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Development of an open source Web GIS tool for Borehole Data Management and spatial Analysis: A case Study of Addis Ababa and surrounding Towns

Samuel Zewdu Mekonnen[1], Zemenu Addis Teklemedhin[*1], Ajanawu Fenta Getaneh[1], Tamene Hailu Debela[1] and Abebe Mekonen Abegaz[1]

[1]Ethiopian Water Technology Institute, Department of Research and Consulting, Addis Ababa, Ethiopia
*Corresponding Author: zemenuaddis1@gmail.com

Abstract

This paper has been addressed the key challenges of the management of the groundwater data by introducing the web based geographical information system framework for borehole information management. Traditionally, borehole data management in Addis Ababa and surrounding towns faces challenges in the data integrity, accessibility and utility across multiple sector. The conventional method involves paper records, spreadsheets and isolated database. This approach results in systems that are not user friendly, outdated information and error prone data that are not easily shared with users.The lack of geospatial capabilities in traditional systems further limits effective spatial analysis and decision making. This study addresses the challenges of managing fragmented groundwater data by developing a web based distributed data development system suing open source technologies including GeoServer, MapStore, PostGIS and QGIS. The system transform scattered well data into an accessible analytical resources through an integrated platform ensuring real time availability while maintaining data integrity through standard workflows. In the present study, verification using ground control points that have proven system spatial accuracy with average control error of less than 1.5 meters has been achieved. Geospatial well data can now be visualized and analyzed in depth with the implemented solution. Users can view well locations on interactive maps and perform necessary spatial analysis with the system. The implemented solutions provide comprehensive capabilities for visualized and analyzed geospatial well data. The systems allow users to visualize well locations on interactive maps, extract detailed information and perform necessary spatial analysis. The platform demonstrates how web-based GIS technologies can be effectively integrated to manage essential groundwater information. The study represent a significant change from stand alone GIS to open access web GIS service which offers greater opportunity for sustainable solutions in water resource management and planning. The developed system eliminates the redundancy and inconsistency common in traditional approaches making spatial information easily accessible across enterprises at low cost to the users. In the geological, environmental and construction industries the web based platform provides a foundation for evidence based collaboration and improved decision making.The role of the systems in the supporting sustainable water resource management through advanced spatial data and broad stakeholder engagement has be a major focus of the future work.

Keywords: Addis Ababa; Borehole management; Free open source; QGIS; GeoServer; Web Based

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1. INTRODUCTION

Sustainable groundwater management is key in rapidly urbanized regions such as Addis Ababa where groundwater supports municipalities, agriculture and industries accordingly (Haile et al. 2023). While effective water management relies on systematic well data acquisition, storage and dissemination, the current practices suffer from fragmentation, inconsistent data format and poor accessibility. The scattering of data across multiple institutions impedes holistic groundwater assessment and informed decision making.

With the rapid water management modern approaches, use geographic information system, remote sensing and web services are essential (Verma et al. 2012). The growth of internet and the public demand for web mapping application drive geospatial information. Web GIS is particularly transformative because it makes easier to analyze and share geographic information over the internet overcoming the limitations of the stand alone systems (Singh and Sigh, 2014). It provides a comprehensive view of the solutions.

Its main strength lies on the rapid publication and sharing of diverse geospatial data to accelerate decision making. This study has been creating a comprehensive borehole information development systems that addresses the lack of research on web GIS applications for borehole data management in Ethiopia. This integrated web platform includes a fully open PostGIS repository for central data management, GeoServer for publishing Spatial borehole data into an accessible analytical resource that enables spatial analysis the real time data access and shared decision making. The novelty of this work lies on providing a practical integrated and scalable open source framework that provides a practical integrated and scalable open source solution tailored to the critical urban water security challenges in Addis Ababa Region and the surrounding towns.

2. MATERIAL AND METHODS

2.1. Description of the study area

The study area is found in Addis Ababa and surrounding Oromia special zone. The geographical coordinates of the region are 8°56’N to 9°32’N latitude and 38°25’E to 39°07’E longitude with a total area of 5444 sq.km (Figure 1). It focuses on the Addis Ababa city and the surrounding areas (six Oromia Special Zone districts). The surrounding towns such as, Burayu, Welemera, Sululta, Sebeta, Akaki, Berehe and Dukem-Gelan are are getting more urbanized. The city borehole data management is insufficient. A complete system that covers the surrounding areas must therefore be established since the demand for water is high and there is poor borehole data management.

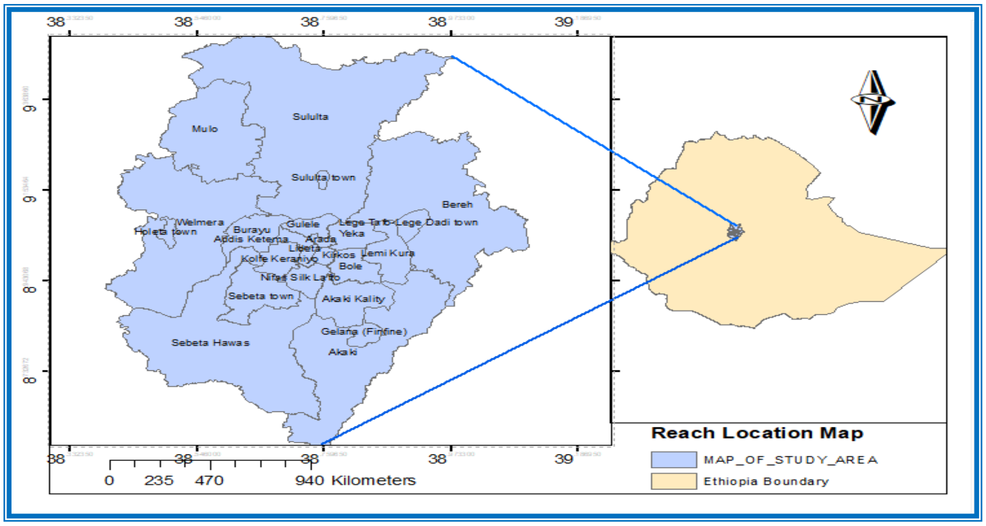

Figure 1: Location map of the study area

2.2. Methodology

The borehole information development system was established as integrated workflow to transform divers borehole datasets into an interactive web based spatial decision support platform. The borehole data were collected from multiple governmental and utilities source including the ministry of water and energy, Addis Ababa water supply and sewerage Authority and surrounding town offices. The collected datasets includes critical attributes such as geographic coordinates, drilling depth, water quality parameters and geographical formation characteristics .

