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HYDROGEOLOGICAL AND HYDROCHEMISTRY INVESTIGATION IN BARA BASIN: A CASE STUDY OF THE NORTH KORDOFAN, SUDAN

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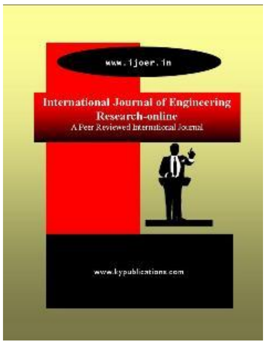

ABSTRACT

The study area is situated in the North Kordofan State-western Sudan the region is characterized by semi-arid and poor savannah climatic zone, where acute shortages of water are experienced. The purpose of this study is to assess the groundwater quantity and quality. The study area is covered by the basement complex (Precambrian age) which is overlain by superficial deposits (Tertiary to Quaternary age).

The sedimentary basin consists of two aquifers called upper and lower, mainly comprising of sand and a few amounts of gravels and clays. The results of pumping test revealed the variation in hydraulic properties of the aquifer. Where, the average transmissibility reach about 225 and 1692 m^2/d and hydraulic conductivity was estimated to be 2.3 m/d. The present investigation has brought to light the fact that the area promising in term of groundwater resources estimated to be 52.5×10^9 m^3 in the Bara basin. The fluctuation in the static water level depending mainly on the annual recharge and discharge rates range between 0.5 to 3.0 m. The volume of annual recharge estimated to be 41% with compared to annual discharge. On the other way, the total annual extraction values of groundwater resources equal about 1.3×10^9 m^3, which is more than the annual recovery rates.

In term of chemical composition of groundwater, the TDS values range from 300 to 3060 ppm and EC values ranges between 415 and 4400 micro ohms/cm. in the study area hydrochemical analysis using standard diagrams to classified hydrochemical characteristics of both aquifers (upper and lower). Groundwater is predominantly of Ca-HCO_3 to Na-Cl type of hydrochemical facies and it is apparently suitable for drinking demands.

Keywords: geological, pumping tests, storage capacity, groundwater quality, Bara

INTRODUCTION

The geological units act as containers for content in both quantity and quality. Two types of formations, which are inter-connected with each other, cover the study area. These formations include Basement Complex, Um Ruwaba formation and superficial deposits. Therefore, the groundwater supply for the people depend either on hand dug (boreholes) or drilled wells with modern water pumps excavation and extracting groundwater mostly from deeper horizons (water yards).

Location and Accessibility

The study area lies in North Kordofan State (NKS) west of the White Nile river in the west-central Sudan, bounded by latitudes 13º 15´ to 13º 40´ N and longitudes 30º 05´ to 30º 35´ E, covering an area of 3500 square kilometers. Bara town lies approximately in the north of El Obeid and far about 50 km (**Fig. 1**).

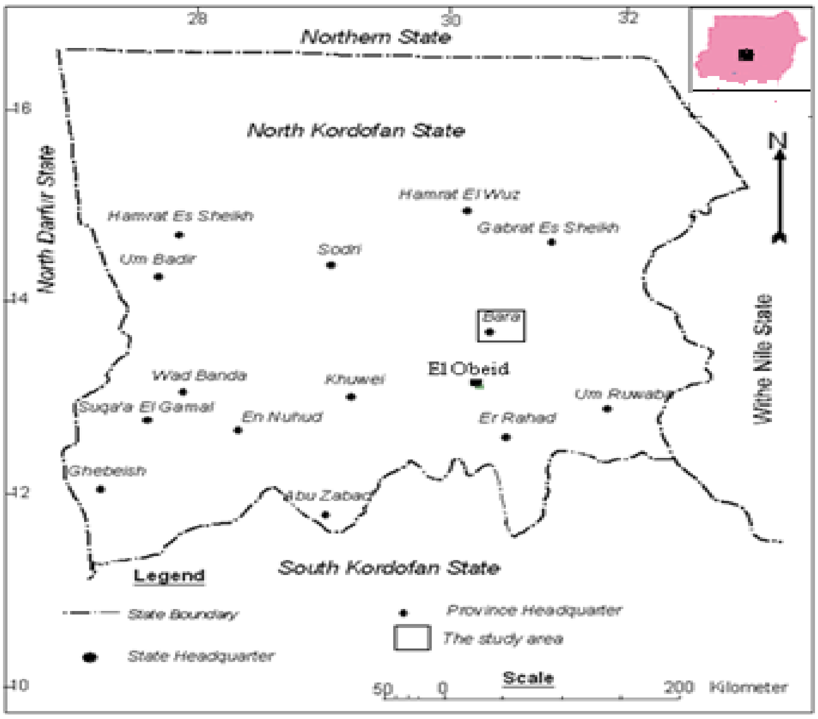

Figure (1): Location map of the study area.

