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# GIS-Based Groundwater Information System (GWIS) of Al Waseetah area: Case study

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**Abstract:** Since groundwater is the main water resource in Libya, groundwater information system (GWIS) is required as a decision support system (DSS) where it promises great potential for effective management and assessment of groundwater resources, and enhances the sustainability and efficient use of groundwater resources. This paper discusses the requirements and the design approach for the preparation of GWIS using geographic information system (GIS) techniques, where Al Waseetah area in Al Jabal Al Akhdar region was selected as a case study because of the availability of the hydrogeological data. The system structure and characteristics were defined and designed to store and manipulate the groundwater data, where 155 groundwater wells data were used to test and implement the GWIS system, in addition to remote sensing data as well as previous geological and hydrogeological studies. A series of maps and the hydrogeological map were produced and used to evaluate and interpret the groundwater system in Al Waseetah area.

**Keywords:** GIS; Water Resources; Groundwater.

## INTRODUCTION

Water is an essential commodity to mankind, and the largest available source of fresh water lies underground. As the world's population increases, the demand for fresh water has necessitate the call and need for the development of underground water supplies. Globalization and the inevitable processes of progress in the form of modernization and urbanization have magnified the problem of the search for freshwater supplies. Efforts, systems, and technologies have increased to solve these problems; methods for investigating the occurrence, patterns, and movement of groundwater have improved, better means for extracting ground water have been developed, principles of conservation have been established, and researches of several types have contributed to a better understanding of the subject (Todd, 1963). Management and decision making in water sector essentially are based on Water Information System (WIS), where it represents the key for water resource assessment and sustainable management. These involve different levels of stakeholders concerned with water data in different purposes of assessment and management.

At present, holistic management of groundwater resources suffers from a large number of noted groups involved with respect to their divergent interests on the one hand, and the lack of essential information and the complexity of the geological system on the other. Various hydro-geological, climatic, water-economical, chemical and biological interrelations have to be taken into account. Thus, the traditional approaches in information retrieval and management, for example, single reports in hardcopy form, isolated data maintenance and hardly automation which are characterized by high

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standards and time expenditure, are not sufficient (Uwe Rueppel and Thomas Gutzke, 2004). Also, the groundwater has a spatial extent, therefore, Geographical Information Science and System (GIS) can be a powerful tool for developing solutions for groundwater resource problems. GIS involves the essential developmental system and techniques for assessing water quality, determining water availability, preventing flooding, understanding the natural environment, and managing water resources on a local or regional scale (Asadi et al., 2007). Moreover, Foglini (2004) maintains that GIS is:

- GIS is able to efficiently manage groundwater issues such as groundwater data management (for example stratigraphy, drilling information, aquifers and aquitards geometry, hydrogeological parameters such as transmissivity, specific storage, and horizontal and vertical hydraulic conductivity).
- Tools (or interfaces to tools) to support experts in their data interpretation.
- Groundwater modeling facilities to address underground conceptualization, modeling data input (that is a definition of boundary conditions, internal sources/sinks) and simulation tasks.
- Management policy analysis, including assessment of optimal strategies in water supply, aquifers protection and remediation measures.

There are several Ground Water Information System (GWIS) platforms around the world that are used to collect, input, process, implement, and display data in interactive reports with maps and associated statistics. For example, the GWIS Figure (1) is the local authority of Berlin (Senatsverwaltung von Berlin) uses the GeODin platform developed by FUGRO CONSULT GMBH for regional database which comprises 130,000 boreholes with log profiles, 8000 wells with several thousand chemical groundwater analysis and over 6 million water levels, which is maintained by GeODin running an Oracle database (GeODin, 2018).

Another example is the Australian National Groundwater Information System (NGIS), which is a spatial database for GIS specialists that contains a range of groundwater information submitted by respective Commonwealth States and Territories. The system contains more than 850, 000 borehole locations with associated lithology logs, bore construction logs, and hydrostratigraphy logs. In addition, 2D and 3D aquifer geometries are also available for some areas. Jurisdictional groundwater management area boundaries are the most recent addition to the system (Australia Bureau of Meteorology, 2018). Moreover, the NGIS data can be viewed, visualized, and retrieved through the interactive tool Australian Groundwater Explorer as in figure (2). The majority of the Libyan land is categorized as arid to semi-arid. About 90% of the land is a desert characterized by low rainfall rates, diurnal temperature variations, poor soils, and seasonal winds. Moreover, groundwater accounts for 97% of the total water abstracted for different uses, and the country total water abstraction is about 4.98 billion cubic meters per year (GWA, 2006).


