

**GROUNDWATER WATER QUALITY WITH SPECIAL EMPHASIS ON  
CHEMICAL PROPERTIES, ZAMZAM CAMP, NORTH DARFUR, SUDAN**

AnasJafar Ali Mohammed

Department of water resources, Faculty of Natural Resources, Al Fasher University, North  
Darfur Sudan.

Mobile: Code (00249) No. (912512512),

**ABSTRACT**

The main objectives of the study are to assess the groundwater chemistry and delineate the hydro chemical facies at study area aquifers system. Fourteen (14) water samples were collected for chemical analyses, from water wells distributed throughout the study area and analyses have been done at Water and Environmental Sanitation Project laboratory (WES) at Al Fashir town. All water samples were analyzed, according to standard methods for water examination. GIS technique was used to construct water sample location sites and Strater Demo-4 software for great cross-sections. Chemical data were manipulated using Piper diagram for chemical facies and SPSS software for statistical analyses such as basic statistics (minimum, maximum, mean and standard deviation). Generally the chemistry of the groundwater in relation to major ions (cations and anions) visualizes increase of concentrations to the northern and south-eastern side of the study area. According to Piper Diagram the dominant water type is  $\text{Na}^+\text{-HCO}_3\text{-SO}_4$ -facies. The groundwater geochemistry controlled by dissolution of silicate minerals and carbonates as. The results show that, the groundwater in area are good for domestic uses with a few exception found to be above the recommended values given by (WHO, 2006) and (SSMO, 2009).

**Keywords:** hydrochemical facies, chemical facies, minerals, water

**INTRODUCTION**

Water is one of the most essential needs of human beings and is the most abundant natural resources on the surface of the earth (Oyinloye and Jegede, 2004), while groundwater is the largest reservoir of drinkable water and due to the natural filtration, it is less contaminated as compared to surface water (Aiyesanmi et al., 2004). Groundwater is an important source of water for agricultural and domestic use especially in developing countries like study area, due to long retention time and natural filtration capacity of aquifers. However, leachate from municipal, solid waste, landfills is potential sources of contamination of both surface water and groundwater (Odukoya et al., 2002). Chemical characteristics tend to be more specific in nature

than some of the physical parameters and are thus more immediately useful in assessing the properties of a sample. It is useful at this point to set out some basic chemical definitions (Tebbut, 2002).

## 2. Study Area:

The study area situated at latitude of 13<sup>0</sup> 29' N, longitude of 25<sup>0</sup> 18' E and altitude of approximately 714 m above mean sea level. The area could be described as flood plain where the dominant soil types are silty-clay-sandy alluvium deposits. Sand dunes (sand qoz) are the subdominant soil type that engulfs Wadi El Ku plain (El Tom, 2009) (Fig, 1). The climate of study area, it is a typical phases of the semi desert and the winds its north-east mostly of the year and dries (Fadul, 2004). The average annual rainfall ranges from 150 mm to 286 mm, and the rainy season extends from July to September, with maximum rainfall in middle August to September. The average temperature is 17.7<sup>0</sup> C and it rises up to 34.7<sup>0</sup> C in the summer season (El Fasher Meteorological Station, 2017). On geological viewpoint the area is composed of Basement Complex and Wadi alluvial deposits (Gachet, 2006) (Fig, 2 and 3). The basement rocks comprise Metamorphosed group of banded genesis, schist and low grade meta sediment rocks and Post metamorphic group of igneous intrusions mainly granitic (Vail, 1989). The main lithological units of the area are the alluvial deposits of Wadi El Ku. These deposits comprise sandy, clayey-sand and silt-clay deposits. Superficial aeolian sand and sand dunes surround wadi banks (El Tom et al, 2009).

## 3. Methodology:

Several methods were adopted to collect data for this study. These methods include field work, laboratory work and deskwork for gathering of important data in order to achieve the study objectives. Groundwater samples had been collected from 14 wells evenly distributed throughout the area (Fig, 1). The pH, TDS and EC of samples were measured at the field by using pH meter WE 30200, TDS meter 30200 and EC meter WE 30200 respectively, whereas the concentration of major cations and anions were analyzed at the laboratory by standard analytical procedures, by using a device called WagteckSpectrophotometer 5000 (Table, 1). Aquichem software was used to delineate hydrochemical facies. GIS technique was used to construct water sample location sites, Strater Demo-4 used for greatcross-sections. Statistical analyses were performed using SPSS computer software. The statistical tests applied were basic statistics (minimum, maximum, mean and standard deviation) (Table, 2).

## 4. Results and Discussions:

### 4.1 Result of Chemical analysis:

The chemistry of groundwater is often controlled by the mineralogical and the chemical composition of rocks beside the infiltration of water from surface land to the aquifer down through rocks and soil in the area (recharge), as well as climate factors. Chemical analyses of 14 wells (Table, 1 and Fig, 1) were carried out where concentration of Total dissolved solids (TDS), pH, Electric conductivity (EC) and the major constituents (TH, K, Na<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup> and HCO<sub>3</sub><sup>-</sup>) were determined. (Table, 2) shows minimum, maximum, mean concentration and standard deviations of all parameters studied.

#### 4.1.1 The Hydrogen Ion (pH):

Is a measure of the acidity and alkalinity of water, which is measured by a pH-meter in field, and in the study area varies from 7.2 to 7.7 with a mean and a standard deviation of 7.5 and 0.17, respectively (Table, 2 and Fig, 4). From (Table, 1) the lowest concentration value of pH (7.2) found in samples taken from well No. 4 which located at the eastern side of the area, while the highest concentration (7.7) appeared in well Nos. 1, 2, 5, 8 and 14 lies at the north-east, south-east and southern part of study area, respectively. The spatial distribution of pH visualized decreasing toward eastern side of study area, whereas, increasing at the northeastern, southeastern southern part of the study area, and this may be related to the presence of fine aquifer sediments mixed with mud (Fig, 5).

