Hydro-chemical Analysis and Isotopic Characterization of Groundwater in Western Bank of the River Nile, Dongola Basin, Northern State, Sudan

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Abstract

The aim of the present study was to evaluate groundwater quality and chemical features of groundwater in the western bank of River Nile, Dongola Basin; Northern State, Sudan. Detailed geochemical study of groundwater was carried out, and the origin of the chemical composition of groundwater has been quantitatively addressed. To realize the objectives of the current study, (No. of samples here) samples were analyzed for various physico-chemical parameters such as temperature, pH, salinity, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^- and SO_4^{2-}. The majority of water samples were moderately hard water, and temporary hard (carbonate and bicarbonate hardness). The dominant anions are carbonate and bicarbonate (CO_3^{--}, HCO_3^-); and the dominant cation is sodium (water type (Trona rocks). The majority of water samples were (sodium-calcium-magnesium)-(bicarbonate – sulphate) type. (Sulphate –Chloride) type was found in some samples; (Sulphate) types and (Chloride) types were detected in other samples. Using environmental and stable isotopes based on tritium concentration, groundwater is , classified into three groups; the first one is > 20 T.U., the second one is varying from 3 to 20 T.U., and the third group < 3 T.U., therefore recognized as paleo-water. According to stable isotopes (Oxegen-18 and Hydrogen-2), groundwater is categorized into another three groups; recent water with evaporation the second is mixing water and the third is paleo-water, because depletion of the stable isotopes was recognized. The Total Dissolved Solids (TDS) in some groundwater samples TDS increases with $\partial\ ^{18}O$.

Keywords: Groundwater Quality, Isotopes, Dongola Basin, River Nile, Northern State, West Bank

1.0 Introduction and Hydrological Setting

Water quality analysis is one of the most important aspects in groundwater studies. The Hydrochemical study reveals quality of water that is suitable for drinking, agriculture and industrial purposes. Further, it is possible to understand the change in quality due to rock-water interaction (Kelley, W.R., 1940; Wilcox, L.V., 1948; Siddig, M.E.; O.A.O. Al-Imam & Hussein, A. H., 2013 & Elzien, S.M. & Hamed, B. O., 2016) or any type of anthropogenic influence. Groundwater often consists of several chemical elements e.g. Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, HCO_3^{-} and SO_4^{2-} etc. The chemical parameters of groundwater play a significant role in classifying assessing water quality (Sadashiraiah, C., et al. 2008) considering the individual and paired ionic concentration, certain indices are proposed to find out the alkali hazards. Residual sodium carbonates (RSC) can be used as a criterion for finding the suitability of irrigation waters.
Hydrological Structure of the Dongola Basins is considered as one of the most important groundwater basins in Sudan in terms of groundwater availability, water quality and degree of utilization. The basin is considered as the northern extension of the Blue Nile–Khartoum rift basin. Groundwater occurs in the sandstone aquifers of the Wadi El Melek Formation and lesser extent in Wadi Howar Formation and the Sandy lenses of the River deposits. Depth to groundwater is controlled by topography, Basement configuration, proximity to the River Nile, as well as existing pumping regime (Ibrahim M.E., 1985; Lahmeyer International, 2006).
Groundwater in the basin occurs generally, under free water table conditions and depth varying from 2-5meters below ground surface along the Nile strip and the Qa'ab Depression, 10-25meters along Wadi El-Mugaddam. In the study area, groundwater occurs generally, under free table conditions, and may be some places are slightly confined resulting from the presence of sandstone or clayey lenses. The Lowest groundwater level is that around Al Selaim Canal (Mohamed, K. Omar, 1983).
Depth of groundwater generally, increases away from the River Nile, however, when thick pelitic sediments of Wadi El-Melek dominants the upper layers, groundwater occurs under semi-confining to confining conditions. This is case in Qa'ab El Bab well which is 300m deep and where the water level rises to 1.38m above groundwater level.
The basement configuration divided the Dongola Basin into hydraulically connected sub-units; namely Dongola, El-Debba and Wadi El-Mugaddam sub-basins (Mohamed, K. Omar, 1983).

The groundwater reflects the mineralogical composition of the rocks in the aquifer also can be used to localize recharge areas and to determine the origin of groundwater (meteoric, marine, fossil, or water) and of individual chemical components (e.g. carbonate, sulphate, nitrate and ammonium).
The water compositions can also give information about processes of water-rock interaction and microbial processes in the water chemical precipitation controlled by the solubility of a substance, and chemical alteration by e.g. oxydo-reduction and complexation processes. Cations in the water types derived mainly from the leaching of the rock, minerals and the soil whereas; the anions come mainly from lithological sources.
The purpose of this paper is to assess the interactions between surface and groundwater in Dongola basin area, using environmental and stable isotopes.
The study area lies along River Nile in the Northern State, Sudan. The area forms an elongated shape and generally (Dongola Basin) bounded by longitudes (29° 27' 52.13" – 31°.92 00 E and latitudes 17° 19' 00" - 20° 55' 59.42" N (**Fig. 1**).

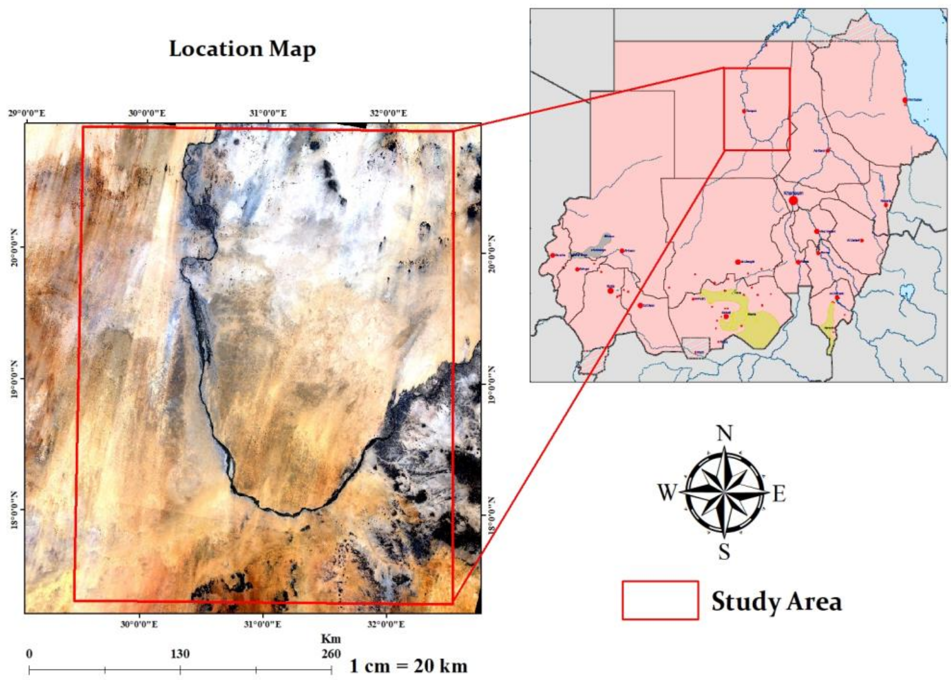

Fig. 1: Location of the Study Area

2.0 Physiographical Features

The River Nile is the most important source of water for irrigation and supply approximately about $800*10^6$ m^3 yearly. It is the only perennial surface water resource, available in this area. High water level occurs during high flood period (August – September) and the minimum water level during (December – June) the difference between the highest and lowest level is about 4.59 m at Dongola (Groundwater and Wadis Directorate & International Atomic Energy Agency, 2000).

The area lies in the arid desert climatic region, in which rainfall is very low /negligible. The winter season is distinctly pleasant; from October to mid March, the mean daily temperature is below 20 °C, in the early morning, the temperature may fall to zero (0°C. The humidity is low, and there is very little cloud cover and no rain (Bonfica Geoexpert, 1986a).

The wind blows from the north with a mean speed between 15 – 20 Km/h. Summer is long and very hot; from the beginning of May until the end of September, the mean daily temperature reaches 40°C; humidity is high particularly in August, and the normal wind speed falls about 12Km/h; and blows from different directions (Bonfica Geoexpert, 1986b).