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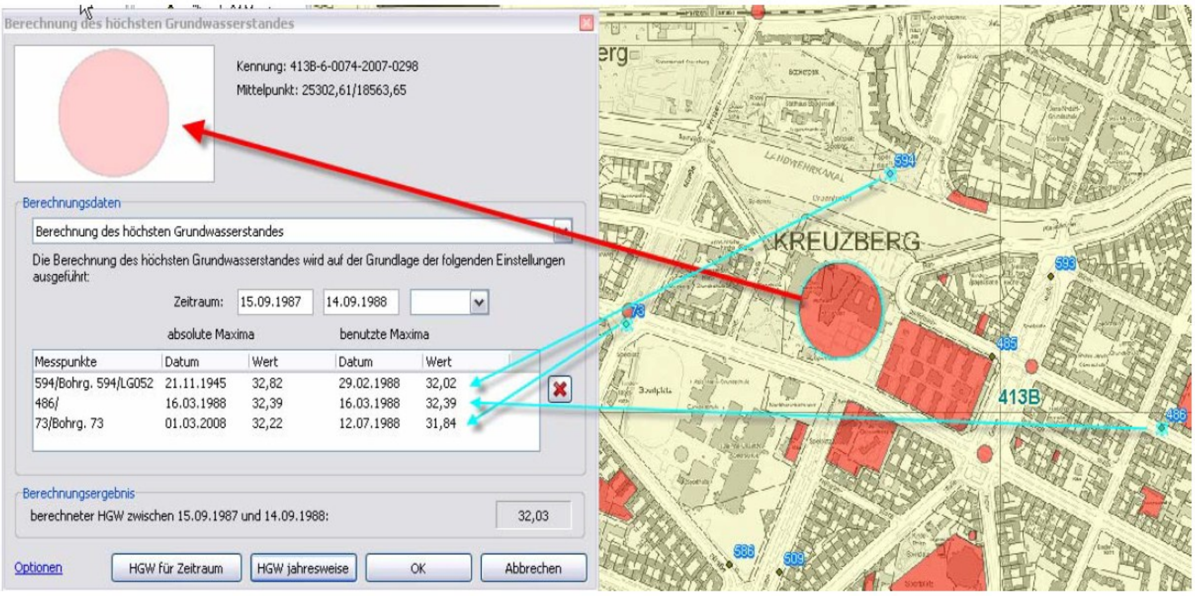


**Figure (1).** GeODin platform developed by FUGRO CONSULT GMBH (GeODin, 2018)

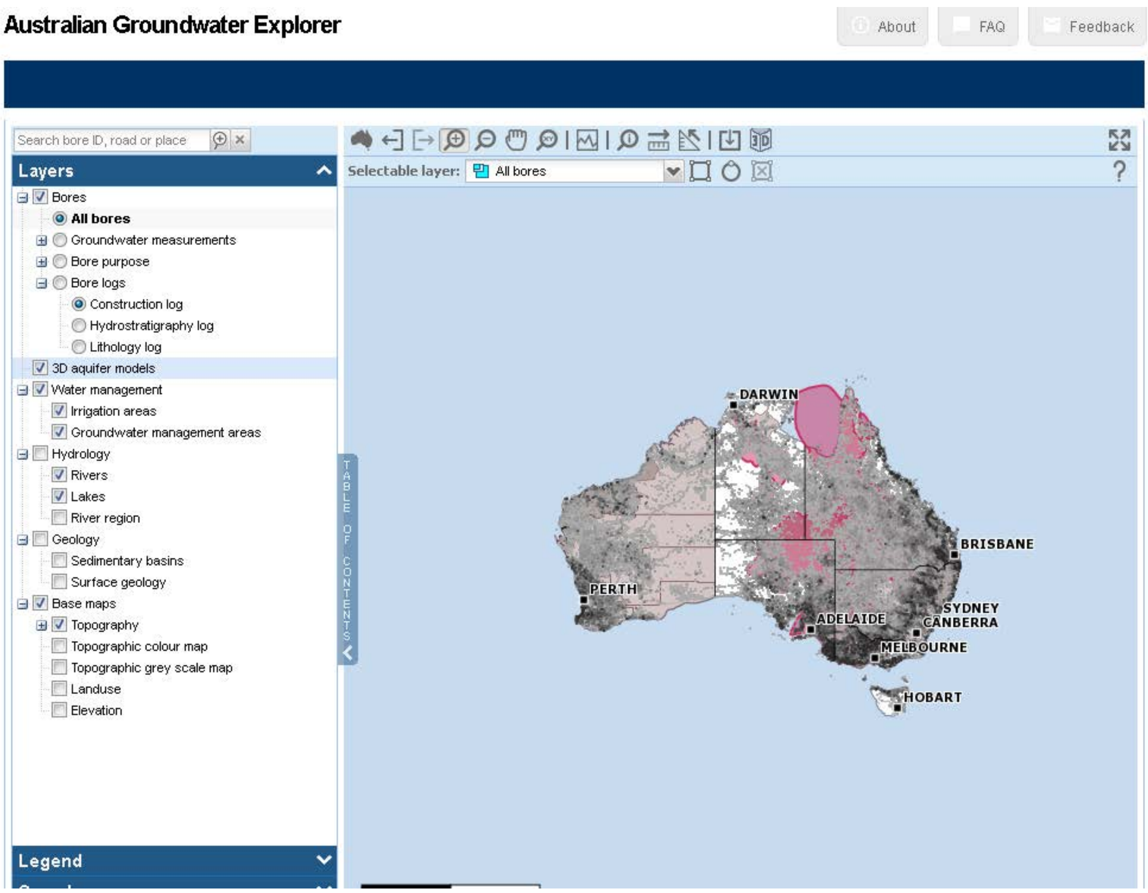


**Figure (2).** Australian Groundwater Explorer (Australia Bureau of Meteorology, 2018)


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There are many major issues in groundwater management facing the Libyan water sector. One of these issues is the lack of groundwater information system at the country and local levels which need to be addressed based on the introduction of innovative solutions that serve this sector and thus, contribute to information management process of groundwater resources. Moreover, it is important to note that before embarking on the creation of the GWIS to firstly identify the data sources, the water institutions in Libya faces obstacles and challenges, which can be summarized in the following points (Hamad, 2012):

- The overlap of water institutions responsibilities.
- The lack of coordination between the water institutions.
- Organizational instability.
- Limited structuring among the functional levels.
- Inadequate institutional capacity at regional and local levels.
- Limited experience in integrated management.
- less participation of the stakeholders.
- Lack of monitoring of groundwater resources.
- Lack and poor quality of data.

