18-SS19	37.5
>50–75	Poor quality	5	D1-D2-PS6-PS7-SS4	12.5
>75–00	Very poor quality	2	SS11-SS15	5
>100	Non-potable water	7	PS9-SS1-SS13-SS2-SS3-SS5-SS8	17.5

Table 3. Overview of groundwater quality according to the IQM index

Stations	WQI values		Stations	WQI values	
	Winters	Summer		Winters	Summer
B1	3.300	3.300	BM6	2.700	3.300
B2	1.000	1.700	BM7	2.000	4.000
B3	4.700	2.300	BM8	1.000	3.300
B4	1.700	2.000	BM9	2.000	2.700
B5	1.700	1.700	S1	1.300	1.000
B6	1.700	5.000	S2	3.300	4.000

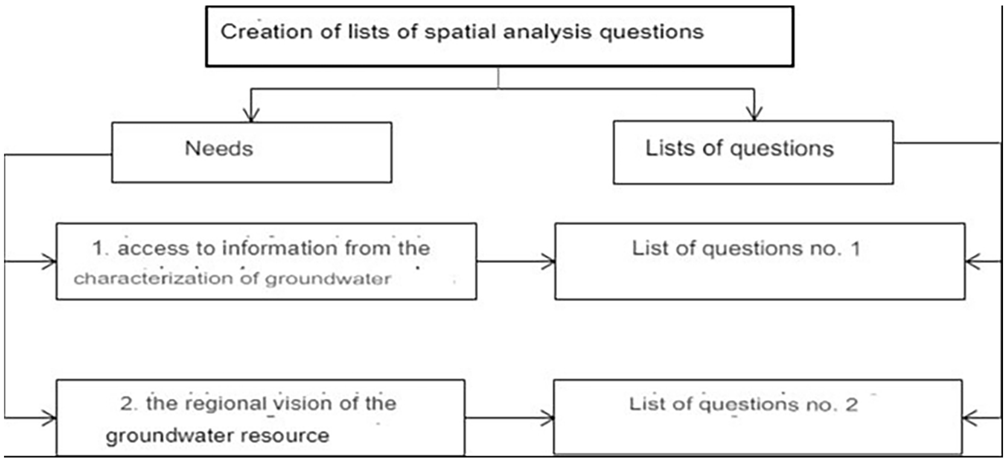

Figure 4. Creation of lists of spatial analysis questions

Spatial modeling of the system

Spatial modeling translates real-world needs into a digital representation. This involves identifying and defining spatial elements (points, lines, polygons) within a geographic space and layering them accordingly. The process unfolds in four key steps (Fig. 5):

- Identifying entity classes: This defines the broad categories of elements within the model (e.g., rivers, wells, water quality zones).
- Identifying entity subclasses: This further subdivides the classes into more specific types (e.g., permanent vs. seasonal rivers, high vs. low-quality water zones).
- Identifying entities: This pinpoints individual instances of the elements within the model (e.g., specific well locations, boundaries of a particular water quality zone).
- Identifying attributes: This assigns descriptive characteristics to each entity (e.g., depth of a well, specific water quality parameters).

Development and operating environment

The development of the IMSMS is based on the architecture of three layers – the presentation layer, the business layer and the data access layer. The IMSMS totally uses free and open technologies, which are the subject of Figure 6.

