



## Assessment of Groundwater Quality for Drinking and Irrigation Purposes of Al-Matammah Locality, Shandi Basin, River Nile State, Sudan

Dahab, M. A.<sup>1</sup>; Adil, B. M. Elkrail<sup>1</sup>; Elzien S.M.<sup>2</sup>; Basheer, A. Elubid<sup>1</sup>;  
Khalid, K.M.<sup>3</sup>

<sup>1</sup>Department of Hydrogeology, Faculty of Petroleum & Minerals, Al Neelain University, Khartoum, Sudan P.O. Box 12702

<sup>2</sup>Department of Geology, Faculty of Petroleum & Minerals, Al Neelain University, Khartoum, Sudan

<sup>3</sup>Department of Geophysics, Faculty of Petroleum & Minerals, Al Neelain University, Khartoum, Sudan  
Corresponding Author: email: [siddigzien@gmail.com](mailto:siddigzien@gmail.com)

### Abstract —

The main objectives of this paper are to evaluate the groundwater quality characteristics and appraise their groundwater potentiality. The comparative and temporal variations of aquifer properties in Matammah locality have revealed their close relation to the geologic, stratigraphic, lithologic characteristics as well as variations in hydrogeological and hydroclimatological cycles. The general geologic units encompass; basement complex, Cretaceous sedimentary Formation (Nubian sandstone) and Superficial deposits. The main aquifers include the upper and lower Cretaceous sedimentary and alluvial aquifers. Unconfined and semi confined to completely confined aquifers condition were prevailing. The chemical analyses for groundwater samples to determine its suitability to uses according to international [1] and Sudanese Laboratories Standards (SLS) were performed using the standard laboratory methods. Different software and techniques were used for aquifer stratigraphic model and maps preparation, land-sat image enhancements and interpretation. The groundwater is more or less suitable to domestic uses with few exceptions of those pockets of high salinity zone (236 ppm to 486 ppm) at the Kali.

**Key words** — Groundwater quality, aquifer, total dissolved solid, suitability for irrigation

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### I. INTRODUCTION

Matammah locality is located in north central Sudan at the western bank of the river Nile, geographically between longitudes 31° 51' E and 33 43'E and latitudes 16° 20' N and 17° 22' N, Fig.1. Groundwater flow influences hydrochemical patterns as a result of leaching mechanism from recharge to the discharge areas of the aquifer system. Understanding the hydrochemical characteristics is crucial for groundwater planning and management in the study area. Generally, the motion of groundwater along its flow paths below the ground surface increases the concentration of the chemical species [2]. Hence, the total dissolved solid could reveal important information on the geological history of the aquifers and the suitability of groundwater for domestic, industrial and agricultural purposes.

Groundwaters typically have a large range in chemical composition [3]). Groundwater flow, which is considered a major erosional agent (by dissolution), may accentuate the differences or add to the diversity by sequential leaching of reactive phases from the aquifer matrix. High-flow zones are often much earlier depleted in the products of water–rock interaction than low-flow zones, mainly because of less accumulation of weathering products; and higher flow rates generally combine with an originally lower amount of reactive solids (less clay and organic matter in the more permeable strata). Hence, hydrochemical characteristics of the groundwater system has become more meaningful and an integral part of hydrogeology. Not only of value in quality assessment but also proved to be essential in understanding the flow mechanism and the distribution of ground water types that controlled by the properties of rock through which it has passed.

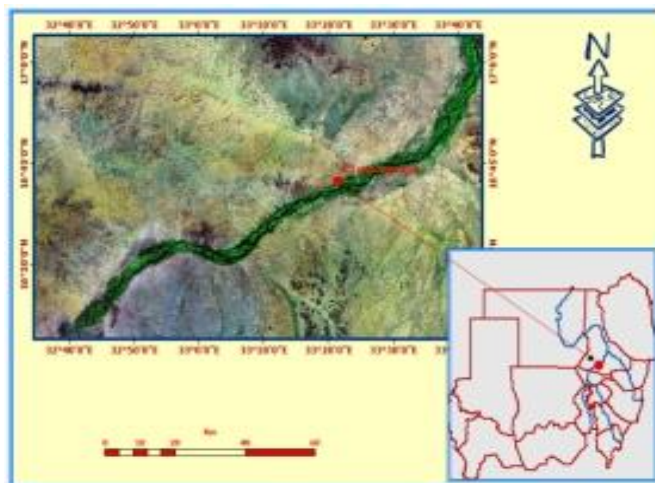


Fig.1: Location Map of the Study Area.

## II. GEOLOGY OF THE STUDY AREA

The main geologic units in the study area encompass; basement complex, Cretaceous sedimentary Formation (Nubian sandstone) and Superficial deposits. The basement complex constitutes the southern part of the basin. Gneisses and granitic rocks were exposed at Sabaloka igneous complex. The basement complex overlain by clay plain and Cretaceous sedimentary rocks and exists as different isolated hills like Jebel Barda, Jebel Abu Tolih. Cretaceous sedimentary Formation occurs in the subsurface as clastic fill at the Shandi basin. The sedimentary rocks consists of Jurassic, Cretaceous, and Tertiary sequences of sandstone, siltstone and mudstone (mainly deposited within alluvial environment), sandy clay and clay deposits and characterized by rapid facies changes over greater part of the area. It rests unconformably on the basement complex [4].