These obstacles and challenges have made it difficult than expected for interested scientists and analysts. Therefore, the goal of this research is to prepare a simple design architect system for GWIS, and the structure of data required for the testing and implementation using real data of groundwater from a small hydrogeological unit.

## MATERIALS AND METHODS

In this research, some of the hydrogeological methods were applied in the integration with the science of Geographic Information System (GIS), and that plays the main role in understanding the spatial characteristics of the groundwater system. The design steps of GWIS are summarized as illustrated in figure (3). Where the identification of the data sources is the first step in a system analysis, as the water resources of Libya managed in a traditional way, groundwater data are often dispersed among different water institutions, water users, and other stakeholders, therefore, there is a crucial need for establishing a plan of communication between stakeholders for data collection. In the second step, once the data become available, they will be classified according to their availability either in hard copies or electronically (for example: Excel, GIS, AutoCAD, dbase.... etc.). In the third step, the data will be classified into spatial and non-spatial data. Selection of the spatial database and GIS platforms will be in the fourth step of the system analysis to finish the design and testing of the GWIS.

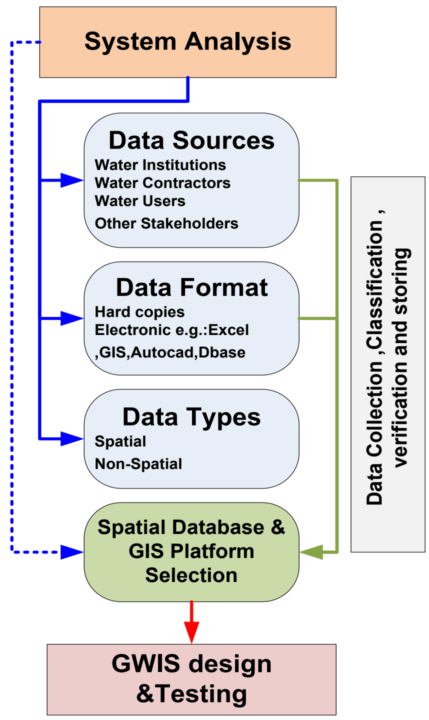


**Figure (3).** GWIS design steps

The final design of the GWIS is illustrated in figure (4), which consists of two main components. The first is the data component that is divided into spatial data and non-spatial data, and the second component is the GIS interface. Moreover, the processes box in the middle of the figure, which represents the common operations. Therefore, the deliverable will be in different forms (data reports, statistics, maps, and


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charts.etc.) to be available for the beneficiaries including the government, water institutions, water users, and other stakeholders for different purposes of groundwater assessment, planning, management, and decision-making.