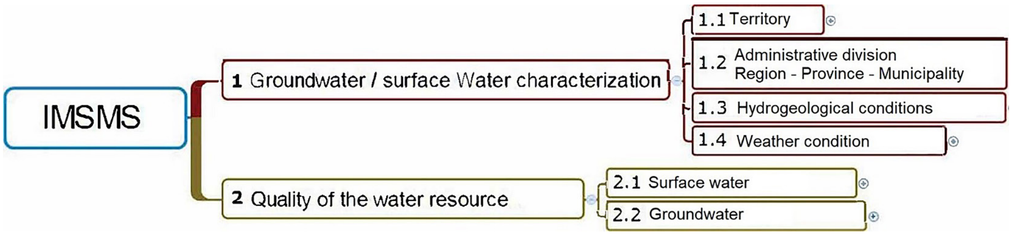

Figure 5. Identification of entity classes

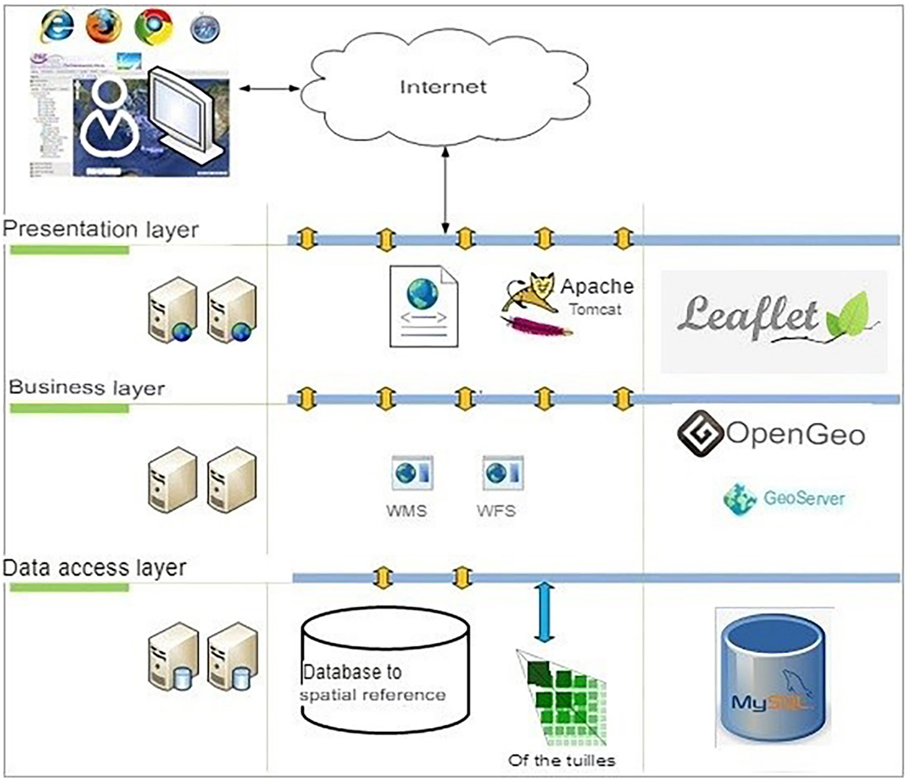

Figure 6. Three-layer architecture for the development of the IMSMS

An interactive mapping system has been developed to meet the needs and questions of water users. The development of this system consists of the following three main stages:

- Configure a database management system: This step consists of transferring the vector data into a spatially referenced database with the MySQL RDBMS;
- Configure the map server in WMS/WFS mode for each layer with a predefined display style in styled layer descriptor (SLD) format: GeoServer is the map server used for dynamic mapping. He can communicate with the database in MySQL to have the necessary data for the production of the requested map. GeoServer offers the possibility of directly taking the data from a table in the database to define a map layer. In addition, GeoServer offers the possibility of creating an SLD stylesheet by defining the display appearance of the layer. It is an XML script sheet that defines the style associated with the layer such as the color, the shape, the object size in the layer.
- Create a map interface for displaying layers: The Leaflet library allows you to create tools such as layer trees, navigation toolbars, layer legends, etc. Also allows you to load, display and render layers on the web browser.

RESULTS OF INVESTIGATIONS

The spatial reference database

A spatial reference database has been created in a MySQL relational database management system. This database includes two categories of

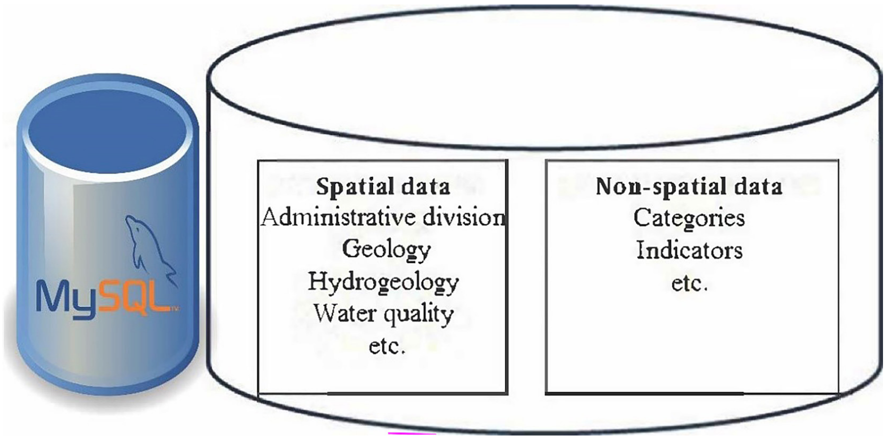

Figure 7. The structure of the spatial reference database

data: spatial data and non-spatial data that were collected in the study area (Figure 7).

