PAPER

A Practical Approach of Data Visualization from Geographic Information Systems by Using Mobile Technologies

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ABSTRACT

The purpose of this paper is to demonstrate a practical approach to data visualization by using mobile technologies and desktop geographic information systems. To do that, we analyze public data for Black Sea water pollution on Varna's beaches by using real data in real time. Geographic information systems (GISs) are used for visualization, and statistical software is used for correlation analysis. In our approach, the use of open-source software products is essential, namely QGIS and PSPP software. The methodology includes using one dataset, and after extract-transform-load procedures, additional analysis is conducted. Mobile technologies are used to demonstrate the results of the correlation analysis to a wide audience, and data visualization helps for better understanding. A similar visualization approach may be conducted for other subjects and fields of interest.

KEYWORDS
mobile applications, data analysis, data visualization, geographic information systems (GISs)

1 INTRODUCTION

Geographic information systems (GISs) are designed to collect, store, retrieve, analyze, and visualize information related to spatial data. GIS-type systems provide different functionalities for creating dynamic maps, studying relationships between spatial objects, and analyzing territorial data for modeling, forecasting, and resource optimization. Primary data usually comes from various sources, and after their processing, new information is created and knowledge is extracted to aid in making informed and justified decisions in the context of the relevant subject area of application.

Geographic information systems-type systems improve various processes and decision-making in urban planning, transportation, environment, agriculture, ecology, and health. Hence, their application is not limited to only a narrow circle of

specialists in the field of geography or geology but is useful to architects, ecologists, farmers, and household users.

Historically, in first-generation GISs, spatial data was stored in simple "flat" files without a well-defined format. Second-generation GISs store part of the data in a relational database [1, 2, 3], while third-generation GIS data is stored and processed entirely in a relational database. Thus, we can conclude that the evolution of GISs is in the direction of fully integrating spatial data with a relational database (see Figure 1).
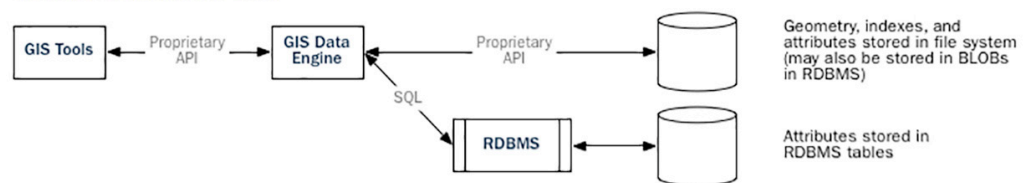
Fig. 1. Evolution of GIS architecture [4]

However, a significant problem is that the main data types in traditional relational database management systems are limited to integers and real numbers, fixed and variable-length character strings, date and time, binary large objects (BLOBs), and those similar that do not fully cover the needs of GISs. They usually work with spatial objects such as points, lines, and polygons, which include multiple components for representing the various spatial characteristics of the object (see Figure 2).
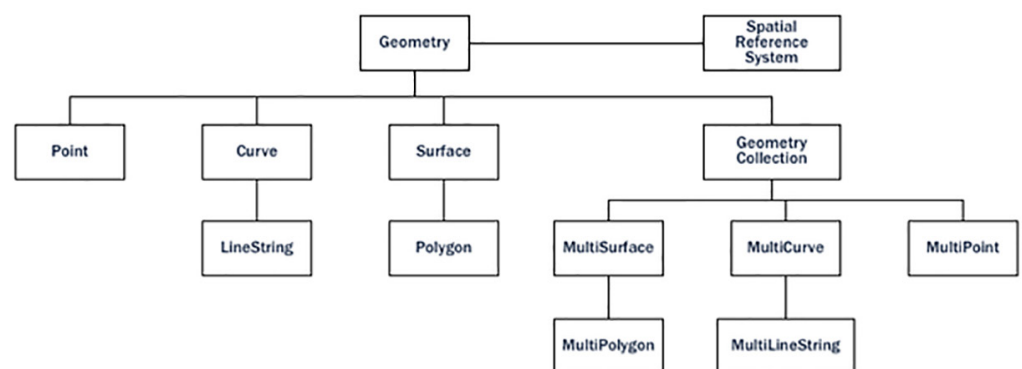
Fig. 2. Basic types of spatial objects and hierarchical dependencies [4]

Different approaches have been used to solve this problem in various relational database management systems, often by adding an additional program library as an extension to the main system. The syntax used when working with these extensions is often incompatible. For example, the approach applied to the Oracle Spatial [5] and Graph extensions to the Oracle Database cannot be applied directly to the SQLServerSpatialTools extension to Microsoft SQL Server [6].