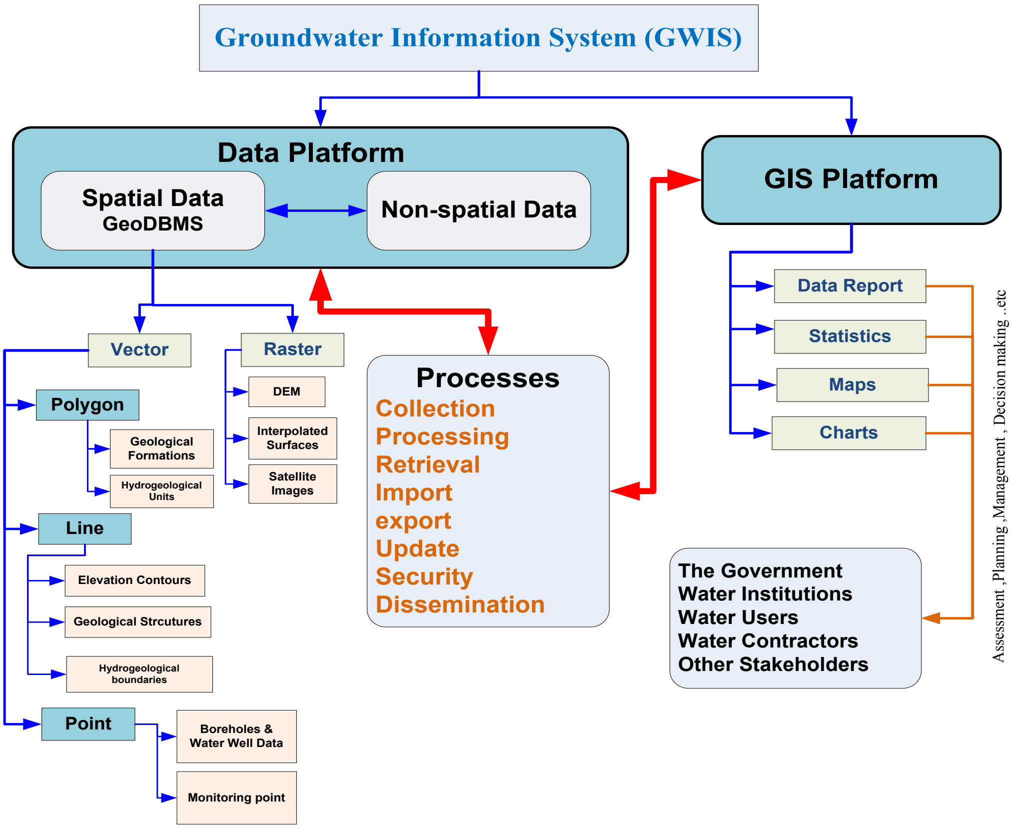


**Figure (4).** The design architect of GWIS

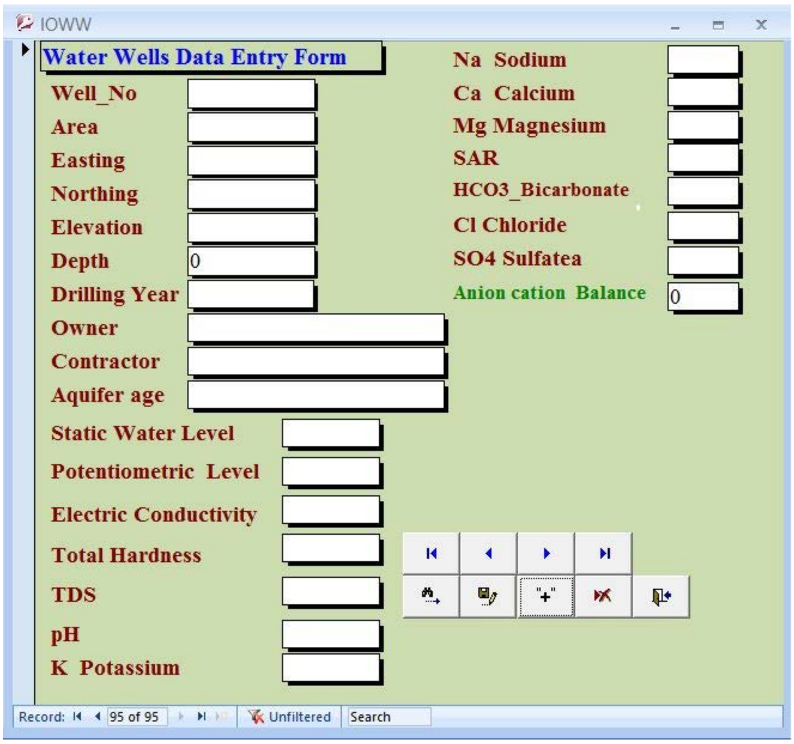


**Figure: (5).** Input form for water wells data


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The spatial data in the overall data-set component is divided into two categories. These include a vector data containing geological formations, hydrological units, faults, hydrological divides, and water wells data, which are represented by points linked to data entry form using Microsoft access database as in figure (5). The second, is the raster data comprising satellite imagery, digital elevation models, and previous geological and hydrogeological maps; these will be used for delineations and extraction of the geological structures and the hydrological boundaries. In addition to the raster data from the spatial interpolation, which is the process of using points with known values to estimate values at other unknown points (QGIS, 2018). In this research, the raster data are produced by Quantum GIS (QGIS), a very effective open source software using spatial interpolation techniques for interpolating water depth level and the total dissolved solids raster. Vector and raster data will be stored in PostGIS spatial database. The non-spatial data will be stored in folders and DBMS. Also, the following maps will be produced and used for the interpretation of groundwater system:

- Water well location map
- Elevation map
- Depth to water level map
- Total dissolved solids map
- Hydrogeological map

The selected area for implementing the GWIS is known as Al Waseetah area, which is located in Northeast Libya within the Al Jabal Al Akhdar region as presented in figure (6) with an aerial extent of 410 square kilometers. The selection of the area was done according to; first, the availability of the data and secondly, the area represents a subunit of the main hydrogeological unit Al Bayda -Al Bayydah. Moreover, the data shown in table (1) will be used to implement the GWIS.

**Table (1).** The Collected, Extracted, and Implemented Data**.**

| Data | Type | Source |
|---|---|---|
| Water wells | vector | Data from 155 water wells from Libyan General water Authority and The General company of water and wastewater in Al Marj and Al-Baydah municipalities, the data contains:<br>• Depth to Water levels<br>• Chemical Analysis results and calculated parameters |
| Digital Elevation Model (DEM) | Raster | Space Shuttle Radar Topography Mission (SRTM), Spatial resolution of 30 meters |
| Satellite Image | Raster | Landsat 8, Spatial resolution of 30 meters |
| Geological Structures | vector | Extracted from satellite image according to geological map of Libya; 1:250 000 sheet, Al Bayda sheet NI34-15 and the geological map of Al Baydah - Al Bayadah area by Hydrogeo Consulting Engineers |
| Geology | vector | Geological map of Libya; 1:250 000 sheet, Al Bayda sheet NI34-1515 and the geological map of Al Baydah - Al Bayadah area by Hydrogeo Consulting Engineers |
| Hydrogeological units | vector | Compiled according to previous hydrogeological maps and depth to water level data of 155 water well. |
| Water Divide | vector | According to previous hydrogeological maps and depth to water level data of 155 water well. |
| Boundary | vector | Generated from Digital Elevation Model and satellite Image of land sat 8 |
| Coast | vector | Generated from Digital Elevation Model and satellite Image of land sat 8 |
| Escarpment | vector | Generated from Digital Elevation Model and satellite Image of land sat 8 |
| Roads | vector | Open street map |
| Depth to Water level | Raster | Interpolated using spatial interpolation techniques for the vector point data of 155 water well |
| Total dissolved solids | Raster | Interpolated using spatial interpolation techniques for the vector point data of 155 water well |


