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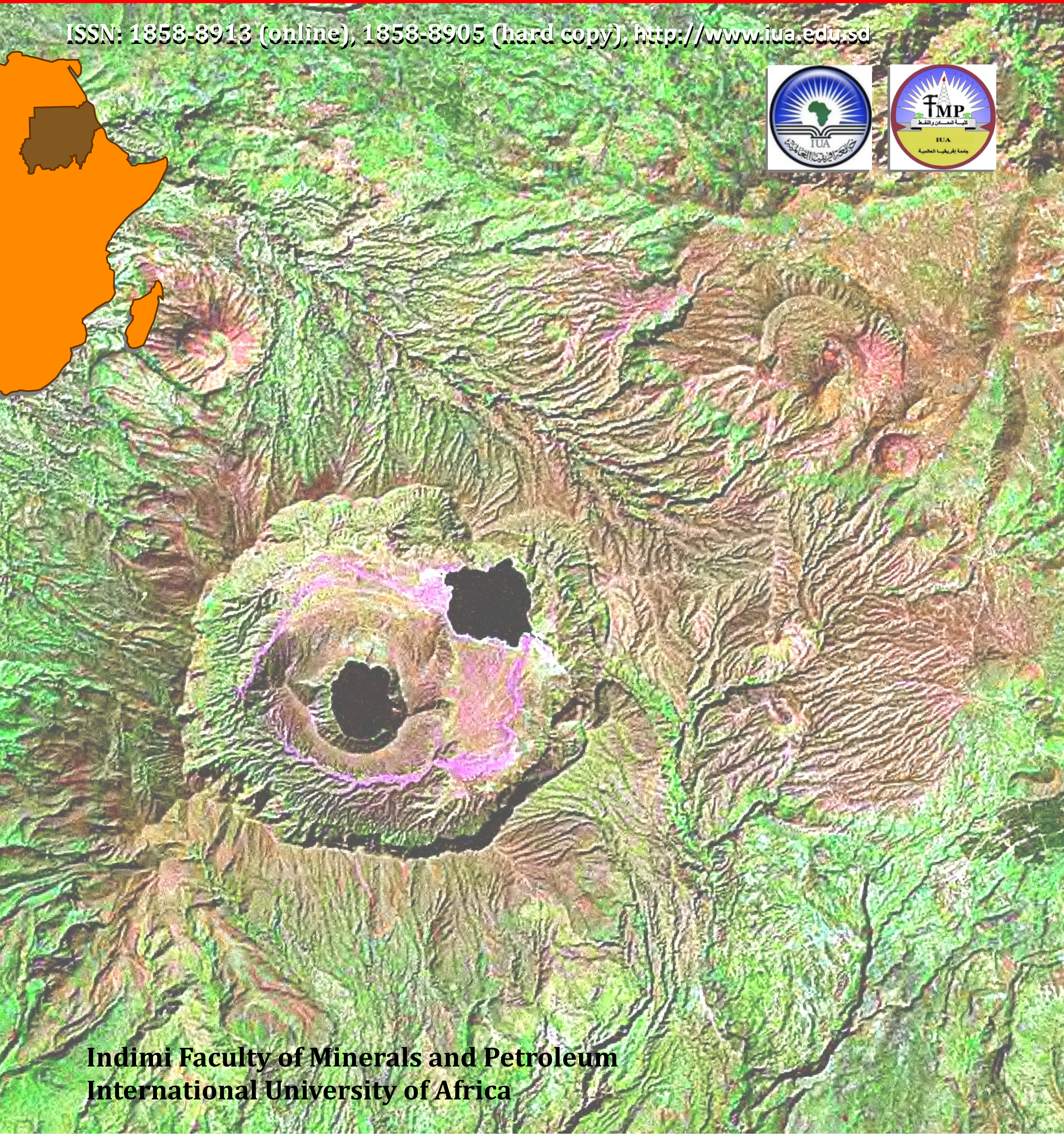