## III. HYDROGEOLOGY

Nubian sand stone Formations, alluvial deposits, fractured zones and weathering products of crystalline rocks play significant role as potential water-bearing units. The sand dunes act as a permeable zone within which perched water occurs. Groundwater occurrence in the sediments can be divided into two aquifer types namely; shallow aquifer comprises the alluvial deposits and deep aquifer (Nubian sand stone). Aquifer in alluvial deposits is very common and is the only exploitable source of potable ground water in the area. Valley fills and pediments are most important groundwater resources in the crystalline terrains. Generally, Groundwater occurs under unconfined and semi confined to completely confined conditions. The sub-basin can be observed, as main water supply resource to Matammah town from it is composed of sandstone that interrelated by clay and overlain by sand dunes of superficial deposits.

## IV. METHODOLOGY

The field collected groundwater samples (**Fig.2**) were analyzed for the major ion chemistry, using the standard laboratory methods. Electric conductivity (EC) and hydrogen ion concentration (pH) were measured immediately at the field site, using portable Orion EC- and pH -meter. Further analyses for major ions were performed in the Water Research Central Laboratories (WRCL) [1]: total dissolved solids (TDS) were measured by sample evaporation techniques. The collected hydrochemical dataset were tested using different hydrochemical software's such as Arc GIS, surfer and Rockware software's AQ-QA and Phreeqc interactive software in order to calculate the saturation index (SI) value and various related minerals such as calcite, aragonite, dolomite and gypsum, in order to evaluate the chemical equilibrium between minerals and water in natural environment. On the other hand, multivariate statistical analysis was conducted using Sigma Plot 14 software. Whereas, the correlation based on the Pearson's correlation coefficient, principle component analysis (PCA) and the relationship between the different variables of the analyzed hydrochemical parameters, this had been done to evaluate the factors affecting hydrochemical components of the groundwater resources in the study area, and also were used for spatial distribution of chemical species and hydrochemical maps.

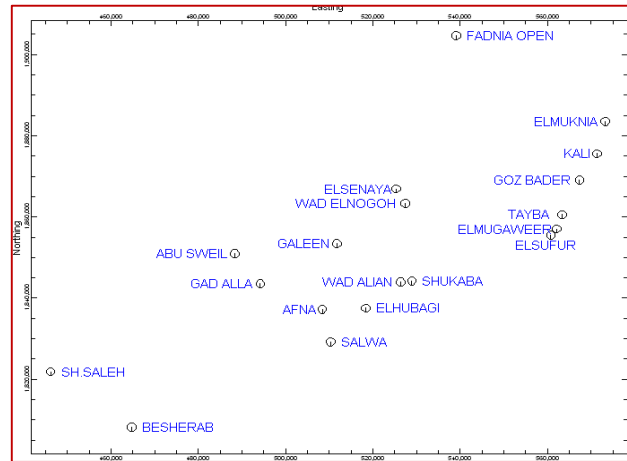


Fig. 2: Wells Location Map

## V. RESULTS AND DISCUSSION

### 5.1 Physico-chemical Parameters

The physico-chemical properties of the water in the study area were measured in the field in August 2011. Physical parameters such as electrical conductivity (E.C) temperature, measured in situ with a portable kit (E.C-Meter). Also colour, taste and odor were measured.

The colour of drinking water is usually due to the presence of coloured organic matter associated with humus fraction of soil. Colour is strongly influenced by the presence of iron and natural impurities or as corrosion products. To detect colour change we compare water sample with the pure distilled water or chloroform. Taste and odor originate from natural and biological sources or process from contamination. Taste and odor may also develop during storage in aquifer. To check odor and taste we smell and taste the water sample respectively. Test in few wells are detected in (Sulloap, Shokapa, Tyba Alkhwad, Alafna and Gnama boreholes).

The temperature was determined instant usually in the field by thermometers. The results were expressed in degree centigrade( $C^{\circ}$ ). The temperature of groundwater in the study area ranges between  $30 C^{\circ}$  to  $31 C^{\circ}$ . Turbidity is the amount of solid particles that are suspended in water and that cause light rays shining through the water to scatter. Thus, turbidity makes the water cloud or even opaque in extreme cases. However, water from boreholes is not turbid, except from open wells, and ponds (Hafirs).

### Hydrogen ion concentration (pH)

The pH of water samples are measured by portable instrument called pH meter. The result was expressed in pH unit. PH range from 0 to 14: from 0 to 7 that means water is acidic and from 7 to 14, that water is alkaline. However, groundwater in the study area has pH units ranging between 7.6 and 8.5. With comparative between above limit the groundwater reveal alkaline in the study area.

### Electrical Conductivity (EC)

Ppm to 486 ppm that means groundwater in study area is fresh water and good quality. The electrical conductivity EC is measured immediately in the field during Sample collection. Electrical conductance apparatus are used and the EC are measured in  $\mu\text{s}/\text{cm}$ . the electrical conductivity increasing toward the boundaries. However, the (EC) range from 110 to 860  $\mu\text{s}/\text{Cm}$  in the study area and it is very good water to available drinking water.

### Total Hardness (TH)

The hardness of water is expressed interims of the amount of calcium carbonate, the principal constituent of limestone or equivalent minerals that would be formed if the water were evaporated [5]. Total hardness TH was determined by titration samples with EDTA (ethylene diamine tetra acidic acid), and expressed in ppm, the total hardness in study area varies from 108 to 268 ppm. The ground water in the study area is classified was Hard water with an average concentration 242 ppm.