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## RESULT AND DISCUSSIONS

The data presented in table (1) were used for implementing the GWIS, where data of 155 water wells sourced from the local offices of General Water Authority and General Company of Water and wastewater in Al Marj and Al Bayda municipalities. These data consist of geographic location and the depth to water levels, and chemical analysis results consists of major cations and anions. In addition to the previous geological and hydrogeological work, there were remote sensing data; Digital Elevation Model (DEM) from Space Shuttle Radar Topography Mission (SRTM), and satellite imagery from Landsat 8.

Geological data such as, geological formations, and geological structures, were delineated and extracted using the geological map of Libya Al Bayda-sheet compiled by the Libyan Industrial Research Center in 1974, geological map of Al Baydah - Al Bayadah Area was provided by Hydrogeo Consulting Engineers in 1996, and the interpretations of the satellite imagery and the DEM as in figure (7).

For the data to be interpolated since there are many spatial interpolation methods available with respect to their application in GIS, in this research the spatial interpolation for some of the groundwater data was carried out using Quantum GIS software Interpolation Plug-in, where the depth to water level and total dissolved solids maps were interpolated using Inverse Distance Weighted (IDW) method as in figures (8) and (9).

Hydrogeological boundaries and water divides were delineated according to the hydrogeological map by (Hydrogeo Consulting Engineers 1996), the piezometric map for groundwater of Al Jabal Al Akhdar by (Arghain and Hamad, 2006), and the result of interpolation for depth to water level data.

**Table (2).** Topographic characteristics of the study area

| | |
|---|---|
| Minimum elevation (meter) | 10 |
| Maximum elevation (meter) | 478 |
| Average elevation (meter) | 195 |
| Maximum slope (degree) | 84 |
| Average slope (degree) | 5 |
| Average aspect | NW (331°) |

Spatial analysis of the DEM was carried out to extract the topographic characteristics of the study area, which is illustrated as in table (2).

The hydrogeological map was produced as illustrated in figure (10), where it represents a key tool for the evaluation of a groundwater system in a certain area, and could be interpreted as in the following:

- The surface and subsurface geology of the study area is consisting mainly of the tertiary formations composed of carbonate and quaternary rocks represented by alluvial and coastal sediments characterized by karst and fractures, which represents the main constitutes of the aquifer's material in the area.
- The hydrogeological divides and boundaries are represented by the Mediterranean Sea in the north, the first escarpment in the south, Wadi Al Kuf in the west, and Wadi Al Uwaynah in the east.
- Depth to water level contours ranges from 54.7 to 229 meter, where the flow system characterized by a gradual descending, also the flow direction is toward the north and northeast directions.
- The chemical quality of groundwater, which is expressed by the total dissolved solids (TDS), ranges from 362 to 2788 ppm prevailing high values in the north of the study area and indicating the effect of seawater intrusion which is caused by excessive groundwater pumping due to intensive agricultural activities, as well as urban activities in the coastal region due to the absence of a proper management of the groundwater resources. Moreover, the values of total dissolved solids are decreasing southward toward the second escarpment of Al Jabal al Akhdar, where the aquifer recharge comes from.


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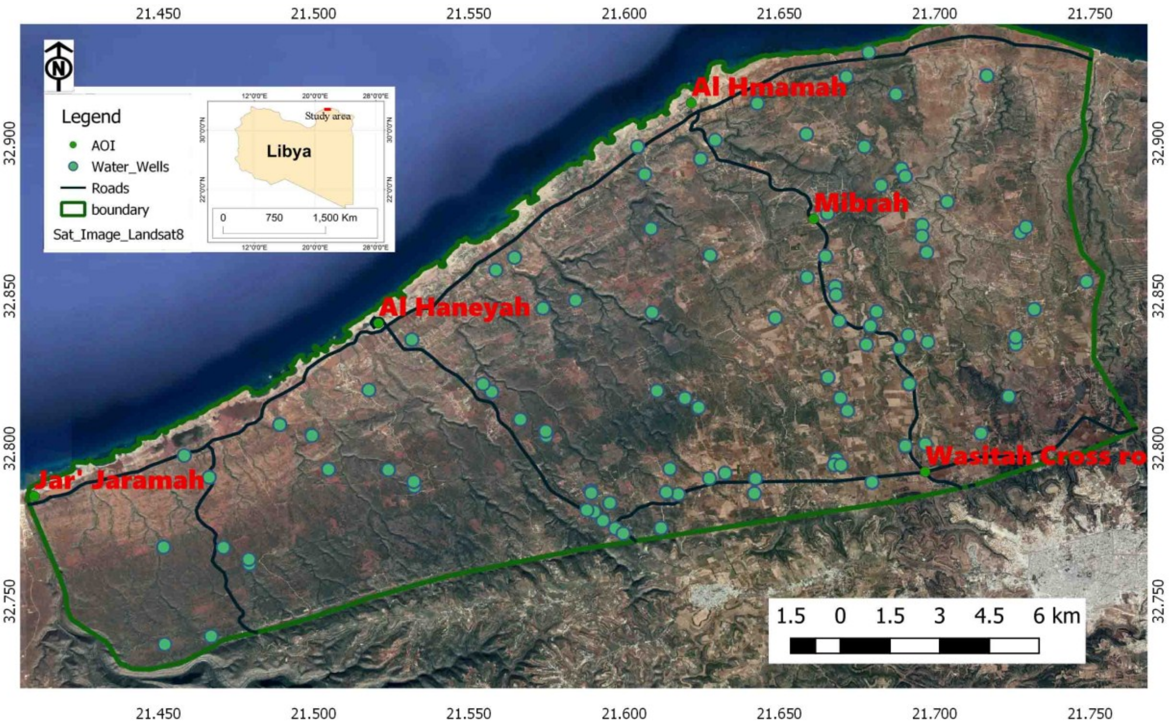