Open-source projects have aimed to extend the capabilities of relational databases that are also open-source, for example, PostGIS. The PostGIS system builds on the capabilities of SQL for working with spatial objects as an extension of the PostgreSQL system [7]. The MySQL system natively supports most of the features of PostGIS (i.e., they can be used directly) [8]. Unfortunately, the MariaDB system, based on MySQL, does not currently support PostGIS features related to geohash encoding and decoding, specifically the functions ST_GeoHash, ST_LatFromGeoHash, ST_LongFromGeoHash, and ST_PointFromGeoHash [9].

PostGIS is a tool for processing spatial data in the popular relational database management systems MySQL and PostgreSQL. A key place in PostGIS is occupied by the program library liblwgeom [10] and, in connection with geohash coding, the file lwalgorithm.c. The library is open source and is therefore used in many other systems as well. For example, the SpatiaLite extension to SQLite uses the liblwgeom library [11].

2   METHODOLOGY

Public data from the Regional Health Inspection Varna (RHIV: https://www.rzi-varna.com/) is used with information about the water pollution of several of Varna's beaches in May, June, July, and August 2023 [12].

The RHIV provides data for the water pollution of Varna's beaches in tabular format, one table per beach. The columns are date (of the observation), indicator 1 ("Intestinal enterococci"), and indicator 2 ("Escherichia coli"). The following indicators, "Intestinal enterococci" and "Escherichia coli," are monitored and measured in MPN/100 cm^3. Levels below 15 are considered normal. The RHIV does not give values below 15. They are given as "less than 15." For data analysis, the value "7" is used. Six measurements are taken every two weeks (bi-monthly).

QGIS is used [13], and an OSM layer [14] is added to visualize Varna's Bay. A new vector layer is also added: "Water_pollution." QGIS has created relevant shape files with extensions: SHP (for the shape file), DBF (for the attribute tables), and PRJ (for the projections). The PSPP open-source statistics program is used to analyze correlations among the variables [15].

3   RESULTS AND DISCUSSION

Information from RHIV is entered in the data attributes table of the newly created layer "Water pollution" (see Table 1).

Table 1. Data attributes table of the newly created layer "Water pollution"

id	location	en1	en2	en3	en4	en5	en6	es1	es2	es3	es4	es5	es6
1	3rd buna beach	15	7	7	93	30	7	15	30	195	15	15	7
2	Officers' beach	15	7	77	15	93	126	15	7	94	209	127	287
3	Central beach	15	7	77	15	125	7	7	15	127	93	307	15
4	South beach	7	15	46	77	126	30	7	7	144	94	327	94
5	Asparuhovo beach	7	15	7	7	7	7	30	7	7	30	127	15
6	Veteran beach	7	7	7	15	61	7	7	7	7	7	30	7
7	Chernomorets beach	7	15	7	7	46	15	7	30	7	7	7	7