Objectives of the Study

The objectives are realized in the current study using the following:

i. Geological study to recognize the main types of rocks, structural features and groundwater occurrence.
ii. Hydrogeological study to estimate the hydraulic properties and assessment of groundwater resources in the study area.
iii. Hydrochemical analysis to evaluate groundwater quality for consumption.

Methodology

The methods of the study have been constructed to achieve the objectives of the study through the forming procedures:

Field Investigation

The hydro-geological work can be done to obtain well locations and formation samples were collected to obtain geological information through the zone of saturation. Continuous pumping tests were carried out, as well as, depth to water was measured, fluctuation and elevation refer to the main sea level by using apparatus such as Global Position System (GPS) and water level indicator. Observation wells were selected to be used for measuring water level periodically by using groundwater recorder instrument. Water samples for chemical analysis were collected from boreholes to measure electrical conductivity (EC) and total dissolved solids (TDS) at the site of the well immediately by the digital of the EC meter.

Laboratory Investigation

The laboratory work can be summarized in:

a. Pumping tests data was analyzed to obtain the aquifer parameters.
b. Measuring fluctuation of water level to evaluate hydrogeological conditions.
c. The chemical analysis for 20 water samples was carried out to determine the concentration of the major cations and the anions.
d. Computer software as aquitest and aquachem programs were used to interpreted data.

Geological Setting

In the target area well logs are descriptions of the different lithostratigraphic units forming the body of the Um Ruwaba formation and recent deposits fill the depression (**Fig. 2**). The geological formations are occupied south of the Central Africa Shear Zone (CASZ). According to the drilling information from oldest to youngest rock types will be divided as follows:

Basement Complex [9] Used the term pre-Nubian Basement Complex to description these rocks. The pre-Nubian Basement Complex rocks (Precambrian age) cover an area of about 50% of total area of the Sudan. They generally consist of granites and meta-sedimentary and meta-volcanic rocks.

The Basement Complex of the North Kordofan region is overlain by the sediment including Um Ruwaba series and superficial deposits respectively. [7] Described the Basement Complex of Kordofan as being composed predominantly of granite, gneiss and schist with quartzites and crystalline limestones. According to [8] most of the Basement Complex rocks are Precambrian in age and taking a consideration share in the geologic structure. [10] and [2] divide the tectonic structures in Sudan into three categories Rift valley structures, Post-Basement structures and Basement structures. [1] divided the Basement Complex rocks into two types including crystalline schist and granites.

Um Ruwaba Formation

The Um Ruwaba Formation is overlies unconformably on undulating Basement Complex and in some cases it rest unconformably on the Nubian Sandstone surfaces (**Fig. 2**). The superficial deposits of qoz sand and fluvial deposits overlie this formation and completely cover it, so that its existence and lithology are known only from borehole data collected by the writer from the area. **[3]** proposed the name Um Ruwaba Series for thick superficial deposits that occur on the central Sudan, which consist of unconsolidated sands, sometimes gravely, clayey sands, and clays. The writer believes that the increase or decrease in thickness of Um Ruwaba Series sediments depends largely on the depth of basins and on the irregularity of the Basement erosion surface.