#### 4.1.2 Electrical Conductivity (EC):

This property depends on the ionic strength of water and it is related to the nature of various dissolved substances, it is easily measured in the field by an EC meter, and in the area the concentration ranges between 940 and 3590  $\mu\text{S}/\text{cm}$  with a mean and a standard deviation of 2266.5 and 976.4  $\mu\text{S}/\text{cm}$ , respectively (Table, 2 and Fig, 6). From (Table, 1) the lowest concentration value of pH (940  $\mu\text{S}/\text{cm}$ ) found in samples taken from well No. 14 lies at the southern side of the area, whereas, the highest concentration (3590  $\mu\text{S}/\text{cm}$ ) appeared in well No. 6 lies at the southeastern part of the study area. The spatial distribution of EC visualized decreasing toward southern of study area, whereas, increasing at the southeastern side of the study area, and this may be related to leaching processes and high rates of evaporation (Fig, 7). According to (SSMO, 2009) the concentration of EC is more than the maximum permissible limits at the southeast side of study area in well Nos. 2, 3, 5 and 6 respectively. Based on (Wilcox, 1995), 7% of samples classified as Good (C2), 43% Doubtful (C3) and 50% Unsuitable water (C4&C5).

#### 4.1.3 Total Dissolved Solids (TDS):

It is make up the whole mineral constituents dissolved in water, which include the soluble anions and cations as well as any dissolved silica, and it is easily measured in the field by EC-

meter. In the area the concentration ranges from 590 to 2513 mg/l with a mean and a standard deviation of 1581.7 and 690.8 mg/l, respectively (Table, 2 and Fig, 8). From (Table, 1) the lowest concentration value of TDS (590 mg/l) appeared in samples taken from well No. 14 lies at the southern side of the area, whereas, the highest concentration (2513 mg/l) appeared in well No. 6 lies at the southeastern side of the study area. The spatial distribution of TDS visualized decreasing toward southern part of study area, whereas, increasing at the southeastern side of the study area, and this may be related to dense mudstones beds and solubility of minerals from geological formation, all samples classified as excellent water. According to (SSMO, 2009), samples taken from wells in the study area, classified as 7% Good, 43% Poor and 50% Unacceptable Water, and the concentration of TDS is more than the maximum permissible limits at the southeast, west and north side in well Nos. 2, 3, 5, 6, 11, 12 and 13 respectively.

#### 4.1.4 Total Hardness (TH):

It is a property of water that causes the formation of a residue or a film (scale) on the walls of boilers, and it is primarily produced by the  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  present in water, and the concentration in water wells at study area varies from 90 to 600 mg/l with a mean and standard deviation was measured as 310.5 and 183.5 mg/l respectively (Table, 2 and Fig, 10). From (Table, 1) well No. 14 has a lowest value (90 mg/l) lies at the southern side of area, whereas, well Nos. 2 and 3 shows the highest value (600 mg/l) sited at the southeastern part of the area. The spatial distribution of TH visualized decreasing concentration at the southern side of study area, whereas, increasing at the southeastern part of the study area (Fig, 11), and this related to natural dissolution processes of carbonate mineral at the upper soil zone and weathering of host rocks. Based on (SSMO, 2009) classification, 7% classified as moderately, 29% hard, 64% very hard water.

#### 4.1.5 Potassium ( $\text{K}^+$ ):

Although it is one of the abundant elements on earth it is concentration in most natural water rarely exceeds 20 mg/l probably because most  $\text{K}^+$  bearing minerals are resistant to decomposition by weathering. In water wells in the study area ranges from 4.5 to 17.6 mg/l with a mean and a standard deviation were measured as 8.1 and 3.8 mg/l respectively (Table, 2 and Fig, 12). From (Table, 1) the lowest concentration of  $\text{K}^+$  value (4.5 mg/l) observed in well No. 7 lies in the north-eastern side of the study area, whereas, the highest concentration of  $\text{K}^+$  value (17.6 mg/l) appeared in well No. 11 lies in the southern side of the study area. The spatial distribution of  $\text{K}^+$  visualized decreasing concentration at the north-eastern side of study area, whereas, increasing at the southern side of the study area (Fig, 13), and this may be related to decomposition by weathering and decomposed which can be absorbed by clay minerals.

#### 4.1.6 Sodium ( $\text{Na}^+$ ):

Because  $\text{Na}^+$  compounds are very soluble in water this element is abundant in all natural water and it is important member of alkali metal group in natural water. In the study area the concentration in water wells varies from 35 to 200 mg/l with a mean and a standard deviation of 130.5 and 49.4 mg/l, respectively (Table, 2 and Fig, 14). From (Table, 1) the lowest concentration of  $\text{Na}^+$  value (35 mg/l) observed in well No. 10 lies in the western side of the area, whereas, the highest concentration of  $\text{Na}^+$  value (200 mg/l) appeared in well No. 9 lies in the northern side of the study area. The spatial distribution of  $\text{Na}^+$  visualized decreasing concentration at the western side of study area, while, increasing at the northern part of the study area (Fig, 15), and this may be related to the silicate weathering and/or dissolution of soil.

#### 4.1.7 Calcium ( $\text{Ca}^{2+}$ ):

It usually occurs in water as ( $\text{Ca}(\text{HCO}_3)$ ,  $\text{CaCO}_3$  and  $\text{CaSO}_4$ ), although in some high salinity water, ( $\text{CaCl}_2$  and  $\text{CaNO}_3$ ) can also be found, and the concentration in the study area varies from 5.6 to 61.2 mg/l with a mean and standard deviation was measured as 18.7 and 16.4 mg/l, respectively (Table, 2 and Fig, 16). From (Table, 1) the lowest concentration of  $\text{Ca}^{2+}$  value (5.6 mg/l) observed in well Nos. 12 and 13 sited at the north and west side of the area, whereas, the highest concentration of  $\text{Ca}^{2+}$  value (61.2 mg/l) appeared in well No. 10 which located at western side of the study area. The spatial distribution of  $\text{Ca}^{2+}$  values in the study area decreasing toward north western part of the study area, whereas, increasing at western side of the study area, and this result of dissolution of the carbonate minerals.