The raw data quality checking was undertaken in detail during the pre-processing stages using the QGIS since the data was sourced from various institutions. This included systematic error detection and correction handling, filling in missing values, eliminating duplicates and standardizing the data into consistent formats like shape file and GeoJSON. The foundational spatial operations including buffering and proximity analysis were also executed to enhance spatial readiness and support advanced querying and visualization. The quality validation procedures ensured data accuracy and integrity throughout the pre-processing stage. Processed datasets were stored in a PostGIS enabled PostgreSQL database which is served as a centralized responsibility. A Customized database scheme was implemented to efficiently manage geometric coordinates, thematic attributes metadata and spatial indexes. Complex spatial queries were run directly within the database environment employing a strategy which kept redundancy to minimum and ensured data integration. To provide web based access and interoperability of the data, GeoServer was utilized to publish the spatial database as standard complaint web services including web map service for visualization and web features for querying and editing. This configuration allowed seamless integration with various client application and remote accessibility of spatial information. The MapStore web frameworks was used to develop an interactive user centiric translation which is fully integrated with GeoServer services. The interfaces provide intuitive navigation tools by zooming and panning advanced querying capacity and effective visualization of the borehole database enabling users to perform spatial analysis and derive actionable insights. A comprehensive maintenance and update protocol was implemented to ensure systems sustainability relevance. This include routine database updates with new data entries system backups, performance operations security monitoring and continuous engagement with stakeholders operations and iterative improvement. While initially intended for Addis Ababa and the towns, the systems architecture was built with scalability in mind allowing for additional data in the future (Figure 2). Figure 2 shows the overall methodological workflow which is illustrated additional data integration and system reconfiguration.

Figure 2 : Methodological workflow for the Borehole Information Development System (BIDS)

2.3. Data Collection Methods

To achieve the objective of this research, primary data were collected using GPS by individual members of the data collection team capturing ground control points across selected sample sites within the study area. The secondary data included borehole information, administrative boundaries of Addis Ababa and the surrounding area, world street map data and digital elevation models obtained from relevant governmental and institutional sources. Additionally, previous reports of scientific journals and textbooks were used. And online resources were consulted to supplement and validate the secondary data.

2.4. Materials Used

The following tools and technologies were employed for system implementation:

QGIS: For data pre-processing, cleaning, and spatial analysis.

PostgreSQL/PostGIS: For centralized, spatially-enabled data storage.

GeoServer: For publishing spatial data as web services.

MapStore: For developing the interactive web mapping interface.

Apache Tomcat: As the web server for hosting the application.

2.5. Data Analysis: Organizing and Verifying Borehole Data

The purpose of data verification is to ensure the collected data are as accurate as possible and to minimize human and instrument errors, including those arising during data processing. Data verification can be described simply as the process of checking data for accuracy. There are two main types of data verification: full verification, in which all data contained in a database are checked for accuracy, and sampling verification, which involves checking a small sample of the data.

2.5.1. Statistical Analysis and Data Quality Test

During data collection, a total of 1144 borehole data were collected from the concerned governmental bodies and the following are summary and analysis of data quality test. The results of this test are summarized in Table 1.

Table 1: Summary of data quality tests for collected borehole parameters

Characteristics of the data	Elevation	Well depth	Static WT	Discharge	Draw_Down	Specific_y	Transmissi
Missing error	65	38	349	316	690	780	680
Missing%	6%	3.30%	31%	28%	60%	68%	60%

As shown in Figure 3, the data quality test reveals significant issues with missing information across key borehole locations. The percentage of missing data is notably high for critical well characteristics, particularly for discharge and specific yield, which show missing data rates of 28% and 68%, respectively. Other parameters such as draw-down and static-water level also exhibited substantial missing data, reaching about 60 % and 31%, respectively. Well depth is the most complete field data with only 3.3% missing values in the data collected. Furthermore, carrying error with a coefficient of determination (R^2) value of 0.87 indicates a strong correlation and potential systematic error in the data collection or recording process. These observations highlight the need for data clearing and validation before any robust hydrogeological analysis can be reliably reformed. Primary limitations of this study is the incomplete nature of the available dataset. As can be seen in Table 1, the records did not include significant amount of crucial information such as the static water level and well depth. This data gap necessarily constrained the depth of analysis preventing a comprehensive assessment of the aquifer state. In order to make decision about sustainable management and more accurate hydrological modeling, future efforts must prioritize the systematic collection and reporting of these fundamental groundwater inventory data. The comparison of recorded and verified coordinates using linear regression analysis showed a strong positive correlation (R^2 =0.87). This indicates that about 87% of the variability in the verified locations can be explained by the recorded measurements (Figure 3). The strong, consistent linear relationship supports the hypothesis that a systematic error such as a datum or calibration miscalculation occurred during initial data collection, rather than the the occurrence of random noise. The remaining 13% of unexplained variance might have happened due to minor random measurement errors.

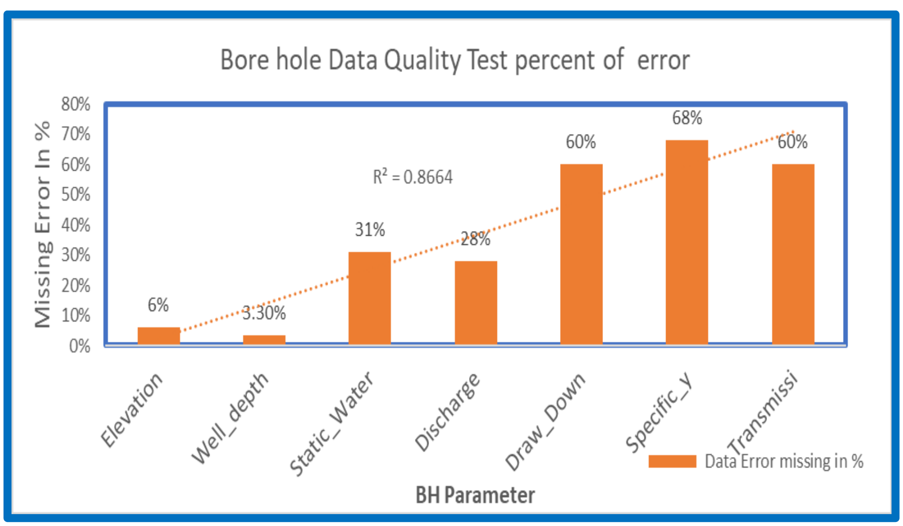

Figure 3: Graphical Representation of the Missing data for Key borehole parameters

2.5.2. Ground Control Point Data Verification

Ground control points were collected through GPS field survey for 18 selected borehole sites in the Addis Ababa and Oromia regions to verify the borehole database spatial accuracy. These verification points cover five major towns in the study area as shown in Table 2, providing comprehensive geographic coverage for accuracy evaluation. The control points were used to precisely align the records in the borehole database during the field verification process. This spatial consistency between field collected GPS data and existing borehole locations demonstrate high positional accuracy within the system establishing reliable Geo-reference for subsequent spatial analysis and decision-making application.

