Web-Based GIS Software and Database Tools for Water Resources Management

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ABSTRACT

Water is a precious natural resource that is in short supply. Thus, to ensure sustainable development, water resource management has become a critical component of global concern, particularly in arid and semi-arid countries. The field of open source GIS software has grown at a breakneck pace over the last few decades. This software quickly established a key and significant role in academic and applied research. The purpose of this study is to examine the characteristics and design of a Web GIS Platform for monitoring water resources in the study area to disseminate, exchange, and manage information via the internet. The platform-developed application demonstrates that by leveraging Open Source software and database tools, it is possible to create a flexible and interoperable tool for water resource management that provides critical information to decision-makers and interested stakeholders. The support tools, which will be built on open-source desktop GIS technology, will enable users to see, change, and display the geographic location on the map and conduct spatial query research.

Keywords: Geographic Information System, Water Resource Management, Open Source GIS Software, Iraq.

1. Introduction

Water resources are among the most important things in human life in dry areas. The Badiyah Al-Samawah is considered one of the areas with scarce rain in general. The floods were always a threat, and there was no interest in benefiting from the water [1]. Water Management is a challenge, especially in the developing part of the world, given limited access to the GIS technology, widely used in all stages of the water management cycle. These challenges will intensify unless effective and concerted actions are taken. These challenges call for innovative approaches, like Modelling, Remote sensing, Geographic information systems (GIS), Interoperability, Data models, Web services, Web-based GIS, and Mobile GIS, because of the dramatic change in water resource management that has occurred during the past few years [2]. This study examines the applicability of web-based open-source geographical information systems for sharing and distribution of data for water resource management and to develop Web GIS-based Spatial Decision Support Systems (SDSS) that will address specific water resource challenges and problems resource applications. Since the 1990s, various researchers have adopted Web GIS and Free Open Source Software (FOSS) approach for natural resource management, i.e., water resources, which gained popularity in recent years. Fletcher et al. [3] developed GIS for stream water management in West Virginia. Choi and Engel [4] have shown that geoprocessing via the web is possible by creating a web-based watershed delineation system. Their tool uses the University of Minnesota's Map-Server (University of Minnesota, 2006) as the backend engine. This map system obtains an outlet point from the user to begin the delineation process. Their implementation uses a "double-seed array-replacement algorithm to obtain a watershed boundary from point coordinates. Nowadays, GISs have revolutionized many aspects, especially with the advent of the Internet and Web. In Web GIS, the internet technologies are connected with GIS to take advantage of their special characteristics, such as easy usability, use the GIS data such as input, adjustment, manipulation, analysis, the output of geographical information, and bring out related services on the Internet [5]. Whereas previous standalone GISs had restricted application capability on the network, the Internet GIS makes it possible to retrieve and analyze spatial data through the web.

2. Study Area

The study area is located within the administrative boundaries of Al- Muthanna Governorate, west of Samawah city center, between longitudes (46.59 ° - 44.52 °) in the east and latitude (29.3 ° - 31.3 °) in the north, with an area of (46254.5) km2. It occupies three-quarters of the lands of the Al-Muthanna Governorate, which is equivalent to 89.38% of the total area of the governorate, which is 51,750 km2, and it includes desert and is not populated. It is bordered on the south by the Governorate of Basra and from the north and northwest by the Najaf Governorate [6]. The southwest and west borders form part of the international border between Iraq and the Kingdom of Saudi Arabia, as shown in Figure 1.