**Figure (6).** Location map

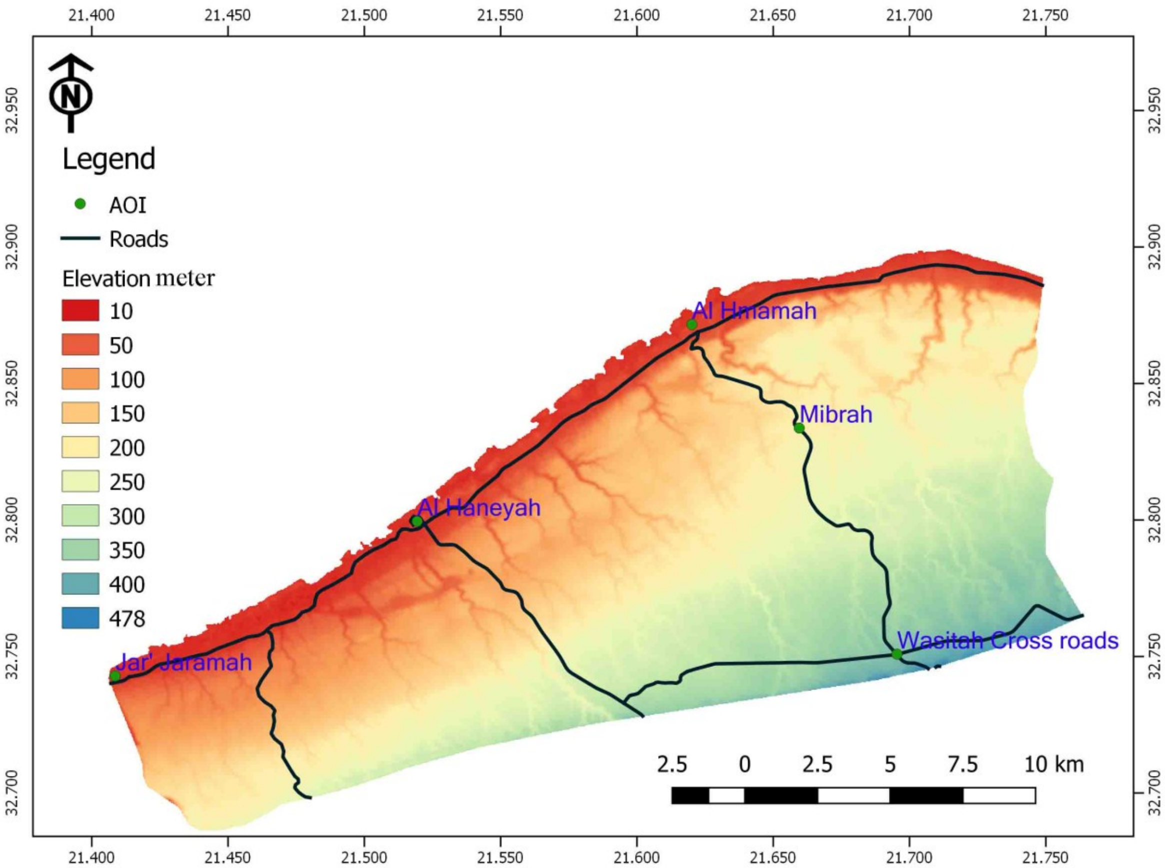


**Figure (7)**. Digital elevation map


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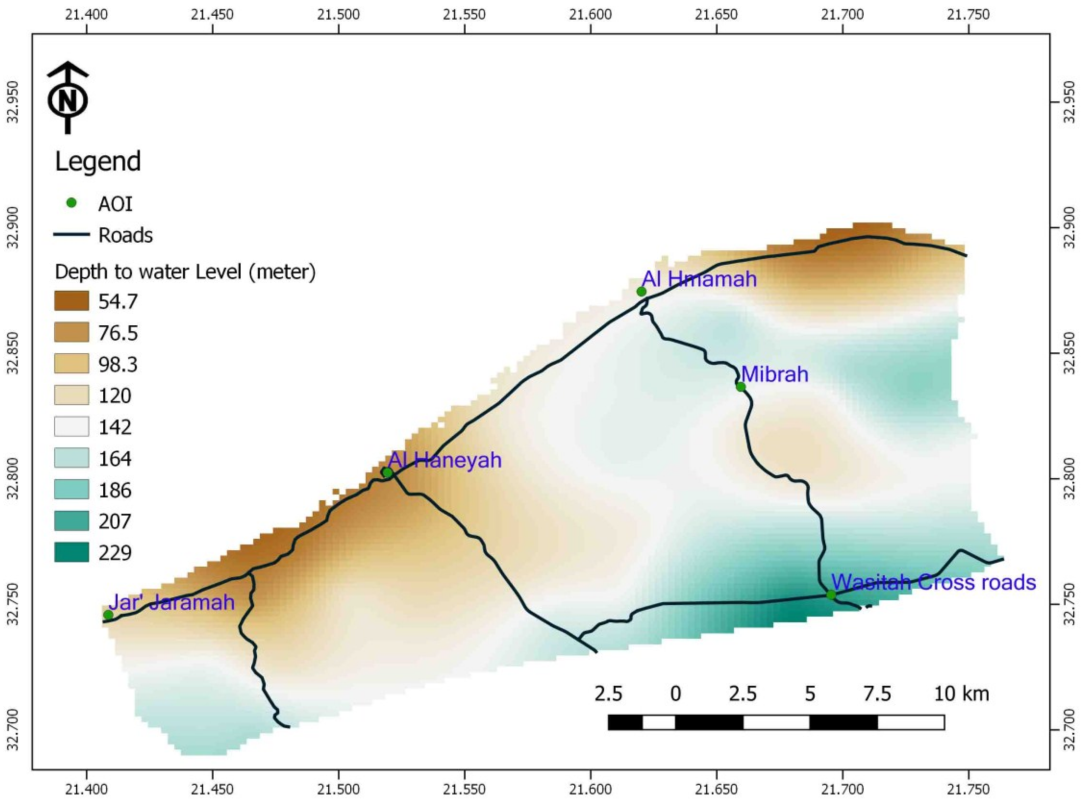


