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Evaluation of Ground Water Quality in North East Wadi Halfa, Northern State, Sudan

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Abstract In this current study, groundwater quality is the main hydrological problem. The study aims to define the groundwater quality in the Assessment and Evaluation of Ground water Quality in North East Wadi Halfa, Northern State, Sudan. Physical, chemical and biological analyses were carried out on 10 water samples collected from the existing wells. For investigating different cations and anions the titration, spectrophotometer and flame photometer were used. Chemical analysis shows high concentration of sulfates and nitrates. The hydrochemical classification of groundwater explained for groups: ($Na^+ + K^+$), HCO_3^- water, ($Na^+ + K^+$), ($SO^{++} + Cl^-$) water, ($Ca^{++} + Mg^{++}$), HCO_3^- water and ($Ca^{++} + Mg^{++}$), ($SO^{++} + Cl^-$) water. Bacteriological analysis was made for 10 samples; water is free of contamination. A comparison has been made between two-water analysis in 1991 and 2019, as a result decreasing in the salts concentration in the latter. Therefore, according to the results of this study, it is recommended and guided for further pumping and continuous using of the water well in agriculture purposes.

Keywords: *cations, anions, analysis, hydrochemical, contamination*

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1. Introduction

Water plays a vital role in the development of any country. Productivity of groundwater is quite high compared to surface water. The underground water is considered to be the main water source in arid and semi-arid regions in Sudan. In the study area, the aquifer belongs to the Nubian sandstone Nile aquifer. The recharge source is The Nubian lake through the sedimentary beds and fractured basement rocks. This aquifer extends from east Kordofan basin to the Egyptian border. The quality of water is depending on its physical and chemical properties to be use. Climatic condition in the study area is predominantly arid to semi-arid, in summer temperature ranges 47°C – 30°C while in winter ranges 20°C – 5°C, rarely annual rainfall, drainage system is very poor and humidity sometimes high up to 83% due to the great surface area of Nubian lake.

2. Study Area Description

2.1. Location and Accessibility:

The study area is located in north east of Wadi Halfa city cutting the international Sudan – Egypt road confined between latitude 21° 59' 58", 21° 42' 30" and longitude 31° 30' 40", 31° 19' 60" in the north situate Ashkiat village near the Ashkiat customer towards south Dabroosa, Diegem and Angash villages. It can be easily accessible from the international Sudan – Egypt road going to sandy road by four-wheel car.

3. Study Problem

It's noticed that from the few drilled wells the salinity of water is very high. The current study searches for solving this problem, which will be, shear by addition quantity of water for future irrigation projects in Wadi halfa town.

4. Objectives of the Study

The Objectives of the study are to:

1- Evaluate the groundwater quality based on physical, chemical and biological properties of the groundwater.

2- Comparison between two-water analysis in 1991 and 2019.

3- Treatments of the water salinity.

4- Detect its suitability for different uses.