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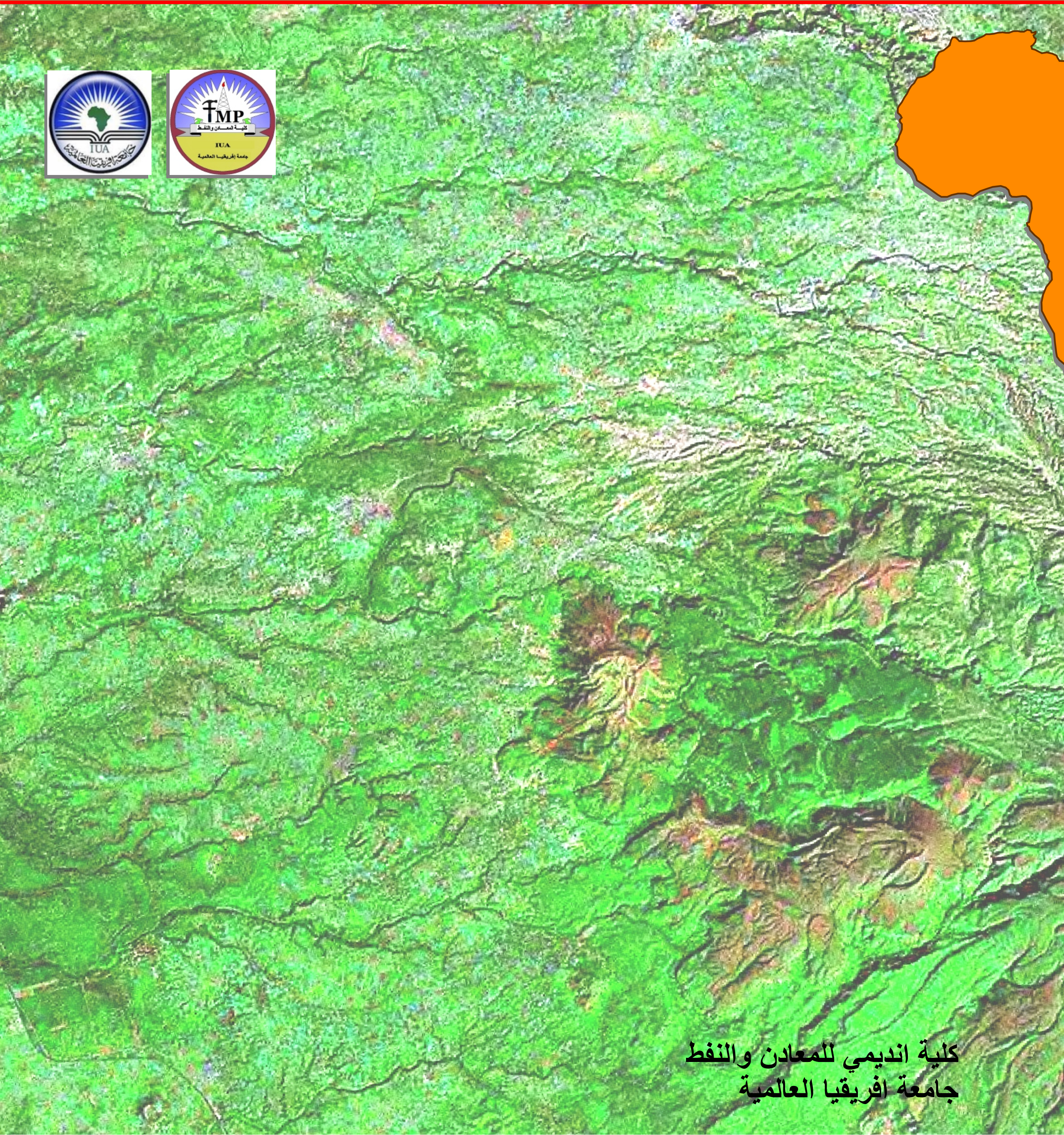

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Geophysical Investigations and Hydrochemical Characteristics of Groundwater in Part of the Eastern Nile Region, Khartoum State, Sudan

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Abstract
Total of 24 vertical electrical sounding were conducted in the area of Eastern Nile, Khartoum state. The VES data were used with bore hole data to detect the thickness of the sedimentary layers and to evaluate potentiality of the ground water aquifer as well as its water quality. The resistivity data were analyzed and interpreted by using 2IPI2win for data inversion, whereas the bore hole data were interpreted by using Chemists and Aquichem software borehole data. The interpreted data were presented in a form of geological sections, the hydrogeological maps and piper diagram. The results confirmed that the Nubian sandstone is the main groundwater aquifer in the area where the sandstone and conglomerate represent the water bearing horizons, which has a thickness varies from 10 to 250m. In the northeastern part of the area the Nubian aquifer is separated by mudstone strata into upper and lower aquifer whereas in south and southeastern part. The aquifer separated by fine sand layer. The thickness of the lower aquifer in the south is greater than the thickness of the northern part of the area. The salinity in the northern and northeastern parts (about 5000 to 7000ppm) is to the attributed presence of evaporates (gypsum and carbonates) and decreases toward the southern part. The water type varies from (Ca-Mg-HCO_3) near the Nile to sodium, chloride Bicarbonate (Na, Cl, HCO_3) and sodium, chloride sulfate (Na-Cl-SO_4) water types at the center and eastern part of the area.

Key words: ER VES, hydrochemistry, Eastern Khartoum, groundwater pollution

1. Introduction
The study area lies on East Blue Nile- locality of Khartoum state, bounded by latitudes 15° 31′ & 15° 35′ N and longitudes 32° 35′ & 32° 51′ E (Fig. 1). It covers an area of about 180 square kilometers extend from the Blue Nile in the West to AlShiek Alamin Village in the East. The topography of the area is generally flat intersected by small valleys. The general slope from Alsheik Alamin in the east to the west in the direction of Blue Nile.