The variables en1, en2, ..., en6 point to six measurements of the indicator 1 ("Intestinal enterococci"), while the variables es1, es2, ..., es6 point to six measurements of the indicator 2 ("Escherichia coli") (see Figure 3).
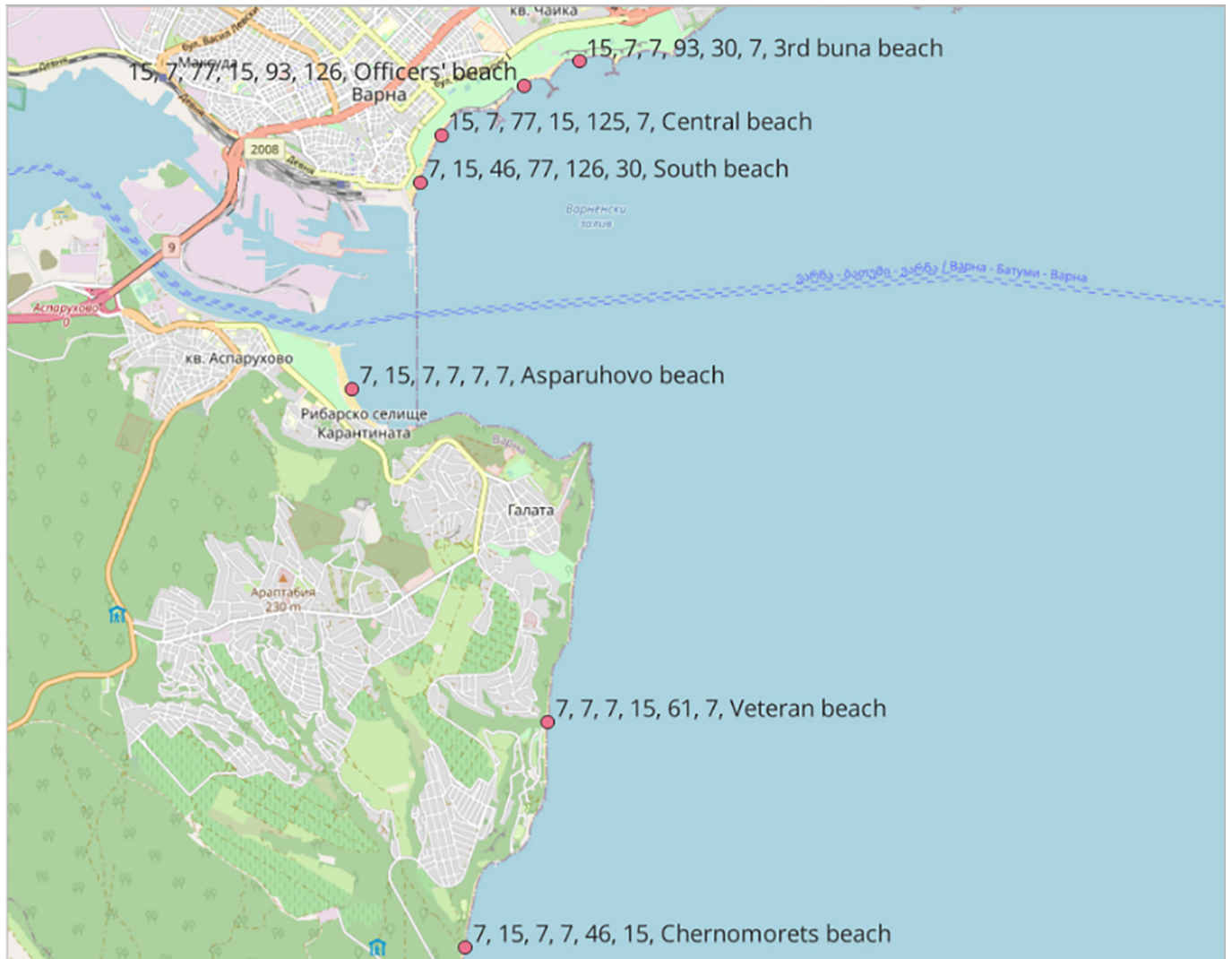

Fig. 3. Visualization of time series data for indicator 1 "Intestinal enterococci," Varna's beaches May-August 2023

QGIS allows the display of single labels. However, several values are visualized with the help of the concatenation function (see Figure 4).
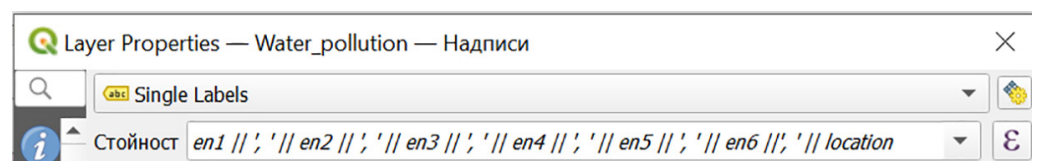

Fig. 4. Showing several values (time series values) for "Intestinal enterococci"

