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Groundwater potentialities assessment of the River Atbara alluvial sediments El Girba-New Halfa area, eastern Sudan

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Abstract
The study area lies in the upstream of the River Atbara basin in the Kassala State, eastern Sudan. The availability of fresh water governs the population distribution and settlement. The objective of the study is to assess the groundwater potentialities of the River Atbara alluvial sediments using hydrogeological and geophysical methods. These methods were applied to detect the basin boundary and to identify the saturated zones and the lithological variations within the basin. The main geological units in the River Atbara watershed include the old Precambrian basement complex, Triassic to Cretaceous Sandstone, Tertiary basalt and Pleistocene to Recent alluvial sediments. The River Atbara alluvial aquifer is extended under the *Karab land* for about 2-3 Km on each side of the river banks, it consists of alluvial deposits. The depth to basement ranges between 50-65m below the land surface. The Transmissivity values range between 1000 - 1500 m^2\day. The groundwater storage capacity in the study area was estimated to be 1450 Million cubic meters. The depth to water level does not show great variations during the year; it ranges between 30 - 40m on the western bank and between 11 – 40m on the eastern bank. The outcome of the present study states that there is no noticeable variation in water levels between the wet and dry seasons. The River Atbara and its tributaries represent the main source of recharge to the aquifers. The general groundwater flow direction is towards the NW direction with average hydraulic gradient of 0.005.

1. Introduction

Upper Atbara area suffers from shortages in potable water supply, particularly during the dry seasons. The River Atbara is a seasonal river that flow in a short period during the year, after which the obtaining of fresh water become a problematic issue. In addition, the surface water is considered as unsafe source of drinking water when it used without treatments. Therefore, groundwater represents an important alternative source of water that deserves to be investigated.

The study area lies in Kassala State, eastern Sudan at about 70 km southwest of Kassala Town, the capital of the state. It is bounded by latitudes: 15°00′00″ and 15°30′00″ N; and longitudes: 35°40′00″ and 36°00′00″ E, occupying an area of about 2,400 km^2 Fig (1). According to 2008 census, the estimated population in the study area is approximately 27,500 with increasing rate of about 2.5% per year. The population is concentrated in the western bank of the River Atbara, where the New Halfa Agricultural Scheme is located, with a very small number of peoples living in the eastern bank. The availability of fresh water governs the population distribution and settlement in the area.

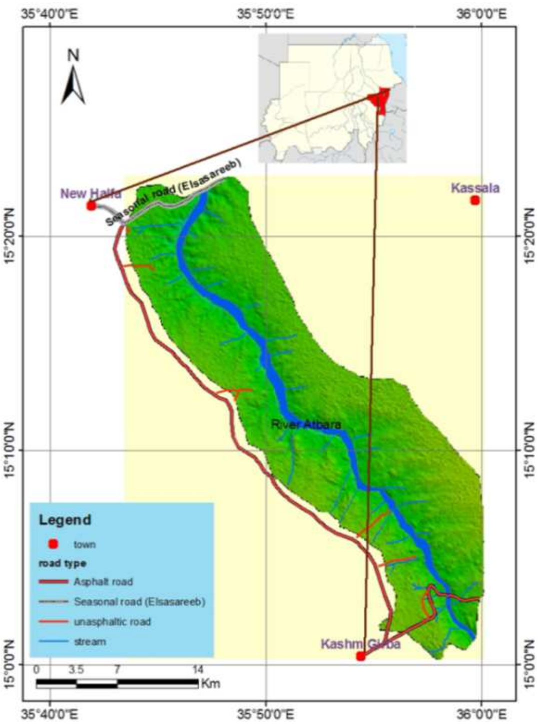

Fig. (1). *Location map of the study area*

The investigated area is located within arid zone, where the winter (Nov. – Feb.) is dry and cool with minimum average temperature around 15°C and the winds usually come from the North. The summer (March-June) is hot and dusty, where the maximum average temperature is around 41°C. The wind turns direction and very often violent dust storms occur. The rainy season starts in July and lasts by the end of September. The annual average rainfall is about 230 mm and the annual average evaporation is 185mm. The vegetation cover consists of a variable mixture of grasses and herbs, which frequently associated with scrub bushes up to 2 meters high. The decrease in rainfall in recent years has produced species more tolerant to dry climate conditions [1].