The climate of the area is classified as semiarid with hot dry summers (April- October) and a cold dry winter. The rainy period starts in late of June and ends in the early of October. The vegetation cover consists of some trees and grasses. The area study is populated near the Blue Nile and density of population drops rapidly away from the Nile. The major tribes of the area are Bataheen, Shukria, Musallemiya, and Hassaniya. Peoples in this region bread sheep and goat, and some depend on agriculture during the rainy season.

The study area studied previously by Kheiralla (1966), and Whiteman (1971), who described the geology of the Nubian formation with special references to the groundwater geology for the area between latitudes, 14◦N and 17◦N. Whiteman in his book on the geology of the Sudan gave a review about the nomenclature. Saeed (1976); described the theoretical interrelations and possible classification of groundwater hydrochemistry in Khartoum Province. During Sudanese German Exploration Project (1979) field investigations were carried out for evaluating the groundwater resources in the area of the three towns of Khartoum Province. Haggaz, and Kheiralla (1987) studied the aspect of recharge to the Nubian aquifer system near the confluence of Blue and White Niles using isotopes and water chemistry techniques. Salim (2005) determine the hydrogeology of the area East of river Nile, Khartoum Province. Daffalla (2009) applied the groundwater flow model to determine the groundwater resources East of the Blue and River Niles.

The objectives of this study are to assess the resources and salinity of the ground water, and to comment on its validity for domestic use, agricultural purposes, animal breeding, and for sustainable development, with specific objectives such as:

To delineate aquifers depths and the ground water flow, the source and direction of increasing salinity should be inconsideration.

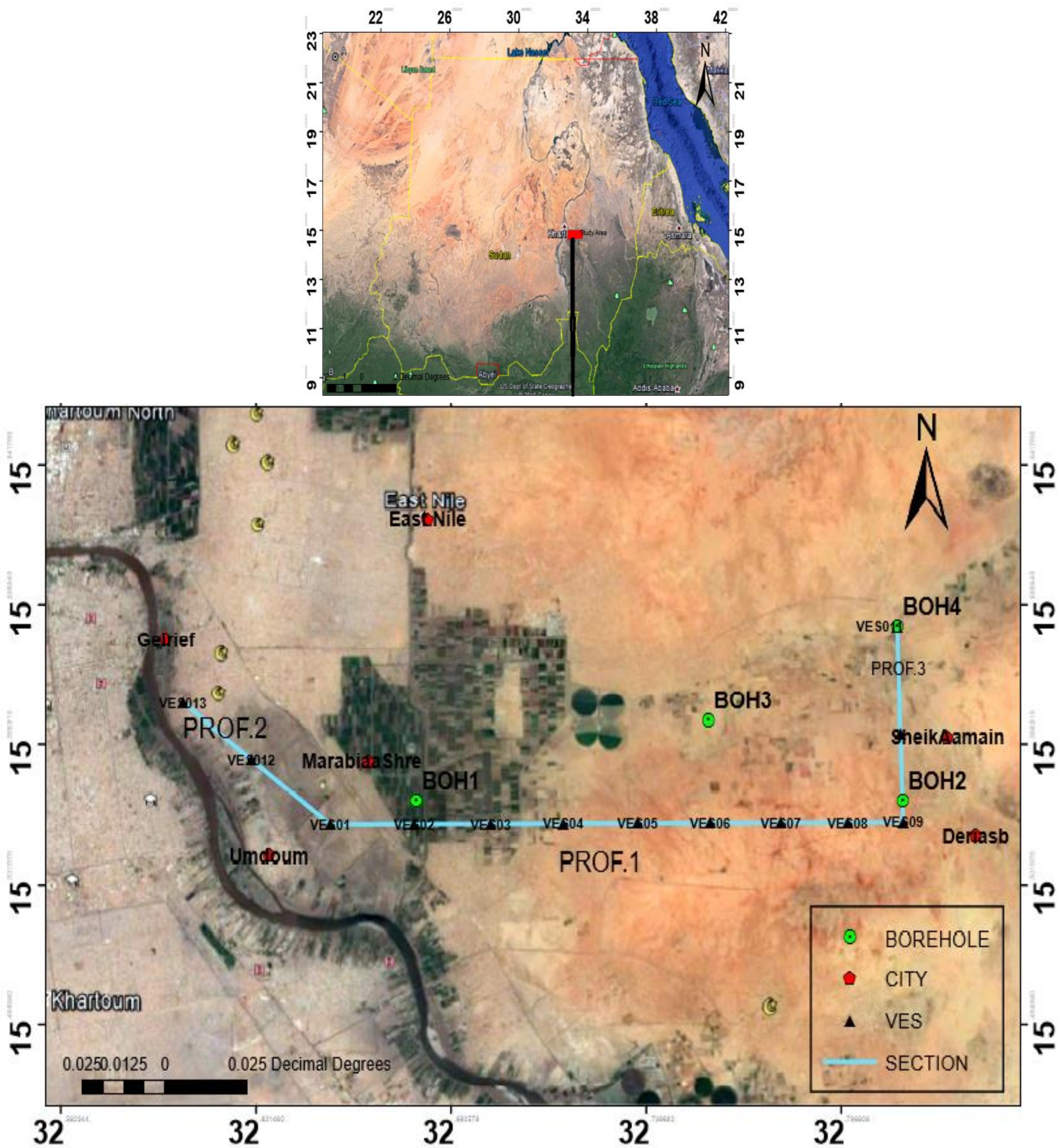

Fig. 1. Location map of the study area.