In general, the beds are unsorted, show rapid lateral facies changes are very common within relatively short distances and are characteristics of the deposit that is typical and lacustrine deposits. The precise age of the Um Ruwaba type sedimentary deposits is as yet unknown, and commonly as Tertiary to Quaternary; some are more probably Pleistocene **[6],[11].**

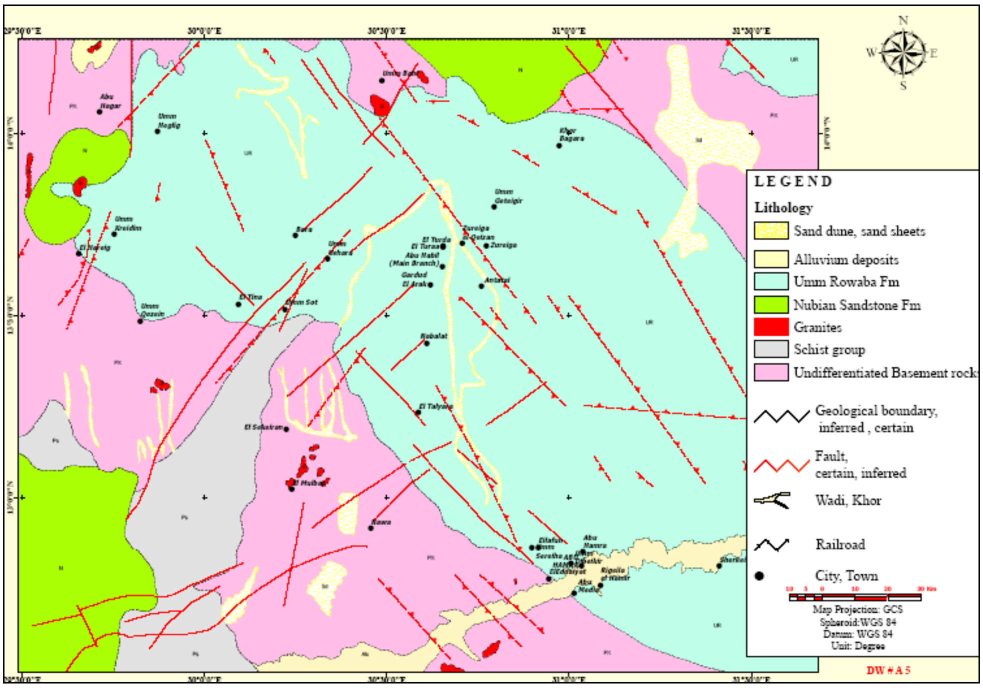

Figure (2): Geological map of the Bara Basin (modified after [5]

Superficial Deposits

The older rocks of the Basement Complex and the Um Ruwaba Formation in the area covered in many places by superficial deposit, which is recent age deposited in vast surface, covers of stabilized and mobile dunes (**Fig. 2**). The alluvial basins cover about 2% of the surface area of Sudan, however, these are composed of unconsolidated materials, and they are occur in various thickness and different types as seen from well logs.

Many writers believed and suggested that the origin of the aeolian sands has brought from the desert, weathering of the Nubian Sandstone Super group and the Um Ruwaba Formation. According to him, they were carried by the wind and covered almost the whole of the region west of the White Nile.

Structural Setting

The structural features formed due to the tectonics activities led to the formation. In October 1966 Kordofan was shaken by strong earthquakes especially in J.Damber that have great attention to hydrology due to the formation of fractured zones among the rock of the Basement Complex and sedimentary basin. The structure of the area is not complicated and it cannot be detected from the surface, this is because the majority of the area is covered by loose sand. However, geological and geophysical studies in the area have revealed that the rocks have been subjected to faulting (**Fig. 2**). These structures were influence of groundwater occurrence and flow **[4].**

Lithological Log

The correlation and interpretation of the geological section traverse is based mainly on the drilling logs geo-electric data and geological information to detect reconnaissance stratigraphical sequence and to determine the types of water bearing formations (**Fig. 3**). The study area has been divided into two geologic units including superficial deposits and sedimentary rock units.

This section conducted in the part of the area in sedimentary basin passes along three boreholes from Bara at the west, through Um Ushara to Um Debos at the east direction (**Fig. 3**). The study of the top layer of this section reveal the existence of sandy layer (superficial deposits) ranging in thickness from 0 to 70 m in depth, which overlies clay layer is observed at different levels of the section, it acts as an aquiclude layer and responsible for causing local flowing conditions through which groundwater leaks from the upper aquifer to the lower aquifer of the Um Ruwaba water bearing formation. The thickness of these layer ranges from 75 to 120 m. The lower aquifer made up of medium to coarse sand and a few gravels and clay.