The mapping distribution interface

The IMSMS includes two modules (Figure 8): (1) thematic map and (2) interactive map.

Thematic maps module

A thematic maps module has been developed to disseminate all the thematic maps generated as part of this study. This module makes it possible to synthesize the data generated by the research at the level of groundwater and surface water, hydrology, geology, water quality. The maps produced have been grouped and are represented visually. The map with its legend is presented in the center of the application. A library of available maps is presented at the bottom of the current map. Users can easily choose and broadcast the desired map (Figure 9).

1. The main board,
2. The list of available maps,
3. The link allows you to download all the maps available in PDF format,
4. Choose a map from the list of base maps and click on this map so that it becomes the main map.

Interactive maps module

An interactive maps module has been developed as part of this research. Access to the interface requires a login via a username and password, or a prior registration to be able to log in (Figure 10).

An interactive map takes center stage in the application, allowing users to explore various thematic maps alongside their corresponding legends and layouts (designed according to graphic design principles). Zooming and map display are seamlessly integrated into the navigation experience. Located to the right of the map (as seen in Figure 11) is a list of available maps (Table 4). The right panel further details the layers included in each active map, with

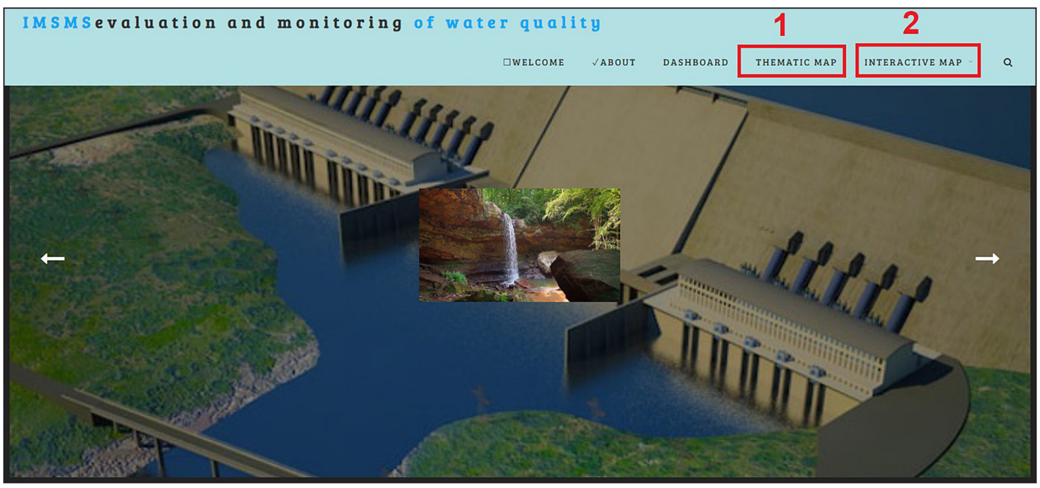

Figure 8. The home page

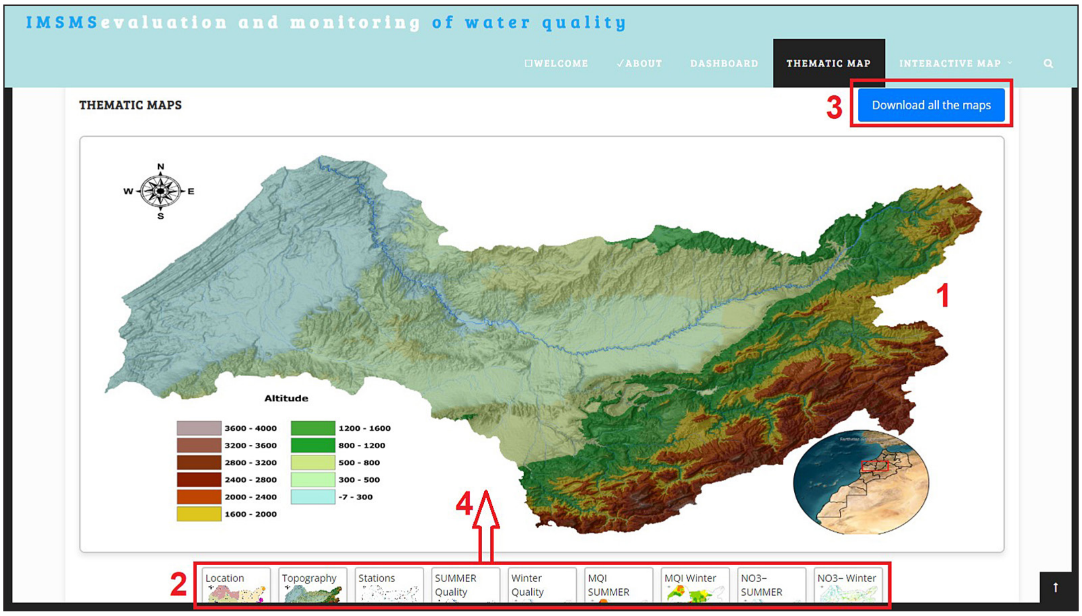

Figure 9. Representation of the "thematic maps module"

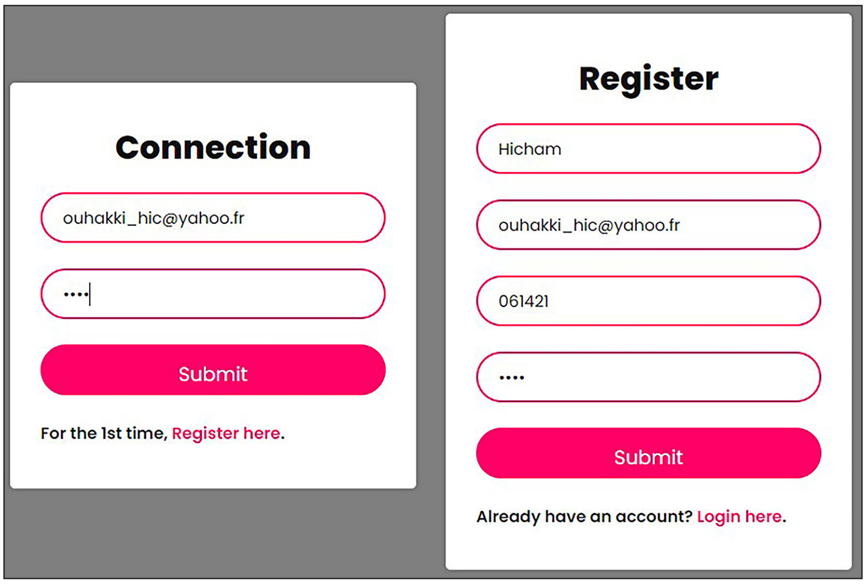

Figure 10. Secure access to the interface of the interactive maps module

clear labeling. This list of layers was designed based on the research's conceptual model to ensure it meets user needs and facilitates exploration of their questions. A toolbar positioned at the top of the map offers tools for user interaction – zoom in/out, printing functionalities, search options, a button to reset the zoom level, a layer manager, a report download option, and access to real-time precipitation and temperature data (Figure 12):

- The right panel: the list of maps with layers (more detailed information in Figure 12),
- The toolbar,
- The map,
- The logged in user.

Implementation of the IMSMS

The interactive multi-scale mapping system (IMSMS) is now operational online (Figure 13). After a rigorous initial configuration, the integration of data from multiple sources, the development of an intuitive user interface and exhaustive testing phases, the IMSMS offers users a reliable