#### 4.1.8 Magnesium ( $\text{Mg}^{2+}$ ):

Found in sedimentary rocks especially the carbonates and it is evaporates. It is a relatively abundant element in the earth's crust and hence a common constituent of natural water and in water wells ranges from 10 to 39.1 mg/l with a mean and standard deviation of 20.4 and 8.4 mg/l, respectively (Table, 2 and Fig, 4.18). From (Table, 1) the lowest concentration of  $\text{Mg}^{2+}$  value (20.4 mg/l) observed in well No. 10 lies in the western part of the area, whereas, the highest concentration of  $\text{Mg}^{2+}$  value (39.1 mg/l) appeared in well No. 13 lies in the northern part of the study area. The spatial distribution of  $\text{Mg}^{2+}$  values in the study area decreasing toward western part of the study area, whereas, increasing at northern side of the study area (Fig, 19), and this results of evaporates processes from sedimentary rocks.

#### 4.1.9 Chloride ( $\text{Cl}^-$ ):

Usually present in natural waters, and a high concentration occurs in waters that have been in contact with chloride-containing geological formations, and in the study area, the concentration varies from 12.1 to 46.7 mg/l with a mean and standard deviation of 27.4 and 10.2 mg/l, respectively (Table, 2 and Fig, 20). From (Table, 1) the lowest concentration of  $\text{Cl}^-$  value (12.1 mg/l) appeared in well No. 10 lies in the western part of the area, whereas, the highest concentration of  $\text{Cl}^-$  value (46.7 mg/l) appeared in well No. 3 lies in the southeastern part of the study area. The spatial distribution of  $\text{Cl}^-$  values in the study area decreasing towards western part of the study area, whereas, increasing at the southeastern side of the study area (Fig, 21), and this related to leaching processes of saline residues in upper formations and mudstone.

#### 4.1.10 Sulphate ( $\text{SO}_4^{2-}$ ):

Has a wide range in natural water; from a few mg/l to several thousand mg/l and the source in water is the dissolution of Gypsum and other Sulphur deposits as well as from the seawater intrusion, the concentration in water wells in the study area varies between 12 and 200 mg/l with a mean and standard deviation of 115.5 and 57.5 mg/l respectively (Table, 2 and Fig, 22). From (Table, 1) the lowest concentration of  $\text{SO}_4^{2-}$  values (12 mg/l) observed in well No. 7 lies in the northeastern side of study area, whereas, the highest concentration of  $\text{SO}_4^{2-}$  value (200 mg/l) appeared in well No. 11 lies in the southern side of the study area. The spatial distribution of  $\text{SO}_4^{2-}$  values in the study area decreasing at the northeaster side of the study area, whereas, increasing towards southern side of the study area (Fig, 23), and this related to leaching processes of upper soil layers or evaporate deposits intercalated at the upper horizons of the sedimentary sequences.

#### 4.1.11 Bicarbonate ( $\text{HCO}_3^-$ ):

Carbon species occurs in naturally circulating water as bicarbonate ( $\text{HCO}_3^-$ ) and carbonate ( $\text{CO}_3$ ), where within the normal pH range of fresh waters, in the study area, ranges from 205 to 380 mg/l with a mean and standard deviation of 321.5 and 49.4 mg/l, respectively (Table, 2 and Fig, 24). From (Table, 1) the lowest concentration value of  $\text{HCO}_3^-$  (205 mg/l) found in well No. 5 lies in the south-eastern part of the area, whereas the highest concentration value of  $\text{HCO}_3^-$  (380 mg/l) found in well No. 13 lies in the northern part of the study area. The spatial distribution of  $\text{HCO}_3^-$  values in the study area decreasing towards south-eastern side of the study area, whereas, increasing at the northern side of the study area (Fig, 25), and this related to driven from dissolution and weathering of parent rock materials as well as dissolution of the carbonate rocks.

The results show that groundwater in the study area are good for domestic uses with few exception found to be above the recommended values according to (WHO, 2006) and (SSMO, 2009) standards.

#### 4.2 Hydrochemical Facies:

The results of the chemical analyses of the total wells in the study area were plotted on Piper diagrams (Fig,26) for hydrochemical facies. The major cations of groundwater samples are almost totally located close to the ( $Mg^{2+}$ ) end. The position of the groundwater in the anions triangle indicates dominance of the  $HCO_3^-$  and  $SO_4^{2-}$ , but comparatively low  $Cl^-$  in the waters. Hence, groundwater is significantly dominated by bicarbonate type. The result of chemical analysis of the study area have been plotted on the Piper trill near diagram reveals that the water type is  $Na^+ - HCO_3^- - SO_4^{2-}$ . It is worth noting the change in anion content in the groundwater, increasing bicarbonate and decreasing sulfate concentration. This may be related to evaporate deposits at upper soil layer, thickness mudstones and increased anthropogenic activities.

#### 5. Conclusion:

The results show that groundwater in the study area are good for domestics uses with a few exception found to be above the recommended values given by (WHO, 2006) and (SSMO, 2009). Based on Hill-Piper trilinear diagram, reveals that the chemical water type is  $Na^+ - HCO_3^- - SO_4^{2-}$ . Processes of water-rock interaction that are assumed to modify the original chemical composition of groundwater in the studied system are mainly carbonate dissolution, which affects  $Ca^{2+}$  and  $HCO_3^-$ , reverse ion-exchange reactions with clay minerals that affect  $Na^+$  and  $Ca^{2+}$  and dissolution of silicate minerals that affect  $Na^+$ .

#### References:

- Aiyesanmi AF, Ipinmoroti KO and Oguntimehin II. (2004). Impact of automobile workshop on groundwater quality in Akure Metropolis. J. Chem. Soc. Nig. (Supplement to 2004 Proceeding) (pp. 420–426).
- El Fasher Meteorology Station.(2017). El Fasher Airport, North Darfur State, Sudan.
- El Tom, A., Fathelrahman, A., Sami, O., Nuha, E., Salah, B., Yousif, M., and Salim, A. (2009).Study and Design of Artificial Recharge Facilities in North Darfur State, Abu Shouk/El Salam and Zamzam IDPs Areas (Section 2).
- Fudal, A, A. (2004).Natural resources management for sustainable peace in Darfur, Int. Conference Proceedings, Environment, Degradation as a cause of conflict in Darfur, Khartoum-Sudan, December 2004 (Part 3).
- Gachet, A. (2006). "Water Exploration in Darfur, Sudan".Report, Radar (Part III).
- Odukoya OO, Arowolo TA and Bamgbose O. (2002).Effect of Solid Waste. Landfill on underground and surface water quality at Ring Road, Ibadan. Global J. Environ. Sci., 2(2): (pp. 235–242).