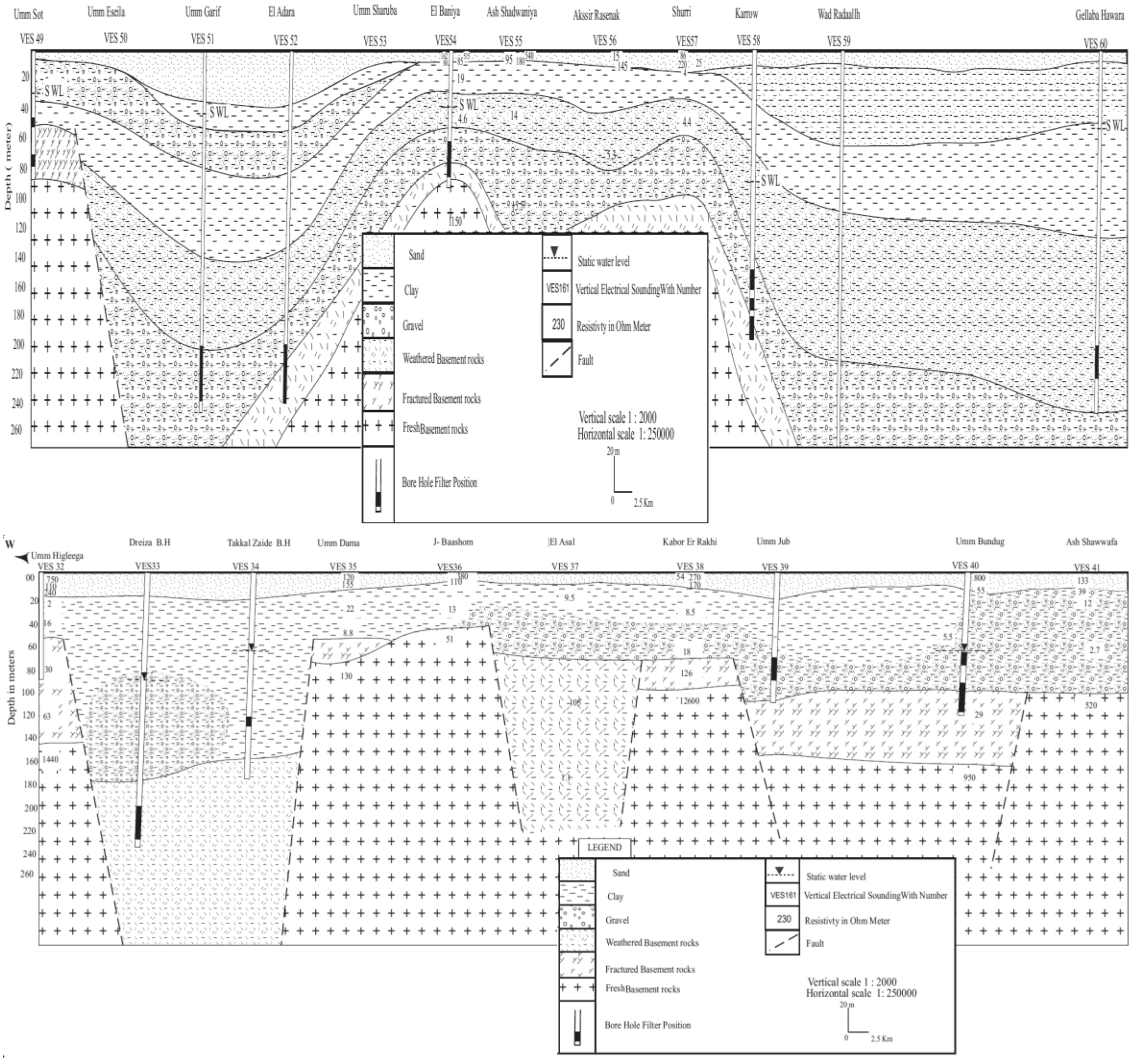

Figure (3): Lithological logs showing the variation within sedimentary profile.

Hydrogeology

Bara basin is the main aquifer in the target area. Water-bearing saturated zones vary in depth, depending upon the dip of the strata, enclosing impervious beds, recharge areas, and other factors, so that depth to standing water may be up to much as 250 meters or more below surface. At few places, the water table reaches the surface and oasis occur, this especially observed in the northeastern and north of Bara out of the study area at Um Balgi and El Bashiri village respectively.