2. Geology

The general geological sequences in the study area are as follows:

- Basement Complex (Pre-Cambrian).
- Sileitat- ElsSufer igneous complex (Middle Jurassic).
- Nubian sand stone formation (Late Cretaceous /early Tertiary).
- Volcanic rocks (Tertiary).
- Superficial Deposits (Cenozoic/ Quaternary)

The above sequences (Bireir et al., 1997) presented on Eastern Khartoum.

In the study area this group of rocks include Sabaloka igneous complex, Abu Tulieh complex, Sileitat complex and Qeili complex. These are group of shallow level igneous activity comprising volcanic and equivalent plutonic rocks. Delany (1952) recognized that the ElSilitat Es –Sufur has been centrally regarded as close relation of Sabaloka ring complex. Almond and Ahmed (1993) considered the ElSilitat complex to be younger on the ground than the Sabaloka and Abu Tulieh complex.

The Cretaceous Sedimentary Rocks (Nubian sandstone Formation) is the most extensive and largest aquifer in Sudan.

The Nubian sandstone Formation cover the whole area of the study based on the logs of the pore holes drilled in the study area. There are three main lithological sequence within the Nubian Sandstone Formations in the study area Haggaz and Kheiralla (1987):

The Recent and superficial deposits, cover the underlying sedimentary and basement rocks, can be subdivided into (Haggaz and Kheiralla 1987):

2/4-A- wadi filled deposits or Wadi-blown sand. It consists of unconsolidated gravel, sand and silt deposit range in thickness from 3 to about 20 meters (Haggaz and Khierallah 1987).

2/4- B- Nile Alluvium and wadi filled deposits, are consisting of gravels,micaceous sand, silt deposit annually after the Nile flooding forming material carried largely as suspended load (Haggaz and Khierallah 1987).

The Alluvial deposit range in thickness from 3 meter to about 20 meters in the study area.