### Chemical Properties

The major chemical ions in groundwater include; Calcium, Magnesium, Sodium, Potassium, Bicarbonate, Chloride and Sulfate, (Table 1). In the study area variable ions concentrations are due to the variation of local

geological conditions at which the mineral compositions of rocks, rock type, Basement rocks, limestone, clay and kaolin plays the great role for the natural contaminations.

*Total Dissolved Solids (TDS)*

The simplest classification of water is based on the total concentration of dissolved solids (**Fig.3**). The classification used in this thesis is given in following Table 1, this is similar to a classification suggested by [6]. The total dissolved solids (T.D.S) at study area generally range from 236 to 531mg/l.

Table 1: Concentrations (mg/l) of Cations & Anions in the study area

S.N	Ca	Mg	Na	K	Cl	SO <sub>4</sub>	HCO <sub>3</sub>	CO <sub>3</sub>
1	47	29	12	3	21	25	219	12
2	34	23	31	5.9	14	24	298	6.1
3	60	30	35	5.1	20	60	243	1.0
4	44	24	13	3	9	14	298	6.1
5	30	67	36	2	20	28	439	18
6	16	23	16	6.6	65	20	268	12
7	60	20	20	5	50	30	213	6.1
8	50	10	15	5	20	55	134	6.1
9	50	40	60	30	30	20	140	6.0
10	36	17	32	5	20	14	201	6.0
11	50	17	14	5.4	15	7	280	36
12	50	20	18	7	13	0.0	305	24
13	41	19	34	5	12	2.5	256	0.0
14	34	14	16	3.9	9.9	25	170	0.0
15	38	21	31	9.0	10	11	280	6.0
16	30	10	26	5.0	23	14	231	3
17	25	70	35	14	65	30	317	18
18	36	30	35	5.1	21	23	207	0.0
19	50	40	60	30	30	20	170	6.1
20	15	34	71	7.8	42	14	378	12
21	60	17	57	0.0	15	18	102	14
22	28	27	75	0.0	20	42	293	0.0
23	20	9.3	76	11	16	58	201	3.0
24	36	9.7	47	0.0	19	32	256	0.0
25	40	10	39	0.0	42	20	207	0.0

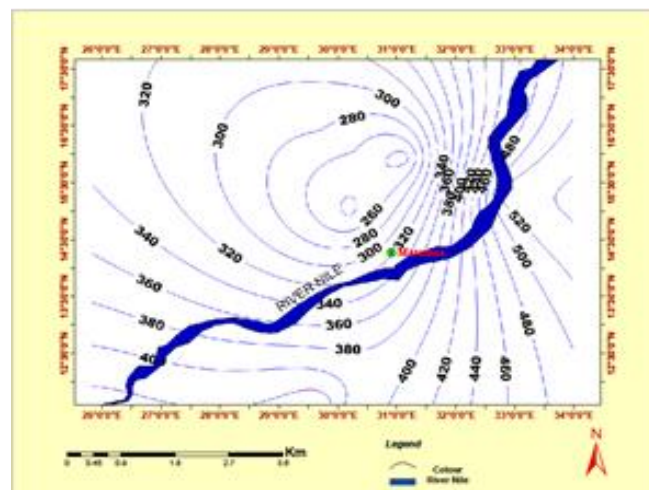


Fig. 3: The aerial distribution of total dissolved solid (mg/l) in the study area

*Sodium & Potassium:*

Na<sup>+</sup> and K<sup>+</sup> are alkali metals respectively, and were enrichment occurs as result of leaching weathered feldspar and clay minerals. In the study area Sodium content varies between 12.2 – 76ppm with the average concentration 44.1ppm. And Potassium in study area range from 2 – 30ppm with the average concentration 16ppm.

*Calcium & Magnesium:*

The main sources of Ca<sup>++</sup> and Mg<sup>++</sup> respectively are clay alteration of granite. The concentrations of Calcium in study area range from 16.6 – 60 ppm, with the average concentration 38.3ppm. The concentration of Magnesium in study area was range from 9.3 to 70ppm with the average concentration 39.7ppm.

*Major Anion:*

As range of the following concentrations:

**5.2.1 Carbonates & Bicarbonate**

The main source of  $\text{CO}_3$  and  $\text{HCO}_3$  is the atmosphere and the soil. The concentration of Carbonates & Bicarbonate in the study area attributed to the Kankar minerals that are very common in the litho logy of borehole, and value of Carbonates its range between 6 to 18.2 ppm, with the average concentration 12.1ppm, and Bicarbonate in study area range from 122 – 280.6 ppm, an average concentrations 201.3ppm.

*Chloride and Sulphate*

Concentration of Cl generally low in groundwater. In the study area it is in range from 10 to 66ppm.  $\text{SO}_4$  it is derived from gypsum. In study area the minimum concentration of Sulphate is 7 ppm, while the maximum concentrations are the 280ppm, these value detected in Matammah borehole.

**VI. HYDROCHEMICAL FACIES**

*Piper diagram*

The hydrochemical facies of groundwater in the study area are revealed from the trilinear diamond diagram also called [7-10];1 were used (Fig. 4&5) to classify the groundwater of the study area.

The graphic procedure of some diagrams i.e. (Piper diagram, Ternary Diagram, Durov Diagram, and other helping charts) was used for presenting water chemistry data to help in understanding the sources of the dissolved constituent salts in water.

The analytical results achieved from the samples when plotted on Piper’s plot, explained that the alkaline elements ( $\text{Na}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  &  $\text{K}^+$ ) were relatively equally distributed with rare increased of Ca, and the weak acidic ( $\text{HCO}_3^-$ ) appear considerably over the other strong acidic anions ( $\text{Cl}^-$ ,  $\text{CO}_3^-$ , &  $\text{SO}_4^{2-}$ ). According to the plotting from diagrams, most of the elements of water type are named within the  $\text{CaHCO}_3$  zone.