- Oyinloye AO, Jegede GO. (2004). Geophysical Survey, Geochemical and Microbiology Investigation of ground well water in Ado-Ekiti, North, South Western Nigeria. *Global J. Geol. Sci.*, 2(2): (pp. 235-242).
- SSMO.(2009). Sudanese Standards and Metrology Organization, Drinking Water Standard, ICS 13.060.00.
- Tebbut, T. H.Y. (2002).Principle of WATER QUALITY CONTROL, (5 Eds), Linacre House, Jordan Hill, Oxford OX28DP.
- Vail, J.R. (1989). Tectonic and Evolution of the Proterozoic Basement of NE Africa In: Elgaby, S. & R.O. Greiling (Eds). The Pan-African belts of NE Africa and adjacent areas, FriedrUieweg and Sohn: (pp. 185-226).
- W.H.O. (2006).Guidelines for Drinking-water Quality, Geneva, Switzerland.
- Wilcox, L. V. (1955). Classification and Use of irrigation Waters, U.S.A. Salinity lab.Circulation.No. 969.

Table 1: Chemical analysis of groundwater samples in the Study Area

Sample No.	pH	EC	TDS	TH	Ca	Mg	Na	K	CL	SO <sub>4</sub>	HCO <sub>3</sub>
		<i>µm/cm</i>	<i>Mg/L</i>								
1	7.7	1505	1053.5	122	12.1	17.9	147	4.9	19.2	32	363
2	7.7	3554	2487.8	600	12.1	17.9	147	6.6	45.4	138	245
3	7.6	3580	2506	600	6.2	23.8	175.7	14.8	46.7	155	315
4	7.2	1375	962.5	220	22.4	16.4	120	4.7	24	87	363
5	7.7	3450	2415	500	8.3	16.8	153.7	4.7	25	116	205
6	7.4	3590	2513	550	7.7	19.8	160.7	7.1	41.2	128	285
7	7.6	1498	1048.6	145	46.8	17.5	175	4.5	25.6	12	373
8	7.7	1509	1056.3	165	15.2	11.5	152	7.7	19.2	87	330
9	7.5	1590	1113	210	13.2	26	200	7.7	20.6	133	330
10	7.6	1402	981.4	175	61.2	10	35	6.6	12.1	100	340
11	7.4	2700	1890	390	22.4	16.4	120	17.6	25.6	200	330
12	7.3	2658	1860.5	300	5.6	36.7	84	9.2	28.4	193	300
13	7.5	2380	1666	280	5.6	39.1	38	10	27.7	178	380
14	7.7	940	590	90	22.4	16.4	120	7.4	23	54	342



Table 2: Elementary statistics of chemical data of groundwater in the study area

Statistical Calculation	Mean	Standard Deviation	Minimum	Maximum
pH	7.5	0.17	7.2	7.7
EC ( $\mu\text{m/cm}$ )	2266.5	976.4	940	3590
TDS ( $\text{Mg/l}$ )	1581.7	690.8	590	2513
TH ( $\text{Mg/l}$ )	310.5	183.5	90	600
Ca ( $\text{Mg/l}$ )	18.7	16.4	5.6	61.2
Mg ( $\text{Mg/l}$ )	20.4	8.4	10	39.1
Na ( $\text{Mg/l}$ )	130.5	49.4	35	200
K ( $\text{Mg/l}$ )	8.1	3.8	4.5	17.6
CL ( $\text{Mg/l}$ )	27.4	10.2	12.1	46.7
SO <sub>4</sub> ( $\text{Mg/l}$ )	115.2	57.5	12	200
HCO <sub>3</sub> <sup>-</sup> ( $\text{Mg/l}$ )	321.5	49.4	205	380