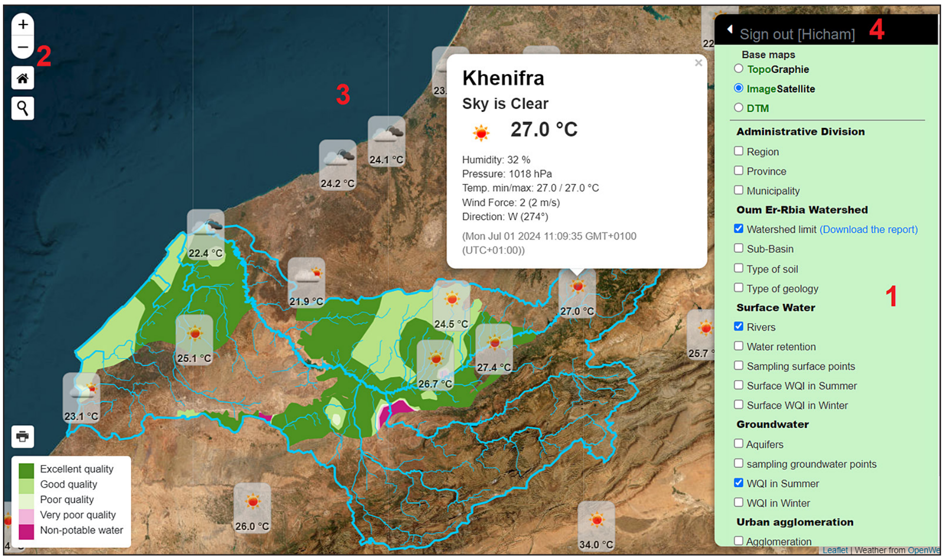

Figure 11. Representation of the "interactive maps module" for the allocation of the territory

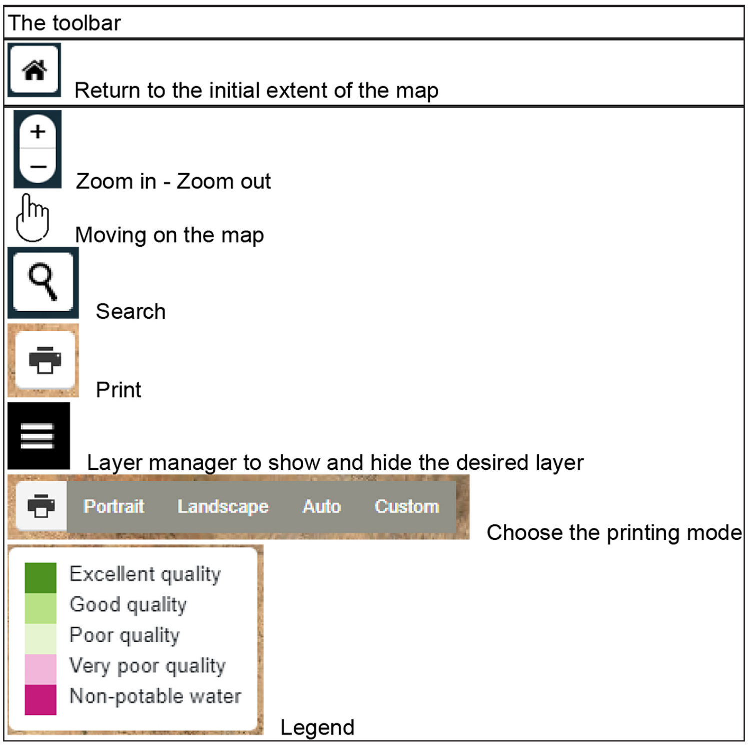

Figure 12. Toolbar positioned at the top of the map offers tools for user interaction

and interactive platform to visualize and analyze the geospatial data of the basin studied and meteorological. Thanks to continuous maintenance mechanisms, the system guarantees regular updating of information and optimal performance. In the next step, the research actors will verify the IMSMS. The system is currently available online at the following link: http://www.qwater.42web.io. Its final version will be distributed after consultation with all partners.

DISCUSSION

The study has demonstrated the effectiveness of interactive web-based GIS (Geographical Information System) in facilitating risk communication and public awareness campaigns. The developed web GIS platform offers a user-friendly and readily accessible interface, enabling the dissemination of critical information in a clear and comprehensible manner. This visual representation of risk data