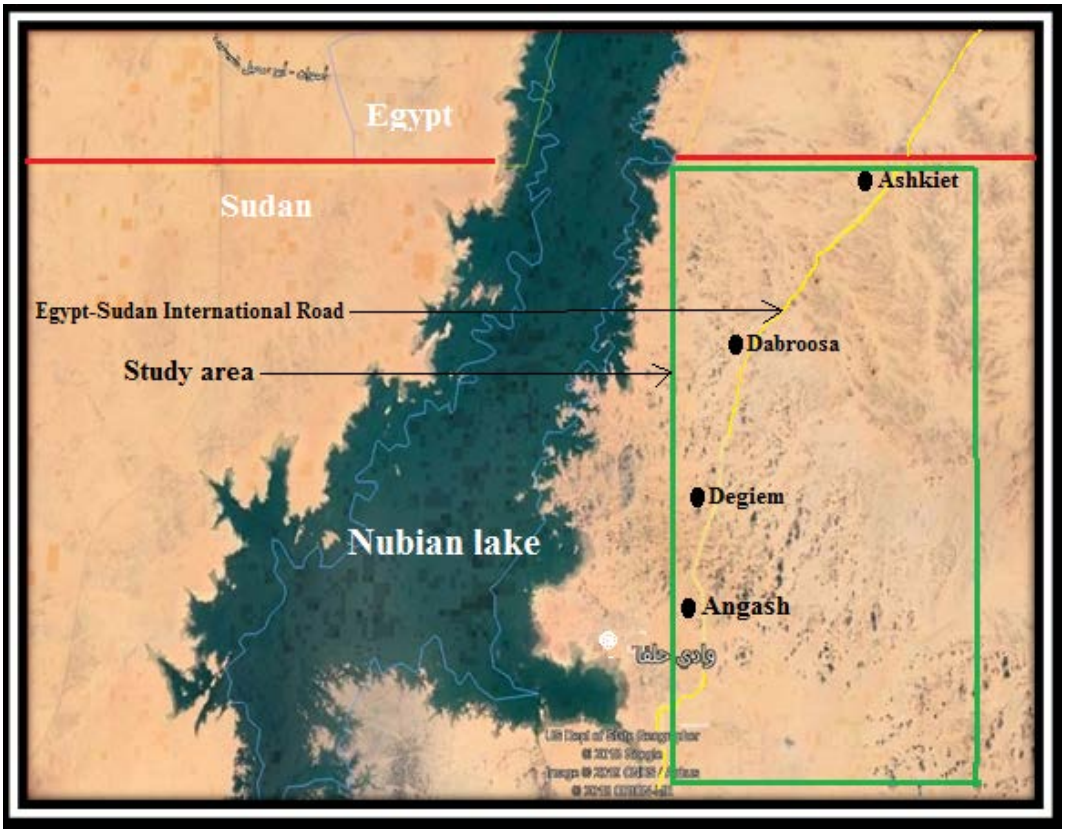

Figure 1. Location map of the study area

5. Method and Materials

The following steps have been adopted to achieve the objectives.

5.1. Field Work

1- Number of water samples collected from the wells in 1991.

2- *pH meter* is used for Physical properties measurements as *pH*, EC and temperature.

3- Groundwater level measurements.

4- GPS measurements and geological survey.

5.2. Laboratory Work

1- Hydrochemical analysis of water samples to define the concentrations of different cations and anions by means of;

• Two titration methods:

- Precipitation reaction method for detecting Ca^{++}, Mg^{++}, Cl^{-} and total hardness

- Neutralization reaction method to determine HCO_3^{-}, CO_2^{-}

2- Spectrophotometer method, based on photosensitivity of chemical compounds to light spectrum for NO_3^{-}, NO_2^{-}, SO_4^{--}, Fe^{++}, Cu^{++} detecting

3- Flame photometer for Na^{+}, K^{+} detection

4- Biological analysis of 16 samples was made for determining biological contamination e.g: coliform bacteria.

All results from both fieldwork and laboratory work were interpreted and software was used.

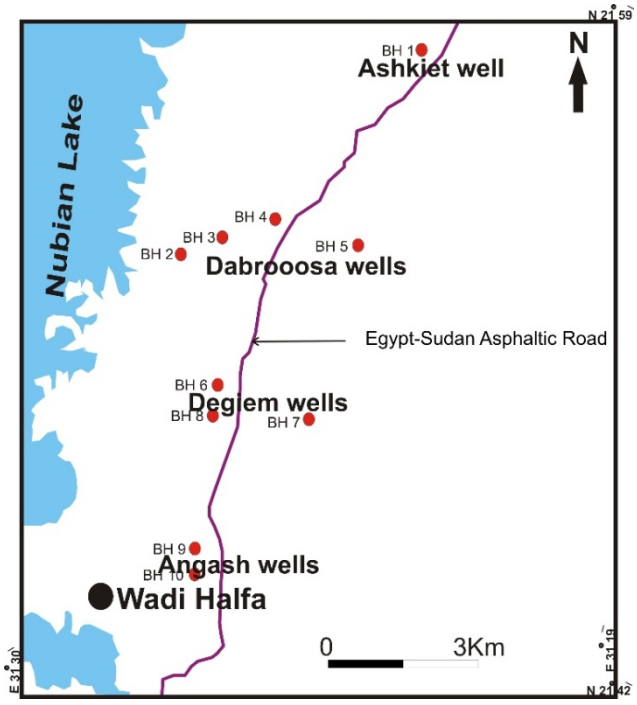

Figure 2. Locations of the water wells and samples taken from the wells

6. Previous Work

Dealing with the geology and hydrogeology, few studies were carried out in the study area. [1] have studied Wadi Halfa oolitic iron ore in north and north east part towards Egyptian border within the sedimentary rocks, with existence of volcano-sedimentary rocks. Schandelmeier

et al., [2] have studied the basement outcrops west of the nile and Wadi Hower north Sudan. Abo Sarri region has been maped geologically by [3] and [4] differentiated the rock units around Wadi Halfa. Nadi et al. [5] wrote about the geology and economic importance of Elbeer south Wadi Halfa. [6] described the Paleozoic sedimentary sequences.