Similarly, the values for single labels are changed *("es1 || ', ' || es2 || ', ' || es3 || ', ' || es4 || ', ' || es5 || ', ' || es6 ||', ' || location")*. Time series data for the second indicator ("Escherichia coli") are visualized (see Figure 5).
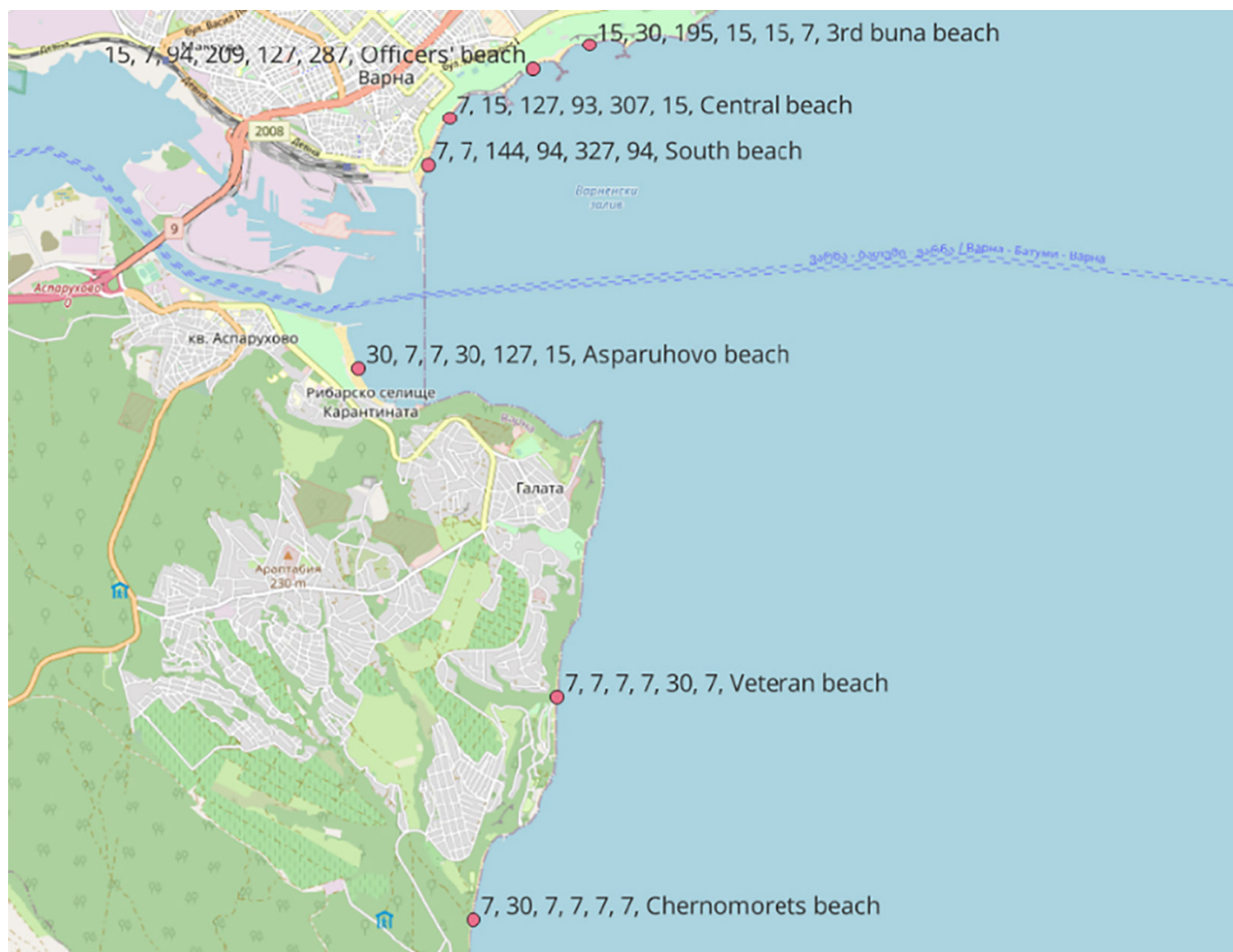
Fig. 5. Visualization of time series data for indicator "Escherichia coli," Varna's beaches May-August 2023

Table 2. Correlation analysis for water pollution in Varna Bay; May-August 2023 (dataset 1)

Variable 1	Variable 2	Formal Description	Explanation
en3	en5	$r = 0.825$, $p < 0.05$, $n = 7$	The values of "Intestinal enterococci" in the fifth period are positively correlated with the values in the third period. Possible lag effect in pollution.
es3	en4	$r = 0.820$, $p < 0.05$, $n = 7$	Ambiguous dependency; no meaningful explanation
en3	es4	$r = 0.885$, $p < 0.05$, $n = 7$	Ambiguous dependency; no meaningful explanation
es4	en6	$r = 0.891$, $p < 0.01$, $n = 7$	Ambiguous dependency; no meaningful explanation
es5	en5	$r = 0.784$, $p < 0.05$, $n = 7$	Same time period; Possible period of pollution
es6	en6	$r = 0.989$, $p < 0.01$, $n = 7$	Same time period; Possible period of pollution
es4	es6	$r = 0.925$, $p < 0.01$, $n = 7$	Possible lag effect after pollution with "Escherichia coli" in time period 4, visible in time period 6.