The final result of the data analysis showed that there are three water types of the studied area as: **52%**  $\text{Ca-HCO}_3$ , **32%**  $\text{Mg-HCO}_3$ , and **16%**  $\text{Na-HCO}_3$ , **8%**  $\text{Na-Cl}$ , **0.7%**  $\text{Ca-SO}_4$ , and the other rare type for  $\text{Mg-SO}_4$  and  $\text{Ca-Cl}$  water types (Table 2).

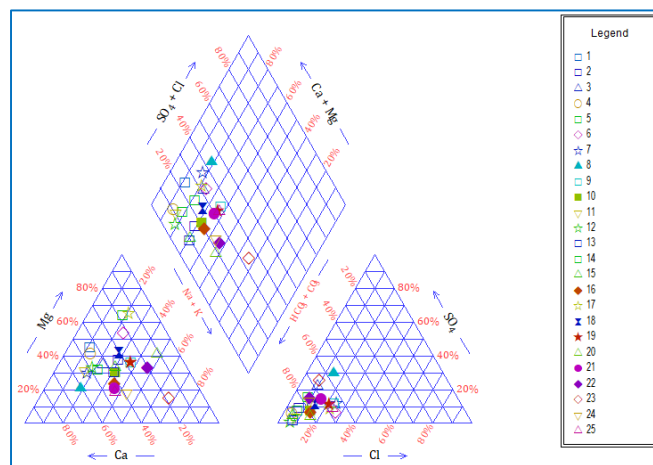


Fig.4: Piper diagram for groundwater chemistry in the study area (Piper, 1953).

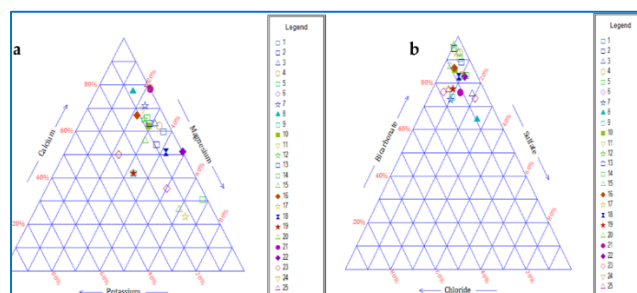


Fig. 4: Ternary Diagram, a- alkaline elements cations & b- acidic elements anions

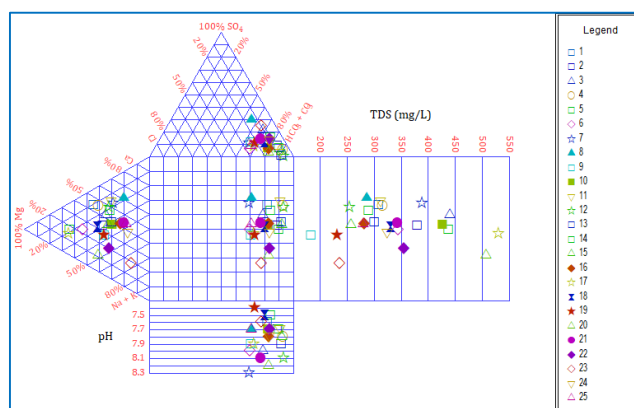


Fig. 5: Durov Diagram presented of groundwater chemistry in the study area [9].

Table 2: Water Ty

Sample ID	Water Type	Sample ID	Water Type	Sample ID	Water Type
03	Ca-HCO <sub>3</sub>	01	Mg-HCO <sub>3</sub>	20	Na-HCO <sub>3</sub>
04	Ca-HCO <sub>3</sub>	02	Mg-HCO <sub>3</sub>	22	Na-HCO <sub>3</sub>
07	Ca-HCO <sub>3</sub>	05	Mg-HCO <sub>3</sub>	23	Na-HCO <sub>3</sub>
08	Ca-HCO <sub>3</sub>	06	Mg-HCO <sub>3</sub>	24	Na-HCO <sub>3</sub>
10	Ca-HCO <sub>3</sub>	09	Mg-HCO <sub>3</sub>		
11	Ca-HCO <sub>3</sub>	17	Mg-HCO <sub>3</sub>		
12	Ca-HCO <sub>3</sub>	18	Mg-HCO <sub>3</sub>		
13	Ca-HCO <sub>3</sub>	19	Mg-HCO <sub>3</sub>		
14	Ca-HCO <sub>3</sub>				
15	Ca-HCO <sub>3</sub>				
16	Ca-HCO <sub>3</sub>				
21	Ca-HCO <sub>3</sub>				
25	Ca-HCO <sub>3</sub>				
Water Type %		52%		32%	
				16%	

pe of Water samples

**Durov Diagram**

In the study area Durov diagram (Fig. 5) was recognized two facies of groundwater hydrochemistry i.e. Bicarbonate (sodium and potassium facies) and (transit facies).

**VII. GROUNDWATER SUITABILITY AND USES**

The quality of ground water is a measure of its suitability for human and animal consumption and for use in agricultural and industrial purposes. However, Table 3 classification of water according to possible uses is more important.