The mean annual rainfall is about 9.280 mm / annum (Fig. 2) (1989 – 2008), rainfall characterized by low variability 17.1223(Table1)

Vegetation in the study area is restricted to the banks of the River Nile and the floors of the big seasonal water resources such as Wadi El-Melek, Wadi Al-Mugaddam, Khor Abu Sunt and Khor Masur. In these stream beds, coarse grasses and *Acacia tortilis*, *Acacia mellifera* and Acacia Seyal are found. Along both sides of the Nile Date Palms are intensively farmed. Some isolated trees of Sidr (*Ziziphrus spina*), Haraz *Acacia Albida* and some green Nile grasses are also found. Herbs and fine grasses spring up after the very rare rain shower during the summer but they soon disappear (Salih Lh. M., 1987).

Table 1: Annual Rainfall Variability at Dongola

Lowest (mm)	Highest (mm)	Average Rainfall (mm)	Standard Deviation
0.0	74.2	9.280	17.1223

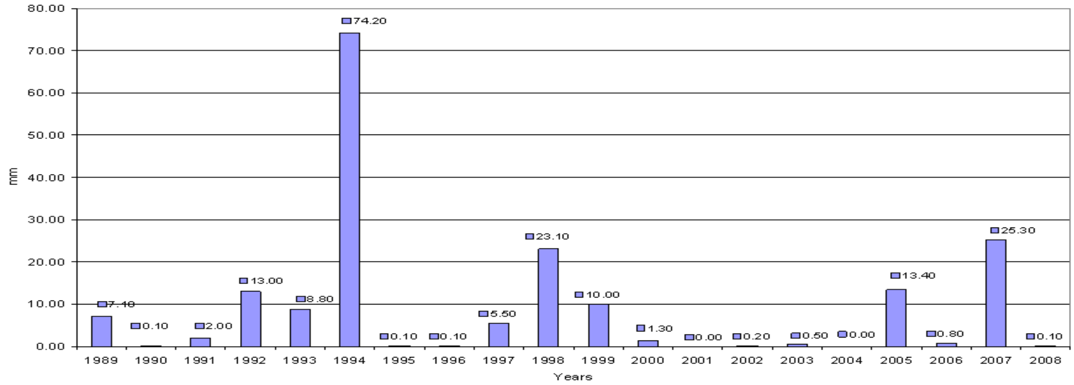

Fig. 2: Dongola Annual Average Rainfall 1989 - 2008

3.0 Statement of the Problem

Water quality becomes one of the important issues for the socio-economic development in all countries; the determination of chemical quality of water becomes problematic in developing countries like Sudan. Many places contain saline water aquifers or subjected to mix or interaction by saline water. Salts can be introduced either through complicated chemical processes or simple addition or mixing from surface or subsurface saline source. One or many processes may contribute to this problem. The current study will concentrate on salinity problems at the western bank of the River Nile, Norther State, Sudan. The source of saline water, which in specific aquifers, in relation with other water bodies either surface or groundwater, will be defined and groundwater chemical results, will be treated statistically to see its significant characteristics and differences.

4.0 Geology of the Study Area

The Northern State in general consists of two different zones, the extremely ancient rocks; crops out along the River Nile in the north of Karma and south of Kariema. These rocks are Precambrian-Cambrian in ages, and overlain by Nubian Sandstone Formation covered by superficial deposits ranging from Mesozoic to Quaternary (Andrew, G., 1948).

The Basement Complex extended along the River Nile between Karma and Kariema and extends southwards to lower Wadi El Mugaddam and Wadi El-Melek. The Basement Complex rocks are mainly composed of metavolcanics and metasediments and gratified rocks (Kheralla, K. M., 1966).

The Nubian Formation unconformable overlies the Basement Complex. It is dominated by argillaceous and arenaceous beds with mudstone and siltstones. Calcareous and ferruginous beds are common (Kheralla, K. M., 1966). The formation is characterized by rapid facies changes in all lithologies. The Nubian Sandstone in Dongola area is referred to as Wadi El-Melek Formation which is divided into three units; pelitic sandstone at the top, followed by argillaceous sandstone of fine to medium intercalated with silts and clays with lateral and vertical facies changes. In general, this unit represents the major sandstone sequence, thickness ranges from 100-180m and conglomeratic sandstone lies unconformable over the Basement Complex and consists of medium to coarse sandstone, this unit appears at deep well (Kadruka Pilot Farm) in the northeast of this area and (Kheralla, K. M., 1966).

Wadi El-Melek Formation shows great vertical and lateral variability originated by cyclical deposition of fluviatile-lacustrine environments of limited extension and under increasing subsidence within the indicated graben structure (Klitzsch, E. & Squyres C. H., 1990). The lithological structure of Wadi El-Melek Formation is composed of three major lithological units (Ibrahim, M.E., 1985). These units covered by thick superficial deposit composed of sand, silt and clays of alluvial origin, varies in thickness between 2-20m. The Nile deposits are including fine alluvial deposits near the River Nile and the coarser alluvial deposits further away (Bonfica Geoexpert, 1986a). The sediments in the study area classified as Nubian Sandstone (Late Cretaceous- Paleogene) which is the most important water bearing formation in the Sudan.

5.0 Materials and Methods

Groundwater samples and measurements were collected from 131 boreholes and the River Nile in the West River Nile Bank. (Omer, H.M.A.M.,2012) (Fig.3), The GARMIN GPS was used to locate the exact coordinates of the sample collection to continue monitoring purposes. Methods of collection and analysis of water samples followed are essentially the same as given by (APHA, 1998). Samples were collected in one litre capacity polyethylene bottles. Prior to the collection, bottles were thoroughly washed with diluted HNO_3 acid and then with distilled water in the laboratory before filling bottles with samples. Each bottle was rinsed to avoid any possible contamination in the bottling, and every other precautionary measure was taken. For chemical analysis (major anions and cations), the physico-chemical parameters were measured in the field (E.C, pH and TDS) with potable meter; also TDS was measured in the lab. By the dryness method, carbonate, bicarbonate (HCO_3^-) concentration were determined by acid titration of 0.02N H_2SO_4. Sodium (Na^+) and potassium (K^+) were determined by Flame photometry. Calcium (Ca^{2+}), magnesium (Mg^{2+}) total hardness and total alkalinity were measured titrimetrically using standard EDTA method. Chloride (Cl^{1-}) by standard $AgNO_3$ titration sulphate, nitrate, and nitrite ammonia were measured by spectrometric method. The analytical precision for ions was determined by ionic balances calculated as 100x (cations-anions)/ (cations + anions), which is generally, within±10%. The equipment and instruments were tested and calibrated with calibration blanks and serious of calibration standards as per specifications outlined in standard methods of water (APHA 1998). Total Hardness (TH) was calculated by the following equation (Raghunath, 1987), TH = (Ca + Mg) x 50 where, TH is expressed in meq/L, and the concentration of the constituents are expressed in meq/L.

The sodium absorption ratio (SAR) was calculated by the following equation given by Richards (1954).

Thirty-six and three samples were taken from boreholes and River Nile in the western bank to determine the radioactive and environmental isotopes (tritium, deuterium and oxygen-18), using liquid scintillation counter analyzer and mass spectrophotometer.