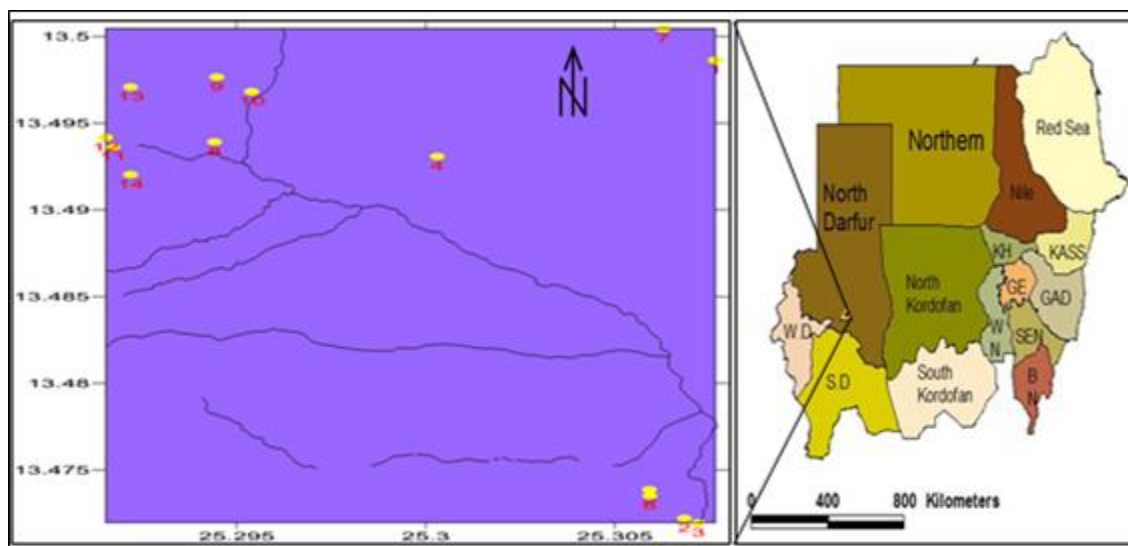


Fig (1): Groundwater samples location map

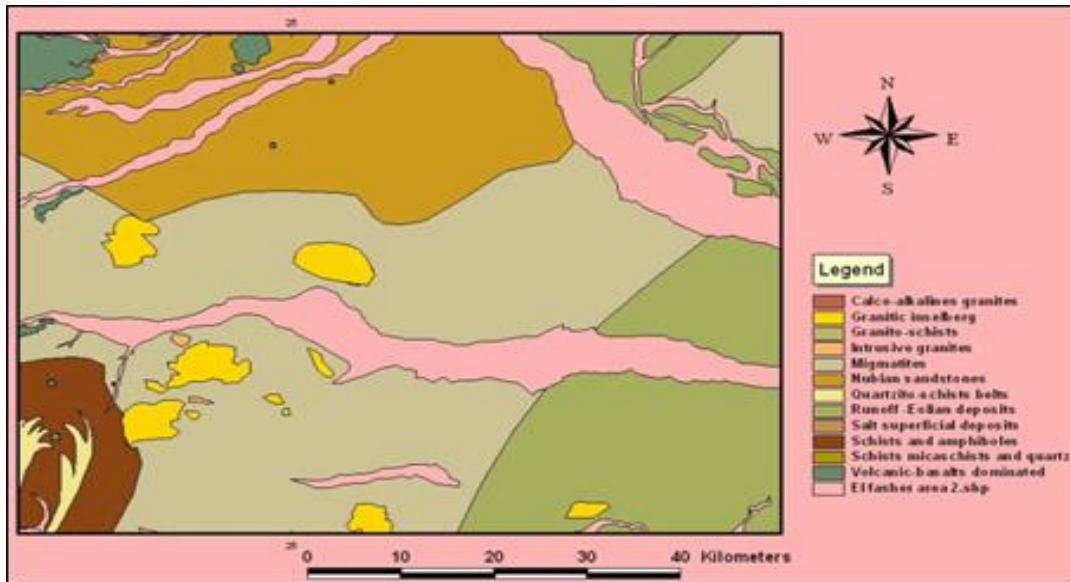


Fig (2): Geological map of Study area

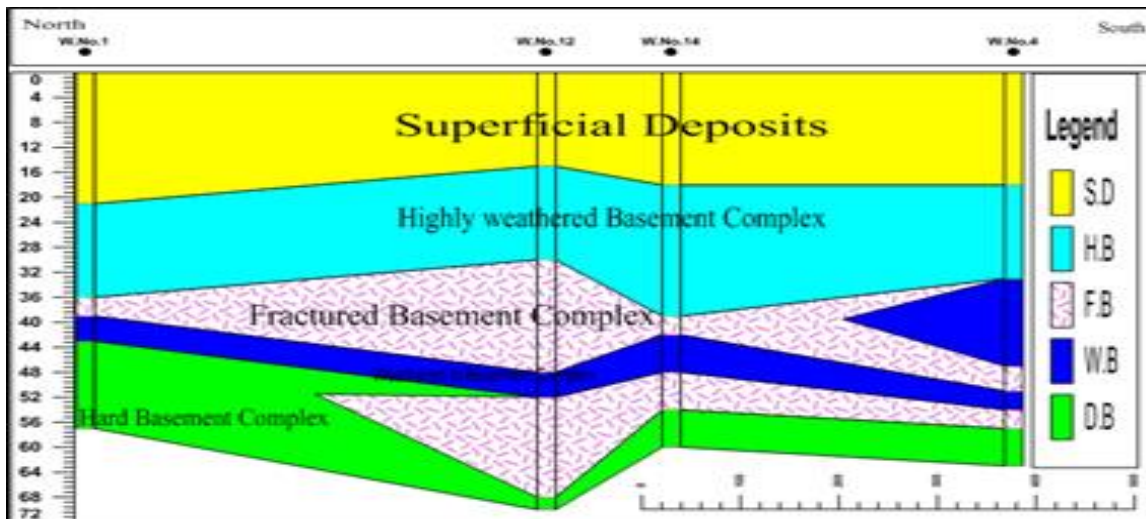


Fig (3): Geological cross-section through the subsurface of the study area (Note: SD: Superficial Deposits, HB: Highly weathered Basement Complex, FB: Fractured Basement Complex, WB: Weathered to Basement Complex and DB: Hard Basement Complex).