Table 3: Concentration of Hydrochemical Properties in the Study Area

S.N	pH	EC ms/cm	TDS mg/l	TH mg/l	SAR meq/l	RSC meq/l	S.W.L (m)	HEAD (m)
1	7.6	441	308	194	0.7	0.12	69.5	333.5
2	7.7	542	379	182	1.04	1.51	63	316
3	8	660	440	280	1.3	-1.31	37	319
4	7.8	401	316	210	0.27	0.28	4.40	350.6
5	7.7	620	437	260	0.84	0.36	80	337
6	8.0	493	345	232	0.68	0.4	64	309
7	8.3	551	388	212	0.6	-0.5	80.30	332
8	7.7	409	286	104	1.6	0.32	41	332
9	7.9	261	182	100	0.86	0.5	79	332
10	7.7	610	427	182	1.9	1.11	9.30	380.7
11	7.7	447	313	176	0.7	2.53	63	293
12	8.1	410	255	200	0.00	0.1	22	344
13	7.9	428	300	188	0.5	1.18	16	354
14	7.5	410	290	145	0.2	-0.1	20	344
15	7.8	469	258	184	2.1	-1.1	19	333
16	7.8	403	282	118	0.4	1.5	25	346
17	7.9	752	531	130	1.5	2.37	23	343
18	7.5	473	331	116	3.6	0.85	19	346
19	7.4	332	232	132	1.4	0.18	10	357
20	8.2	725	507	176	2.3	3.05	50	302



21	8.1	490	343	220	0.6	-2.2	15	339
22	7.6	507	355	184	0.9	1.1	33	332
23	7.6	339	236	90	0.6	1.3	14.3	357.7
24	7.8	463	324.1	130	0.7	1.6	17.3	339.7
25	7.7	400	280	144	0.4	0.5	-	-

*Suitability for Irrigation*

The suitability of water for irrigation can be indicated with the sodium Adsorption - Ratio (SAR), in study area S.A. less than ten its range from zero to three, which is defined by [11]:

$$SAR = Na / \sqrt{(Ca + Mg) / 2} \dots\dots\dots (meq/l).$$

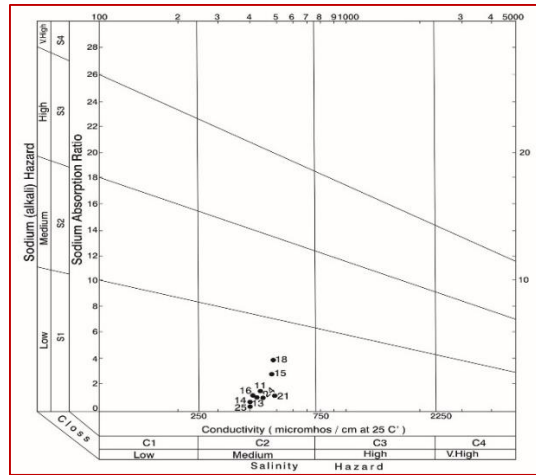


Fig.6-A: Classification of groundwater for irrigation, in the area [12].

Where; Concentrations are expressed in (meq/l).

Groundwater of the Matammah approximately is excellent grade for irrigation according to the recommended water classification for (S.A.R), [12], Fig. (6-A& B) follows Table 3:

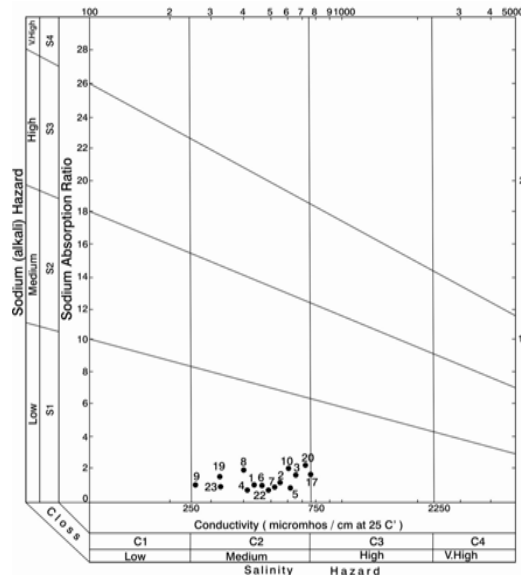


Fig.6-B: Classification of groundwater for irrigation in the area [12].

*Residual Sodium Carbonates (RSC):*

The residual sodium carbonate, RSC, influences the suitability of ground water for irrigation and can be expressed as:

$$RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{+2} + Mg^{+2})$$

Where are concentrations expressed in epm if residual sodium carbonate exceeds 2.5 epm, the water is unsuitable for irrigation. If the value is between 1.25 to 2.5 epm the water is of marginal quality while less than 1.25 epm indicates that the water is probably safe ([www.lenntech.com](http://www.lenntech.com) Website 2011). Ground water in the study area is probably safe and ranging from 0.1 to 1.0 epm except few sites at Kali and Gekika boreholes are unsuitable for irrigation where 2.73 and 3.5 epm were recorded.

### VIII. SATURATION INDICES (SI)

Saturation indices can be a useful tool to assess corrosion and encrustation hazards. The saturation index (SI) is defined as follows:

$$SI = \log (IAP/K)$$

In this equation, IAP represents the ion activity product and K is the solubility product (representing the equilibrium). Hence, a SI of 0 means that there is equilibrium between the mineral and the solution. A negative SI indicates sub-saturation and a positive SI indicates super saturation [13].

Before giving details about the calculation procedure and the obtained results, the most important aspects of corrosion and encrustation are presented in the following paragraphs.

The calculation of saturation indices focused on the carbonate minerals calcite ( $CaCO_3$ ) and dolomite ( $CaMg(CO_3)_2$ ), but also gypsum ( $CaSO_4 \cdot 2H_2O$ ) was included in the assessment.