The study area is mainly a flat plain which is generally sloping from southeast to northwest, with gentle minor slopes towards the River Atbara. Near the river, the drainage pattern forms a special land form, locally known as the "*Karab Land*", which is a typical characteristic of the River Atbara deposits. Small *Khors* (seasonal streams) flowing towards the river form a sort of dendritic to rectangular drainage pattern (Fig. 2).

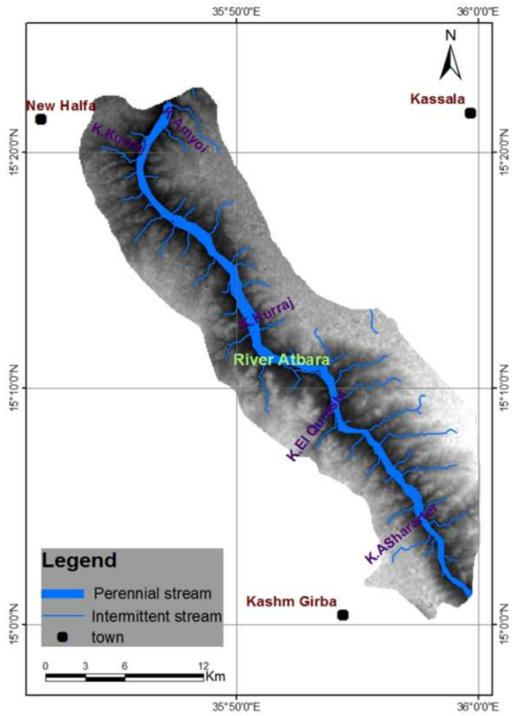

Fig. (2). *Drainage map of the study area based on DEM data*

The main objective of the present study is to investigate the groundwater potentialities of the River Atbara sediments using hydrogeological methods and geophysical techniques. The study aims at detecting the basin boundary and lithological units within the basin, define the hydrogeological parameters of the aquifers, study the groundwater flow regime and estimate the groundwater storage capacity.

The study area has not ever been subjected to intensive hydrogeological assessment, with the exception of some very minor efforts. Scattered studies were carried out in the area including geological studies, groundwater exploration and groundwater quality investigations. [2] studied the geology at the confluent of Atbara-Setit Rivers. The Technical Committee – Kassala [3] conducted a geophysical survey on the western bank of River Atbara. A team from the University of Khartoum [4] made geophysical and hydrogeological surveys along the eastern bank of River Atbara. This work was sponsored by the Drinking Water Corporation of Kassala State. A research team [5] carried out a combined geophysical and hydrogeological investigation to evaluate the groundwater potential in eastern Sudan. From their interpretations two major basins were identified, which are located to the southeast of the study area: Wad Elhelew and Elshowak. The first is a NNE – SSW trending basin with maximum thickness of 2.2 km, while the other is a shallower one with a maximum thickness not exceeding 0.25 km. Within these basins, groundwater occurs essentially in two major aquifers: the Nubian aquifer and the Neogene – Resent deposits. [1] carried out study to estimate the grass area of the *Karab lands* along the Atbara River and its tributaries. They estimated the rate of annual loss of arable land caused by gully erosion and its environmental effects. [6] studied the hydrological interaction between Atbara River and the main Nile at the confluence near Atbara Town.

2. Geological Setting

The River Atbara watershed passes through the following geological units: old Precambrian basement complex, Triassic to Cretaceous Sandstone, Tertiary basalt and Pleistocene to Recent alluvial sediments (Fig. 3).