Table 2:Ground control points coordinate used for spatial validation

No	Region	Local Name	Water Point	X (m)	Y (m)	Z (m)
1	AA	AAWSA/Kotebe Kara	AdBh0855	484190	998500	2480
2	AA	AA-Jehova Witness Kotebe Well No.1	AdBh0978	483350	999064	2487
3	AA	AAWSA F7 at Koye	AdBh1068	481337	982304	2190
4	AA	S Ayat	SANFTW-3	481012	984597	2192
5	AA	Kotebe S/Vocational Training No.3	AdBh1030	481878	1000148	2546
6	AA	AA-Water III Testwell-B11	AdBh0759	466200	988800	2246
7	AA	Akaki Utility Factory-5	AdBh0497	477232	978999	2070
8	AA	AA-Artificial Insemination	AdBh0719	475300	983800	2120
9	AA	AA-Water III BoreholBH19	AdBh0789	478019	977985	2070.2
10	AA	Akaki	SWAWF2	475697	979915	2055
11	Oromia	Sululta Depot	AdBh1059	472975	1011144	2650
12	Oromia	Dukem NOC	AdBh0037	480641	977009	2121
13	Oromia	Dukem MBI	AdBh0038	483567	976037	2133
14	Oromia	Sebeta-Aztoki Imp	AdBh0039	463635	988675	2296
15	Oromia	Burayu	Well1	466306	1000367	2490
16	Oromia	Sebeta	BH1	473767	1003324	2614
17	Oromia	Burayu	Well 2	464042	1002650	2556
18	Oromia	Burayu	Well 3	457294	1001268	2628

2.5.3. Quantitative Analysis of Ground Control Point (GCP) Verification

This study assessed the positional accuracy of borehole coordinates by comparing it with field measured Ground Control Points (GCP) against high accuracy reference value. The sample datasets correspond to realistic validation conditions, with errors ranging from 0.1 to 1.5 meters, indicating common uncertainties associated with GNSS limitations. Additional challenges included point identification issues and observed measurement variability during borehole site surveys. Table 3 shows the details of recorded and verified data point values.

Table 3: Quantitative Analysis of Ground Control Point (GCP) Verification

No	Region	Local Name	Water Point	X (m)	Verified X (m)	ΔX (m)	Y (m)	Verified Y (m)	ΔY (m)
1	AA	AAWSA/Kotebe Kara	AdBh0855	484190	484189.2	0.2	998500	998500.2	-0.2
2	AA	AA-Jehova Witness Kotebe Well No.1	AdBh0978	483350	483349.7	0.3	999064	999063.9	0.1
3	AA	AAWSA F7 at Koye	AdBh1068	481337	481336.5	0.5	982304	982303.2	0.8
4	AA	S Ayat	SANFT W-3	481012	481011.1	0.9	984597	984596.3	0.7
5	AA	Kotebe S/ Vocational Training No.3	AdBh1030	481878	481876.2	1.4	1000148	1000149.3	-1.3
6	AA	AA-Water III Testwell-B11	AdBh0759	466200	466199	1	988800	988801.2	-1.2
7	AA	Akaki Utility Factory-5	AdBh0497	477232	477231.3	0.7	978999	978998.5	0.5
8	AA	AA-Artificial Insemination	AdBh0719	475300	475299.5	0.5	983800	983801	-1
9	AA	AA-Water III BoreholBH19	AdBh0789	478019	478018	1	977985	977984.2	0.8
10	AA	Akaki	SWAW F2	475697	475696.4	0.6	979915	979914.7	0.3
11	Oromia	Sululta Depot	AdBh1059	472975	472975.5	1.5	1011144	1011145.5	-1.5
12	Oromia	Dukem NOC	AdBh0037	480641	480640.5	0.5	977009	977008.3	0.7
13	Oromia	Dukem MBI	AdBh0038	483567	483566.2	0.8	976037	976036	1
14	Oromia	Sebeta-Aztoki Imp	AdBh0039	463635	463634	1	988675	988674.2	0.8
15	Oromia	Burayu	Well1	466306	466305.3	0.7	1000367	1000366.5	0.5
16	Oromia	Sebeta	BH1	473767	473765.9	1.1	1003324	1003322.8	1.2
17	Oromia	Burayu	Well 2	464042	464040.5	1.5	1002650	1002649	1
18	Oromia	Burayu	Well 3	457294	457292.5	1.5	1001268	1001267.5	0.5

The GCP verification analysis showed coordinate discrepancies between the database and verified values, with errors in the X direction spanning from 0.2 m to 1.5 m and errors in the Y direction ranging from 0.1 m to 1.5 m. These discrepancies indicate the presence of both systematic and random inaccuracies in the original data collection. The possible sources of these errors include: 1. Poor initial survey in which a hand held GPS with 2-5 m accuracy was used in original data collection; 2. Coordinate system misapplication that might have used Adindan UTM Vs WGS 84 UTM or local grid not properly transformed ; 3. Reference point errors arising from erroneous initial coordinates, which then propagated through the survey via relative measurements as systematic errors; 4 Field logging mistake that involve transposition of digital (e.g. 484190 Vs 484189.2) and rounding errors during data entry and 5. satellite Geometry issue which emanates from multi-path effects or poor visibility during original GPS surveys in built-up area. The validation outcome included mean of ΔX= 0.86 m (Std Dev: ±0.41 m) and mean of ΔY= 0.76 m (Std Dev: ±0.40 m). Overall the Mean Positional Error was 0.81 m. The largest error was observed at Sululta Depot with ΔX=1.5 m, ΔY=-1.5 m and Burayu Well 2 with ΔX=1.5 m.

2.6. Spatial Database Design

A spatial database was designed and created to provide all spatial layers (via WFS links) and enable automatic updates. The combination of four software components such as QGIS, PostGIS, GeoServer, and Apache Tomcat was used to achieve this. The vector data were stored in PostGIS database which provides a structured data storage environment. QGIS software was used to import the data into the database, which was afterwards connected to GeoServer. Data services were then published through GeoServer, and the GeoJSON service was integrated into the WebGIS application script.

2.7. Installation and Configuration of Open-Source Software

The development of the Borehole information Development system was built upon an integrated open source software stack. The cost effectiveness, interoperability and solid support for geospatial data standards influence the choice of this architecture. The three tier architectures of the system which includes the database, application and client layers in each component play a distinct and key role. The specific software tools, their versions and primary functions in this study are detailed in Table 4.