Pumping Tests

It's used to estimate the hydraulic properties of the aquifer such as transmissibility and hydraulic conductivity certain location. The pumping tests could be determined from 6 wells include pump wells without observation wells. Many type of aquifers observed in the study area, confining and semi-confined aquifers were recorded in the sedimentary basin when the upper aquifer is overlying and separated by confining layer as clayey strata.

In the study area the highest transmissibility values obtained by drawdown and recovery tests recorded in El Sarha borehole range between 625.3 and 507 m^2/d respectively and the lowest values estimated about 13.4 to 156 m^2/d recorded in El Sider well and the average value equal about 225 m^2/d (Table 1). The average values of the hydraulic conductivity reach about 2.3 m/d. The variations in the results from these methods are due to the accuracy of the graph construction and matching field data to the type curves (Fig. 4).

Table 1: Results of the pumping test obtained from sedimentary basin

Borehole	Cooper-Jacob		Theis & Hantush		Theis-Recovery		Average	
	T m^2/d	K m/d	T m^2/d	K m/d	T m^2/d	K m/d	T m^2/d	K m/d
Hamdan	53.1	3.8×10^{-1}	45.1	3.2×10^{-1}	281.2	4.7	126.5	1.8×10^{0}
El Sarha	625.3	5.4	323.5	2.8	506.9	6.8	485.2	5.0×10^{0}
El Sider	140.8	1.2	13.4	1.2×10^{-1}	155.9	1.9	103.4	1.1×10^{0}
Mugeiseiba	455.9	4.0	329.1	2.8	353.3	2.4	379.4	3.1×10^{0}
Bara	137.4	3.4×10^{-1}	13.6	3.4×10^{-2}	309.0	5.2	153.3	1.9×10^{0}
El Rokab	37.8	1.7×10^{-1}	41.7	1.9×10^{-1}	221.8	2.1	100.4	8.2×10^{-1}
Pumping test mean for sedimentary basin							224.7	2.3×10^{0}

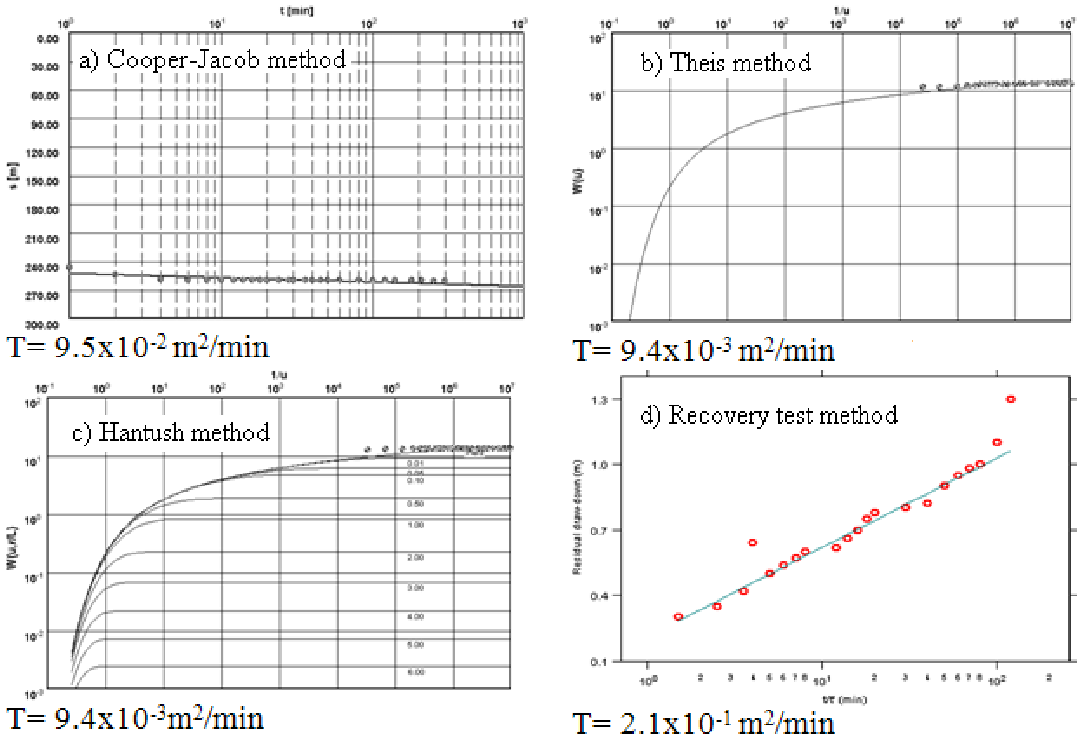

Figure (4): Pumping Test Data of the Bara well.