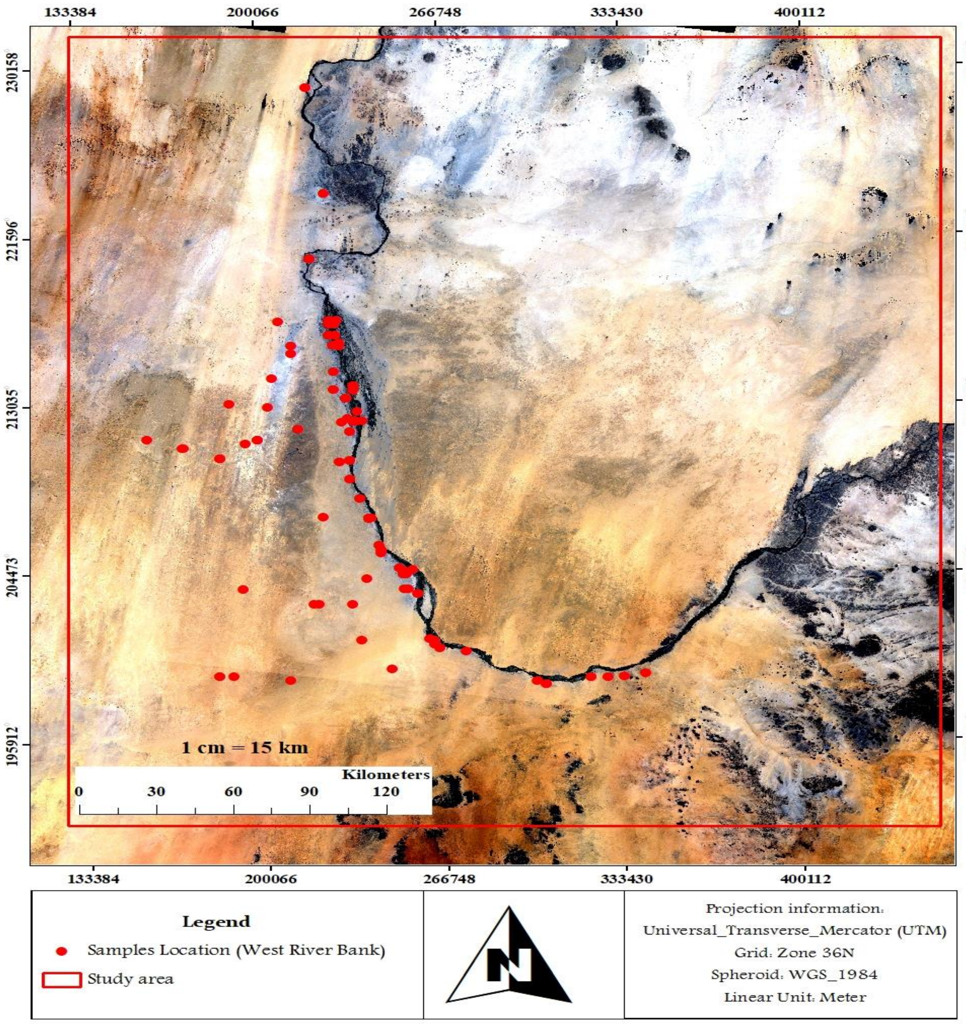

Fig. 3: Location of water samples from the Western side of the River Nile Bank, Dongola Basin.

6.0 Results and Discussions

6.1 Hydro-geochemistry

Electrical conductivity is a parameter related to total dissolved solids (TDS). The importance of TDS and EC lies in their effect on the corrosivity of a water sample and their effect on the solubility of slightly soluble compounds such as $CaCO_3$ (Nas, 2010). Accordingly, to Langenegger (1990), the importance of electrical conductivity is an indirect measure of salinity in many areas, which generally affects the taste and thus, has significance on the user acceptance of the water as potable. 91.6% of the analyzed samples from the studied boreholes have TDS less than 1000 ppm. All of them represent fresh water, according to classifications of water after Currell 1985 for TDS range (0-100ppm).TDS - EC relationship (= geochemical coefficients) for the area West River Nile bank demonstrated Figs.4 &5, the coefficients of 0.7066 (West Side) and becomes to one decimal (0.7). About 8% of West River bank water samples represent brackish water. Seven samples had values greater than the standards (1001 -10000 mg/l) their concentrations were as follows: 2160 mg/l, 1701, 1512,1736,3885,3052 and 3052 mg/l (**Table 2**). The high concentrations of TDS in the open and shallow wells are due to evaporation and in the deep wells are due to leaching of rocks and concentration of chemical ions in the aquifer.

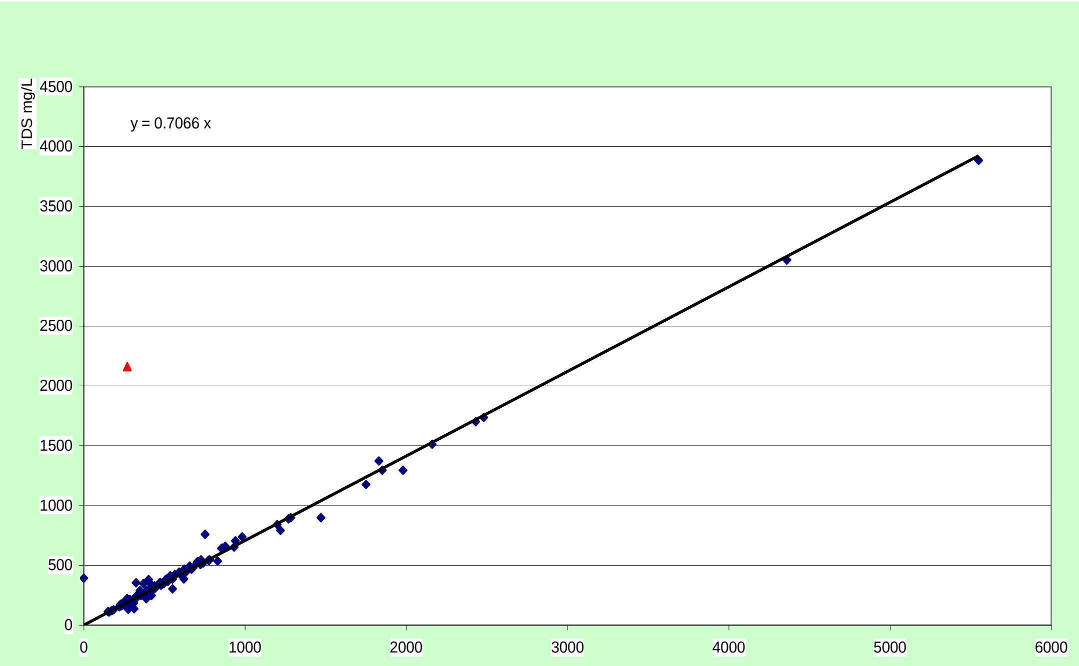

Fig.4: TDS Vs. E.C. in the Study Area West River Nile Bank

6.2 Suitability for Drinking

Table2: The Drinking Water Problems of the Study Area - West River Bank

Parameters	Within the Range of WHO Std.		Greater than WHO Range			WHO Std.
	Wells NO.	%	Wells NO.	%	Remarks	
pH	94	71.76	37	28.24	About 30% of samples	6.5-8.5
TDS	124	94.66	7	5.34	Samples 2,62,66,75, ,117 and 119	1000mg/l
Total Hardness	127	96.95	4	3.05	Samples 75,98,100 and 119	
Potassium	130	99.24	1	0.76	Sample 66	
Sodium	121	92.37	10	7.63	Ten samples	
Calcium	125	95.42	6	4.58	Six samples	
Magnesium	128	97.71	3	2.29	Samples 75, 117 and 119	
Chloride	123	93.89	8	6.11	Samples 59,66,72,75,109,112,117 and 119	
Sulphate	118	90.08	13	9.92	Thirteen samples	

Fluoride	126	96.18	4	3.82	Samples 23, , 117, 118 and 119	1.5 mg/l
Ammonia	131	100	0	0	No sample	
Nitrite	131	100	0	0	No sample	
Nitrate	131	100	0	0	No sample	

At the West River bank, the minimum concentration (Table 2) was 0 mg/l (sample No37); but there were three samples with values greater than standards (samples Numbers. 75,117 and 119). It is anticipated that the chemical composition of aquifer rocks is void of magnesium ion, or constituents of water may become modified by subsequent chemical reactions, such as cation exchange, absorption of dissolve ions and biological influences, also to our point of view; high magnesium concentration is related to high dolomite minerals if calcium ions are found in the aquifer. The maximum concentration of calcium ions in the water samples at West bank at the study area is 120mg/l: The concentration is due to chemical composition of calcium ions in the rocks. The rock maybe basalt (composition) among sedimentary rocks. Calcium is also a dominant cation in most river water samples.

Sodium ions concentration of groundwater samples taken in the study area were 0 mg/l Na^+ at the West bank samples 2, 10 and 11. The chemical composition of groundwater in this aquifer is without sodium like anhydrites, calcium carbonate dolomite and sylivite. The concentration of sodium in sample 119 is 1537mg/l and the concentration of bicarbonate is 285 mg/l suggesting that the water type in this well is sodium bicarbonate water having pH values above 8.4, It shows high sodium with high chloride suggests solution of halite; if considerable sulphate and calcium are also present.

The variations of sulphate ions concentrations in the study area are due to sedimentary rocks with evaporates comprising gypsum ($CaSO_4.2H_2O$) or anhydrite ($CaSO_4$). Ion concentrations in the study area varied from 0 mg/l to 2 mg/l (WHO 1.5mg/l).