Table 4: Core software stack for the Web-GIS implementation

Core software version use for the Web-GIS implementation		
Software	Version	Primary Role in this Study
QGIS	3.4	Data pre-processing, cleaning, and spatial analysis
PostgreSQL / PostGIS	16 / 3.4	Centralized, spatially-enabled data storage and management
GeoServer	2.21	Publishing spatial data as WMS/WFS web services
MapStore	2024.01	Developing the interactive web mapping client interface
Apache Tomcat	11	Application server for hosting GeoServer and MapStore

The conceptual Framework of the system is built on a modular three tier architecture that separate data management application logic and user presentations. This structure is illustrated in Figure 4 which ensures scalable and efficient data flow from source database to the end users of web browser. The architectural framework ensures seamless data flow from source materials through database storage to final visualization enabling efficient spatial data management and accessibility for diverse users.

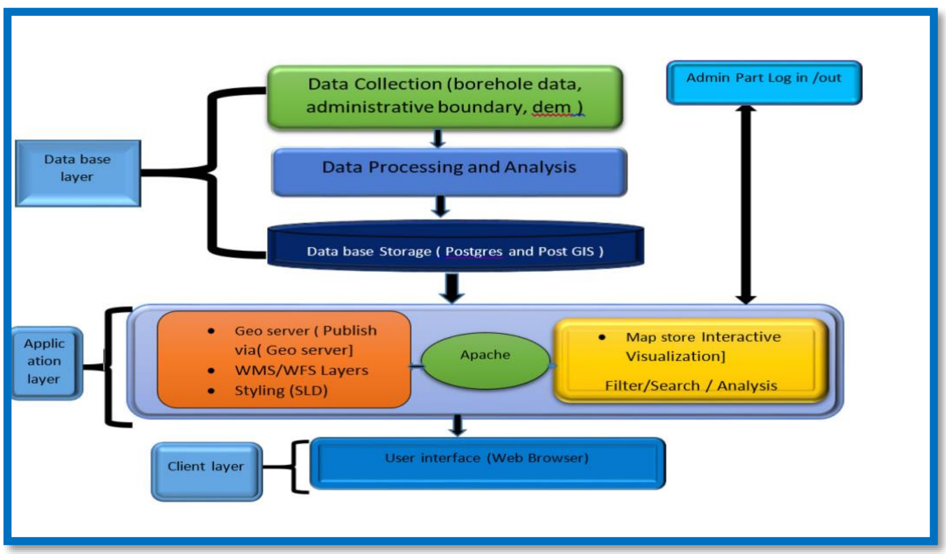

Figure 4: The three-tier software architecture of the web-based borehole information systems

3. RESULTS AND DISCUSION

3.1. Demonstration of the Spatial Analysis of Borehole

The spatial analysis of the identification of optimal borehole locations and assessment for groundwater availability was done using QGIS. Results show that boreholes concentrate in central, northern, and southeastern areas within the elevation bands of 1500-2000m, 2100-2300m, 2400-2500m, 2600-2800m, and 2900-3300m (Figure 5). The location of Valley areas (1500-2000m) serve as prime drilling targets, consistent with productive aquifers in the Central Rift Valley (Berhanu et al., 2022). Mid-elevation sites (2100-2800m) indicate expansion of fragmented aquifers, while high-elevation zones (2900-3300m) likely act as recharge areas. A strategic plan for planning sustainable water security necessitates exploratory drilling to close the data in western portion of the study area.

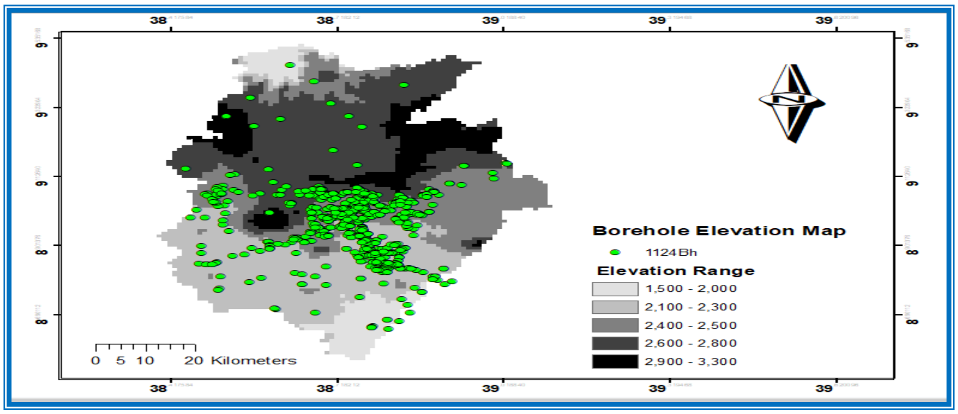

Figure 5: The spatial data distribution of the borehole across elevation zones in the studies area

3.2. Identification of shallow and deep wells

A total of 1125 borehole analyzed on the elevation ranges of (1456 - 3 431), 822 (73 %) are deep wells and 303 (26.9%) are shallow wells (Figure 6), showing groundwater is predominately deep-seated especially at higher elevations. This pattern matches with the main Ethiopia rift valley where deep aquifers are primarily characterized by salinity (Tamiru, 2021). The Shallow wells are limited to lowlands revealing complex aquifers with slow flow. These findings highlight the need to protect high elevation recharge zones and implement sustainable managements practices for deep aquifers with slow flow. The protection of high-elevation recharge zones is essential to implement sustainable management practices for deep aquifers.

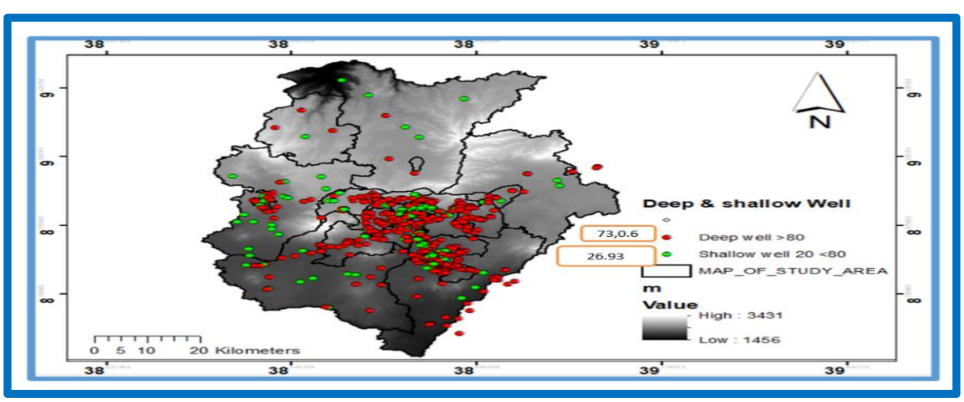

Figure 6: Shallow and deep wells

3.3. Spatial analysis of borehole-to-borehole distances

In study area, the borehole distribution shows great clustering, with nearly two-third of them located within 5 kilometers, reflecting zones of high-water demand, a pattern consistent with African urban corridors (World Bank, 2023). On the far side of these clusters, the well distribution is becoming more dispersed with 22% spaced four to thirteen kilometers apart indicating less clustering. Remotely located wells are situated thirteen to twenty-seven kilometers apart and rare frontiers beyond twenty-seven kilometers. This spatial pattern is also linked to topography varying from 1456 to over 3431 meters. Figure 7 highlights clustered well locations attributed to valleys and vast mountain gaps, directing future exploration areas for equitable water use planning.