7. Regional Geology of the Study Area

The northern state geology composed of the following rock unites from older to younger:

1- Basement complex rocks.
2- Nubian formation.
3- Tertiary volcanic.
4- Superficial deposits.

7.1. Basement Complex Rocks

Many out crop of gneiss rocks, which as generally described as metamorphic rocks extended south Wadi - Halfa. The mineral grains in the rock were flattened through tremendous heat and pressure and are arranged in alternating gneiss [7]. Schist is metamorphic rock with well-developed foliation exist south Wadi – Halfa. At the study area they are usually of psamitic (quartz felspathic gneiss), pelitic (mica schist) and volcanic (chlorite schist) origin [8]. Emplaced into these rocks are a number of post-orogenic igneous bodies including granite and associated basic dykes and gabbro [9]. At the study area plutonic of (syn-late-post) organic intrusive rocks were prevailing, common and widely occurring many types of granite which as general intrusive, felsic, igneous rock, usually have a medium to coarse grained texture. Occasionally some individual crystals (phenocrysts) are larger than the groundmass in which case the texture is known as porphyritic. Diorite, granodiorite and rhyolite are another type of intrusion. Metasediments of metaconglomerate Scattered 10km south Halfa, few outcrops were seen, composed of metamorphosed porphoritic gravel and metaquartz black in colour shows very hard rock, Metaquartz outcropping and intruded the metaconglomerate, black hard mainly pure quartz, (Figure 3).

7.2. Nubian Formation

First time for the Nubian formation refers to the late cretaceous deposits in Nubian Desert south Egypt and it has been used from that time to north east and central Africa regions. The Nubian succession unconformable lies over the weathered basement complex surface and occurs either out-cropping in flat-topped plateau of forms the substratum over which the Pleistocene and recent deposits have been deposited [10], (Figure 3). The thickness of the Nubian successions in the area ranges from a featheredge to a maximum of 500m and are composed of slightly dipping, loosely to highly consolidated beds of sandstones, mudstones and conglomerate of extensive lateral extension, [1].

Mostly consists of alternating conglomeratic and sandstone, medium to fine massive sandstones marked with parallel lamination, cross bedding and alternating sandstone and mudstone beds.

In north Sudan Nubian Sand Stone Formation were differentiated into three depositional periods from bottom to top as follow:

- Lower cycle: containing marine deposits e.g: Kurkur-Umm ras-Wadi elmalik Formations of Ordovician-Late Carboniferous.
- Meddle cycle: consists of continental deposits of Late Carboniferous-Lat Tertiary e.g: Lagia formation.
- Upper cycle: composed of continental marine deposits Of Late Jurassic-Late Cretaceous e.g: Gielf elkbier-Selima-Wadi hower- Kababiesh-Gabel abide Formations [11,12].

All these formations include marine and continental fossils. The ground surface of the study area is generally low relief plain, many rock outcrops of small heights to high ones reaches 1500m.

7.3. Tertiary Volcanic

It extends from Late Cretaceous to Early Tertiary with definite occurrence in Sudan mainly basaltic group and rock debris, consists of basalt olivine, sheared gabbros and trycite.

7.4. Superficial Deposits

North Sudan is overlain by unconsolidated continental sand and sandy clay, which may vary considerably in litho logy and thickness [13]. The Quaternary Deposits fall into three main categories namely; the alluvial Deposits of the Nile Valley and of the main wadies, the lacustrine deposits in Laqiya and Selima oases and the Aeolian sand deposits almost everywhere [14].

The Nile Alluvium varies from fine alluvium mainly of silt close to the river to coarse alluvium of pebbly sand on the old terraces along its banks. The valley fill deposits occur at the course and along the banks of Wadi Howar, Wadi El Milk and Wadi Muqaddam south the study area and extend from Karema to Dongola till Abu fatma, around the study area were found at the bank of Nubian lake and consist of silts, sand and gravel indicating their torrential nature. The Lacustrine Deposits are mostly clay and marls with variable carbonate cement and occasional gypsum streaks. The Aeolian sand Deposits occur in the form of mobile and stabilized dunes and sand sheets of variable thickness covering most of the area.

7.5. Tectonic Setting

The tectonic situation is very complex in the basement and far simpler in the Nubian formation; the basement consists of a more deformed lower Gneiss complex in tectonic contact with a less deformed upper Green schist complex.