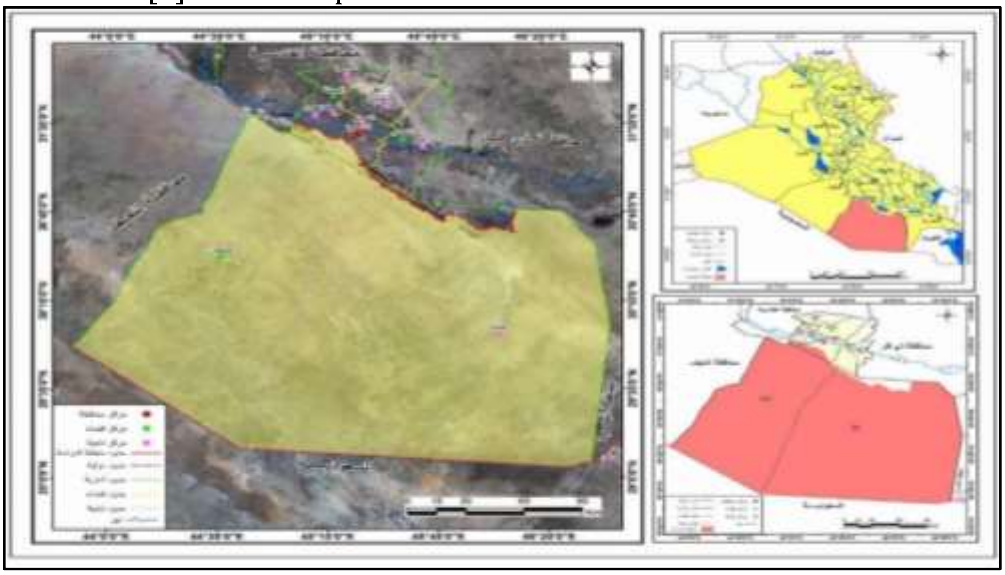

Figure 1. Study area.
Source: U.S. Geological Survey, Landsat 8: Satellite Imagery & DEM, Shuttle Radar Topography Mission (SRTM) 1 Arc Second Global, Endeavour, 2016

3. Methodology

The methodology of this research was based on desk research and the practical implementation of a prototype. The project was developed to combine the real-world experience of the water management community with academic knowledge by examining the information needs and technical considerations that influence the use of web-based GIS. The study of that experience helped the development of a framework for building a prototype based on the open-source web-based GIS and testing its applicability to the solution of problems associated with water management operations. The combination of the desk research and the building and testing of the prototype constituted an action-research-based strategy using one iteration only.

There would have been several iterations of this process in ideal circumstances with further refinement of the academic research and prototype system. However, the result obtained through the one iteration allowed carrying out a critical interpretation of the result and the development of a grounded theory based on the result and the obtained experience but constrained by the limitations of the research. Figure 2 depicts the adopted structure of the research, which also served as an implementation guideline.

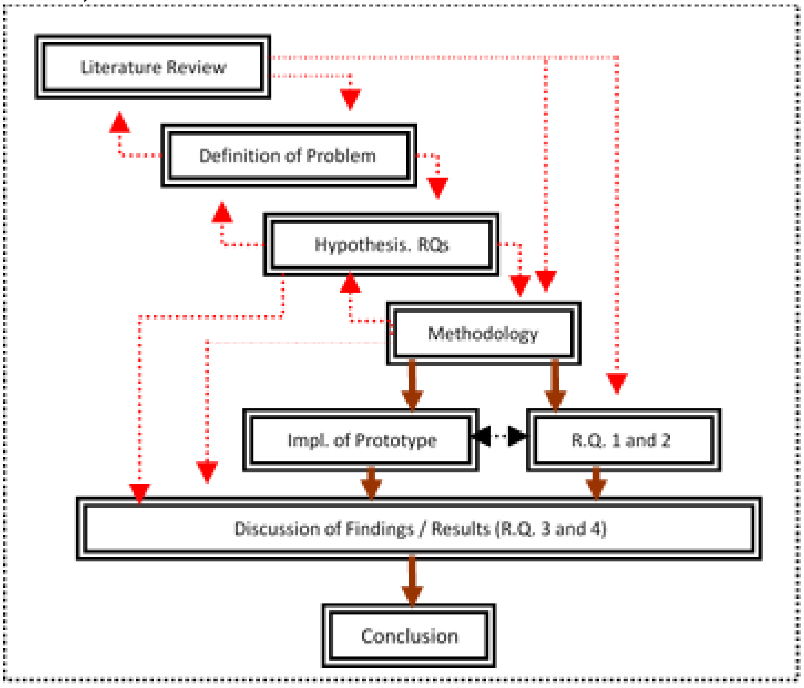

Figure. 2 The research structure

3.1. Desk Research

The review of the available literature supported answering research questions: what are the primary information needs for the water management, and what are the technical requirements from the user's perspective concerning access to geospatial information. The implementation of the prototype was a central theme of the research based on the use of open-source software. Therefore interviews and social surveys were not conducted, and the desk research was carried out as an alternative method. Equal weight was assigned to the sources of information, which were categorized into academic journals, technical literature, and web resources.