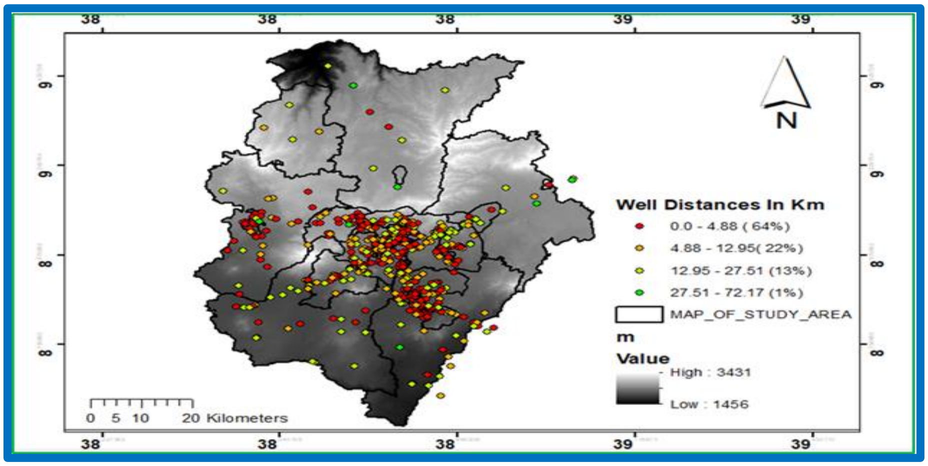

Figure 7: Spatial analysis of borehole-to-borehole distances

3.4. Calculated groundwater level

The groundwater ranges from 1 to over 500 meters deep showing a clear pattern for shallow water levels and deep wells. The shallow wells (1–28 meter) are sparsely located in study area suggesting recharge zones while deep wells (28-500m) are located mainly in central area study site suggesting more water demand and aquifer penetration attributed to major urban centers (Figure 8). These shallow and deep wells periphery align with Awash Basin findings of urban water table depression (Alemayehu et al., 2023). The extreme peripheral depths indicate severe depletion from historical extraction revealing stressed aquifer system. The map shows protections of central aquifers and managed extraction to present further deepening.

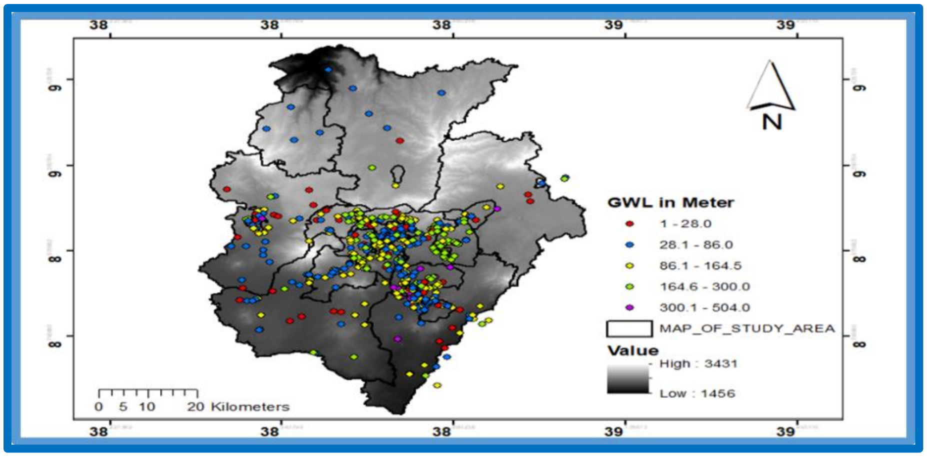

Figure 8. Figure 8: Interpolated groundwater level depths across the study area

3.5. Centralized Data Management

The regional groundwater mapping indicates that storing borehole data in a PostGIS spatial database facilitated organized management and efficient spatial querying. As illustrated in Figure 9, the PostGIS setup, along with shape files imported through QGIS, enabled streamlined creation and management of the SQL/PostGIS database via its plugin, providing an effective method for handling environmental data (Kumar and Patel, 2024). All PostGIS functions were accessed using PgAdmin and the QGIS DB Manager. This open-source approach supports sustainable hydrogeological data management practices (World Bank, 2023).

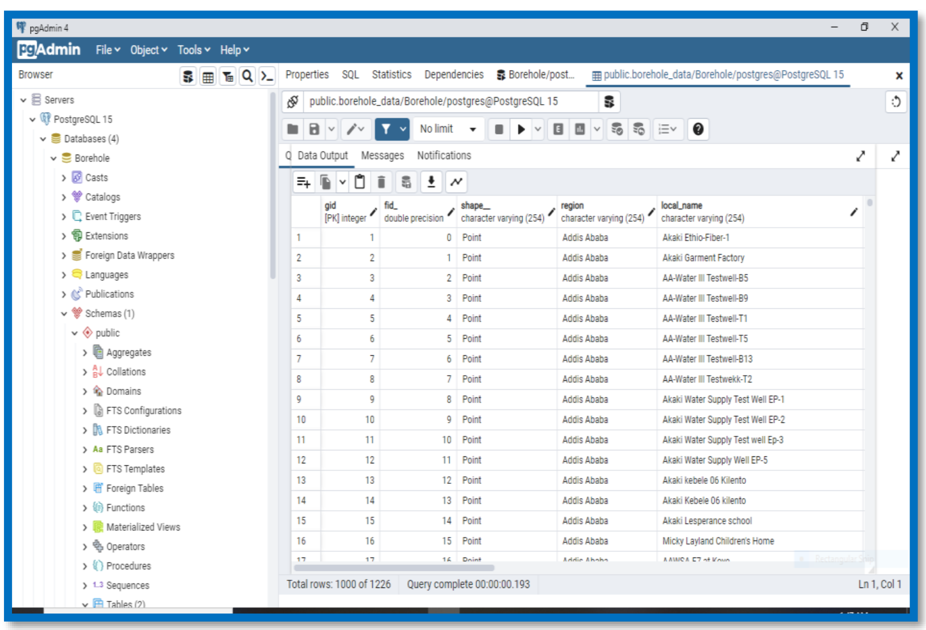

Figure 9: the viewed of borehole attribute data within The PostGIS database management system

3.6. Interactive Data Visualization

An interactive borehole data system was established using a web-based GIS platform. The PostGIS served as the central spatial database for management of borehole data attribute enabling efficient storage and querying, an approach aligned with African water management initiatives((Mati et al., 2024). The GeoServer Apache Tomcat acted as middleware transforming data into OGC compliant with WMS and WFS services (Kumar & Patel, 2024). Hosting was made reliable by Apache Tomcat. Figure 10 shows the GeoServer interface demonstrating this interoperable framework.