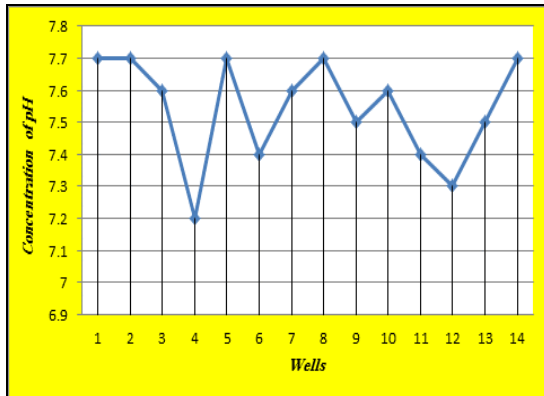


Fig (4): Concentration of pH

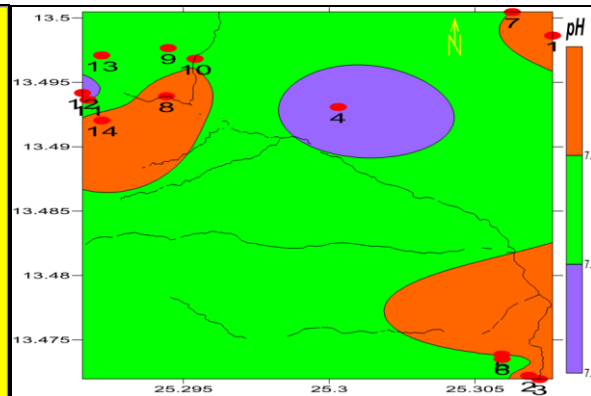


Fig (5): Spatial distribution of pH

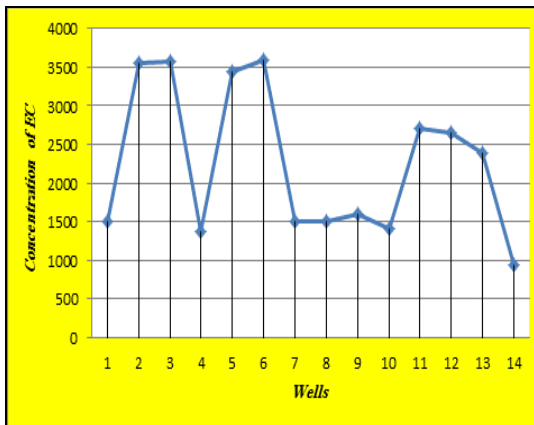


Fig (6): Concentration of EC

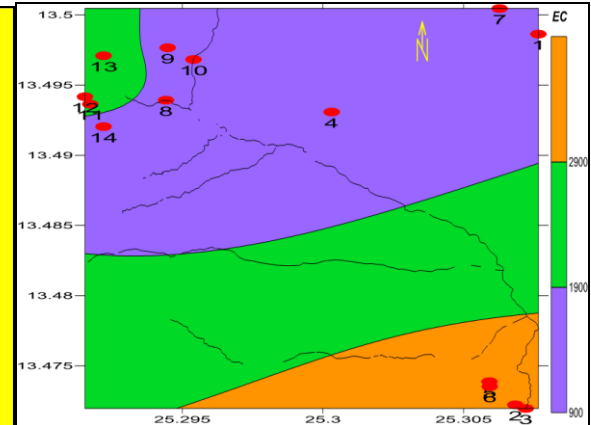


Fig (7): Spatial distribution of EC

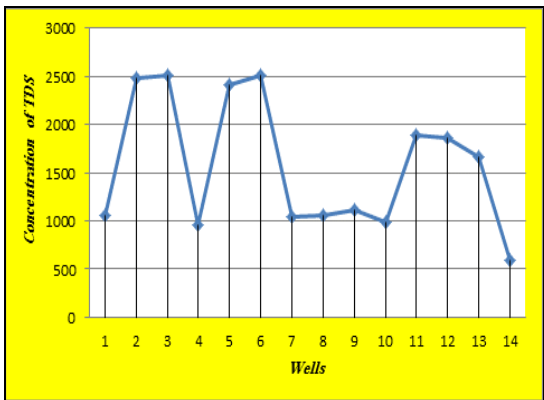


Fig (8): Concentration of TDS

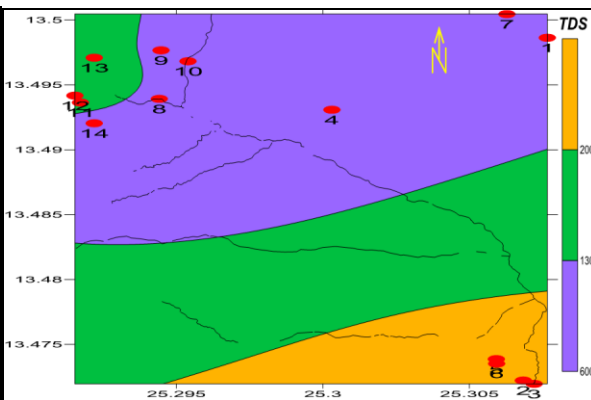


Fig (9): Spatial distribution of TDS

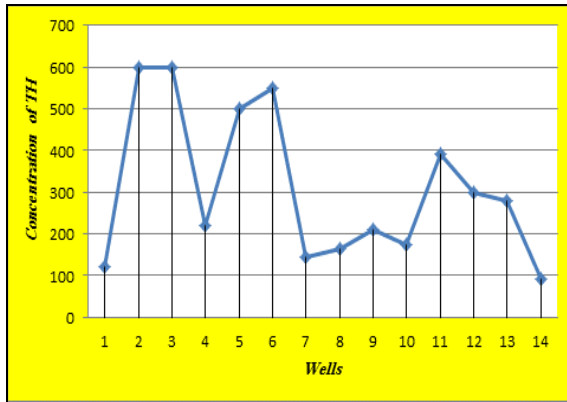


Fig (10): Concentration of TH

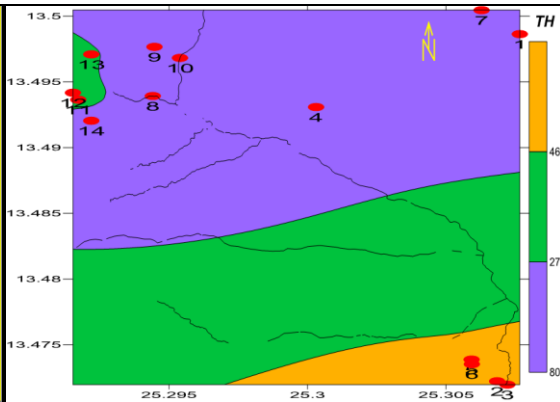


Fig (11): Spatial distribution of TH

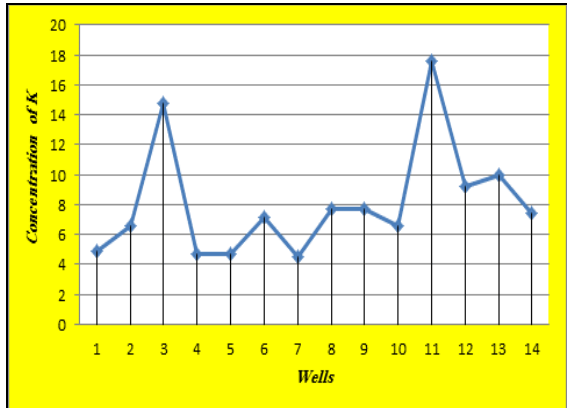


Fig (12): Concentration of K<sup>+</sup>