The late Mesozoic, Tertiary and Quaternary tectonics of NE Africa in general and of the study area in particular is characterized by prevailingly vertical displacements: in fact, the Nubian formation layers are practically sub – horizontal. The main tectonic trend of North State is N - NE and this influence of the Nile here when the structures cross the river, cataract appears. East of the Nile at about latitude 21º N two granite ring structure occur [15,16].

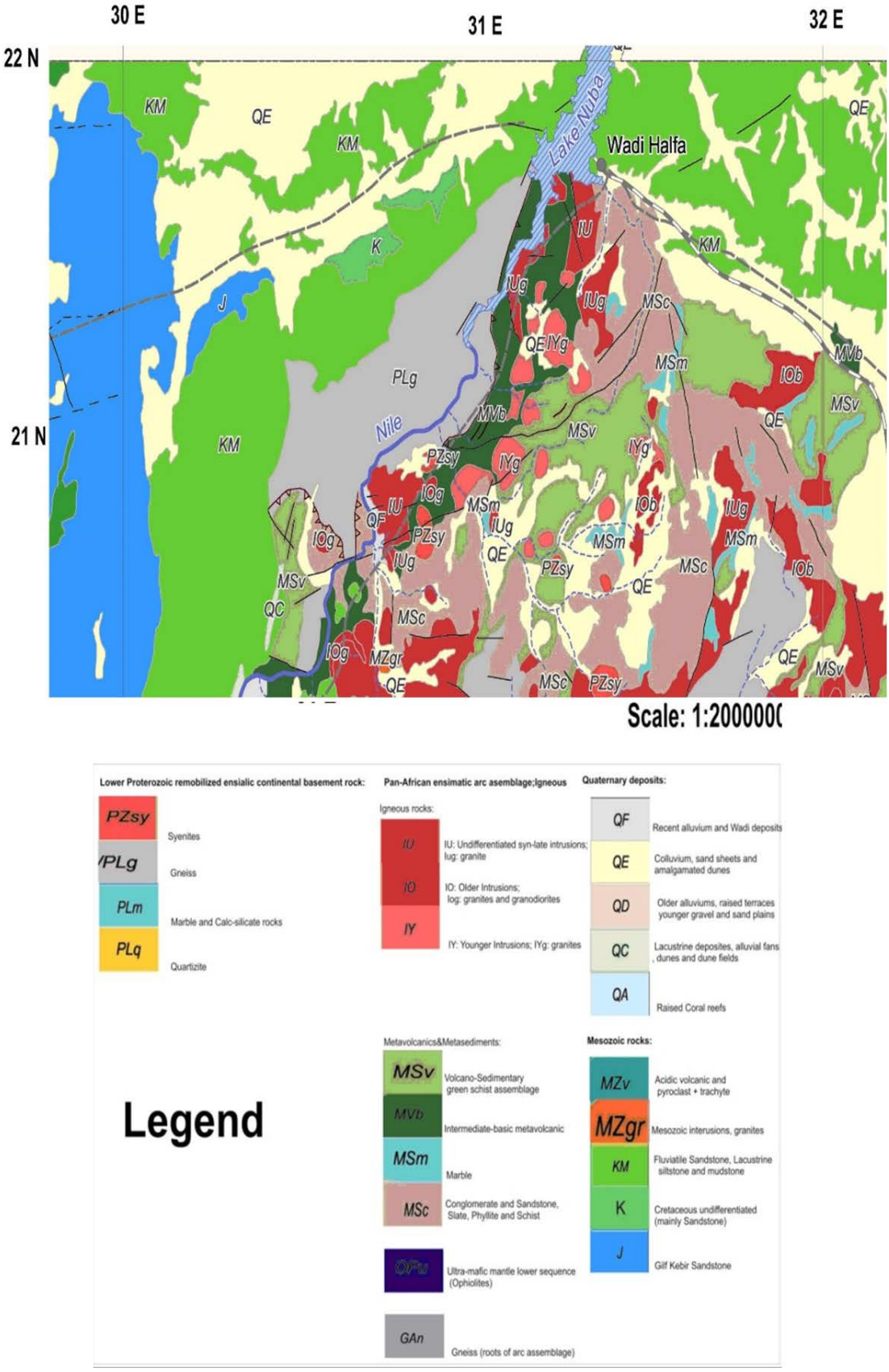

Figure 3. Regional Geological Map of the Study Area modified after GRAS 2004

North East Pan African Tectonism lead to opening of the Red Sea, the later caused the separation of the Arabian- Nubian shield and the collision of these two plates consist many volcanic mountains of island volcanic arc represented in Wadi ateery and Elbeer area south the study area. Abed elrahman [17] described the Ophiolite occurrence due to the collision between the Arabian-Nubian shield and the Nubian shield was formed.