In all rows in Table 2 "n = 7," because there are 7 beaches which are included in the analysis.

The initial dataset used in QGIS (see Figure 1) is transposed to create time-series variables. Each variable had a certain beach and a specific indicator. A new dataset is created (dataset 2) with 14 variables (seven beaches multiplied by two indicators) and rows (six cases; six measurements in equal periods). The variables in dataset 2 are constructed as time-series variables (refer to Table 3).

Table 3. Creating dataset 2 using transpose

Location	3rd Buna Beach	Officers' Beach	Central Beach	South Beach	Aspar-Uhovo Beach	Veteran Beach	Cherno-Morets Beach
	b1_en	b2_en	b3_en	b4_en	b5_en	b6_en	b7_en
en1	15	15	15	7	7	7	7
en2	7	7	7	15	15	7	15
en3	7	77	77	46	7	7	7
en4	93	15	15	77	7	15	7
en5	30	93	125	126	7	61	46
en6	7	126	7	30	7	7	15
	b1_es	b2_es	b3_es	b4_es	b5_es	b6_es	b7_es
es1	15	15	7	7	30	7	7
es2	30	7	15	7	7	7	30
es3	195	94	127	144	7	7	7
es4	15	209	93	94	30	7	7
es5	15	127	307	327	127	30	7
es6	7	287	15	94	15	7	7

Dataset 2 is imported into PSPP, and correlation analysis is conducted (refer to Table 4).

Table 4. Correlation analysis for water pollution in Varna Bay; May-August 2023 (Dataset 2)

Variable 1	Variable 2	Formal Description	Explanation
b3_en	b6_en	$r = 0.816, p < 0.05, n = 6$	Beach 6 is situated to the south of beach 3. Water flows in the Black Sea move water from north to south, an expected correlation.
b4_en	b6_en	$r = 0.891, p < 0.05, n = 6$	Beach 6 is situated to the south of beach 4. Water flows in the Black Sea move water from north to south, an expected correlation.
b4_en	b4_es	$r = 0.918, p < 0.05, n = 6$	Possible pollution of beach 4 (South beach) with sewage water or water flows are moving contamination from north to south.
b6_en	b7_es	$r = 0.940, p < 0.01, n = 6$	Continuous contamination on neighbor beaches.
b6_en	b6_es	$r = 0.989, p < 0.01, n = 6$	Possible pollution of beach 6 (Veteran beach). Water flows are moving contamination from north to south. The wind moves sea water to the beach.
b3_es	b4_es	$r = 0.964, p < 0.01, n = 6$	Water flows are moving contamination from north to south.
	b5_es	$r = 0.868, p < 0.05, n = 6$	
	b6_es	$r = 0.905, p < 0.05, n = 6$	
b5_es	b6_es	$r = 0.974, p < 0.01, n = 6$	

In all rows in Table 4, "n = 6" because there are six measurements (six periods). Some statistically significant correlations were found in dataset 2, but they were not meaningful, so they are not included in the analysis.

4 HYBRID MOBILE APPLICATIONS FOR DATA GATHERING AND VISUALIZATION

Water pollution requires rapid and precise monitoring. Using mobile applications to capture data in real time eliminates the traditional delay associated with data acquisition and processing. By providing mechanisms for immediate capture and feedback, mobile applications ensure that the information accessed is the most recent and pertinent, allowing decision-makers to respond quickly and effectively.

Hybrid mobile technologies, which combine the benefits of native and web applications, offer promising avenues for the collection, visualization, and analysis of water pollution data in a timely manner. Hybrid mobile applications are built with web technologies such as HTML, CSS, JavaScript, and frameworks such as Ionic and then packaged in a native container for deployment (see Figure 6).