Groundwater Storage Capacity

Storage capacity (S_c) is the volume of water that can be drained by gravity or can be pumped from the water-bearing formation. It mainly depends on rock materials and on the hydraulic gradient. The total storage capacity of the groundwater available for pumping of boreholes in the sedimentary rocks (Bara basin) is estimated about 52.5 x10^9 m^3 (52.5 milliquard of cubic meters) given in (**Table 2**) after multiple (volume of the aquifer m^3 in specific yield %) equation (1) as follow:

$$S_c = v_o.S_y \qquad \text{...} \; (1)$$

Table (2): Estimate of groundwater storage capacity of the sedimentary aquifer

Zone No.	Surface area (m^2)	Ave. saturated thick (m)	Volume of aquifer (m^3)	Ave. specific yield %	Storage capacity (m^3)
1	3.5 x10^9	75	262.5 x10^9	20	52.5 x10^9

Water Level Fluctuation

Annual groundwater level fluctuations related to groundwater recharge and discharge in the aquifer system. The water level in the target area fluctuates in response to the variation in the recharge periods was rise due to the seasonal rainfalls and decline in the summer and during droughts. Seasonal groundwater level fluctuations have been studied with the help of monthly water level data of twelve hydrograph stations (**Fig. 5**) including both upper and lower aquifers were selected in the Um Ruwaba formation. Hydrographs of the observation borehole sites have been prepared (**Fig. 6**). The above mentioned water level fluctuations were negligible throughout the years depend on type of aquifers and recharge and discharge conditions, and additional, annual groundwater level fluctuations are quite small as compared to the thickness of the aquifer system (hundred of meters). in the study area hydrographs (**Fig. 6**) reveals that the water levels registered minimum and maximum rise about 0.5 meter from the land surface during the year 2003 at the El Sider, El Gahman and El Hideid borehole for upper aquifer and 5.0 meter from land surface at the lower aquifer during the year 2004 at the El Regeiba borehole. Further, another minimum decline trends occurred in upper aquifer ranging between 0.5 and 6.0 meter from land surface was observed during the year 2005 and 2003 at the El Togour and Mugeiseiba4 borehole. This aquifer due to suffering increasing of the cone of depression that can mainly be attributed to the lack of recharge or due to over pumping, all this issues may be predicate to make subsidence in the water bearing formation in the future. During the first years fluctuate showed negligible as compared to the fluctuate observed during the last years because the area received more rainfall (420 mm) during the year 2001 as compared to (200 mm) of rainfall received during the year 2003 and 2005 (**Fig. 6**).