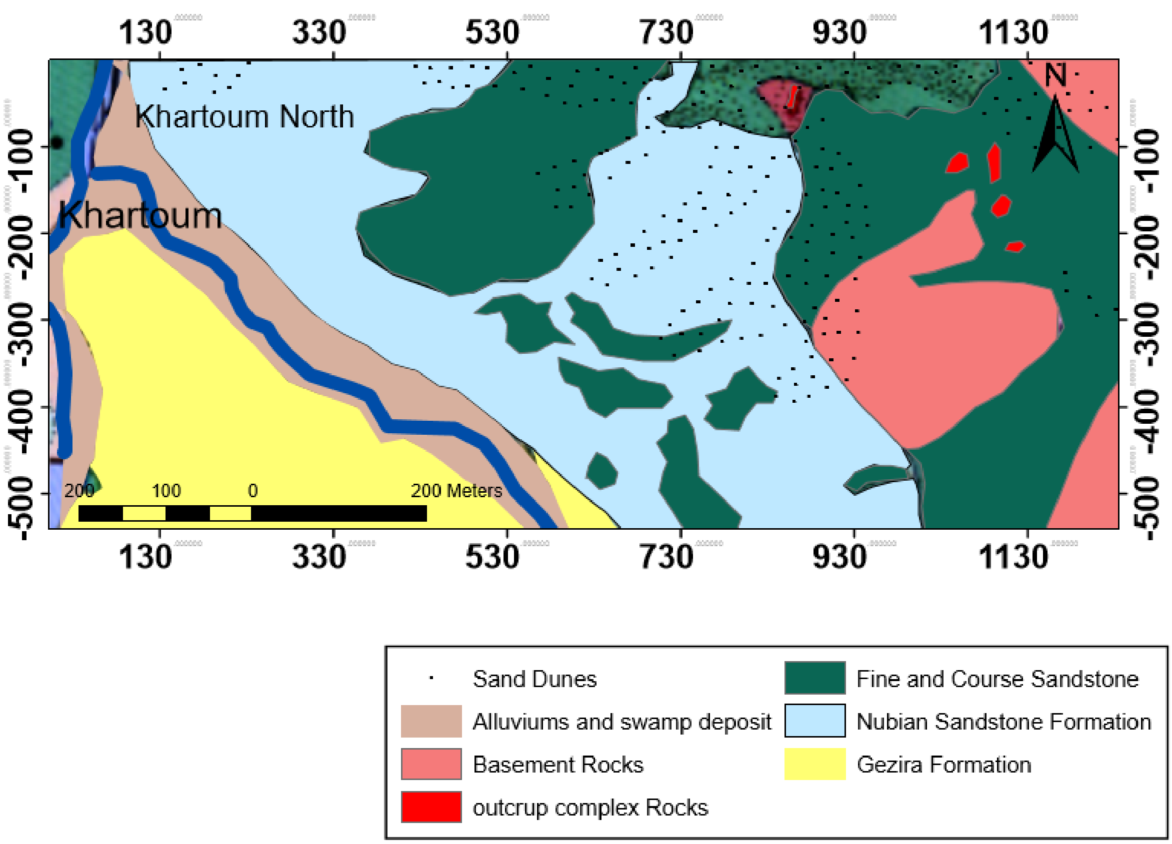

Fig.2. Geological map of the study area

3. Groundwater

Over much of the area, groundwater occurs mainly in the Cretaceous sedimentary (Nubian sandstone) Formation and alluvial deposits of seasonal streams and the Blue and River Niles. The water is transmitted by intergranular flow. Aquifers of the alluvial deposits and the Cretaceous sedimentary (Nubian sandstone) Formation are believed to be hydro logically interconnected (Kheiralla, 1966).

Two aquifers have been recognized in the Cretaceous sedimentary (Nubian sandstone) Formation. An upper aquifer of variable thickness (10-150 m) with transmissivity (T) of 79 m^2d-1 and hydraulic conductivity (K) of 3 md^{-1} and lower one of more than 400 m thick but which has higher value of transmissivity and hydraulic conductivity (e.g. T = 646 m2d-1, K = 216 md-1 respectively) (Haggaz and Kheiralla, 1987).

4. Materials and Methodology

-The electrical resistivity method is the most useful geophysical method for groundwater exploration. In this study the resistivity data were collected where 13 vertical electrical sounding (VES) were performed using Schlumberger electrode configuration. The VES points are distributed along three lines and interval between points is 3000m (Fig.1).

The maximum electrode separation (AB/2) was 1000m, the data were collected by ABEM(SAS4000) Terrameter. The inversion and modeling of the resistivity sounding data is committed by using inversion software (IPI2win)

- 33 samples of groundwater were collected from borehole and wells in the study area for chemical analysis. All data processed by using GIS, Surfer, IPI2Win, Chemtest, Aquitest, GPS computer programs.

5. Results and Interpretation

The resistivity data were analyzed and interpreted qualitatively and quantitatively a check was made by calibration of sounding data with the boreholes data.

The interpreted results were presented in form of tables (1,2,3) and geoelectric sections and lithology of wells using software package such as GIS, GPS, Rock ware. The interpreted VES models along each profile (1), were combined and presented as two dimensional resistivity model.

The geoelectrical sections are discussed below:

Profile 01

Profile (1) is located along the southern on part of the area (fig 1) and its extended (E-W), this profile includes VES01, VES02 and VES03, VES04, VES05, VES06, VES07, VES08, VES09. Summary of results of Profile(P01), is given in Table (1) and the corresponding data curves.

Table 1. Results of Profile (1).

VES No.	Layer No.	Resistivity	Thickness	Type-curve
VES01	1	115	4.7	HKA
	2	13	14.9	
	3	146	60.8	
	4	39.8	178	
	5	31878	-	
VES02	1	82.1	3.6	HKHA
	2	22.9	11.3	
	3	139	50.1	
	4	25.8	200	
	5	24796	-	
VES03	1	96.4	1.9	HKA
	2	166	2.08	
	3	30.7	7.7	
	4	182	16.6	
	5	423	190	
	6	11835	-	
VES04	1	19.6	6.1	KHA
	2	360	6.7	
	3	31.9	195	
	4	4812	-	
VES05	1	19.3	1	KA
	2	6.07	0.7	
	3	43.7	25.8	
	4	73.1	260	
	5	13440	-	
VES06	1	25.6	18.8	KHA
	2	447	21.5	
	3	14.9	200	
	4	2266	-	

VES07	1	18.7	0.9	**KHA**
	2	199	0.91	
	3	51.7	13.2	
	4	9.16	15.2	
	5	43.6	233	
	6	364	-	
VES08	1	13.7	4.9	**KHA**
	2	4.09	23.8	
	3	23	331	
	4	16.7	-	
VES09	1	19.8	0.9	**KHA**
	2	16	2.7	
	3	129	3.7	
	4	39.4	124	
	5	151	125	
	6	507	-	

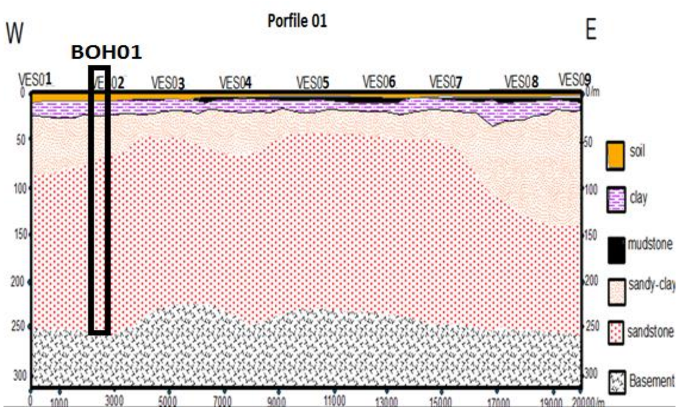

Fig. 2. Geological section of profile-1

The resulting vertical electrical sounding curves correspond to five and four layers' case. The dominant curves types are HKQ and KHA. It shows a high resistivity layer indicating low salinity and/or sand rich aquifer, which represents a good aquifer with low salinity.