**Figure (8).** Depth to water level map

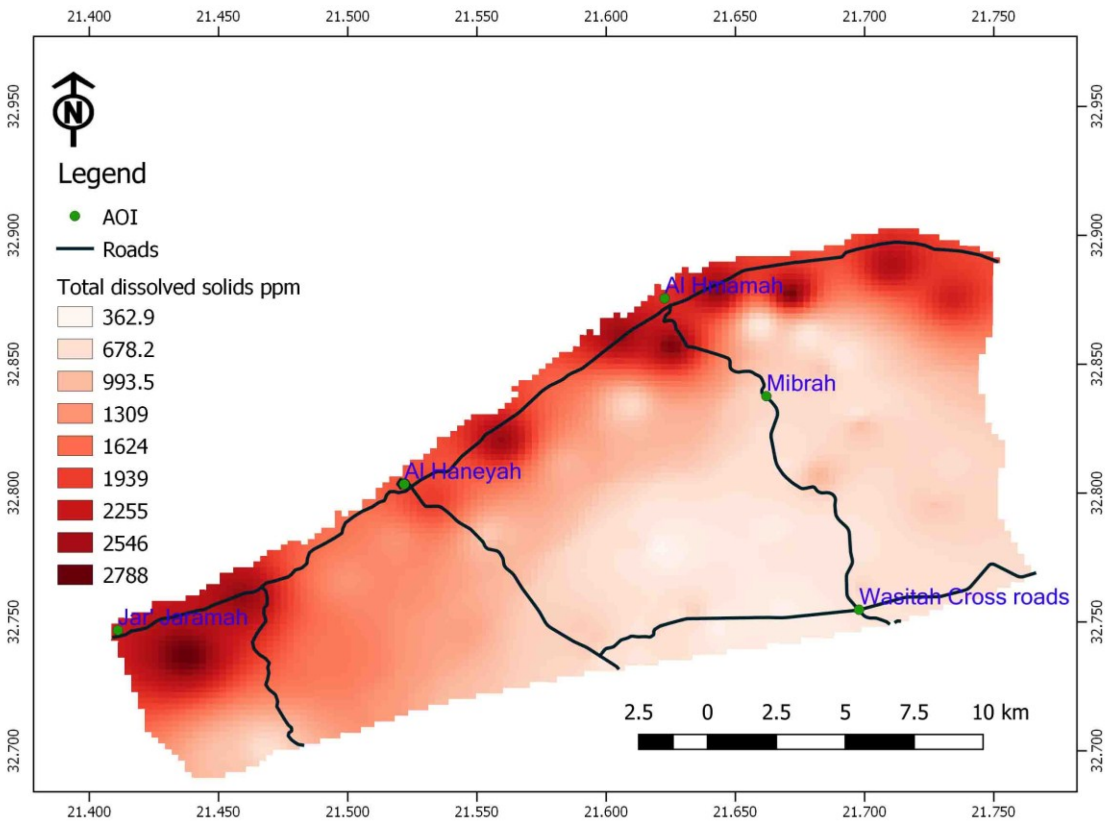


**Figure (9).** Total dissolved solids map


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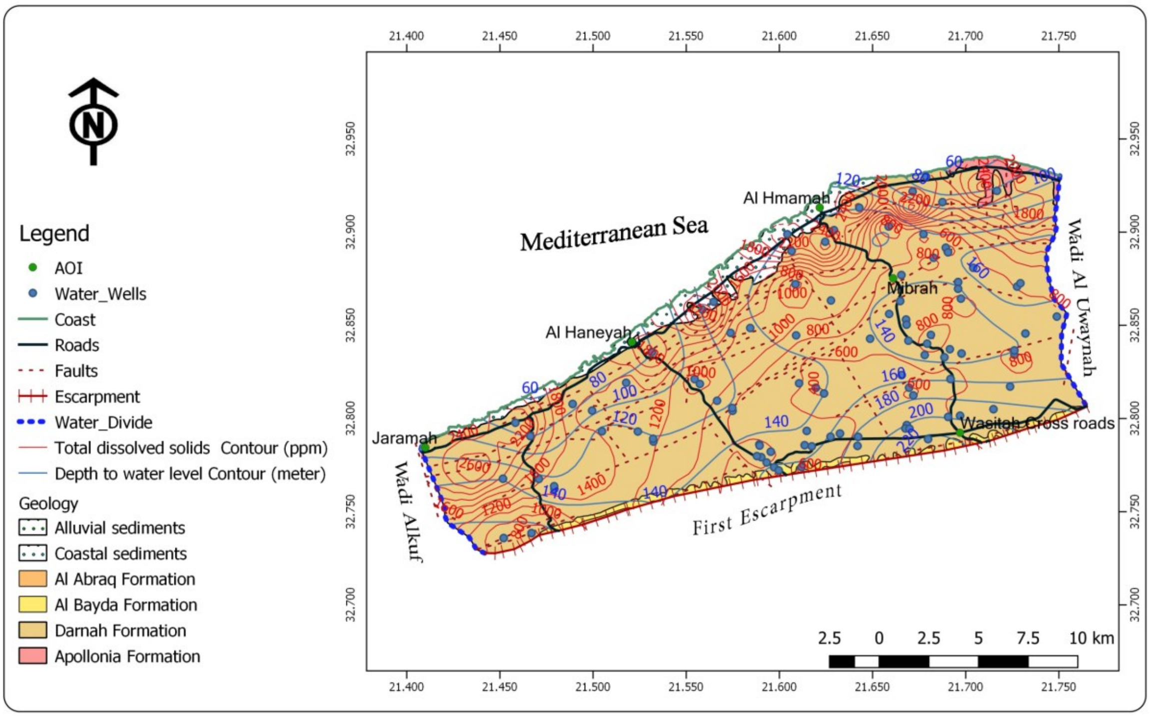


**Figure (10).** Hydrogeological map

## CONCLUSION

Information systems and modern technology have a significant impact in the field of groundwater resources. Many software developers have solutions and services in this field, especially geographic information systems which provides an enabling environment to integrate all the data of groundwater resources that enable storage and processing of the spatial data. These are of concern to stakeholders and decision-makers in the field of groundwater resources. However, the following should be taken into consideration:

- The best GWIS is the system that involves all the stakeholders concerned with groundwater resources to ensure comprehensive and integrative data system and processes.
- Groundwater resource authorities may call and argue that they lack the financial resources and the ability to obtain software tools that would be used for the establishment of GWIS, especially the commercial software. Therefore, open source software such as Quantum GIS has a very good capabilities that could be initiated or even adopted for GWIS.
- The technology must be accompanied by proper data, processing, and implementation methods.