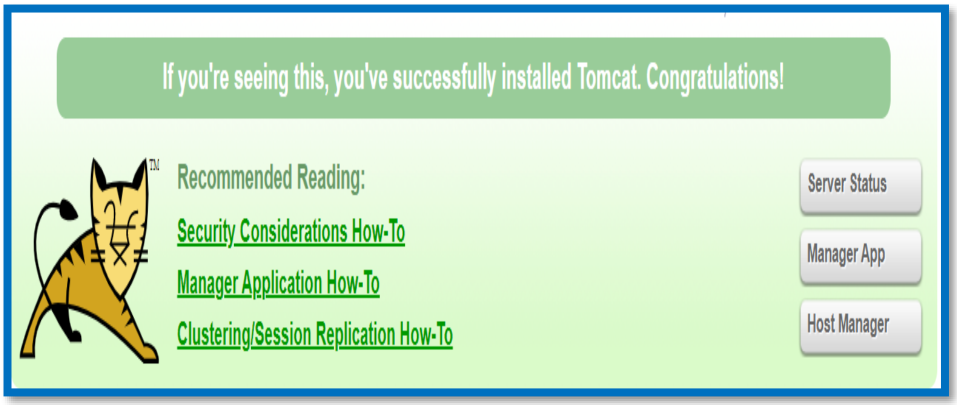

Figure 10: Apache Tomcat web server

The GeoServer web interface manages web based GIS application (Figure 11), making it possible to publish spatial data as web map services, web feature services or Web coverage services (Graham et al., 2023). Users can manage layers apply styles and configure setting similar to east Africa groundwater studies (Mekonnen and Tadesse, 2022). It controls services access and performance while ensuring Open Geospatial Consortium compliance, consistent with water resource Web-GIS implementations (Abebe et al., 2024). User and role administration enable secure data sharing, aligning with spatial data infrastructure frameworks and corroborating Ethiopian borehole management systems (Tesfaye et al., 2023).

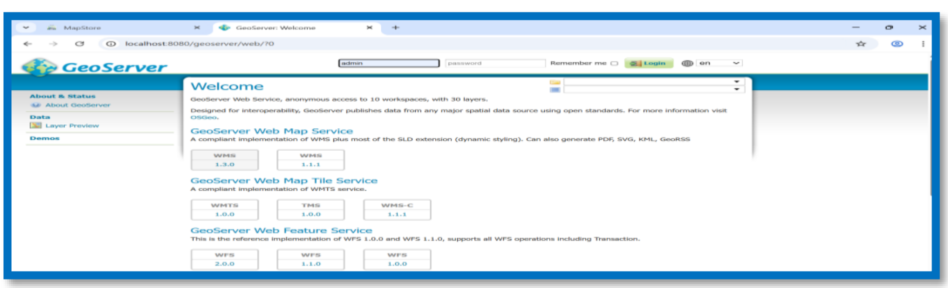

Figure 11: The administrative of the GeoServer software Used to Publish spatial web services

Figure 12 shows GeoServer Layer Preview which is vital for checking web based GIS applications. It makes possible to quickly view spatial layers in a browser using web-map services. Data upload styling and projections verification are crucial quality control steps in water resources data infrastructure (Haile et at , 2023). User test output formats and visualization for client compatibility mirroring east African Web GIS Validation workflows (Mekonnen and Tadesee, 2022). This conforms to best practices for publishing groundwater data via standardized services ensuring accuracy, quality control and accessibility (Graham et al., 2023).

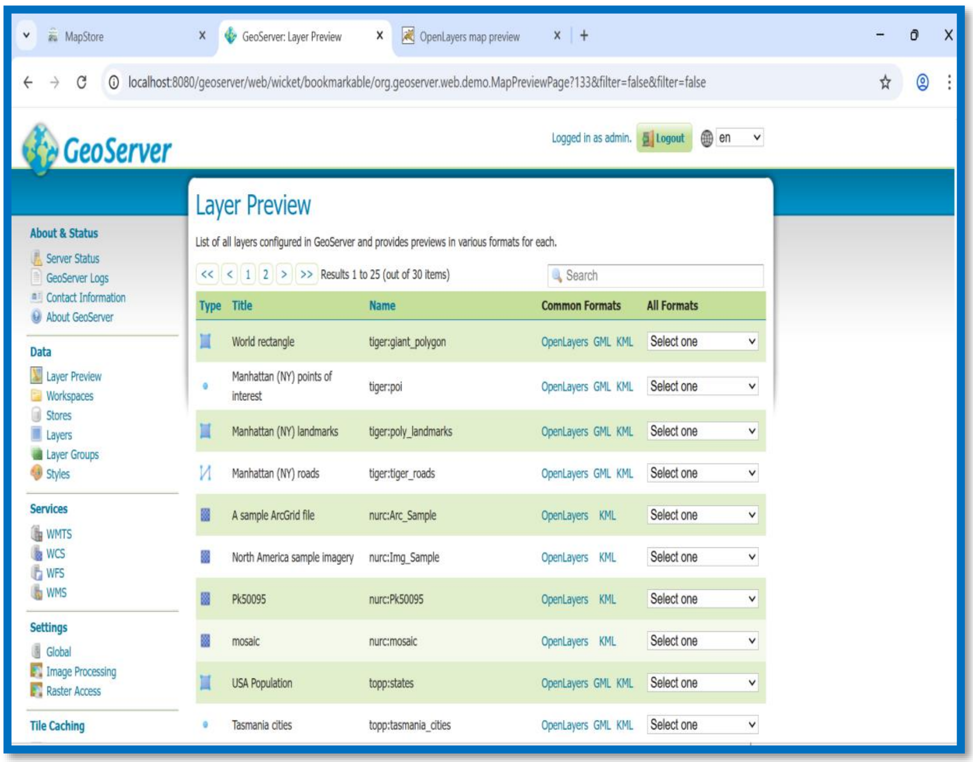

Figure 12: Geoserver layer preview interface displaying published borehole data layer

The boundaries of the studied area in and around Addis Ababa are depicted in the GeoServer layer preview (Figure 13), confirming the area size prior to the analysis. This validation step follows best practices in spatial data infrastructure, ensuring that separate layers are integrated within a consistent geographic framework for water resource management. This tool allows for efficient visual verification without requiring external GIS software, ensuring the correct geographical context for borehole data integration.