A combined geological and geoelectrical correlation model constructed from a combination of VES and lithological logs obtained from the boreholes, show two Nubian Sandstone aquifers, upper one consists of fine sandstone and intercalated with clay layers, and lower aquifer consists sandstone (coarse, pebbly, etc.) intercalated by clay. The two aquifers are separated occasionally by low permeability layer in some places it is considered as one aquifer. The groundwater salinity (TDS) ranges 500 to 1000PPM.

Profile 02

Profile (2) is located on the west part of the area (Fig 35) and it extend (NW-SE), this profile includes VES01, VES012 and VES013, Summary of results of Profile2, is given in Table (2) and the corresponding data curves.

Table 2. Results of Profile (2).

VES No.	Layer No.	Resistivity	Thickness	Type-curve
VES01	1	115	4.7	HKQ
	2	13	14.9	
	3	146	60.8	
	4	39.8	178	
	5	31878	-	
VES12	1	22.2	4.7	HKQ
	2	92.2	7.03	
	3	6.82	21.2	
	4	137	35.5	
	5	44.4	151	
	6	9239	-	
VES13	1	24.1	2.8	HKQ
	2	5.5	2.4	
	3	181	22.7	
	4	56.6	230	
	5	27971	-	

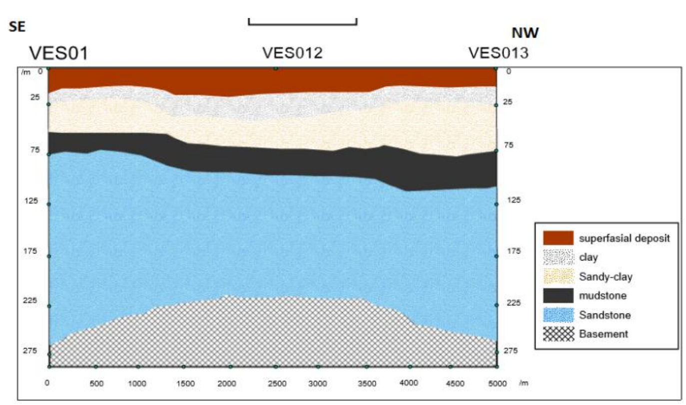

Fig. 3. Geological section of profile-2

The interpreted VES models along profile(P02), were combined and presented as two dimensional resistivity model. It shows a high resistivity layer indicating low salinity and/or sand rich aquifer. The basement complex shallow onVES012(185m) at middle and deep on VES01(270m) at South east profile, and also at VES013(275m), thickness sand layer is set on basement along the profile is refers to lower aquifer with low salinity, and mudstone layer overlies it covered by sandy-clay layer is refers thin upper aquifer of water it is relatively high salinity.

The two aquifers are separated by low resistivity zone (‹ 5 ohm-m) possibly suggesting clay and mudstone layer. The lower aquifer is a thick and low salinity compared with upper aquifer (150 – 200m), resistivity (50 – 120 ohm-m) due to intercalation of sandy/clay layers, and the two aquifer are separated by mudstone layer which is thicker at VES01 and VES012, and thinner at VES013.

Profile 3

Profile (3) is located in the Eastern part of the area (Fig 14) and extends (N-S), this profile includes VES9, VES10 and VE11, Summary of results of The Profile1is given in Table (3) and the corresponding data curves.

Table 3. Results of Profile (3).

VES No.	Layer No.	Resistivity	Thickness	Type-curve
VES09	1	19.8	0.9	KHA
	2	16	2.7	
	3	129	3.7	
	4	39.4	124	
	5	151	125	
		507	-	
VES10	1	333	2.84	HA
	2	42.6	20.1	
	3	11.5	91	
	4	475	-	
	5	-	-	
	6	-	-	
VES11	1	55	3.4	KHKQ
	2	306	4.58	
	3	8.15	8.96	
	4	47.9	63.4	
	5	6.6	91.5	
	6	1951	-	

The interpreted VES models along profile (P03) were combined and presented as two dimensional resistivity model. The model shows two possible groundwater aquifers. The upper aquifer is thin in the northern and middle part (VES09, VES010, VES011), and thick in southern part (VES03), it contains fresh water.