6.3 Suitability for Livestock

Table 3: The Guideline of California Control Board, (1963) for West River Nile Bank

Quality Factor	**Threshold Conc. mg/l**	**Limiting Conc. mg/l**	**Maximum Conc. in the Study Area**
			West River Bank
TDS	2500	5000	3885mg/L (NO. 109)
Ca^{++}	500	1000	149mg/l (NO. 117,119)
Mg^{++}	250	500	196mg/L((NO. 117,119)
Na^+	1000	2000	1553.7 (NO. 110)
HCO_3^-	500	500	1464mg/L (NO. 130)

Cl^-	1500	3000	1314mg/L (NO. 109)
$SO_4^=$	500	1000	1225mg/L(NO. 109)

According to The Guideline of California Control Board, (1963) (**Table 3**), the West River Nile Bank, there were three water samples unsuitable for livestock because the quality factor of bicarbonate was above 500mg/l (Sample No. 130).

6.4 Suitability for Irrigation

Table 4: Irrigation Problems in the Study Area, (West River Bank)

Irrigation Problems		**No Problems**		**Increasing Problems**		**Severe Problems**	
		No. of Wells	**%**	**No. of Wells**	**%**	**No. of Wells**	**%**
Salinity		105	80.15	23	17.56	3	2.29
Permeability	Adj. SAR	118	90.08	7	5.34	6	4.58
Specific Ion Toxicity	Adj. SAR	103	78.63	22	16.79	6	4.58
	Cl^-	121	92.37	7	5.34	3	2.29
Miscellaneous	NO_3^-	74	56.49	55	41.98	2	1.53
	HCO_3^-	7	5.34	121	92.37	3	2.29
	pH	0	0	0	0	131	100

Most of water samples in the study area indicated that so far there is no salinity problems, TDS values within the WHO and SLS (1500 mg/l, fresh water) also Electrical Conductivity (EC) measurements in mmhos/cm varied within the permissible range (<0.75). All water samples in the study area can be used for different types of irrigation according to the mentioned suitability classification for irrigation (**Table 4**).

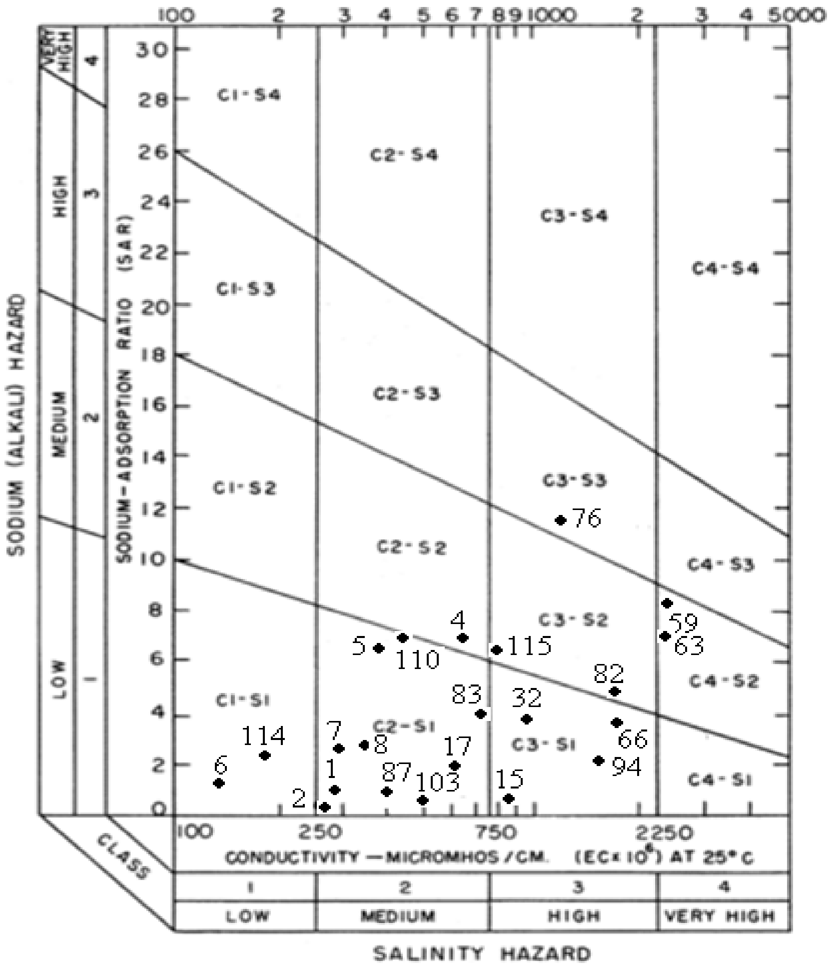

Fig. 5: Plots showing relationship between SAR & EC for groundwaters from the west side of the River Nile (USSL 1954)

The analytical results achieved from the water samples of Dongola, west of the River Nile are plotted on Piper's and Durov's (**Figs. 6,7&8).** They explained that the alkaline (Na^+) appears considerably over the alkaline elements (Ca^{2+}, Mg^{2+} & K^+), and the weak acidic (HCO_3^-) appears considerably over strong acidic anions (Cl^- & SO_4^{-2}). According to these diagrams, most of the elements of water type are named within the $NaHCO_3$ zone.

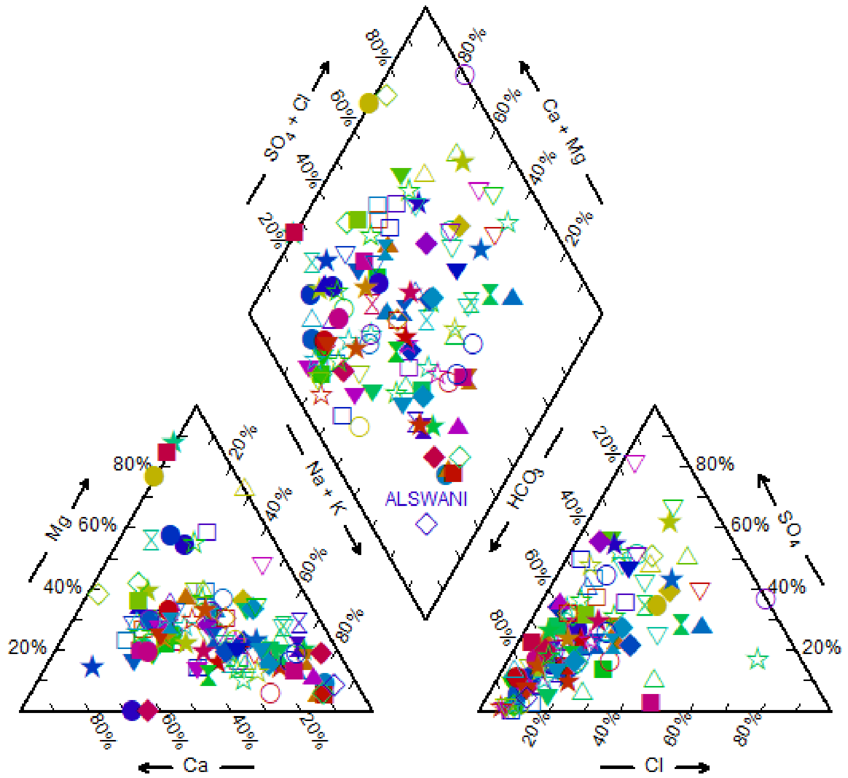

Fig.6: Trilinear diagram showing hydrochemical facies of groundwaters from the western side of the River Nile, Dongola Basin. (after Piper 1953)