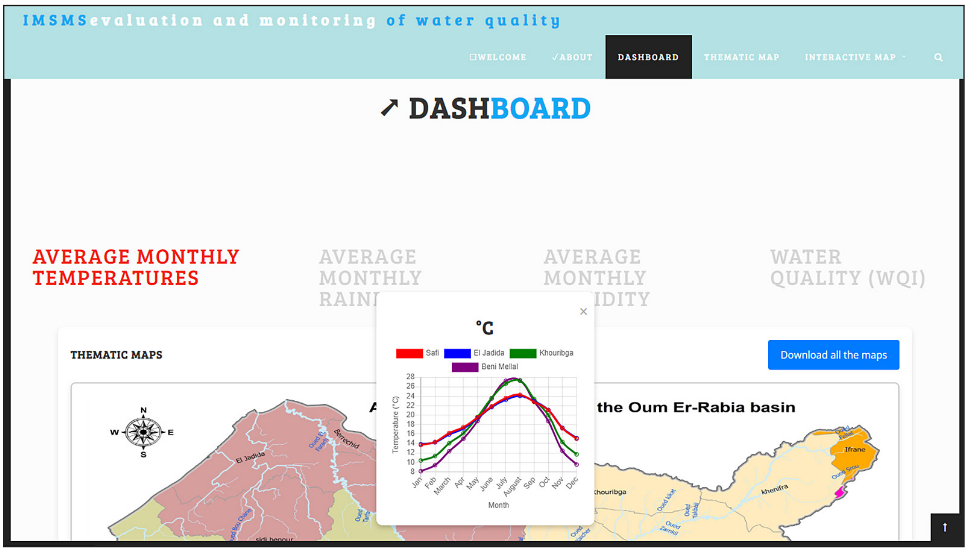

Figure 13. The IMSMS broadcast online

simplifies complex information, making it easily understandable to a wider audience. The implementation of the web GIS platform aligns with the principles of disaster risk reduction, which emphasize the importance of proactive measures to mitigate potential hazards. As highlighted by (Sharma and Mishra, 2017), the development of simple, cost-effective, and standardized risk mitigation strategies is crucial for building resilient communities. The web GIS platform serves as a valuable tool in this regard, empowering stakeholders to effectively manage and reduce flood risks within the Ouagadougou municipality (Kafando et al., 2024).

In the context of the Oum Er-Rbia watershed, the Multi-scale Interactive GIS Management System (IMSMS) stands out as a user-friendly tool tailored to the needs of territory managers. Its design aligns with the conventional dashboards utilized by these professionals, ensuring seamless integration into their workflows. The research's two primary objectives were successfully achieved:

1. Knowledge synthesis: The creation of a spatially referenced database effectively consolidated existing knowledge pertaining to groundwater and surface water resources in the study area.
2. Interactive cartographic system: The development of an online multi-scale interactive cartographic system facilitated the characterization and visualization of groundwater and surface water resources.

The realization of the first objective enabled stakeholders involved in groundwater and surface water management to effectively publish and disseminate their knowledge. Thematic cartography, encompassing a library of over 20 maps and interactive features, provided a comprehensive spatial representation of available information (Dodge et al., 2011; Slocum et al., 2022). Addressing the second objective involved

Table 4. List of maps with layers

Catégories	Layers
Base layer	Study Area (Oum Er-Rbia Watershed)
Base maps	Satellite image Topography Digital terrain model
Administrative division	Regions Provinces Municipalities
Boundaries of basins and sub-basins	Level 1 watershed Sub-basins of the Oum Er-Rbia River Sub-basins of the Oum Er-Rbia River South-West
Soil type	Soil type
Type of geology	Type of geology
Surface water	Rivers Dams Sampling surface points Index of surface water quality in summer Index of surface water quality in winter
Groundwater	Aquifers Groundwater sampling points Index of surface water quality in summer Index of surface water quality in winter
Urban Agglomeration	Agglomeration
Real weather	Current temperature Current rainfall