They offer several benefits [16, 17, 18]:

- Cross-platform deployment permits using a single codebase for Android and iOS.
- They avoid the need for distinct codebases and teams to save money.
- They offer access to device features: despite being web-based, the application provides access to device-specific features, such as a GPS, and camera.
- Updates are available without requiring users to obtain new versions from app stores.
- However, hybrid applications encounter obstacles such as:
- Reliance on web page views causes performance issues and delays in gaining access to the most recent native features.
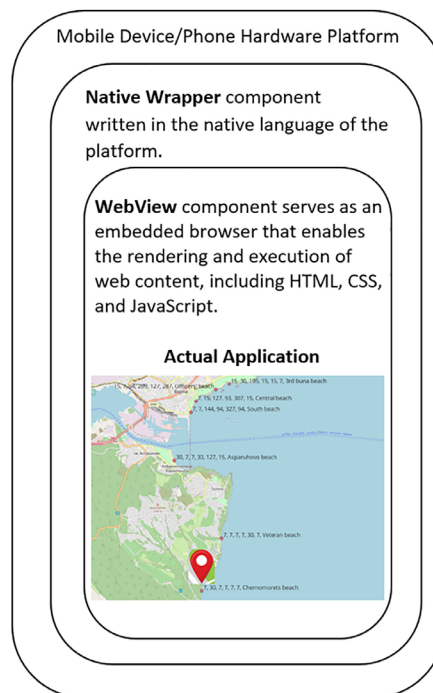- The hybrid nature of app stores results in extended approval times.

Fig. 6. Diagram of Native Wrapper and WebView core components in hybrid mobile app development strategy

In the realm of hybrid mobile apps developed for the purpose of data collection and visualization, it is crucial to clearly define the fundamental functional and non-functional needs. From a practical standpoint, it is essential for such applications to include a diverse array of data collection approaches. This encompasses the acquisition of data via user inputs, the use of device sensors such as cameras and GPS, the extraction of information from external databases, and the utilization of application programming interfaces (APIs). The use of an integrated method enables the collection of data in offline settings while also providing the ability to synchronize the gathered data once the Internet connection is reestablished. In addition, the use of dynamic visualization technologies is of great importance as it enables users to create and engage with diverse graphical depictions, including bar graphs, heat maps, and geographical mappings. The efficacy of this feature necessitates the reinforcement of secure user authentication procedures, including not only robust login methods but also role-based data access. To enhance user engagement, it is essential to have features that allow for the exportation of visualized data in various formats and facilitate sharing across many platforms. Additionally, the inclusion of push alerts and sophisticated search functionality is crucial.

However, in addition to these functional criteria, non-functional needs are arguably of equal importance. The performance criteria place emphasis on the implementation of a responsive design that can effectively adapt to different device dimensions. This design should facilitate efficient retrieval and presentation of data. The foundation of the user experience is usability, which prioritizes an intuitive user interface and ensures that users can navigate without encountering unnecessary complications. In the realm of security, it is essential to implement rigorous procedures that involve the secure management and transfer of data while also ensuring unwavering adherence to data privacy rules. The increasing amounts of data and user numbers have led to a heightened importance of the system's scalability. This necessitates the implementation of a modular design that is both durable and capable of expansion. The significance of maintaining a high level of application uptime highlights the need for availability, while the concept of interoperability guarantees compatibility across a wide range of device platforms and third-party integrations. In conclusion, the lifespan and adaptability of the application are guaranteed by its maintainability and offline capabilities, while its worldwide reach is enhanced by localization efforts. In conclusion, achieving success in the development of hybrid mobile apps for data-centric activities relies on maintaining a well-rounded emphasis on both functional and non-functional elements.

The application integrates with a GIS backend that provides visualization and analysis capabilities for geospatial data. Water quality information, including pollutant concentrations, is plotted on a dynamic map. Among the benefits are real-time insights, increased public awareness through data democratization, and scalability, including additional data sources and aquatic bodies. Concerns regarding data security and dependable integration with IoT devices are among the obstacles.

QField and Mergin Maps are instruments for collecting and visualizing geospatial data [19, 20]. Utilizing QGIS projects, QField is predominantly a mobile utility for visualizing and capturing geospatial data in the field. Mergin is a cloud-based infrastructure for geospatial data and project storage, synchronization, and collaboration. For a GIS workflow involving field data collection, one could design a project in QGIS, deploy it to the field using QField, and transfer and share the data using Mergin for collaboration or backup. Table 5 provides a comparative description to distinguish between the two.