3.2. Implementation of Prototype

The methodology for prototype implementation was influenced by the findings of the desk research, the availability of open-source technology, and the feasibility of its implementation within the time limits of the research project. The implementation of the prototype's main purpose was to assess the applicability of an open-source web-based GIS solution for the distribution of geospatial data and maps in the internet environment, based on the standards and specifications developed by the Open Geospatial Consortium (OGC). Considering the scope and the purpose of research, the prototype concentrated on conceptual rather than a true representation of selected feature types and objects with a limited number of spatial and non-spatial attributes. To conform to the accepted practices in project planning and management, the framework for the design and implementation of the prototype was drawn from the methodologies set in Roger Tomlinson's 'Thinking About GIS' planning guidebook for managers [7, 8]. This allowed complying with the standard and systematic planning and implementation, substantiating the validity of the result and providing a reference framework for analysis of the findings.

1) Scope of the System

① *Data Needed in the GIS Database*

A list of required data for water management systems was identified and categorized, see Table 1.

Table 1

Commonly Used Features In Water Management System

Features		Spatial data type	Typical attributes
Infrastructure	Road	Polyline	Location, Name, Type, Number of lanes, Width, Surface, Speed limit.
	Communications	Polyline	Location, Type, Operator, Capacity.
	Water distribution networks	Polyline	Location, Description, Capacity, Service area, Operator
	Electricity supply network	Polyline	Location, Type, Operator.
	Fire services	Point	Location, Description.
	Hospitals	Point	Location, Name, Description, Capacity.
	Residential areas	Polygon	Location, Name, Description, Demographics, Amenities, Building material, Vulnerability
	Evacuation area	Polygon	Location, Description, area capacity, Amenities.

② Software

First -. Mapping Server

GeoServer supports the concept of Thin Client as all of the processing of the requests is carried out server-side, and the final output is generated and sent to the Client application. The software as well as the source-codes are freely available for download from the GeoServer project web site at http://geosever.sourceforge.net.

Second - Client Application and Web Server

The World Wide Web interface (Internet Explorer 6.0) and HTT as a client application and a web server. Both the web browser satisfied the main requirements for the Client application being wide popular applications running on top of the Internet infrastructure, the Open Geospatial Consortium (OGC) specifications in other words serving as the main ‘highway’ receiving requests, data retrieval and display. Both of the applications are widely used in mobile devices such as notebooks and PDAs for Internet connectivity and web-access.

Third - Back-end GIS Software

ArcGIS Desktop applications (ArcMap, ArcCatalog and ArcToolb) for input and processing of collected data and creation and editing later were incorporated into the database of the GeoServer.

③ Hardware

A local mobile machine, IBM T42 Personal Notebook was use server, with the GeoServer being installed on the local drive(processing power of the machine satisfied the high requirements server. The same machine also hosted the WWW Client application (IE 6.0 browser).

2) Data Model

In this step, once the required data for response phase of water management system has been identified, the data model that identifies the entities and their relationship were designed and required standards were developed. The selected feature types and attributes are listed below:

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① Selected Data Types (real-world)

(a) Streets.

- Spatial object type: Polyline.

- Spatial attributes: Position expressed by geographic coordinates.

- Non-Spatial attributes as following (Street ID, Name (street name),Type (main, secondary), Width (in meters),Number of lanes (from 1 to 8), Type of surface (asphalt, concrete, cobbles)).

(b) Building Clusters.

- Spatial type: Polygon.

- Spatial attributes: Position expressed by geographic coordinates.

- Non-Spatial attributes as following (Block ID, Type (main, secondary), Building types (residential, commercial, public), Building material (concrete, brick, wood, mixed), Vulnerability index (1=low, 2=moderate, 3=high), Level of damage (default value = 0) according to the (USGS, 2005)).

(c) Open Spaces.

- Spatial type: Polygon.

- Spatial attributes: Position expressed by geographic coordinates.

- Non-Spatial attributes as following (Block ID, Type (main, secondary), Building types (residential, commercial, public), Building material (concrete, brick, wood, mixed), Vulnerability index (1=low, 2=moderate, 3=high), Level of damage (default value = 0), allowed values from 1 to 2 according to the (USGS, 2005)).

(d) Standalone Objects of High Priority.

- Spatial type: Point.

- Spatial attributes: Position expressed by geographic coordinates.

- Non-Spatial attributes as following as (Object ID, Name, Type (residential, commercial, public), Number of stores, Building material, Comments (open text)).

② Selected Data Types (hypothetical)

(a) Street Blockages.