The saturation indices have been determined for all chemical datasets which include the parameters temperature, pH value, calcium, magnesium, sulphate, and bicarbonate. For the calculation the software Aqua Chem 10 by Waterloo Hydrogeologic, in which the multipurpose geochemical modelling program PHREEQC is integrated, was utilized. The results are presented in Table 4.

**Table 4: Calculated Calcite, Dolomite, Gypsum Saturation Indices**

S.N	Borehole	SI Gypsum	SI Calcite	SI Dolomite	SI Aragonite	SI Anhydrite	SI Halite	SI Sylvite
1	Hobaje	0.22	1.69	3.29	1.54	-0.08	-5.43	-5.39
2	Salwoap	0.14	1.39	2.74	1.25	-0.16	-5.19	-5.25
3	Wadi Khalil	0.61	1.0	1.82	0.86	0.31	-5.02	-5.21
4	Kemap	0.00	1.62	3.11	1.47	-0.30	-5.75	-5.74
5	Matammah	-0.04	1.72	3.92	1.57	-0.34	-5.00	-5.61
6	ESyal Alsageer	-0.19	1.68	3.65	1.54	-0.49	-4.80	-4.53
7	Hemerap	0.38	2.12	3.90	1.98	0.08	-4.85	-4.80
8	Abdotab	0.60	1.45	2.30	1.31	0.30	-5.37	-5.20
9	Alkareda	0.06	1.67	3.38	1.52	-0.24	-4.60	-4.26
10	Kemaier	-0.03	1.45	2.71	1.31	-0.33	-5.01	-5.16
11	Geweir	-0.25	2.32	4.32	2.18	-0.55	-5.50	-5.26
12	Norab	-	2.54	4.84	2.40	-	-5.46	-5.21
13	Soufuf	-0.73	-	-	-	-1.03	-5.21	-5.39
14	Mgaweer	0.23	-	-	-	-0.07	-5.61	-5.57
15	Taypa	-0.14	1.57	3.01	1.42	-0.44	-5.33	-5.21
16	Qoz bura	-0.02	1.21	2.07	1.07	-0.32	-5.03	-5.09
17	Kali	-0.10	1.82	4.22	1.67	-0.40	-4.51	-4.26
18	Frahseen	0.11	-	-	-	-0.19	-4.97	-5.15
19	Maknia	0.06	1.18	2.41	1.04	-0.24	-4.60	-4.26
20	Sagadi	-0.46	1.82	4.14	1.68	-0.76	-4.36	-4.66
21	Gekika	0.18	2.32	4.25	2.18	-0.13	-4.91	-
22	ESyal Alkabeer	0.25	-	-	-	-0.06	-4.67	-
23	El Shabatab	0.27	0.64	1.03	0.50	-0.04	-4.77	-4.96
24	Qoz Bader	0.33	-	-	-	0.03	-4.87	-
25	Al helila	0.18	-	-	-	-0.12	-4.61	-

The determined calcite saturation indices range between 0.65 and 2.54. 24 waters showed supersaturated ( $SI > 0.7$ ). With respect to dolomite, the values varied between 1.03 and 4.84. Here, 24 waters were supersaturated ( $SI > 1.03$ ). Thus, there are carbonate corrosive waters as well as waters that show a potential incrustation hazard. Nevertheless, it has to be kept in mind that the calculated values just reflect the overall chemistry of the sampled water and that micro-environments with differing physico-chemical conditions might develop. In these local environments, incrustation can occur although the general chemistry of the water suggests sub-saturation and vice versa.

As far as gypsum is concerned, only 15 samples showed equilibrium conditions ( $SI = 0 \pm 0.61$ ). All other saturation indices, namely 10, were negative and the lowest value accounted for -0.73. Hence, the examined waters were mostly under saturated with respect to gypsum, which is ultimately attributable to its relatively good solubility of approximately 2.1 g/l (at 30°C, [14]). With respect to aragonite is concerned 19 samples (0.50 to 2.40) are positive the waters are supersaturated with carbonate and anhydrite shows saturation indices varies between -1.03 to 0.31, four samples only show equilibrium conditions (SI), halite and sylvite show in equilibrium condition and under saturation indices (SI).



### IX. MECHANISM CONTROLLING MATAMMAH WATER CHEMISTRY

The mechanism that control the chemical composition of the major dissolved salts of the waters of the earth have discussed by [15-18], However, [19, 20] has pointed out that the chemistry of water is generally, controlled by the rate of evaporation, chemistry of rocks and rain water. To evaluate the sources of various ions, the chemical data of waters from the area of study (Table 3) were plotted on Gibbs diagram [21]. The plots of the total dissolved solids (TDS) versus  $Cl/Cl+HCO_3$  (Fig.7) suggest that the ions are chiefly derived from the evaporation precipitation towards the seawater dominants and their concentration in groundwater's is mostly due to evaporation. Similar results have been obtained when TDS plotted against  $Na+K/Na+K+Ca$  (Fig.7). Evaporation Precipitation towards the seawater, indicating contribution high evaporation, however, has not played any role in the concentration of ions in the waters in the area of study, the aridity and low rainfall in the area may also help the concentration of different anion and cation give their equilibrium to form different carbonate minerals.