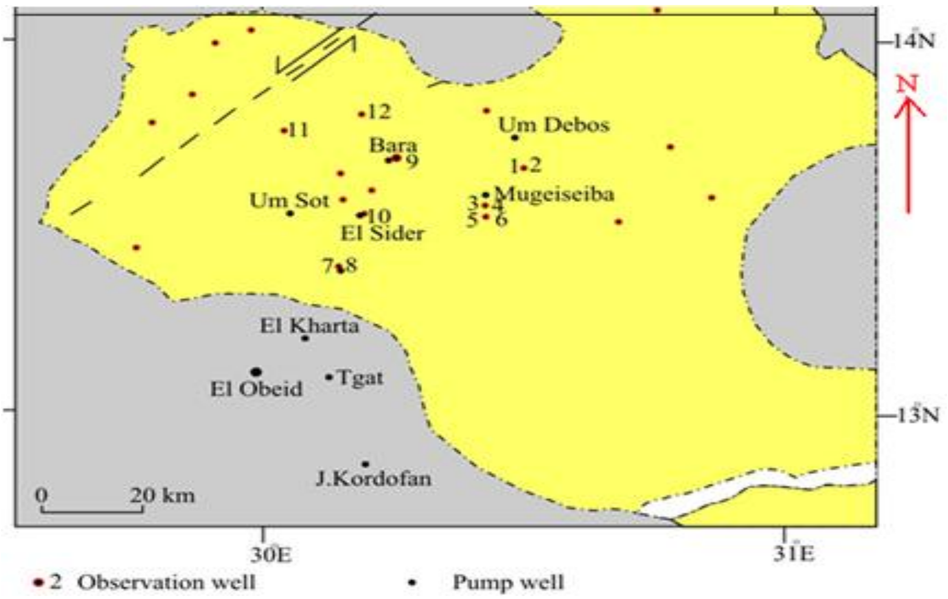

Figure (5): Map present number and location of the observation wells

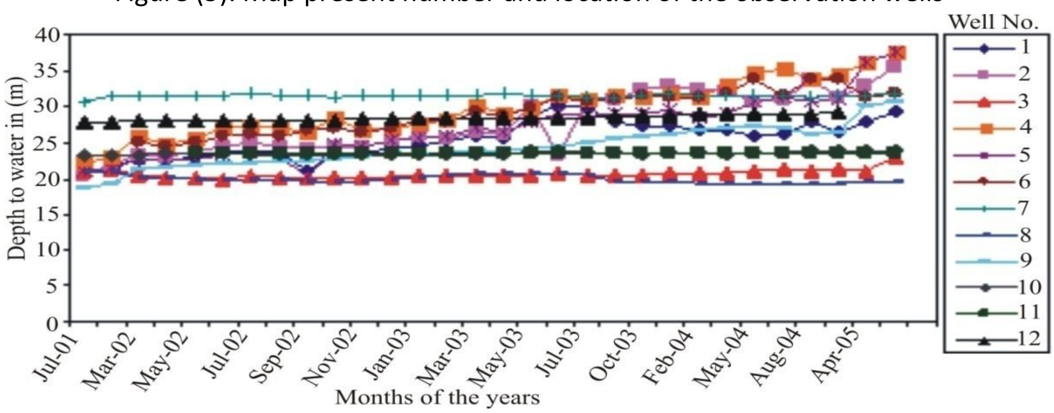

Figure (6): Hydrographs of groundwater fluctuation in the study area per month.

Exploitable and Consumption of Groundwater Resources

To calculate the exploitable groundwater resources (E_x), fluctuation of water levels from 2001 to 2005 are taken into consideration because it concerning with groundwater recharge and discharge. These have been calculated in the following way:

$E_x = A.S_y.r$ ………………………………………… (2)

The value of specific yield is assumed to be 20% on the basis of sub-surface lithology equal 3.5 x10^9 m^2 and an average rise of water level has been calculated to be 1.3 m/y. Putting these values in equation (2), the annual exploitable groundwater resources come to be (3.5 x10^9 x20% x1.3 m^3) or 0.9 x10^9 m^3, this volume of water that enters annually the groundwater system from the sedimentary basin. These resources can be exploited in the area or must be abstract and use for domestic water supply and irrigation purposes by installing tube wells, which is prevent to declining of water level continuously and possible to prevent subsidence of basin in the future. The annual groundwater discharge equal about 1.3 x10^9 m^3 or (3.5 x10^9 x20% x1.9 m^3). Exploitable groundwater resources were also calculated by studying recharge and discharge patterns of the study area and the values obtained match very nicely with the results obtained from equation (2). On the other way, annual consumption of groundwater resources in the target area calculated by using equation (3) multiply total area, specific yield and average of annual recharge and discharge of water level that reach about (1.3 and 1.9 m) respectively, which is equal approximately 1.3 x10^9 m^3/y is more with annually groundwater can be exploitable that reach about 0.9 x10^9 cubic meter, which estimated to be 41% compared to annual consumption of groundwater (C).

$C = A.S_y.r.d$ ……………………………………… (3)

Hydrochemistry

The study of groundwater chemistry can give important indication of the geological history of the enclosing rocks and direction of groundwater movement. A rapid determination of Total dissolved solid (TDS) can be made by measuring the electrical conductivity (EC) of a groundwater sample, because TDS is associated and closely related with EC, where high values of TDS means high readings of EC in the samples and both of them considerable tendency to increase with the flow direction.