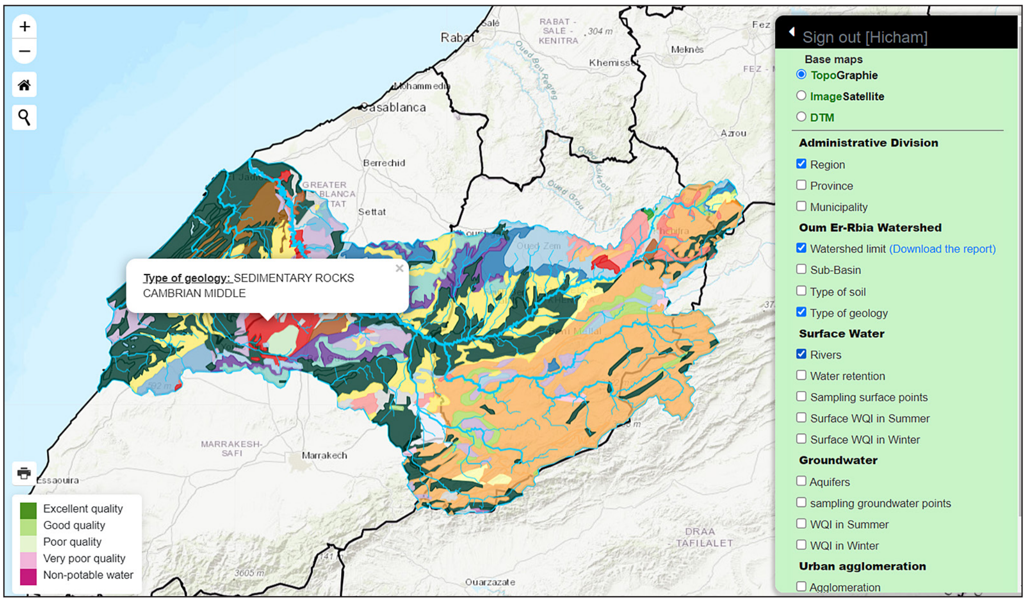

Figure 14. Map of the groundwater and surface water quality of the Oum Er-Rabia basin in the web environment

integrating the complexities of scale into groundwater and surface water management. The resulting user-friendly tool proved accessible even to managers without prior geospatial expertise. The IMSMS has proven to be an invaluable asset for stakeholders engaged in groundwater and surface water management. Its contributions are expected to significantly enhance the management plans for these resources. For groundwater and surface water experts, the tool facilitates rapid dissemination of their findings to a broader audience. Recent challenges related to drinking water quality have underscored the need for public authorities to provide accurate and timely information, further emphasizing the tool's significance in crisis management.

The research's primary focus was on information dissemination. The current solution enables geomaticians to update data on digital maps. Incorporating an administrative component would further enhance the platform's functionality. This would allow system administrators to update data through an online interface. However, such an addition would require additional analysis and development, potentially warranting a separate research research. The objective of this research research was to solve the challenge of disseminating the results of the research "Evaluation and monitoring of the quality of groundwater and surface water" through an IMSMS. This goal has been fully realized. All the maps produced within the framework of this research have been integrated into an online cartographic interface (Caquard, 2013; Cecconi, 2003; Smith, 2016). Once disseminated on the Internet, a wide audience of groundwater and surface water users in the studied region will have access to the results of the research in their respective geographical area. They will be able, for example, to obtain information on the quality of the water in their municipality. Therefore, they will be better informed about how their actions affect the quality and availability of water. The methodology used proved to be effective in developing a system for integrating spatial data relating to groundwater and surface water, as well as for visually disseminating the specific results of the research on the Internet. Thanks to this multi-scale approach, the IMSMS offers water stakeholders and local managers a regional vision of information and characteristics of groundwater and surface water.

The use of free and open source software in this research has proven to be an appropriate, efficient and economical choice. The prototype developed demonstrated that free and open technologies are just as efficient as commercial solutions to meet the requirements of the research and the expectations of the partners (Fig. 14).

It is recommended to continue the development of this tool for other watersheds as well as for surface water and groundwater studies. From the technological point of view, all the developed modules can be easily transferred to other study areas. The main challenge of this transfer lies in adapting to the specific data of each research, requiring an organization and a standardization of the data in a spatial database. Despite its strengths, the web GIS platform has certain limitations. The use of the Leaflet JavaScript library restricts the platform's capacity to handle large volumes of geospatial data. Rendering maps with numerous layers or extensive datasets can significantly slow down application performance. Additionally, data visualization is limited to 2D, precluding 3D cartographic visualization on the platform (Tabacaru et al., 2021). As noted by (Veenendaal et al., 2017), interactive maps can be constrained by server responsiveness to client requests. Nevertheless, these limitations can be mitigated by combining Leaflet with other mapping libraries.

CONCLUSIONS

The utilization of interactive web GIS platforms in this study enabled the creation of a free and interactive website encompassing all the requisite information for describing the water quality of the Oum Er-Rbia basin. This will facilitate enhanced risk communication, knowledge dissemination, and informed decision-making in the context of water resource management. The developed tools have proven to be valuable assets for stakeholders involved in flood risk mitigation and groundwater and surface water management. Further advancements in these tools, including the integration of 3D visualization capabilities and the optimization of large data handling, hold promise for even greater effectiveness in addressing water-related challenges.

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