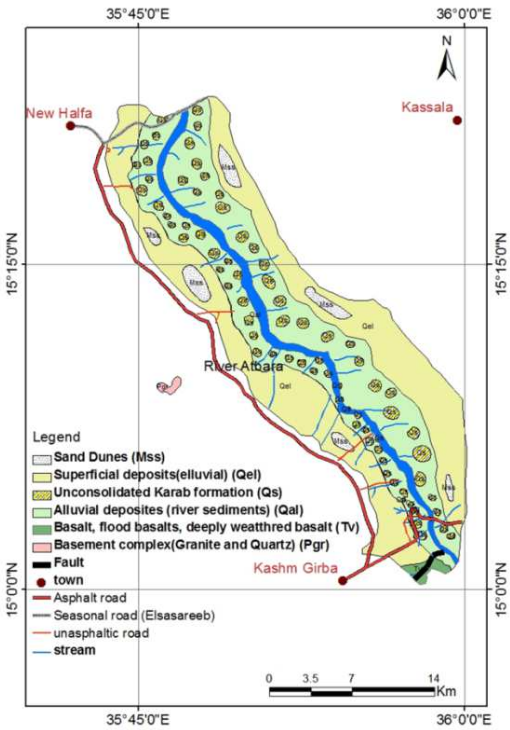

Fig. (3). *Geological map of the study area.*

The basement complex consists mainly of slates, schist, granitic gneisses, quartzite and pegmatitic rocks that form the lower impervious boundary of the aquifer. These rocks generally crop out in the form of scattered hills at the western bank of River Atbara and in the plain near New Halfa Town. The Basement rocks are overlain by thin layers of the Upper Cretaceous (Maastrichtian [7]) Sandstone of the Gadaref Formation. These sediments crop out mostly along the river banks in the upper reaches (Plate 1). They are sometimes injected locally by Tertiary basalts, occurring in the form of flows, sills and dykes.

Miocene to Pliocene age was attributed to the sediments occur on the top of the succession which represent the lands of River Atbara Basin known as *Karab land* [5]. The Quaternary clays (black cotton soil) in the plains were originated as weathering products of the old basement and the Tertiary basalts. The Recent river alluvial sediments are the youngest unit in the area that consists of gravel, silt and clay.

A shallow graben was developed, possibly as a result of a combination of tectonic and erosional activities from the late Tertiary to early Quaternary. This shallow graben is filled with River Atbara sediments. The deposits of the River Atbara sediments consist mainly of conglomerate, silicified sandstones, sands, silt and intercalated layers of clay. These deposits are always underlain by the basement complex. The total thickness of these sediments varies between 10-70m. The conglomerate and sandstones form the lower zone of the aquifer. Some authors related this deposit to old wadi sediments; however, proper verification and detailed geological investigations are required.

The River Atbara is characterized by a special landform called the "*Karab*". The *Karab* (or the rugged topography bad land) is always attached to the banks of the river covering a distance of almost 2-3 km from each bank (Plate 2). It is characterized by extensive gullying along the rivers draining from the Ethiopian highlands [1]. [8] defined *Karab* as sloping soft land, severely dissected and eroded by running water. The age of these sediments is Neogene to Quaternary [5].

Plate (1). *The exposure of the sandstone on the river bank up stream.*

Plate (2). *The undulated topography within the Karab land.*

The superficial deposits are mainly elluvial, colluvial and alluvial deposits of Pleistocene to Recent age. These deposits form extensive huge plain in addition to sand dunes in some parts of area. They are mainly made up of clay, silt, sand, clayey sand and pebbly materials [5].

3. Methodology

The methodology was planned to achieve the objectives of the present study. It involves the collection of previous data, field work (2 tours), the laboratory works and the data analysis/processing using computer software.

The previous Meteorological data includes: the runoff data, temperature, rainfall and evaporation measurements, which were obtained from the meteorological stations of Kassala Town and Khashm Elgirba Dam records. The geological and hydrogeological maps of the study area were prepared based on field survey, measurements and observations.

Two field trips were conducted to the study area, during which the locations of boreholes were checked using Hand held GPS. Monitoring measurements had been taken 4 times during the year. It includes the measurements of water levels and discharge rates. Measurements of Static Water Levels (S.W.L) gave a good idea about the groundwater fluctuation in the study area. Pumping tests were carried out in some wells distributed in the area to recognize the hydrogeological characteristics of the aquifer. Important hydrogeological parameters including the hydraulic conductivity, transmissivity and storage coefficient of the aquifers have been estimated. The geophysical work was conducted using Vertical Electrical Sounding (VES) technique to investigate the subsurface electrical properties in regard to groundwater occurrences (e.g. [9] – [12]). The goal behind the executed electrical resistivity survey is to investigate the subsurface geology that governs the groundwater occurrences, particularly in zones that have limited or no boreholes data. During this survey, 36 VES points were measured throughout the study area (Fig. 4). Resistivity measurements were made using SAS 1000 Terrameter applying Schlumberger configuration. The Data were processed utilizing IPI2win software.

4. Hydrogeological Investigations

4.1. Aquifers Zones in the Study Area

From the geophysical survey and boreholes data, two saturated zones were recognizes: the upper and lower zone, with thickness varies between 15-25m for each one, these are: aquifer under the *Karab land* and aquifer under the flat plain.

The first one extends under the *Karab land*; with lateral extension of about 2-3 Km on each side of the river bank. This aquifer consists of alluvial deposits characterized by lateral and vertical facies changes. Vertical Electrical Sounding (Fig. 4) has been conducted in order to get information about thickness and composition of the bed rock. The calculated depth to the basement rocks is relatively shallow, ranging between 50-65m.