Geologic field in the area has been prevailed some tectonic situations; the most important one is Wadi halfa fault in which displacement at the fault level happened, the southern block was raised where as the northern one was subside down. In such case, the southern block was exposed to weathering leaded to hidinning the sandstone formation from the basement rocks, few residual sandstone was remained on the irregular surface of the basement rocks making an unconformity surface. The northern block, which was subside down, was still preserved in the bottom consisting of sandstone of (Carboniferous-Permotrassic-Cretaceous) characterized by primary geological structures associated with the depositional period e.g.: cross-bedded and lithostratigraphic graduation probably was the reason for formation of the sedimentary basins in the area.

In the east and further south of the study area, it is bordered by Gabgaba Terrain affected in the western part of this terrain by the great shear zone called Keraf shear zone extends from south Egypt till north Sudan parallel to the Nile. This shear zone separates the Nile Craton in the west Nile bank from Gabgaba Terrain in the east Nile bank.

8. Results and Discussion

8.1. Physio-chemical Characterization and Quality Assessment

Significance component of groundwater flow is from southwest to north east, south to north and west to east under variable hydraulic gradient, which decrease at the eastern boundary of the aquifer due to raising basement up towards the east. The main recharge source is the Nubian lake through Nubian Sandstone beds characterized by good permeability. The physic-chemical and biological analysis result is summarized in Table 1 analyzed in 1991. The measured temperature ranges (25.1°C - 25.4°C), Hydrogen Ion concentration (pH) ranges (7.40-7.80), TDS ranges (572-3376 ppm), and EC ranges (931-4065 µs/cm) high values of both are away from the Nubian lake to the east.

All samples analyzed are chemically hard over 600 ppm except one 130 ppm of pH (4). The alkali metals (Na^{+}, K^{+}) vary in concentration between 460 - 1000 ppm and 3.6-9.3 ppm, Alkaline earth metals (Ca^{++} and Mg^{++}) show concentration values 85.4 - 18 ppm and 35.9 - 45.3 ppm. Sodium is the dominant cation in water, which can be produced by the dissolution of the albite feldspars, clay minerals or evaporates that normally, exists within the host rocks [18]. Fe^{++}, Cu^{++} occur as traces, Iron concentration ranges from (0.10 - 1.3 ppm), Cupper from (0.30-0.95 ppm) and NH_3^{+} concentration ranges from (0.038- 0.096 ppm).

Bicarbonates concentration (HCO_3^{-}) ranges from (85.5 - 145 ppm) sulphates show high values (750-1357PPm) increases outwards the Nubian lake to the east. Chloride concentration (54 - 99 ppm), Nitrate (NO_3^{-}) ranges from (42-66.7 ppm) and Nitrite (NO_2^{-}) ranges from (0.030-0.034 ppm).

The biological test shows the samples are free from any contamination (coliform not detected). Total dissolved salts, sulphates, bicarbonates and nitrates are plotted in (Figure 5).

Table 1. Results of physical and chemical analysis, cation and anions are measured in ppm