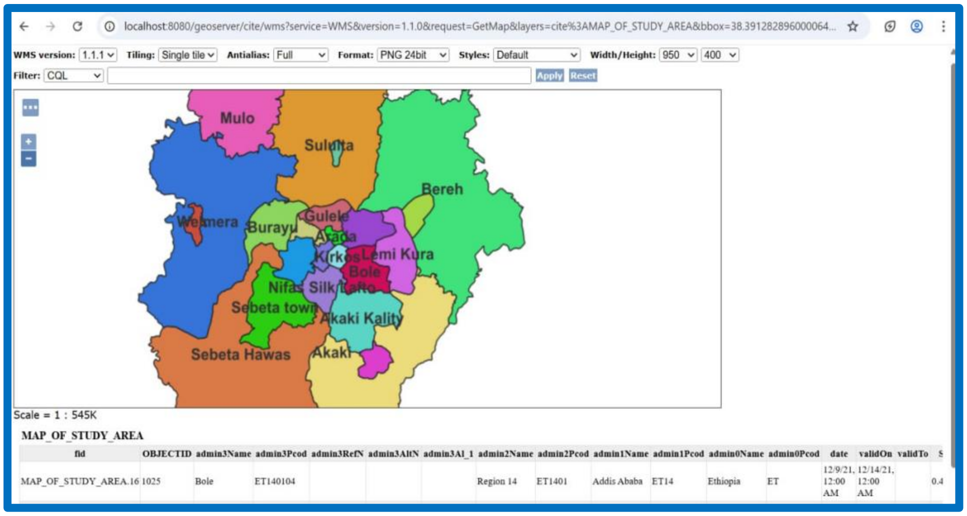

Figure 13: The study area of the boundary layer in GeoServer

The Map Store is an open source web GIS framework for for generate and sharing geospatial data. It integrates base maps with Open Geospatial Consortium services like Web feature services and web map service supporting interoperable spatial portals (Li et al., 2022). It makes multi-user browser access possible when it is installed on a web server. As illustrated in Figure 14, the Map-Store application utilizes Open Layers and ReactTLS, a stack commonly employed in environmental dashboards. This approach is consistent with open-source web GIS initiatives in Africa for water data access (Mati et al., 2024), providing a scalable and cost-effective solution for spatial data dissemination.

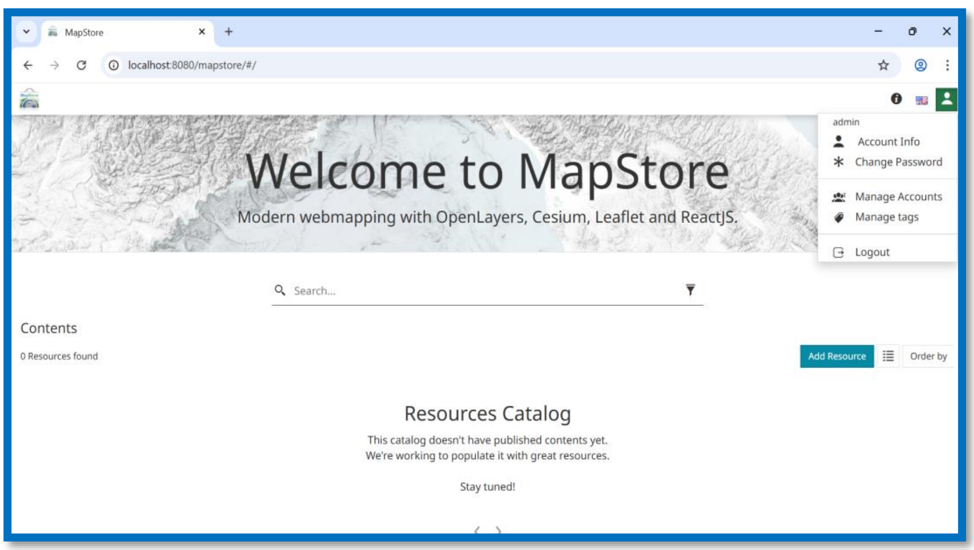

Figure 14:The MapStore Web GIS application initial user interface

Figure 15 shows the data visualization interface of a MapStore web GIS application for a boreholes. The interactive map displays a spatial data layer over key locations like Addis Ababa and nearby towns that indicate areas with borehole data using open street map. The application effectively displays geographic data for analysis following similar interface demonstration approach which involves the core function of transforming raw borehole information into an intuitive map for exploration, a capability that has proven essential for participatory groundwater management in data-scarce regions (Singh et al., 2023).

The implementation of data aligns with global trend in using open source WebGIS Platform to make subsurface water data accessibility to diverse stakeholders, similar to the frameworks utilized in national groundwater monitoring programs. This visualization approach provides a cost effective solutions for the dissemination of spatial data that enables evidence based decision making in water resource management.

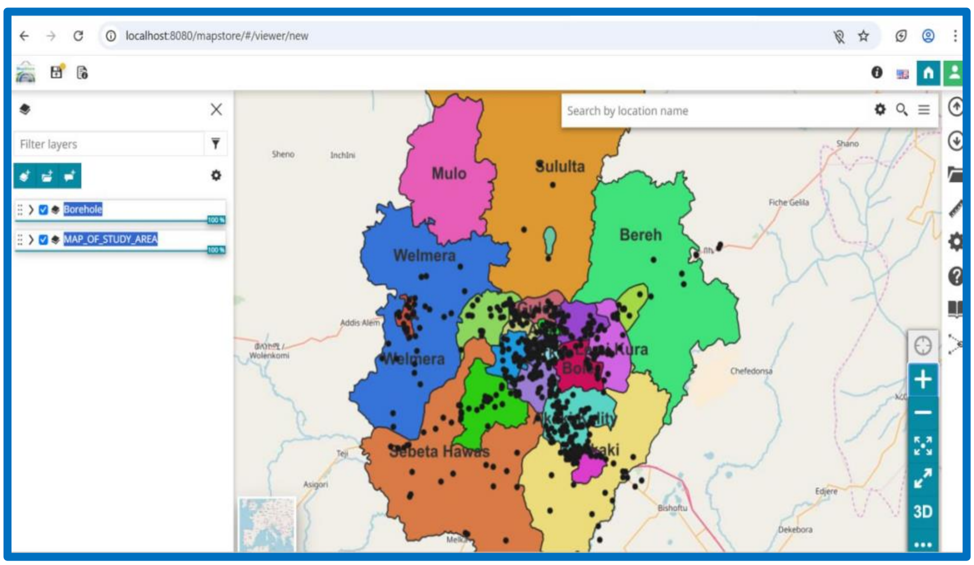

Figure 15: The interactive map interface of the borehole information systems showing borehole locations over a base map