The plain area aquifer on the right and the left banks are immediately adjacent to the *Karab land*, which has a limited groundwater potential. The groundwater potentiality in this zone decreases away from the river as far as 10km from the River Atbara. In this zone, the saturation is affected by the lateral and vertical lithological changes. The Static Water Level is relatively deeper compared to the aquifer near the river bank. The average depth to the bed rocks in the plain area aquifer ranges from 45-80m at the right bank of River Atbara and 50-60m at the left bank of the river (Fig. 5).

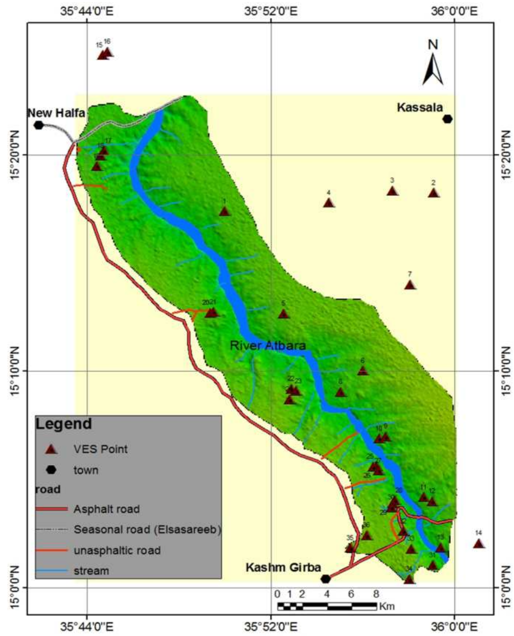

Fig. (4). *The location of measured VESs in the River basin.*

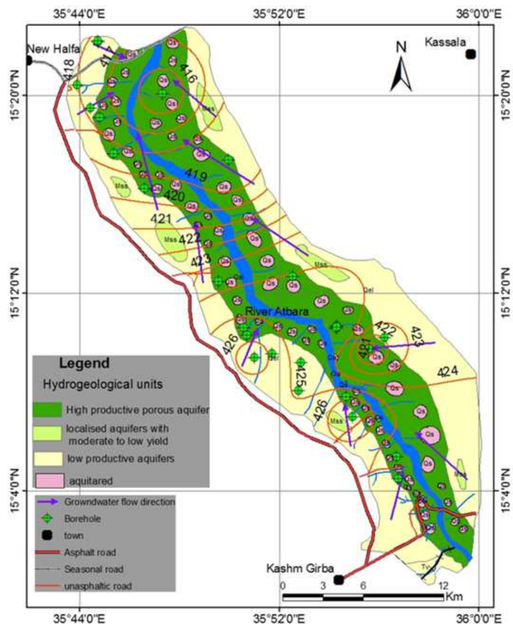

Fig. (5). *Hydrogeological map of the study area (groundwater levels in meters, a.m.s.l.)*

4.2. Aquifer Properties

Table (1). *The aquifer properties of the study area (River Atbara basin)*

Name of the aquifer	Upper Atbara alluvial aquifer
Area covered by the aquifer	400 km^2
Thickness of the aquifer (m)	15 – 25 m
Aquifer condition	confined
Hydraulic conductivity (K)	50 – 75 m/ day.
Transmissivity (T)	T = 1000 - 1500 m^2 \day
Specific yield	0.19 – 0.23
Average hydraulic gradient (I)	0.005
Static water level	Western bank (30 - 40 m) Eastern bank (11 - 40 m)
Well yield	10 - 50 m^3\h

Aquifer storage and recovery is the process of conveying and storing water in the subsurface during times of abundance [13]. Aquifer test analysis represents the most important means of estimating and evaluating the hydraulic parameters from the pumping test data and other tools. Based on pumping test data, the hydrogeological parameters have been calculated such as transmissivity, hydraulic conductivity and aquifer storage capacity. The aquifer parameters of the study area are presented in Table (1).

The transmissivity is the rate of flow under a unit hydraulic gradient through a cross section of unit width over the whole saturated thickness of the aquifer [14]. The transmissivity and specific yield are the most important hydraulic parameters. These parameters are always used for calculating the recharge to the aquifer and the storage quantity of water within the aquifers [15]. Commonly the aquifer types in the study area are confined; therefore, the transmissivity was calculated using Jacob method (Table 2). Based on this method, the field drawdown data of each well were plotted versus the corresponding time on a semi-logarithmic paper, applying the following formula:

$$T = 2.3\ Q / 4\Pi s$$

Where:

T= Transmissivity (m^2/d). Q = Discharge rate (m^3/d) and S = Draw down per one log cycle.