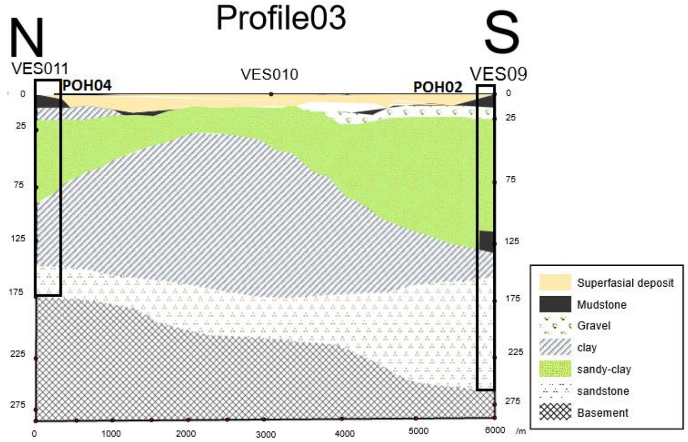

Fig. 4. Geological section of profile-3

The two aquifers are separated by low resistivity zone (‹ 20 ohm-m) possibly suggesting clay and a mudstone layer. The lower aquifer is a thick and has salinity compared with the upper aquifer (125 – 220m). The lower aquifer in north and middle part (VES01, VES02) has relatively low resistivity (20 – 50 ohm-m) due to intercalation of mudstone layers, the high resistivity in south part (VES03) (100 – 200 ohm-m) is due to intercalation sandstone and clay layers.

The lower aquifer is thick and low salinity at the south and south compared with middle profile (150 – 200m), relatively low salinity resistivity (40 – 80 ohm-m) due to intercalation of sandy/clay layers, and low resistivity at middle part (VES021) (20 – 40 ohm-m) due to intercalation mudstone and clay layers.

Chemistry of Groundwater

Generally, the Total dissolved solids(TDS) in the area varies between 446.6 and 7000 mg/l. The middle, northeastern and northern part of the study area have the higher TDS concentration (Table 4). Generally, high values were attributed to the concentration of salt depends on the environment, movement and source of soluble salt in ground water originated from dissolution of rock materials.

Graphical representation is useful for display purposes, comparing analysis and emphasizing similarities and differences. Graphs can also aid in detecting the mixing of water of different compositions and in identifying chemical processes. The most plausible method has to be selected on the basis of hydro geologic evidence it is a trainer (piper diagram; Hem, 1971).