Throughout the study area, TDS was determined for 20 samples from boreholes, which varied from 312 to 3060 ppm. Generally, there was a gradual increase in salinity down gradient in the south and southeast of the study area. The EC in the sedimentary aquifer increase depending mainly on groundwater flow path and range between 415 mmhos/cm at the Bara where groundwater recharge is supposed to take place and 4400 mmhos/cm at the Um Esaila to the southeast with basement rocks contact.

Hydrochemical Facies

Identification of hydrochemical facies in the study area was based on the distribution of water types in the sedimentary rocks. Groundwater analysis was done in the laboratory here is a selection of Piper method (trilinear diagram) for the identification of water samples. The plotting technique has been used to establish these hydrochemical processes and help to classification of the groundwater types for different purposes after the interpretation of the plotting. According to chemical analysis of groundwater samples in the study area has been classified as follows in four different types (groups) of groundwater were recognized in both upper and lower aquifers in the sedimentary rocks. Hydrochemical types encountered in the study area (**Fig. 7**), which shows the groundwater samples to be predominantly sulphate-chloride alkaline-earth water (Ca-Mg-SO_4-Cl type), compared to a predominantly bicarbonate normal alkaline-earth water (Ca-Mg-HCO_3 type), as well as, chloride-alkali water type (Na- Cl type). The evolution and modification of the groundwater is attributing to preferential leaching of highly soluble surface or near surface soil salts and mainly due to leaching of lithological constituents under different water depths, which are completely dissolve during resolution. In comparison with less soluble salts, such as evaporative concentration may also cause the less soluble salts to precipitate out of solution resulting in the percolating water becoming enriched with NaCl.

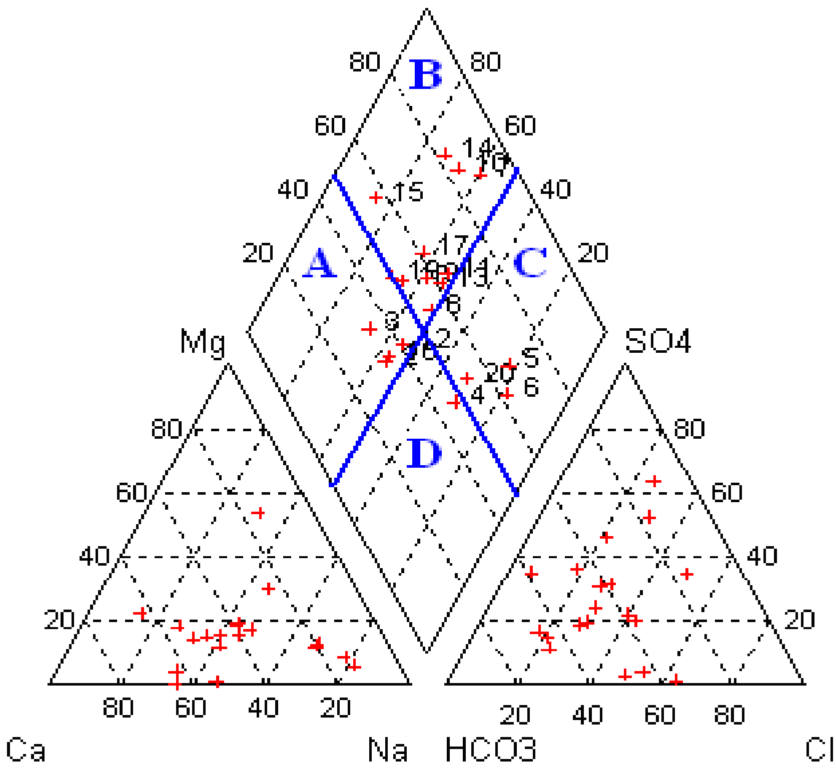

Figure (7): Piper diagram represent the type of groundwater

CONCLUSION

The geological successions within the area consist of three geological units, the crystalline Basement Complex rocks, Um Ruwaba Formation and Superficial deposits which are covered whole area. The hydrogeological system consists of two aquifers; each of these aquifers shows a wide range of variable hydraulic parameters, depending on pumping test. The groundwater chemistry of the study area reflects its geology, mineralogy, and hydrogeology. The concentration of major cations and anions are the results of exchange between the aquifer and groundwater.

Acknowledgement

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