Physical-Chemical Properties	BH 1 Ashkiet	BH 2	BH 3	BH 4	BH 5	BH 6	BH 7	BH 8	BH 9	BH 10
		Dabrossa				Degiem			Angash	
Static water level m	*86.50*	87	87	87	87.50	87	87.10	87.20	87	87.15
Physical properties										
Color	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Odor	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Taste	Saline	Saline	Saline	Normal	Saline	Saline	Saline	Saline	Saline	Saline
Turbidity	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear
T°C	25.3	25.5	25.1	25.2	25.1	25.2	25.2	25.3	25.3	25.4
pH	7.55	7.40	6.85	7.45	7.60	7.70	7.80	7.70	7.80	7.60
ECµs/cm	4065	2085	2032	931	4032	3157	3560	3420	3340	4020
Chemical properties										
TDS ppm	3376	1105	1035	572	3270	2650	3066	3125	2980	3250
T. Hardness ppm	652	647	640	130	610	653	640	652	610	640
Na^{+} ppm	950	530	525	460	940	960	1020	920	1060	1000
Ca^{++} ppm	176	189	129	85.4	112.2	111	113.6	118	118	118
Mg^{++} ppm	30.8	45.3	42	38.75	38.90	38	37.9	37	35.9	36.5
K^{+} ppm	8.2	8.4	9.3	3.6	5.4	6	5.4	5.1	5.7	5.6
Fe^{++} ppm	1.3	0.12	0.13	0.4	0.10	0.12	0.92	0.96	0.18	0.14
Cu^{++} ppm	0.30	0.36	0.95	0.54	0.35	0.34	0.43	0.36	0.36	0.36
NO_3^{-} ppm	62.3	66.7	42	58.3	53.5	54.4	52.3	53.2	56.3	57.2
NO_2^{-} ppm	0.031	0.033	0.030	0.030	0.031	0.030	0.031	0.031	0.034	0.032
NH_3^{+} ppm	0.050	0.081	0.096	0.072	0.088	0.038	0.054	0.042	0.050	0.055
HCO_3^{-} ppm	109	134	97.4	122	145	122	146	105	85.5	121
SO_4^{--} ppm	1267	1357	820	750	1197	1246	1108	985	1139	1176
Cl^{-} ppm	63	65	99	66	67	68	56	54	60	90
F^{-} ppm	0.3	0.3	0.3	0.3	0.2	0.3	0.2	0.2	0.2	0.2
Al ppm	0.10	0.10	0.09	0.10	0.09	0.09	0.09	0.11	0.07	0.07
Pb ppm	0.004	0.003	0.004	0.004	0.003	0.003	0.003	0.003	0.004	0.004
Hg ppm	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Cd ppm	0.000	0.000	0.000	0.000	0.000	0.000	0.0.000	0.000	0.000	0.000
CN ppm	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bacteriological analysis	Total coliform bacteria nil/100 ml in each sample									

8.2. Hydrochemical Facies and Evolution of Groundwater

The following classification diagram [19], (Figure 4) representing the hydrochemical composition of water in the study area, according to the dominated cations and anions, four different groups of groundwater are plotted in (Figure 5):

1- (Na^+ and K^+) and (HCO_3^-) group (8.85 %)
2- (Na^+ and K^+), Cl^- and SO_4^{--} group (32.37 %)
3- (Ca^{++} and Mg^{++}) and ($HCO3^-$) group (15.62 %)
4- (Ca^{++} and Mg^{++}), Cl^- and SO_4^{--} group (43.38 %).

8.3. Process Controlling Groundwater Chemistry

Figure 6 shows 3-D diagram of total dissolved salts, sulphates, bicarbonates and nitrates salts concentration. It is found that TDS or salinity distribution is influenced by salinity of the sedimentary rocks and the location of water close to the basement rocks where its saline water. Most of the samples analyzed are chemically hard, two samples only are soft water, and they are very close to the Nubian lake, of course due to appreciable fresh water recharge from a wide surface of the lake in the study area, Figure 7 Shows TDS distribution as going farther from the lake east ward the concentration increases. Sodium, calcium, magnesium and Potassium cations corresponding to Bicarbonate, Sulphate, Chloride anions are found in equal concentrations in all wells. These substances can be derived from the rock mineralogy of the aquifer lithology or the recharge areas as well as the as upon the hydrodynamic conditions. Sodium cation produced by the dissolution of albite feldspars, clay minerals. Table 2 shows the results of physical and chemical analysis of the major cation and anions measured in ppm.