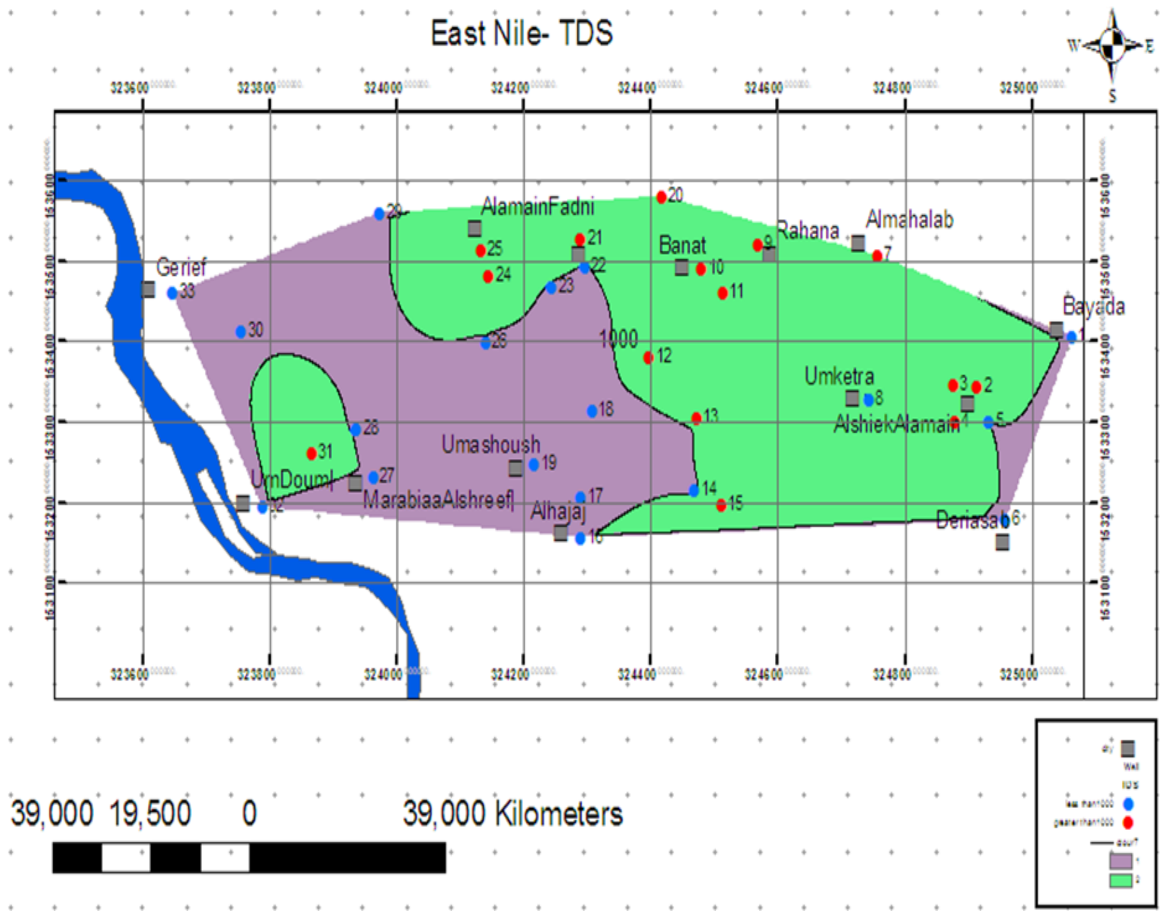

Fig. 5. TDS map of the study area.

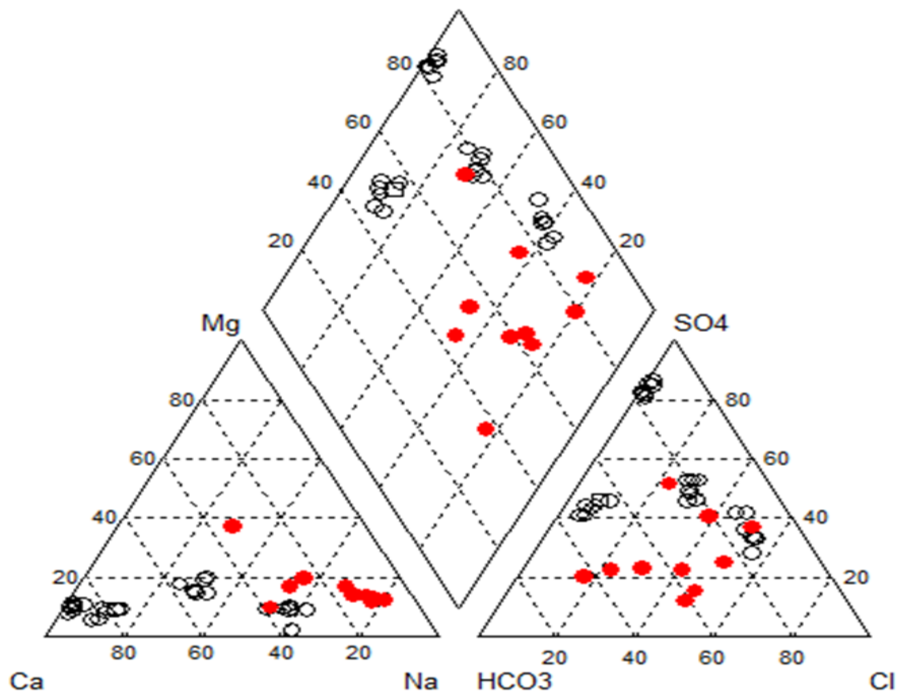

Fig. 6. Piper diagram to indicate the faces of the study area.

According to Chemical characteristic of the water table (4) and piper diagram (Fig. 6). 75% of the Nubian sandstone aquifer samples are characterized by Na - SO4- CL water-type.

Conculsions

The result of the interpretation of the obtained geoelectric data aided by borehole data indicate that:

- There are two aquiferous zones which are separated by thick mudstone layers in the Northern part of the area, and by fine to medium grained sandy clays in southern part of the study area (Deraisab, Wad Alhadou, Almanara, Marabiaa Alshreef)
- In general, the salinity of the upper part of aquifer is higher than that of the lower parts of the aquifer. However, in some places, the lower part of the aquifer is also saline because the impermeable mudstone separating the two aquiferous zones are absent.
- High concentrations of TDS were detected at the north, northwest and southern parts of the study area while the middle and eastern parts are characterized by low concentrations.
- The north eastern parts of the study area are characterized by high salinity ranging from 5000 to 7000 ppm of total dissolved solids.
- About 58 % of the ground water samples in the Nubian and alluvial aquifers (upper aquifer) have TDS more than 1000 ppm (above the permissible limits of WHO). All samples from the lower Nubian aquifer are within the permissible limits. TDS increased in the NE direction.
- 75% of the Nubian sandstone aquifer samples are characterized by Na - SO4- CL water-type.

Recommendations

Based on result and interpretation it is recommended that:

- Geophysical investigations should be carried out first before drilling to delineate the aquifer salinity boundaries.
- Proper aquifer test with observation and piezometric wells are needed to obtain actual values for the hydrologic characteristics of the aquifers. The present information on the aquifers is mainly based on single well test which may have no large significance.
- To monitor the aquifer behavior, observation wells have to be drilled and equipped with automatic water level recorders.
- Ground water modeling for the study area must be done using sufficient amount of boreholes data including water head measurement, pumping rate and lithologic

description of well samples in addition to metrological and hydrological data.

- Ground water quality and pollution should be investigated for future studies using modeling techniques

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