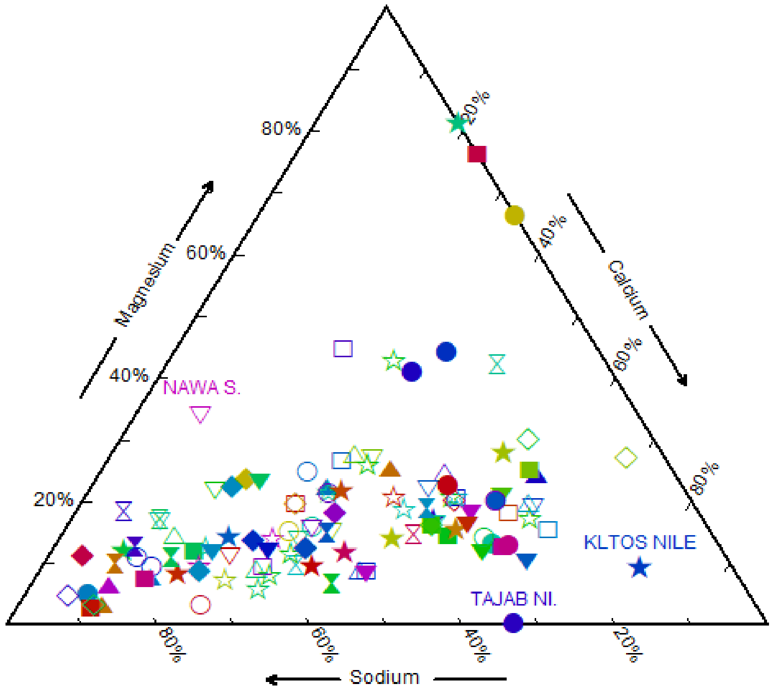

Fig. 7: Ternary Diagram -Dongola West

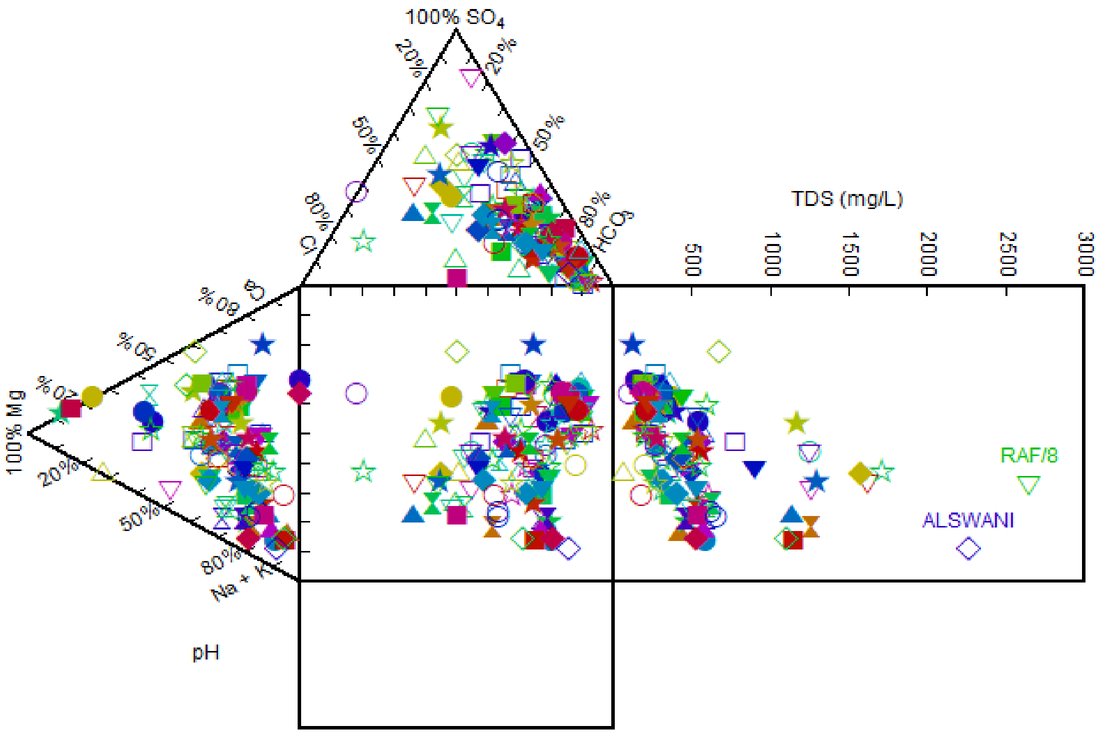

Fig. 8: Durov Diagram -Dongola West

The water type (HCO_3+CO_3) in west side of the River Nile (**Table 5**) included the majority of samples. Based on Piper and Durov Diagram (Figs.6,7&8), which shows:

7- Bicarbonate water type, This water type is divided into the following subgroups:

1. (Na+ K)- (HCO_3+CO_3) type
2. (Na+ K) + (Ca + Mg) –(HC O_3+CO_3) type
3. (Ca + Mg) –(HCO_3+CO_3) type

2- dominate by (HCO_3+CO_3) + (SO_4-Cl) type includes two subgroups. Figs.6,7 &8.

- (Na+ K) + (Ca + Mg) –(HCO_3+CO_3) type
- (Ca + Mg) –(HC O_3+CO_3) type

3- This group was dominated by (SO_4-Cl) type; was divided into the following subgroups: Figs.6,7 &8.

1. ((Na+ K) – (SO_4-Cl) type;
2. (Na+ K) + (Ca + Mg) (SO_4-Cl) type;
3. (Ca + Mg) (SO_4-Cl) type;

Table 5: Water type of groundwaters-Dongola West

WELL_ NAME	LONG	LAT.	WATER TYPE	WELL NAME	LONG	LAT.	WATER TYPE
MOBARK S	302200.00	184400.00	Mg-HCO3	ELGOLEID	304045.00	182940.00	Na-HCO3
GASHABE	310700.00	175900.00	Mg-HCO3	ELBAKRE S.	304145.00	182255.00	Na-HCO3

ABO DOM	310900.00	175800.00	Mg-HCO3	ELJABREA	305200.00	180700.00	Na-SO4
GANATE E	301500.00	175900.00	Na-HCO3	LABAB W.	302730.00	185930.00	Mg-SO4
MOLWAD	303400.00	183500.00	Na-HCO3	GAVADA	302630.00	191640.00	Ca-HCO3
KARMA G	302400.00	193700.00	Na-HCO3	EL GABAH	304530.00	180900.00	Ca-HCO3
KARMA EL	253000.00	201300.00	Mg-HCO3	UMHILAL	300800.00	190500.00	Na-HCO3
ELGABA S	303000.00	181010.00	Na-HCO3	DONGOLA A.	302540.00	191000.00	Ca-HCO3
SAGADAN	302345.00	193115.00	Na-HCO3	KAREMA N.	302430.00	193800.00	Na-HCO3
LTY GASSI	300500.00	182400.00	Mg-HCO3	KULUMASH	302400.00	191900.00	Ca-SO4
ARGIN V.	301600.00	215900.00	Mg-SO4	DONGOLA	303000.00	191030.00	Ca-HCO3
KSERE	302400.00	192400.00	Ca-HCO3	SAGADAN	302300.00	193700.00	Na-Cl
AMANKGE	301900.00	195500.00	Ca-HCO3	ELSAIR	302800.00	192000.00	Ca-HCO3
SAEL ABO	301800.00	204200.00	Ca-HCO3	SHABTOUT	303400.00	183400.00	Ca-HCO3
ABREL	301800.00	204200.00	Ca-HCO3	YACEN K.	312200.00	180000.00	Na-HCO3
DAL S.	303400.00	213000.00	Ca-SO4	FARAH H.	312200.00	180000.00	Ca-HCO3
SALGAR. L.	302300.00	193730.00	Ca-SO4	MOHD AH.	310900.00	175800.00	Na-HCO3
BADEN T.	302300.00	193800.00	Ca-SO4	ABD ELRAH.	310900.00	175800.00	Na-HCO3
ARDOAN	301900.00	19540.00	Na-HCO3	MOHD. MO.	303630.00	180203.00	Na-Cl
ARDOAN M.	301900.00	19550.00	Mg-HCO3	ALTAD. HOS.	311826.00	175956.00	Na-HCO3
WADI HAL.	301900.00	19550.00	Ca-HCO3	ALBAKRI N.	303950.00	182415.00	Na-HCO3
AGOLH S	302200.00	201300.00	Na-HCO3	M.FAGIR	303841.00	182915.00	Na-SO4
ARDOAN H.	301900.00	19550.00	Mg-HCO3	HUSSIEN	303844.00	182815.00	Na-HCO3
KARMA EL	302430.00	193802.00	Ca-SO4	ALI ABD.	303135.00	184334.00	Ca-HCO3
WADI KAL	302730.00	190730.00	Ca-HCO3	M. ALI	303130.00	184343.00	Na-Cl
ARGO T.	302500.00	193150.00	Ca-HCO3	WAD NUM.	302521.00	185909.00	Ca-HCO3
MOROAG.	302500.00	193100.00	Ca-HCO3	AHMED A.	302800.00	182000.00	Na-HCO3
KLTOS NILE	302800.00	192000.00	Ca-HCO3	ABD ELG.	302000.00	182000.00	Na-SO4
MAGASR E.	302900.00	191300.00	Mg-SO4	MANSOOR	302100.00	182000.00	Na-HCO3
TMNAR SH.	302830.00	191030.00	Mg-HCO3	SLSHERIK D.	300000.00	180000.00	Ca-HCO3
DONGOLA	302700.00	191100.00	Ca-HCO3	KARMA O.	300000.00	190000.00	Na-HCO3
DONGOLA T.	302800.00	191020.00	Na-HCO3	KARMA N.	300000.00	190000.00	Na-HCO3
EL SASABA	302730.00	185430.00	Na-HCO3	WAD BAHI	301630.00	190800.00	Na-HCO3
BRG NILE	300000.00	190000.00	Ca-HCO3	UMM HIL.	300800.00	190500.00	Na-HCO3
TAJAB NI.	300000.00	190000.00	Ca-HCO3	UMM HIL.2	300800.00	190500.00	Na-Cl
MASHO FI.	302300.00	193400.00	Ca-HCO3	ELSAWANI	300530.00	190400.00	Ca-HCO3
GAP ELLAG.	301500.00	192850.00	Ca-SO4	BUDRAN	301100.00	192200.00	Na-SO4
MASHO T.	302415.00	193400.00	Ca-HCO3	ELHASSAH	301500.00	193100.00	Na-HCO3
EL TETE M.	302930.00	184900.00	Na-HCO3	MASHU	302300.00	193400.00	Ca-HCO3
ELSAP &H.	313000.00	180100.00	Na-HCO3	KULUMOSID	302400.00	191900.00	Ca-HCO3
EL FONG	300300.00	180000.00	Mg-HCO3	GARADA	302630.00	191640.00	Ca-HCO3
WAD DEAB	304510.00	181000.00	Ca-HCO3	DONGOLA	302820.00	191020.00	Na-HCO3
ABO GASEI	304630.00	180800.00	Na-SO4	ELGURIBA	312530.00	180008.00	Na-HCO3
ALGOLID	303800.00	183000.00	Mg-HCO3	Alagia Omr	2819213.00	2120367.00	Na-HCO3
ELKHANDAC	303345.00	183610.00	Mg-HCO3	MIHELAH	2811102.00	1954791.00	Na-HCO3
LABAB W.	302730.00	185930.00	Ca-HCO3	PA14	2951706.00	1902467.00	Na-HCO3
ALTADAMUN	311826.00	175956.00	Na-HCO3	RAF/8	2944457.00	1904662.00	Na-SO4
MOHAMDE	304376.00	181031.00	Ca-SO4	PA02	3012149.00	1936975.00	Na-SO4