Table (2). *The measurements on the monitoring wells in the western and eastern banks of the River Atbara.*

Well Name	Area	Longitude	Latitude	S.W.L (m, a.m.s.l.)			
				June 1990	June 2010	Oct. 2010	June 2011
Srooba	W. bank	35.94489	15.0901	31.60	32.10	32.19	32.07
Alquerashi	W. bank	35.91566	15.11684	34.20	34.00	34.03	33.97
Ballaa Alhayia	W. bank	35.84306	15. 17684	34.75	34.80	34.79	34.69
Khor Allaban	W. bank	35.84987	15.15689	39.40	38.77	38.68	38.77
Sarab Tawie	E. bank	35.92666	15.16273	31.34	31.31	31.34	31.36
Tagoob South	E. bank	35.90470	15.17665	12.59	12.54	11.01	11.50
Tagoob North	E. bank	35.90514	15.17820	11.00	11.45	12.17	12.44
Tagoob Central	E. bank	35.90493	15.17735	12.39	12.54	12.00	12.24
Elseuel	E. bank	35.83273	15.29014	41.33	40.83	40.83	40.83
Umyouy	E. bank	35.78878	15.33465	28.23	27.50	27.42	27.43

The Transmissivity was calculated to be in the range between 1000 - 1500 m^2\day, where the average transmissivity value is 1200 m^2\day.

The hydraulic conductivity (K) is the capacity of materials to transmit water. It depends on the porosity, size and shape of the pores [14]. The hydraulic conductivity was calculated using the formula:

$$K = T / h$$

Where:

K = Hydraulic conductivity (m/day), T = Transmissivity (m^2/d) and h = Aquifer thickness (m).

Appling the transmissivity values of 1000 m^2/day and 1500 m^2/day, the hydraulic conductivity in the study area ranges between 50 to 75 m/day, while the thickness of the aquifer is 20m in average.

The groundwater storage capacity is defined as the volume of water that can be drained by gravity or can be pumped from materials [14]. The groundwater storage capacity of the study area can be estimated by the following equation:

$$S = A\ d\ Sy\%$$

Where:

S = groundwater storage capacity, A = surface area of the aquifer (m^2), d = average saturated thickness and Sy = specific yield.

Then the calculations of the storage capacity (S) for the aquifers in the western and eastern banks are:

$$S\ (\text{western bank}) = 150 \times 10^6 \times 15 \times 0.2 = 450\ M\ m^3$$

$$S\ (\text{eastern bank}) = 250 \times 10^6 \times 20 \times 0.2 = 1000\ M\ m^3$$

According to the above calculations, the estimated groundwater storage capacity in the study area was found to be 1450 Million cubic meters.

4.3. Groundwater Level Fluctuations

The natural groundwater balance is overturned into an unbalance where the input to water table is comparatively much more than the natural groundwater flow [16]. The depth to water table depends on the topography of the area, geological conditions and hydraulic gradient. From the monitoring data, the depth to water level in the deep boreholes that reach the bed rocks in the study area does not show great variations. It ranges between 30 - 40m in the western bank; and between 11 – 40m in the eastern bank of the River Atbara, with noticeable rise near to the river (Table 2).

The water levels fluctuate primarily in response to variations in recharge and discharge rates. These fluctuations are reflected in the water level changes in monitoring wells. Four monitoring wells were selected in the western bank in the study area and six wells in the eastern bank to study the groundwater fluctuations (Table 2). The measurements show that there is no fluctuation in the water level between the wet and dry seasons (Fig. 6), with the exception of some wells situated in the eastern bank of the river (Fig. 7).