4. CONCLUSION AND RECOMMENDATION

4.1. Conclusion

This study has attempted to solve a major problems of groundwater inventory data which is scattered and hard to get making groundwater management possible in Addis Ababa and nearby towns. We have successfully built and launched a Web Based GIS application for borehole information and spatial analysis by using PostGIS, GeoServer, Apache Tomcat and MapStore which are integrated into new open source tool. The tool unifies all data and makes it simple to share map and services and lets users visually interact with the data. This is a better ways for managing groundwater data compared to the traditional approach which is a disintegrated and uneasy for data management. Using this data, the platform gave us important insights into the study area's groundwater system. We found that boreholes are not spread out evenly. They are heavily grouped in the central, northern and southern area. Also 73% of the wells are deep showing that the region mostly depends on deep aquifers. There is variation in groundwater levels from shallow (less than 28 meters) in the center to very deep (more than 300 meters) in the outer zones. This suggests that the aquifers in the surrounding districts might be under stress.The platform has clearly made data easier access and an assistance tool for expertise involved in groundwater research. It allows for complex searching spatial analysis and visualization of groundwater information. The most significant contribution of this work is its support for sustainable water resource management. By integrating an open-source approach, the present platform establishes a strong foundation for informed decision-making that can improve efficiency, reduce costs, and save time. The system also provides a key framework for more advanced modeling and predictive analysis in the future and hence assist research. Location accuracy was verified using ground control points and was found to be sufficient for management-level mapping, with recommendations provided for improving precision where necessary. Overall, this system represents a major shift from disorganized, fragmented records to a unified, evidence-based platform for managing the region's critical groundwater resources.

4.2. Recommendation

To get the most out of this platform and improve the groundwater management the following recommendations are given:

- Establishing unified data asset is essential: Enact a national policy mandating for the exclusive use of a centralized Web Based GIS application for all borehole operations to standardize decision making and ensure data integrity.
- Implement predictive technology by deploying a real time aquifer monitoring network using Internet of Things based predictive draw down model.This allows planners to forecast water scarcity up to three months in advance and intervene before boreholes run dry.

- Strengthen data infrastructure within 6 up 18 months, bridge existing gaps by standardizing GNSS survey methods and filling data voids in high population areas (specifically the western and northern) and formalizing inter-agency data sharing agreements.
- Build institutional capacity conduct quarterly training workshops for technicians and planners to ensure the systems is unitized effectively for spatial analysis and strategic management.

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Conflict of Interest Declaration

There is no conflict of interest regarding this work among the authors, the funding bodies, or any other third party.

Data Availability

The datasets generated and/or analyzed during the current study are not publicly available due to institutional data privacy policy and the proprietary nature of borehole logs but are available from the author on reasonable request.

REFERENCES

Abebe, S., Getnet, M., & Hailemariam, S. (2024). Web-GIS platforms for integrated water resource management in Ethiopia: Challenges and opportunities. *Journal of Water and Climate Change*, *15*(2), 345–362. https://doi.org/10.2166/jwcc.2024.12345

Alemayehu, T., Tilahun, S., & Yimer, A. (2023). Urban groundwater depletion and deep aquifer response: A case study from the Awash Basin, Ethiopia. *Environmental Earth Sciences, 82*(4), 115. https://doi.org/10.1007/s12665-023-10776-8

Berhanu, K., Tessema, A., & Mosissa, E. (2022). Application of PostGIS for regional groundwater potential mapping in the Central Rift Valley of Ethiopia. *Journal of Hydrology: Regional Studies, 42*, 101165. https://doi.org/10.1016/j.ejrh.2022.101165

guide: Sharing geospatial data with the world. Packt Publishing Ltd. https://www.packtpub.com/product/geoserver-beginner-s-guide-third-edition/9781804618600

Haile, A. T., Berhanu, K., & Tesfaye, Y. (2023). Implementing spatial data infrastructures for water resource management in Ethiopia: Challenges and lessons learned. *Journal of Hydrology: Regional Studies, 47*, 101413. https://doi.org/10.1016/j.ejrh.2023.101413

Kumar, S., & Patel, R. (2024). Streamlining spatial data workflows with cloud-based PostgreSQL/PostGIS and QGIS. *International Journal of Geoinformatics, 20*(1), 45–58. https://doi.org/10.52939/ijg.v20i1.3045

Li, J., Wang, S., & Wu, P. (2022). Open source WebGIS Based Platforms for geospatial data sharing and interoperability : A review of framework architectures. Journal of Geographic Information System, 14(3), 245-261. https://doi.org/10.4236/jgis.2022.143014

Mati, B., Mwangi, J., & Chuma, E. (2024). Open-source Web-GIS for national water resource reporting: Lessons from Eastern and Southern Africa. *Journal of Hydroinformatics, 26*(1), 112–128. https://doi.org/10.2166/hydro.2024.005

Mekonnen, G., & Tadesse, A. (2022). Interoperable web services for groundwater data sharing in East Africa: A review of implementations. *African Journal of Environmental Science and Technology, 16*(3), 112–128. https://doi.org/10.5897/AJEST2021.3105

Singh, A., Sharma, R., & Verma, P. (2023). Participatory groundwater management through open-source web GIS: Lessons from semi-arid regions. *Environmental Management, 71*(4), 789–801. https://doi.org/10.1007/s00267-022-01764-y

Singh, S. P., & Singh, P. (2014). Mapping spatial data on the Web using free and open-source tools: A prototype implementation. *Journal of Geographic Information System, 6*(1), 30–39. https://doi.org/10.4236/jgis.2014.61004

Tamiru, A. (2021). Hydrogeological characterization of deep aquifer systems in the Main Ethiopian Rift: Implications for water security. *Journal of African Earth Sciences, 178*, 104189. https://doi.org/10.1016/j.jafrearsci.2021.104189

Tesfaye, H., Mohammed, A., & Girma, A. (2023). Developing a web-based borehole information system for the Central Rift Valley of Ethiopia using open-source technologies. *Ethiopian Journal of Water Science and Technology, 8*(1), 45–62. https://doi.org/10.4314/ejwst.v8i1.4

Verma, S., Verma, R. K., Singh, A., & Naik, N. S. (2012). Web-based GIS and desktop open source GIS software: An emerging innovative approach for water resources management. In *Advances in Computer Science, Engineering & Applications: Proceedings of the Second International Conference on Computer Science, Engineering & Applications (ICCSEA 2012), May 25-27, 2012, New Delhi, India. Volume 2* (pp. 1061-1074). Berlin, Heidelberg: Springer Berlin Heidelberg.

World Bank. (2023). *Sustainable data infrastructures for water resource management: A guide for practitioners*. World Bank Publications. https://doi.org/10.1596/38102