ALBAKRI N.	303903.00	1824158.00	Na-HCO3	PA14-DW2	2951789.00	190244.00	Na-HCO3
M. FAGI	303881.00	182816.00	Na-SO4	PA27	301427.00	1842157.00	Na-HCO3
HUSSIEN	303844.00	182815.00	Na-HCO3	PA29	302107.00	180336.00	Na-HCO3
ALI ABD.	303153.00	184335.00	Ca-Cl	E. LABAB	301843.00	194871.00	Na-HCO3
M.ALI SAE.	303130.00	184343.00	Na-SO4	QAAB BA	300726.00	185518.00	Na-SO4
WAD NUM.2	302514.00	185910.00	Ca-HCO3	ELMULTAGA	310111.00	175633.00	Na-HCO3
ALFARISI	30104.00	191403.00	Na-Cl	SHIRAN	313137.00	1718212.00	Na-HCO3
ABDALLAH	301029.00	191460.00	Na-HCO3	GAAB ELBAB	301218.00	181400.00	Ca-HCO3
DONGOLA	302830.00	191020.00	Na-HCO3	ELGABAH	304530.00	180900.00	Ca-HCO3
DONGOLA A.	302820.00	191020.00	Na-HCO3	DIAB	304510.00	181000.00	Ca-HCO3
AAAA	302800.00	191850.00	Ca-HCO3	ALSWANI	300497.00	190426.00	Na-HCO3
NAWA S.	303110.00	182700.00	Mg-SO4	ELSHERIK 2	300000.00	180000.00	Ca-HCO3
ALDERAH	2811102.00	1954791.00	Na-HCO3				

6.5 Cluster Analysis

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 (Davis, 1986), 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 (Swanson, et al. 2001).

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 NO_3^{-} (Figs.9&10) 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 softwares AQ.Qa used for water quality and Xisat for statistical analysis

In this study, the Spearman correlation method was chosen which is insensitive to outliers in the data, and the analysis, results are shown in Table 6. As shown in Table 6, the cations Na^{+}, K^{+}, Ca^{2+}, Mg^{2+} and anions Cl^{-}, SO_4^{2-} and bicarbonate, shows positive correlations with each 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 (Elzien, S. M & Hamed, B. O. 2016; Chen, K., Sun LH, Tang, J., 2020).

The relationships among the water chemistry variables of the groundwater samples are shown by rank correlation matrix (Table 6). 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 ((Liu et al., 2003). Moderate correlation was observed between Na^+ and Cl^-, SO_4^{2-}, Mg^{2+}, $H_2CO_3^-$ &Ca^{2+}. There is also moderate correlation between Ca^{2+} and Mg^{2+} Cl^-, SO_4^{2-} and between SO_4^{2-} and Cl^- and moderate between Mg^{2+} and SO_4^{2-}&Cl^- and this may indicate cation exchange between these ions. For the rest of groundwater samples, there is weak correlation between K^+ and Na^+, Ca^{2+}, $H_2CO_3^-$, Cl^- and Mg^{2+} and between Bicarbonate both of Ca^{2+} & Mg^{2+} as well as Cl^- and SO_4^{2-} as shown at the correlation matrix (Table 6). 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 (Subba Rao, 2002).

Table 6: Spearman Correlation of the major ions in groundwater, Dongola West

Variables	Sodium	Potassium	Calcium	Magnesium	Bicarbonate	Chloride	Su
Sodium	**1**						
Potassium	**0.236**	**1**					
Calcium	**0.461**	**0.140**	**1**				
Magnesium	**0.476**	0.020	**0.586**	**1**			
Bicarbonate	**0.739**	**0.121**	**0.159**	**0.172**	**1**		
Chloride	**0.532**	**0.287**	**0.511**	**0.359**	**0.239**	**1**	
Sulfate	**0.587**	**0.192**	**0.694**	**0.722**	**0.150**	**0.505**	

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

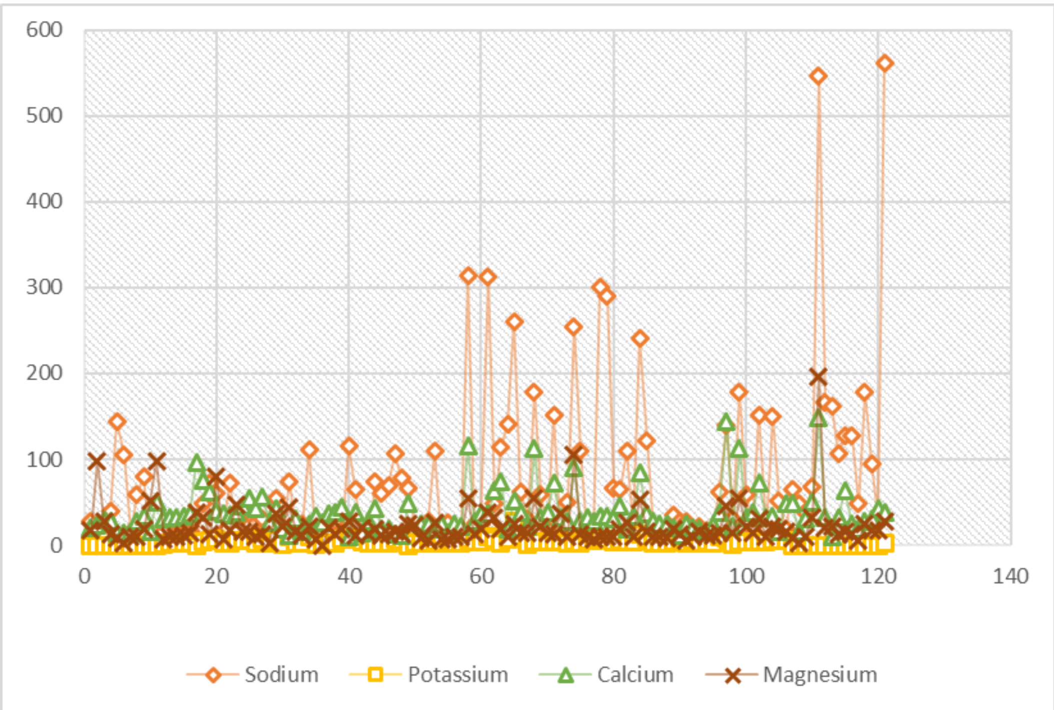

Fig. 9: Relation between the alkaline cations (Ca^{2+}, Mg^{2+} & K^{+}) of the Water samples -Dongola West