- Spatial type: Point.

- Spatial attributes: Position expressed by geographic coordinates.

- Non-Spatial attributes as following as (Blockage ID, Type (debris, cracks, vehicles), Status (static, fixing, opened)).

(b) Locations of Deployed Medical Facilities

- Spatial type: Point.

- Spatial attributes: Position expressed by geographic coordinates.

- Non-spatial attributes as following as (ID, Capacity (serving capacity), Number of served people (approx), Type (first aid, heavy injures)).

3) System Implementation

The practical implementation of the project consisted of the following steps (Figure 3):

① Data collection (GPS data, attribute data).

② Data processing and preparation of shape files.

③ Download, installation and configuration of GeoSever and associated modules.

④ Preparation of WFS and WMS requests (transaction and map requests).

⑤ Testing the prototype with WFS and WMS request.

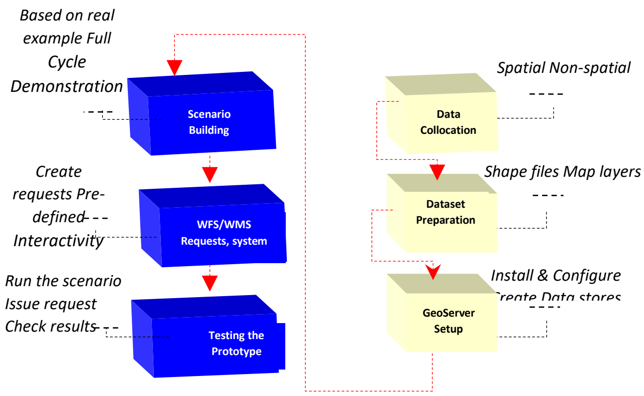

Fig. 3 System implementation.

3.3. Scenario Building

The scenario built for the case is based on a real-life experience of Map Action; this scenario includes mapping data on streets, building clusters, and objects from the GeoServer. The data is available for acquisition either through direct download in Shapefile format or through WMS requests with the graphical output in JPEG, PNG, BMP, or human-readable eXtensible Mark-up Language (XML) (text-based) format. Since the maps are delivered via HTTP protocol and displayed in web browser pages, the Web Mapping Services (WMS) requests can be issued from laptops or mobile devices such as PDAs equipped with the above Client application.

3.4. Constraint and Risk

The methodology development accounted for several constraints imposed by the restricted resources, primarily due to the limited time allocated for the research. Therefore, the project's scope was determined by the extent of time, required data collection, and the availability of the open-source software. The project was largely risk-free due to minimal reliance on the secondary data supplied by the external organization and reliable access to the electronic databases. The research carried out the data collection with GPS equipment with caution and avoided sensitive areas such as governmental and military offices in the covered area. In terms of technology, a moderate level of risk was present when choosing open-source software (GeoServer). However, the risk was mitigated by using the last stable release of GeoServer and justified by the purpose of this research to expose the software for practical application.

4. Results

The findings of the desk research and the results from the prototype tests allowed analyzing the applicability of open-source web-based GIS within a framework of information needs and technical considerations within a wider context of socio-economic implications. The results of the desk research on the identification of the information needs at a water management stage were classified into two categories such as the Information content, Presentation format, Data collection and processing, Data visualizations, Usability (HCI), Performance with the selected

Client (mobile) device, Standards, and Interoperability, and Information delivery mode.

The results were 'filtered' to extract the elements that have significant importance and are supported by the available literature and the opinions of water management. Accordingly, these results served as a reference point for analyzing and interpreting the prototype testing results.

5. Conclusions And Recommendation.

The prototype demonstrated that an open-source web-based GIS can be utilized for the specified purpose with certain limitations and is still subject to additional research and refinement. While it is clear that open-source web-based GIS has significant potential, it should be viewed as a complement to proprietary vendor solutions rather than a direct competitor. Additionally, GeoSever's compliance with standards, interoperability, and implementation of the Open Geospatial Consortium (OGC) specification makes it an effective platform for providing universal access to geospatial information. It is critical to recognize the importance of open-source software for the developing world, owing to its extremely low or near-zero cost. Given the developing world's socioeconomic constraints, such solutions could assist in bridging the digital gap by giving access to functional and interoperable GIS technology.

Due to the limits of open-source web-based GIS, it is advised to be used in conjunction with commercial applications. Additional research should be conducted to ascertain areas for improvement.

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