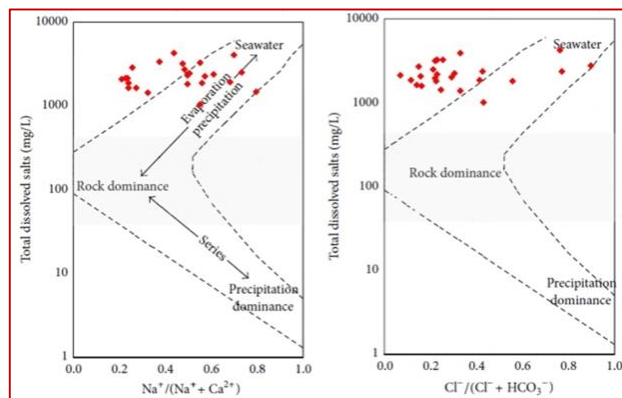


Fig.7: Gibbs diagrams for the groundwater from the Matammah area, River Nile, Shandi Basin

### X. CORRELATION MATRIXES FOR ANALYZED PARAMETERS OF GROUNDWATER

Multivariate statistical techniques, such as factor analysis or principal component analysis, provide more insight into the underlying structure of a data set, the use of these techniques might require further analysis to identify district groups. Cluster analysis [22], on the other hand, is a useful way of objectively organizing a large data set into groups on the basis of a given set of characteristics. This can ultimately assist in the recognition of potentially meaningful patterns [ 23] .

To identify possible groups and relationship among the samples analysis based on major chemical compositions, ions species  $Ca^{2+}$ ,  $Mg^{2+}$ ,  $Na^+$ ,  $K^+$ ,  $SO_4^{2-}$ ,  $HCO_3^-$  and  $CO_3^-$  (Figs. 8&9) were considered as variables for application in Q-mode cluster analysis. The clustering procedure was performed by the ward's linkage method with the Euclidean distance as a measure of similarity of samples using the software's AQ/Qa used for water quality and Xisat for statistical analysis.

In this study, the Pearson correlation Matrix method was chosen which is insensitive to outliers in the data, and the analysis, results are shown in Table 5. As shown in Table 5, the cations  $Na^+$ ,  $K^+$ ,  $Ca^{2+}$ ,  $Mg^{2+}$  and anions  $Cl^-$ ,  $SO_4^{2-}$  and bicarbonate, shows positive correlations witheach other, which can be explained by the dissolution of chlorides and sulfate minerals, because they can release  $Ca^{2+}$ ,  $Mg^{2+}$ ,  $Cl^-$  and  $SO_4^{2-}$  into the water, also by water-rock interaction [24, 25].

The relationships among the water chemistry variables of the groundwater samples are shown by rank correlation matrix (Table 5). The factors were extracted from a correlation matrix of the variables by the principal component analysis. The terms, "strong" "moderate" and "weak" as applied to r values, refer to range of  $> 0.75$ ,  $0.75-0.5$ , and  $0.5-0.3$ , respectively [26]. Strong correlation was observed between  $Na^+$  and  $Cl^-$ , EC;  $SO_4^{2-}$  and EC there also  $Cl^-$  and EC. Moderate correlation was observed between  $Na^+$  and  $H_2CO_3^-$ ,  $SO_4^{2-}$ ;  $Mg^{2+}$ and  $Cl^-$  ,  $SO_4^{2-}$  & EC;  $Ca^{2+}$  and  $Mg^{2+}$  &  $SO_4^{2-}$ ;  $H_2CO_3^-$  and EC. There is also moderate correlation between  $SO_4^{2-}$  and  $Cl^-$ .

This may indicate cation exchange between these ions. For the rest of groundwater samples, there is weak correlation between  $K^+$  and  $SO_4^{2-}$ ,  $Cl^-$  and EC and between Bicarbonate both of  $Cl^-$  &  $SO_4^{2-}$  ;  $Na^+$  and  $Mg^{2+}$ ,  $K^+$ ;  $Ca^{2+}$ and  $K^+$ ,  $H_2CO_3^-$ ,  $Cl^-$ , EC as well as  $Mg^{2+}$  and  $H_2CO_3^-$ ,  $K^+$  as shown at the correlation matrix (Table 5). Almost all analyzed metals showed strong correlation with TDS and electrical conductivity because the latter increases with dissolution of metals through ion exchange, dissolution/ precipitation and oxidation-reduction reactions in groundwater aquifer system [27].

**Table 5: Pearson Correlation Matrix Matammah groundwater Samples**

Variables	Ca	Mg	Na	K	Cl	SO <sub>4</sub>	HCO <sub>3</sub>	CO <sub>3</sub>	P <sup>H</sup>	EC	TDS
Ca											
Mg	<b>0.443</b>										
Na	<b>0.183</b>	<b>0.482</b>									
K	0.718	<b>0.062</b>	<b>0.125</b>								
Cl	<b>0.140</b>	<b>0.059</b>	0.839	<b>0.276</b>							
SO <sub>4</sub>	0.956	0.954	<b>0.200</b>	0.783	0.774						
HCO <sub>3</sub>	<b>0.013</b>	<b>0.013</b>	0.868	<b>0.259</b>	0.589	<b>0.360</b>					
CO <sub>3</sub>	0.634	<b>0.137</b>	<b>0.183</b>	0.828	0.605	<b>0.069</b>	<b>0.083</b>				
P <sup>H</sup>	<b>0.462</b>	0.923	0.975	0.519	<b>0.067</b>	<b>0.452</b>	<b>0.355</b>	<b>0.267</b>			
EC	<b>0.203</b>	<b>0.015</b>	0.944	<b>0.129</b>	<b>0.060</b>	0.572	<b>0.003</b>	<b>0.344</b>	<b>0.048</b>		
TDS	<b>0.172</b>	<b>0.013</b>	0.947	<b>0.114</b>	<b>0.041</b>	0.521	<b>0.005</b>	<b>0.385</b>	<b>0.072</b>	< <b>0.0001</b>	
TH	<b>0.289</b>	<b>0.327</b>	<b>0.196</b>	<b>0.045</b>	0.936	0.626	<b>0.031</b>	<b>0.211</b>	<b>0.026</b>	<b>0.016</b>	<b>0.025</b>