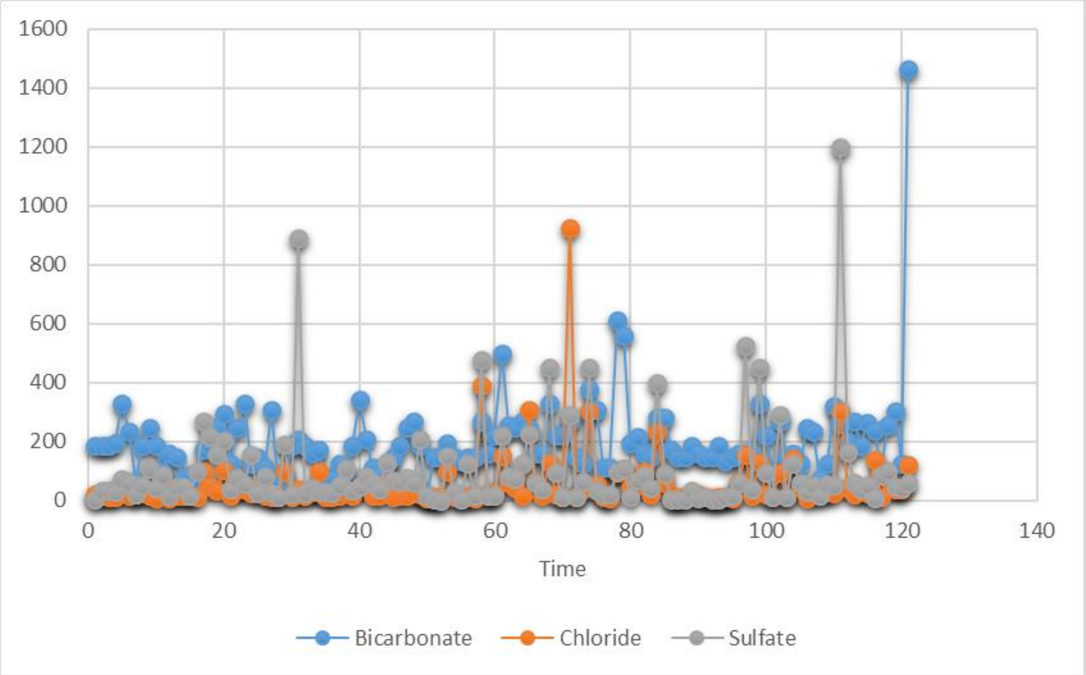

Fig. 10: Relation between the acidic anions (HCO_3, Cl^- & SO_4^{-2} -Dongola West

6.6 Environmental and Isotopes

The isotopic composition of water sample (Stable Isotopes; Deuterium & Oxygen-18)
is expressed in terms of per mille differences (δ‰) of its isotopic ratios R = D/H and R =$^{18}O/^{16}O$ with respect to the isotopic ratios of a standard, the so-called Standard Mean Ocean Water (SMOW):

$$\delta ‰ = (R\ sample/\ R\ SMOW - 1) * 1000$$

The relation between deuterium and oxygen-18 in natural meteoric water, which have not undergone excessive evaporation, is described by the following linear correlation**:**

$$\delta D = 8 * \delta\ ^{18}O + 10 \text{ Global Meteoric Water Line (GMWL)}$$

The importance of environmental isotopes studies in groundwater hydrology in arid and semi- arid zones need not to be emphasized. Isotopes techniques (Craig, 1961a&b) can yield valuable information for solving problems such as:

- Determination of recharge source, recharge rate, and recharge mechanism.
- Residence time
- Interaction between different water bodies.

Tritium concentration in the River Nile measured at Karema in the study area, dropped from 20 TU in 1985 (to 4.9 in the year 2000) indicating that the Nile maintains the natural level before 1962 nuclear bomb explosion.
Tritium concentrations, in boreholes at Khartoum, vary from 3.8 to 103.3 T. U, and with the majority lies within 50 T.U (**Sudanese** – German Exploration Project Technical Report, 1979), and tritium concentration drops from over 100 T.U near the Blue Nile to almost zero at a distance of 5 – 6 Km away from the Blue Nile River. This indicates that the River Nile is the main source of recharge to the adjacent aquifers zones and that groundwater recharge from the local rainfalls is insignificant (Table7)**.**

Table 7: Isotopic Components of the Study Area –West River Nile Bank

NO.	Locality	LONGT.	LATIT.	LONGDEC.	LATDEC.	Oxygen -18	Deuterium	Tritium	TDS
1	Wadi DEAB	304510	181000	30.7528	18.1667	-4.27	-29.00	0.47	175
2	DONGOLA AIRPORT	302540	191000	30.4278	19.1667	-0.70	2.00	7.60	154
3	KAREMA (NILE 1)	302430	193800	30.4083	19.6333	5.35	38.10	6.00	175
4	KULUMASID	302400	191900	30.4000	19.3167	0.18	3.50	0.30	162
5	DONGOLA UNIVERSITY	303000	191030	30.5000	19.1750	-0.49	4.00	0.40	171
6	EL SAIR	302800	192000	30.4667	19.3333	-0.28	4.70	-	221
7	WAD BAHI	301630	190800	30.2750	19.1333	-3.55	-23.9	0.4	296
8	UMM HILAL 1	300800	190500	30.1333	19.0833	-2.66	-16.7	0.1	420
9	UMM HILAL 2	300800	190500	30.1333	19.0833	0.94	-3.10	0.60	641
10	ESSWANI	300530	190400	30.0917	19.0667	-11.20	-85.50	0.50	260
11	BUDRAN	301100	192200	30.1833	19.3667	-4.13	-32.50	0.10	1372
12	HASSAH	301500	193100	30.2500	19.5167	-3.27	-23.20	0.30	545
13	MASHU	302300	193400	30.3833	19.5667	-0.49	4.00	-0.30	204
14	KULUMASSID	302400	191900	30.4000	19.3167	-0.18	3.50	0.30	175

15	GARADA	302630	191640	30.4417	19.2778	-0.32	5.10	0.40	171
16	DONGULA HOS.LAND	302820	191020	30.4722	19.1722	-0.71	3.30	0.50	354
17	EL GURIBA	312530	180008	31.4250	18.0022	0.03	5.50	0.00	277
18	El GABAH NILE	304530	180900	30.7583	18.1500	5.48	38.80	5.70	158
19	DIAB	304510	181000	30.7528	18.1667	-0.95	0.20	0.30	296
20	Al GOLID BAHRI	303800	183000	30.6333	18.5000	-0.67	2.00	0.20	231
21	EL KHANDAC	303345	183610	30.5625	18.6028	-2.10	-6.70	0.30	210
22	LBLAB WEST 2	302730	185930	30.4583	18.9917	-1.11	2.90	0.00	385
23	AL TADAMOUN HOSP.	311826	175956	31.3072	17.9989	-4.44	-29.10	0.80	1176
24	MOHIEDEEN	304376	181031	30.7378	18.1753	-0.60	-2.10	1.00	247
25	AL BAKRI NORTH	303903	1824158	30.6508	18.4042	-1.53	-5.40	0.70	1295
26	KAREMA (NILE 1)	302430	193800	30.4083	19.6333	5.35	38.10	6.00	303
27	KULUMASID	302400	191900	30.4000	19.3167	0.18	3.50	0.30	347
28	DONGOLA UNIVERSITY	303000	191030	30.5000	19.1750	-0.49	4.00	0.40	898
29	EL SAIR	302800	192000	30.4667	19.3333	-0.28	4.70	-	184
30	WAD BAHI	301630	190800	30.2750	19.1333	-3.55	-23.9	0.4	791
41	El GABAHB (NILE)	304530	180900	30.7583	18.1500	5.48	38.80	5.70	534
49	MFAGIR YADY	303881	182816	30.6558	18.4711	-0.84	-4.20	1.00	506
50	HUSSEN YADY	303844	182815	30.6456	18.4708	-1.14	-5.10	0.80	268
51	ALI ABDALLA	303153	184335	30.5314	18.7264	-0.99	0.40	0.80	541
52	M.ALI SAAED	303130	184343	30.5250	18.7286	-1.51	-5.70	0.80	443
53	WAD NUMIRI	302514	185910	30.4206	18.9858	-0.54	-3.00	0.70	3052
54	AFRASSI	30104	191403	30.1678	19.2342	0.12	4.10	0.70	339
55	ABDALLA JALI		191460	30.0344	19.2497	-0.39	4.90	0.80	310
65	EL MULTAGA (3)		175633	31.1167	17.9425	-10.35	-78.30	0.24	334

According to tritium concentration results, there are also two groups.