- The focus should shift from two-dimension to three-dimensional capabilities in the future to give more insights into the groundwater system and its hydraulic characteristics.
- Development of simple interface or plug-in linked to open source GIS software will be useful for extracting reports and statistics for users with limited GIS experience.

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# نظام معلومات المياه الجوفية (GWIS) القائم على نظام المعلومات الجغرافية  منطقة الوسيطة كحالة دراسية

**صلاح مفتاح عبد الله حمد**

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**المستخلص** : بما أن المياه الجوفية هي المورد المائي الرئيس في ليبيا ، لذلك فإن نظام معلومات المياه الجوفية (GWIS) مطلوب كنظام لدعم القرار (DSS) ، حيث يعتبر ذا إمكانية كبيرة للإدارة والتقييم الفعال لموارد المياه الجوفية ويعزز الاستدامة والاستخدام الفعال لموارد المياه الجوفية، حيث يناقش هذا البحث المتطلبات ونهج التصميم لإعداد GWIS باستخدام تقنيات نظام المعلومات الجغرافية (GIS) ، وقد تم اختيار منطقة الوسيطة بمنطقة الجبل الأخضر كحالة دراسية نظرا لتوافر البيانات الهيدروجيولوجية، وتم تحديد وتصميم بنية النظام وخصائصه لتخزين بيانات المياه الجوفية ومعالجتها ، كما تم استخدام بيانات 155 بئر مياه جوفية لاختبار وتطبيق نظام GWIS ، بالإضافة إلى استخدام بيانات الاستشعار عن بعد وكذلك الدراسات الجيولوجية والهيدروجيولوجية السابقة ، ومنها أنتجت سلسلة من الخرائط والخريطة الهيدروجيولوجية التي تم استخدامها لتقييم وتفسير نظام المياه الجوفية في منطقة الوسيطة.

**الكلمات المفتاحية:** نظم معلومات جغرافية، مياه جوفية، نظم معلومات المياه الجوفية، ليبيا.

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