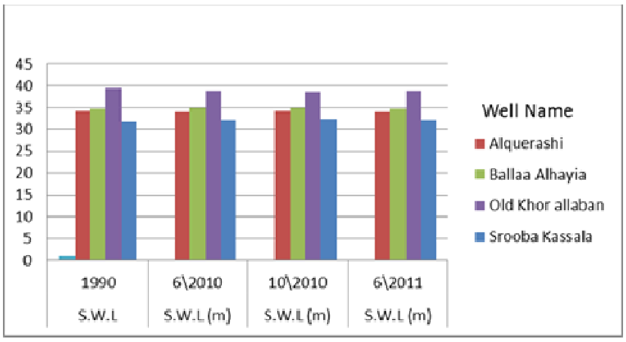

Fig. (6). *Static water level fluctuations in selected boreholes on the western bank.*

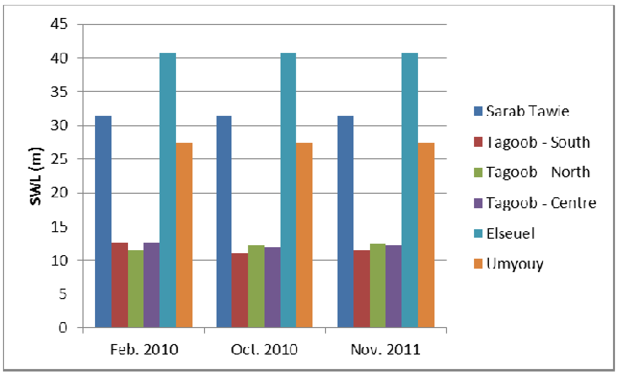

Fig. (7). *Static water level fluctuations in selected boreholes on the eastern bank.*

The groundwater flows in the same direction as the surface water of the River Atbara and its tributaries flow (Fig. 8). The general direction of groundwater flow is towards the NW with calculated average hydraulic gradient of 0.005. The water level contour map indicates that the River Atbara and its tributaries represent the main source of recharge to the aquifers on both sides of the River.

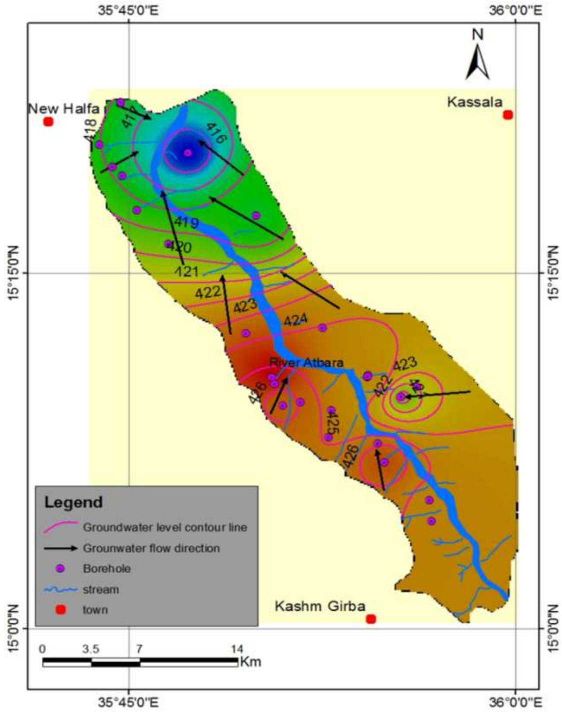

Fig. (8). *Groundwater levels contour map in meters a.m.s.l. (October 2010)*

5. Conclusion

The study area lies in Kassala State, eastern Sudan. The population in the study area is concentrated at the western bank of the River Atbara where the New Halfa Agricultural Scheme is located with a very small numbers living at the eastern bank of River. The area is characterized by arid climate with annual average rainfall around 230mm and the annual average evaporation is around 185mm.

The main geological units in the River Atbara watershed are: Precambrian basement complex, Triassic to Cretaceous Sandstone, Tertiary basalt and Pleistocene to Recent alluvial sediments. The basement rocks generally crop out in the form of scattered hills. It is overlain by thin layers of the Cretaceous Sandstone of the Gadaref Formation which is sometimes locally injected by Tertiary basalts. Miocene to Pliocene age sediments (*Karab*) occur on the top of the succession representing the lands of River Atbara Basin. The Quaternary clays cover the plains away from the river.

The River Atbara alluvial aquifer is extended under the *Karab land* to about 2-3 Km on each side of the river banks. It consists of alluvial deposits with lateral and vertical facies changes. The depth to basement rocks ranges between 50-65m below the ground surface. The Transmissivity values range between 1000 - 1500 m^2\day. The groundwater storage capacity in the study area was estimated to be 1450 Million cubic meters. The depth to water level does not show great variations among the seasons; it ranges between 30 - 40m in the western bank and between 11 – 40m in the eastern bank. The outcome of the present study indicates that there are no significant variations in water levels between the wet and dry seasons. The River Atbara and its tributaries represent the main source of recharge to the aquifers. The general groundwater flow is towards the NW direction with average hydraulic gradient of 0.005.

Acknowledgment

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