Group **I**: 99% of groundwater samples at the West side have tritium concentration < 3 T.U.

Group **II**: This group includes only one sample (Dongola Airport) 7.6 T.U. lay along the River Nile and represents river water infiltrated to recharge the adjacent aquifers zones some 20 years ago.

Group I, the water concentration < 3 T.U at the study area means no water younger than 20 years is present, that is more than 20 years are required for water to reach the sampling points from the recharge area. This case of the most confined aquifers.

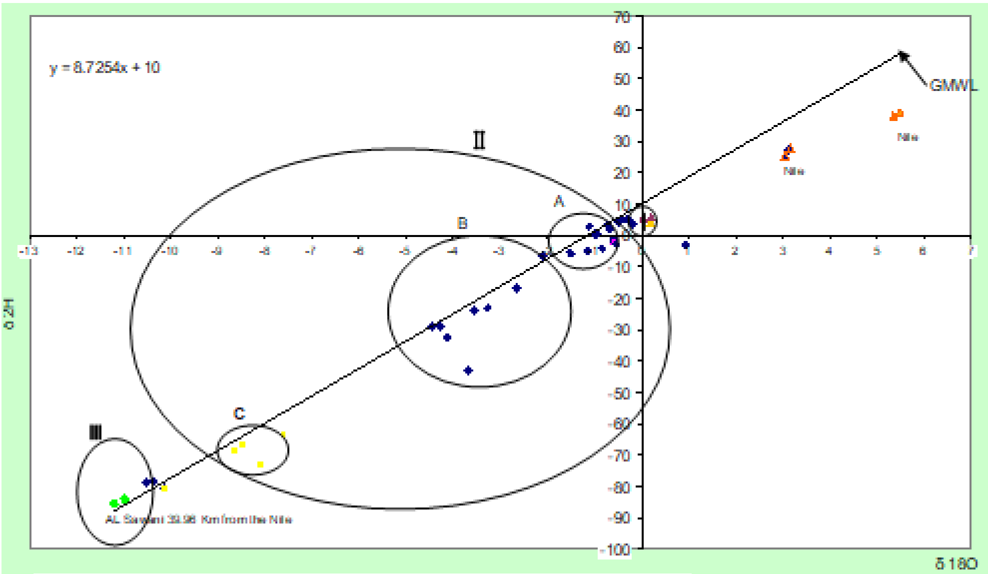

Fig.11: Delta oxygen-18 Vs Deuterium in the Western side of the River Nile Bank

The west side samples were plotted in **Fig.11**. According to this figure the water samples can be classified into the following groups:

Group I

This group represent recent water with evaporation, semi-similar to Nile water, includes three samples near the riverbed maximum value of $\delta\ ^{2}H$ 5.8‰ at Affarisi and minimum value 4.0‰ at Klumuseid and maximum 0.2‰ of oxygen –18 and minimum 0.03 at Guriba.

Group II

Mixing group that means paleo water + recent water. Includes the majority of samples; the rate varies from sample to another. Can be classified this group to three subgroups according to the rate of mixing

A- Recent mixing rate is greater than paleo rate

B- Approximately recent mixing rate is equal paleo rate.

C- Paleo mixing rate is greater than recent mixing rate. This includes two samples.

Group III

Al Swani group this group represents paleo water (depleted in stable isotopes). The distance between AL Sawani and the River Nile about 49.95 Km. so it represents paleo water that means there is no recharge at this distance from the Nile.

6.6.1 Delta Oxygen – 18 against TDS West River Bank

From Fig.12 that the TDS increases with $\delta^{18}O$, it means salinity is due to recharge of surface water (high TDS due to irrigation water). The second shows that $\delta^{18}O$ do not increases with TDS.

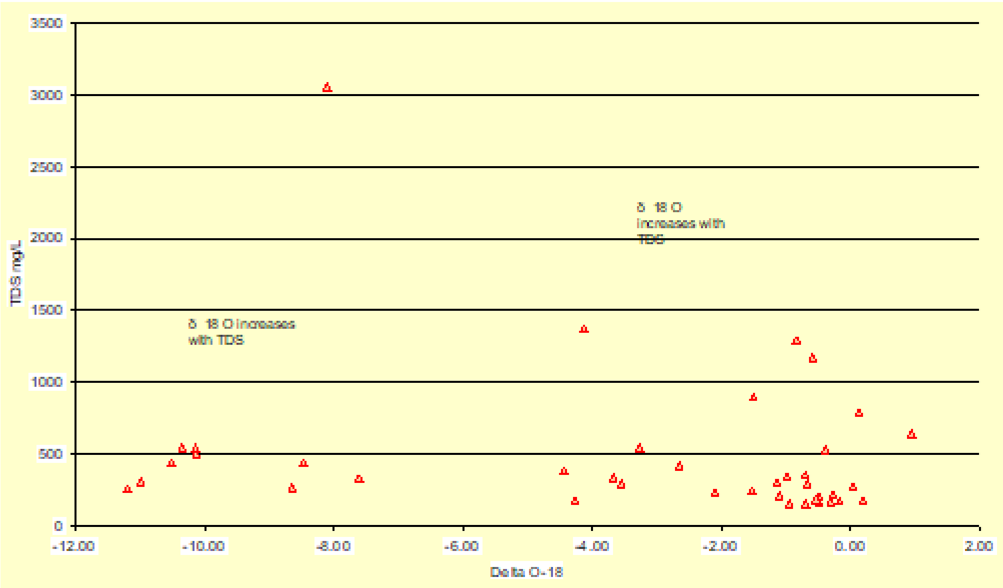

Fig.12: Delta oxygen-18 Vs TDS in the Western side of the River Nile Bank

7.0 Conclusions

The understanding of the composition of groundwater requires recognizing the possible mechanisms that can promote the release of ions into the water. The combined use of multivariate statistics of hydro-chemistry data and interpretation of the isotopic analysis of groundwater has been evaluated to discern the main process controlling the hydro-chemistry of groundwater and characterize the dynamics of groundwater flux.

The study addressed the isotopic and hydro-geochemical relations in the western side of the River Nile. It is found that the majority of water samples at the west River Nile bank are of:

1. Sodium-calcium-magnesium- bicarbonate – sulphate type.
2. Sulphate –Chloride type was found at the west bank of the River Nile.
3. Sulphate type and Chloride type were found also at the west bank.
4. There are three samples at the west River Nile bank which are above the permissible limits. These samples are (Karma Old, Kariema New and Alswani Ali Badawi).
5. As far for suitability of water for irrigation; in the study area water samples vary from suitable to unsuitable for irrigation purposes.
6. All groundwater samples taken in the study area were within the standard limits of nitrogen compounds; (nitrate, nitrite and ammonia).
7. There were some water samples that found to be unfit for human consumption for one or more than one reason.
8. The final result of the data analysis showed that the water types of the Dongola West area are: 39% Na-HCO_3, 30% Ca-HCO_3, 9% Mg-HCO_3, 8% Na-SO_4, 6% Ca-SO_4, 4% Na-Cl, 3% Mg-SO_4, and 1% Ca-Cl.

9. According to investigations of tritium concentration in the study area, the majority of groundwater samples lied under < 3 T.U; that meant that, no water younger than 20 years was present.

10. A few of water samples had tritium concentration that varied from 3 T. U to 20 T. U. This group included (Dongola Airport) 7.6 T. U, Nuri Al-Sagiia 12.4 T. U and Mohamed Saeed 10. 5 T.U. This group lied along the River Nile and represented river water infiltrated to recharge the adjacent aquifers zones some 20 years ago.

11. Due to stable isotopes values ($\delta\ ^{18}O$ and $\delta\ ^{2}H$) in the study area, the limits of recharge at the west River Nile bank is 49.95 Km from the River Nile.

12. The relationship between TDS and $\delta\ ^{18}O$ of some water samples were proportional ($\delta\ ^{18}O$ increases with TDS) which means that salinity was due to recharge of surface water (high TDS due to irrigation water) while for other samples there was no relationship.

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