Values in bold are different from 0 with a significance level alpha=0.5

The relationship between dependent and independent variables is known as Correlation Matrix, and is statistically measured. It assists in predicting the mutual relationship between two variables. The correlation between the parameters differentiates between strong (the range is +0.8 to 1.0 and -0.8 to -1.0), and weak (the range is +0.0 to 0.5 and -0.0 to -0.5). The correlation values obtained in the present study in Matammah area are presented in Table 5. As per the findings of the correlation matrix, it can be inferred that the correlation matrix between parameters is changed during the period of time, which marks the change of the geochemical processes. Q-mode hierarchical cluster (HCA) and principal component analysis (PCA) were simultaneously applied to groundwater hydrochemical data from Al-Matammah, Shandi Basin; River Nile State. Fig.10 shows the Agglomerative hierarchical clustering Dendrogram of the water chemistry from the study area.

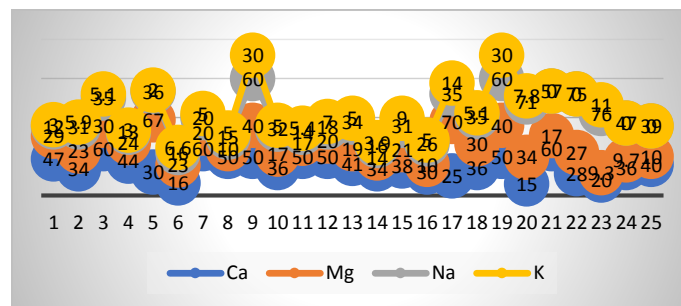


Fig. 8: Relation between the alkaline cations (Ca, Mg, Na, & K) of the Water samples

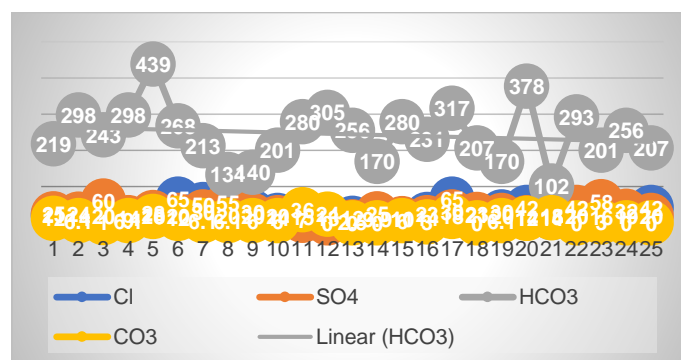


Fig. 9: Relation between the acidic anions (Cl, SO<sub>4</sub>, HCO<sub>3</sub>, & CO<sub>3</sub>)

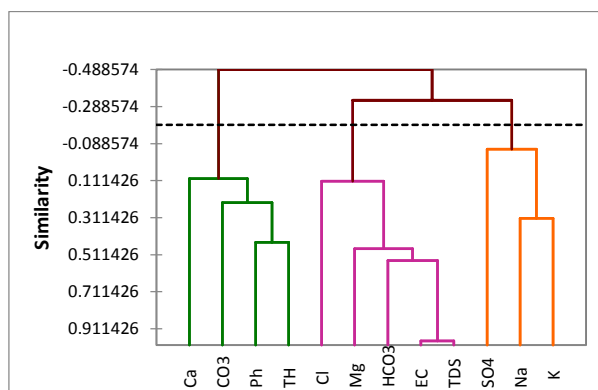


Fig.10: Agglomerative hierarchical clustering (AHC) - Dendrogram of the water sample elements

## XI. CONCLUSION

The subsurface lithology of sub-basin, a hydrogeological structural cross section modeled reveals that there exist two main aquifers. [28] Groundwater occurs under water table and confined conditions (sub artesian and artesian) in the study area. Groundwater occurrence in Nubian sand stone aquifer under deferent condition confined, semi confined, unconfined and perched water. The main water bearing formation is composed of medium to coarse sand stone, and its good quality, the recharge for groundwater from rain fall and River Nile. Pumping tests [25] were conducted for selected numbers of boreholes and the discharge in gallons per hour was measured, also the static water level and dynamic water levels were measured. From this the hydrologic characteristics of the aquifer were computed. The values suggest that the aquifers of sedimentary area are very permeable and transmit large quantities of water. Higher K observed in sedimentary, the results of pumping tests data are shown in. The magnitude and spatial distribution of the aquifer parameters is described as follow: aquifer they suggested that for unconsolidated and poorly cemented sandy material. That feature responsible withdrawing quite enough of groundwater consumptions municipal and agriculture scheme. The final result of the data analysis showed that there are three water types of the studied area as: **52%** Ca-HCO<sub>3</sub>, **32%** Mg-HCO<sub>3</sub>, and **16%** Na-HCO<sub>3</sub>, **8%** Na-Cl, 0.7% Ca-SO<sub>4</sub>, and the other rare type for Mg-SO<sub>4</sub> and Ca-Cl water types.

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