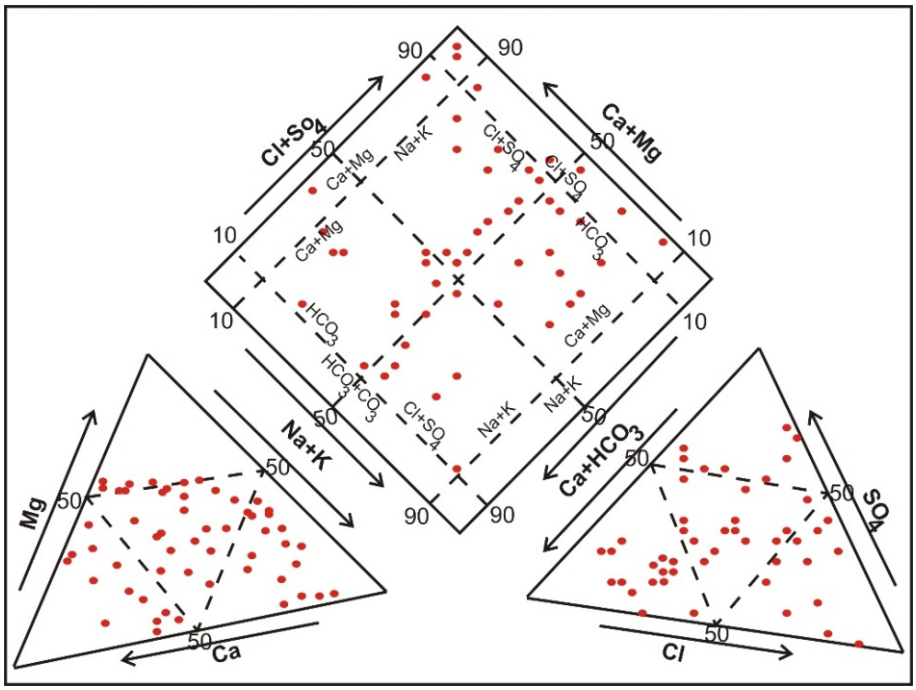

Figure 4. Groundwater classification diagram (1991 analysis)

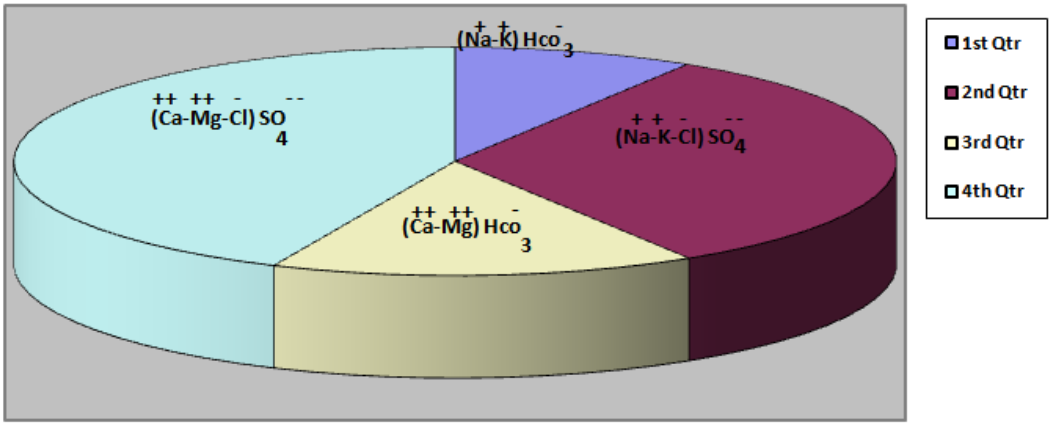

Figure 5. The hydrochemical classification of four different groups of groundwater based on the dominated cations and anions: 1- (Na^+ , K^+) and (HCO_3^-) group (8.85 %) 2- (Na^+ , K^+), Cl^- and SO_4^{--} group (32.37 %) 3- (Ca^{++} + Mg^{++}) and ($HCO3^-$) group (15.62 %) 4- (Ca^{++} + Mg^{++}), Cl^- and SO_4^{--} group (43.38 %), (1991 analysis)

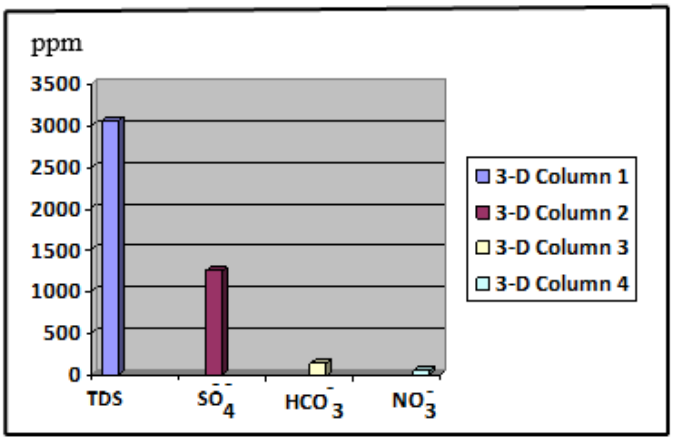

Figure 6. 3-D diagram shows total dissolved salts, sulphates, bicarbonates and nitrates salts concentration, (1991 analysis)