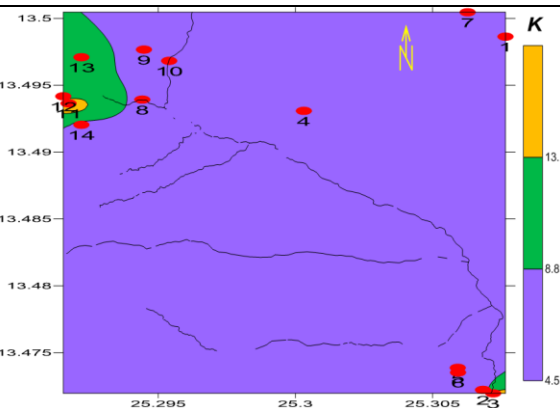


Fig (13): Spatial distribution of K<sup>+</sup>

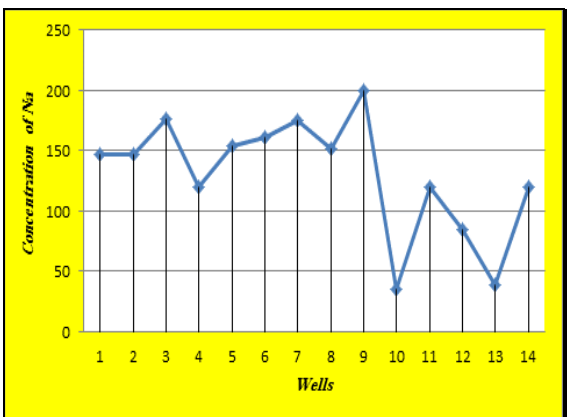


Fig (14): Concentration of Na<sup>+</sup>

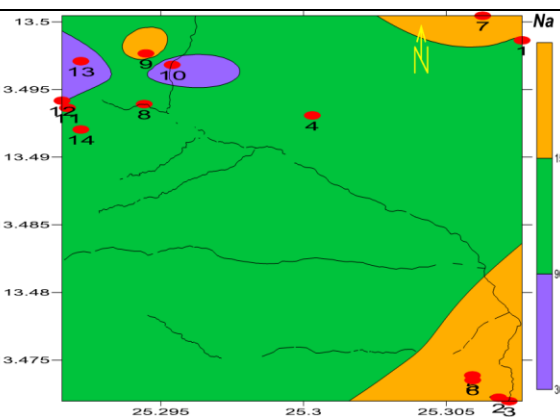


Fig (15): Spatial distribution of Na<sup>+</sup>

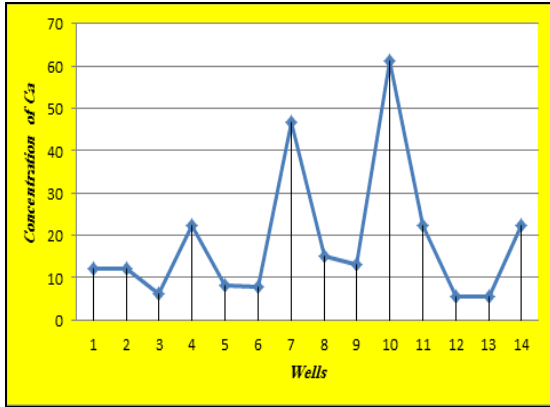


Fig (16): Concentration of Ca<sup>2+</sup>

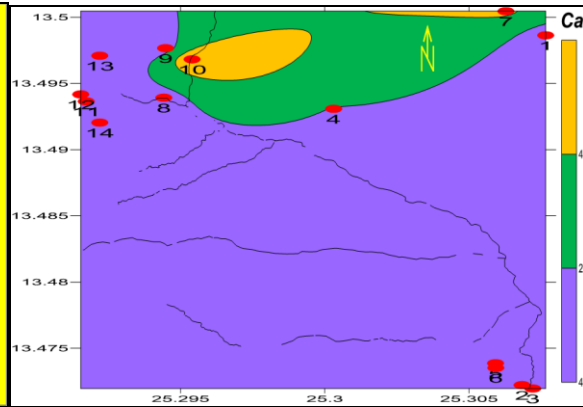


Fig (17): Spatial distribution of Ca<sup>2+</sup>

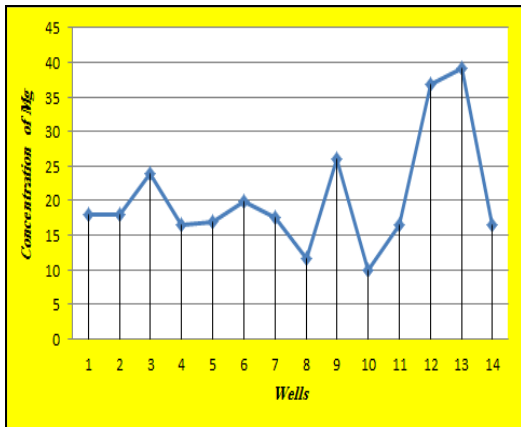


Fig (18): Concentration of Mg<sup>2+</sup>

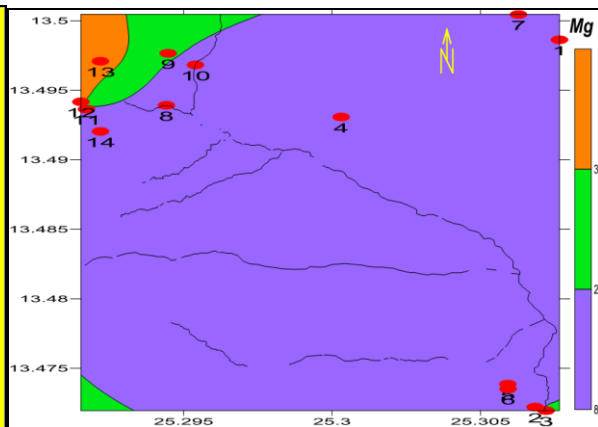


Fig (19): Spatial distribution of Mg<sup>2+</sup>

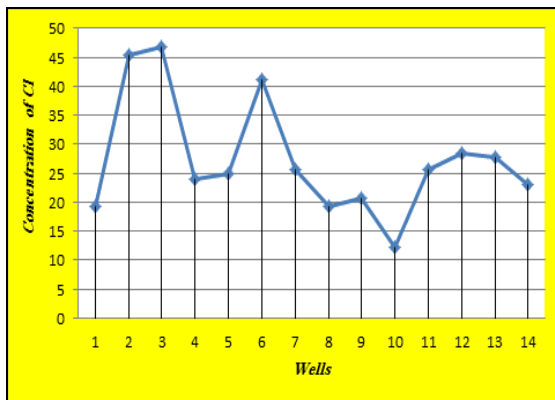