<p align="center">**Table 5.** Comparison between QField and Mergin maps</p>

Mobile Geospatial Instrument	Indicator	Description
QField	Nature	Mobile GIS application for Android and iOS devices
	Main Use	Designed for data collection and visualization in the field. Allows users to collect geospatial data in the field using their QGIS initiatives.
	Key Features	Exploration and presentation of spatial data: editing and incorporating geospatial data; integration of GPS for positioning and monitoring; support for offline mapping for fieldwork without Internet connectivity.
	Integration	Compatible with QGIS projects the map or data collection project is designed in QGIS and transferred to QField for fieldwork.
Mergin Maps	Nature	Cloud-based platform for storing, sharing, and versioning of geospatial data. Supports mobile app for both Android and iOS.
	Main Use	Users can synchronize geospatial projects and data, facilitating collaboration and ensuring data is stored and version controlled.
	Key Features	Control of versions for geospatial data; capabilities for collaboration in real time; integration with QGIS using a plugin; provides a record of all modifications made to a dataset.
	Integration	Mergin is not a direct substitute for QField, but it complements it. QField allows users to capture data in the field, which is then synchronized with the Mergin platform for archiving, sharing, and collaboration. Mergin also integrates with QGIS, allowing users to synchronize projects and data between the desktop and cloud platforms.

Mobile apps provide a paradigm-shifting strategy in the endeavor to tackle water contamination concerns. Mobile apps provide stakeholders with many benefits. Firstly, they provide real-time data access, allowing users to get up-to-date information. Secondly, they offer geolocation services, enabling users to determine their precise position. Lastly, these programs allow users to report and monitor incidents of pollution while on the go. The immediacy and accessibility of these technologies significantly enhance efficiency, allowing for prompt reaction and intervention. In addition to this, cloud-based solutions have extensive storage capacities, facilitating the centralized storage, updating, and accessibility of substantial information pertaining to water quality, pollutant sources, and environmental consequences for all relevant stakeholders. The establishment of this consolidated data repository facilitates the advancement of joint research, enables informed policymaking, and promotes the cultivation of shared responsibility. In addition, the scalability of the cloud enables the system to effectively accommodate growing data quantities and user requirements. Moreover, the analytical tools integrated into the cloud have the capability to provide predictive insights pertaining to future areas of high pollution.

Nevertheless, the process of integration does present some problems. The preservation of data security continues to be of utmost importance, given that breaches or unauthorized access have the potential to compromise critical environmental data. The issue of data accuracy is also a matter of concern, as the decentralized nature of data input from several mobile sources poses significant challenges in verifying the authenticity of each data piece. Moreover, the presence of diverse degrees of technical literacy among stakeholders might provide obstacles to the adoption process. The complexity and lack of user-friendliness associated with these integrated systems may pose challenges for individuals, perhaps resulting in limited use or inaccurate reporting. Moreover, cloud systems provide the potential for continuous accessibility; nevertheless, their functionality is dependent on the availability of stable Internet connections, which may not always be assured, particularly in

geographically isolated or resource-limited areas. The integration of mobile apps and cloud-based platforms has significant advantages for addressing water pollution. However, stakeholders must effectively navigate and handle the associated hurdles in order to fully exploit the potential benefits.

An interesting approach for future work is the incorporation of geocoding through equal area tessellation [21] to speed up the processing of geographic data. Additionally, the adoption of a machine learning analytics framework [22] can provide a diverse array of insights.

5   CONCLUSIONS

The scientific study presents a practical approach to data visualization from geographic information systems by using mobile technologies. In this regard, we used real-time data on water contamination on several of Varna's beaches in the Black Sea region in the period May–August 2023, using GISs for visualization and statistical tools for correlation analysis. We demonstrated how the use of open-source software tools such as QGIS and PSPP aided in investigating water quality indicators and their potential interrelationships. In this way, a wide audience could more easily understand the complicated mechanisms of water contamination and its regional variations.

The study approach highlighted the growth of GIS architecture, from early flat file storage to spatial data integration with relational databases. The difficulties of expressing spatial items within ordinary relational databases were recognized, spurring the creation of extensions such as PostGIS to successfully overcome these restrictions. Furthermore, the article addressed the use of mobile GIS technology in the context of water contamination analysis. Integrating hybrid mobile applications with GIS backends improves real-time visualization and data collection and enables more efficient data collection, greater public awareness, and scalability for additional data sources.

The paper also discussed using field data collection and collaboration technologies such as QField and Mergin Maps, which integrate seamlessly with QGIS projects and cloud-based storage, simplifying data synchronization and boosting collaboration among researchers and professionals.

Similar assessments in other geographical areas and periods can be built upon the methodology and insights offered here.

6   ACKNOWLEDGMENT

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