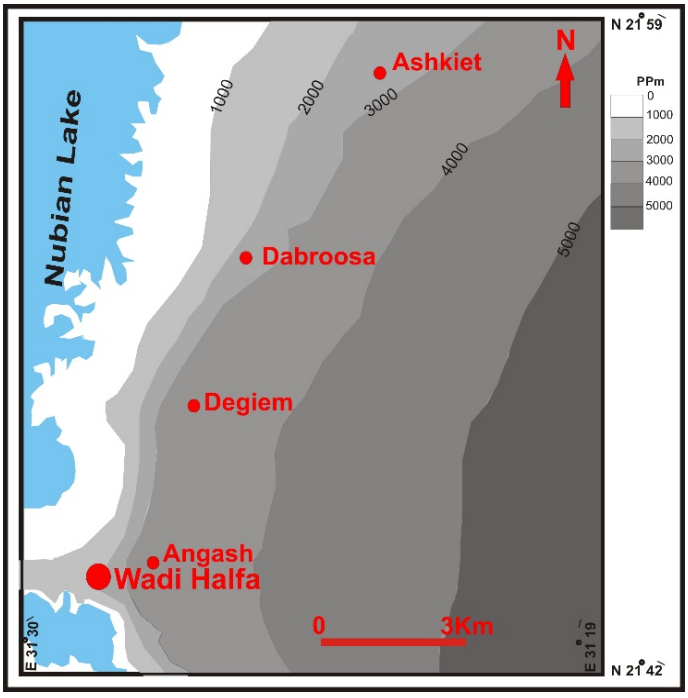

Figure 7. Distribution of total dissolved salts (TDS)

Table 2. Results of physical and chemical analysis of the major cation and anions measured in ppm

Physical-Chemical Properties	BH 2	BH 5	BH 6	BH 8	BH 9	BH 10
	Dabrossa		Degiem		Angash	
Static water level (m)	52.5	52.4	52.5	52.5	52.4	52.4
Physical properties						
pH	7.4	7.5	7.6	7.6	7.7	7.6
ECµs/cm	1004	2100	1005	1018	1012	1006
Chemical properties						
TDS ppm	742	360	1130	1564	1750	1632
T. Hardness ppm	580	563	587	565	589	575
Na^{+} ppm	315	620	625	615	650	650
Ca^{++} ppm	109	105	70	84	76	75
Mg^{++} ppm	42.5	41	37	37	34	35
K^{+} ppm	7.6	5	5	5	5.2	5.1
NO_3^{-} ppm	63.2	51.3	50.4	50.5	54.2	54.5
NO_2^{-} ppm	0.030	0.030	0.029	0.029	0.030	0.030
NH_3^{+} ppm	0.080	0.086	0.037	0.040	0.049	0.053
HCO_3^{-} ppm	130	140	120	101	80.2	117
SO_4^{--} ppm	830	755	760	654	745	740
Bacteriological Analysis	Total coliform bacteria nil/100 ml in each sample					

The correlation of two analysis (1991) and (2019) show decreasing of the amount of salts and increasing in the water level of all boreholes in (2019) analysis. The reason is that in 2018 a great flood and very high rains occurred in Sudan and rivers over flow at the two banks damaged many building and agricultural lands, in addition to, Egypt has been closed the high dam gates, large amount of water recharge the Nubian lake the surface water level in the

lake raised, water became nearly close to the 184 contour. The groundwater recharge ratio increased indicated by the rise of water level from 87m to 52m, as a result salts amount decreased where total dissolved salts and hardness decreased from 3250 ppm as a high value to 1632 ppm and 653 ppm to 587 ppm respectively.

9. Conclusions and Recommendation

9.1. Conclusions

The results show that the groundwater quality is influenced by physical and chemical properties of the geologic formations and ground water dynamics. All salinity comes from the dissolved cations and anions of the sedimentary and basement rocks and these wells is not used for different uses since they has been drilled in 1991, therefore, salts concentrated with great amount leading to high water salinity is resulted. It warranty that to say, the water wells is unfit for use, but a treatment of this problem by continuous pumping to wash up the salts and will become fresh water supported by very good recharge fresh water source of Nubian lake and the results of water analysis in 2019.

9.2. Recommendation

It is recommended to:

- Firstly, before operation for using water wells continuous pump must be done to wash up the concentrated salts and the water pumped must through away far from the dogged wells and from the plain future wells and plain future agricultural lands.
- Using stainless steel, fibreglass, thermoplastic casing and screens when wells are dug to avoid corrosive actions and should be of durable materials that will perform satisfactory for long service life.
- Exploratory drilling to detect horizons that having undesirable physical or chemical properties to be sealed off when designing wells.
- Protecting the aquifer resources from any pollution by monitoring the groundwater quality.
- The distance from a well to pollution source if found should be at great distance nearly not less than 200m.
- Water wells should be located higher than the natural ground to avoiding any undesirable materials entering the well.

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