Fig (20): Concentration of Cl<sup>-</sup>

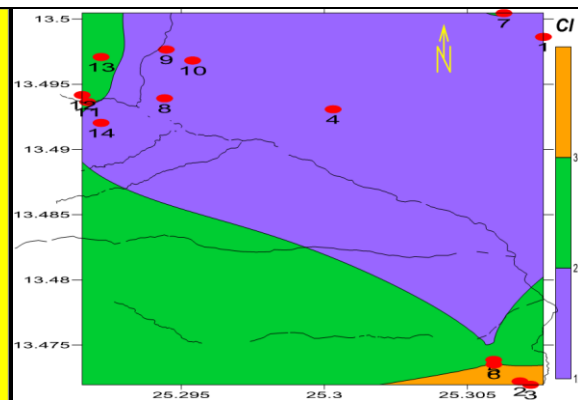


Fig (21): Spatial distribution of Cl<sup>-</sup>

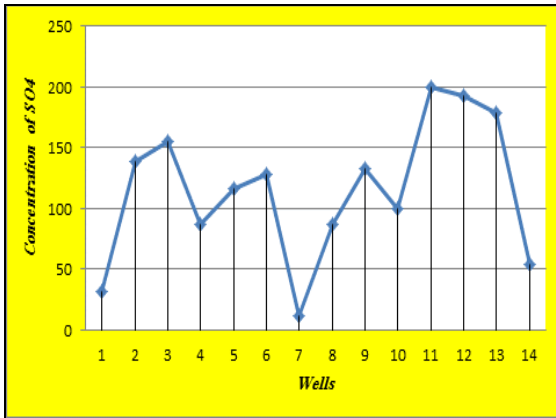


Fig (22): Concentration of SO<sub>4</sub><sup>2-</sup>

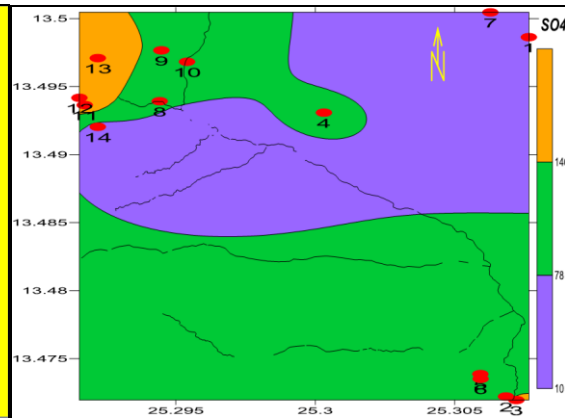


Fig (23): Spatial distribution of SO<sub>4</sub><sup>2-</sup>

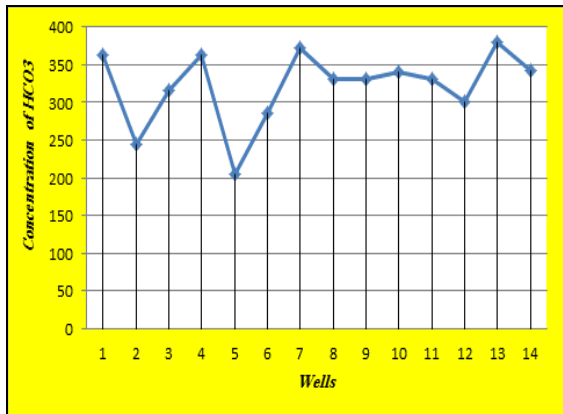


Fig (24): Concentration of HCO<sub>3</sub><sup>-</sup>

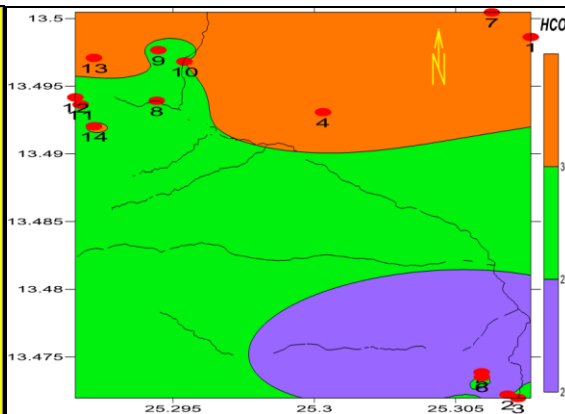


Fig (25): Spatial distribution of HCO<sub>3</sub><sup>-</sup>

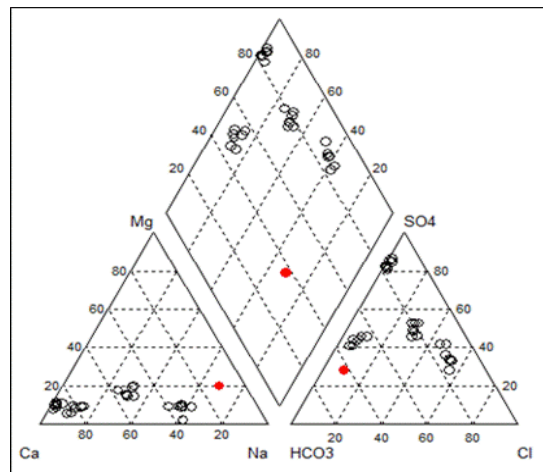


Fig (26): Piper Diagram of groundwater samples (Na<sup>+</sup>-HCO<sub>3</sub><sup>-</sup> -SO<sub>4</sub><sup>2-</sup>)