Evaluation of groundwater quality in Dongula basin: the Northern state of Sudan

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Abstract

The purpose of this paper is to evaluate the quality and chemical features of groundwater in the Dongola basin, Northern State, Sudan. The majority of water samples were moderately hard water, and temporarily hard – carbonate and bicarbonate hardness. The dominant anion is carbonate and bicarbonate (CO_3^{--}, HCO_3^{-}); and the dominant cation is sodium on the west side of the river (water type – Trona rocks). The majority of water samples taken at the west river bank were (sodium-calcium-magnesium)-(bicarbonate-sulphate) type, while at the east river bank, the majority was (sodium-calcium-magnesium)-(bicarbonate) type. (Sulphate-chloride) type was found for samples taken at the two banks of the river while (sulphate) and (chloride) types were found only in samples taken at the west bank.
Keywords: Sudan, Northern State, Dongula, Dongula basin, River Nile, groundwater water types.

1   Introduction

The hydrological structure of the Dongola Basin is considered to be 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 layers of the Wadi El Melek formation and, to a lesser extent, in the 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 the existing pumping regime [1]. The groundwater reflects the mineralogical composition of the rocks in the aquifer and 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 the processes of water–rock interaction and microbial processes in the water chemical precipitation controlled by the solubility of a substance, and chemical alteration by, for example, oxydo-reduction and complexation processes. Cations in the water types came mainly from the leaching of the rock minerals and the soil whereas the anions came mainly from lithological sources.

2 Location and accessibility

The study area lies along the River Nile in the Northern State. The area forms an elongated shape and is generally bounded by longitudes (29°.80 00–31°.92 00 E and latitudes 17°.19 00–20°.21 00 N (Fig. 1).
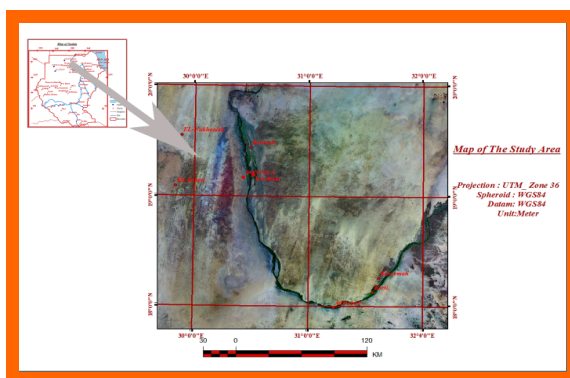

Figure 1:   Location of the study area.

2.1 Drainage system/(s) – The River Nile

The River Nile is the most important source of water for irrigation; about $800*10^6$ m^3 yearly. It is the only perennial surface water resource available in this area. High water levels occur during the high flood period (August–September) and the minimum water level during December and June; the difference between the highest and lowest level is about 4.59 m at Dongola [2].

2.2 Climate and vegetation

The area lies in the arid desert climatic region, in which rainfall is very low or 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), humidity is low, and there is very little cloud cover and no rain [3]. The wind blows from the north with a mean speed of between 15 and 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 [4]. The mean annual rainfall is about 9.280 mm /annum (Fig. 2 – 1989–2008), rainfall characterized by low variability 17.1223 is as shown in Table 1. 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-Meilk, 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 (Ziziphrusspina), Haraz Acacia albida and some Green Nile grasses are also found. Herbs and fine grasses spring up after very rare rain showers during the summer but they soon disappear [5].

Table 1:   Annual rainfall variability at Dongola.

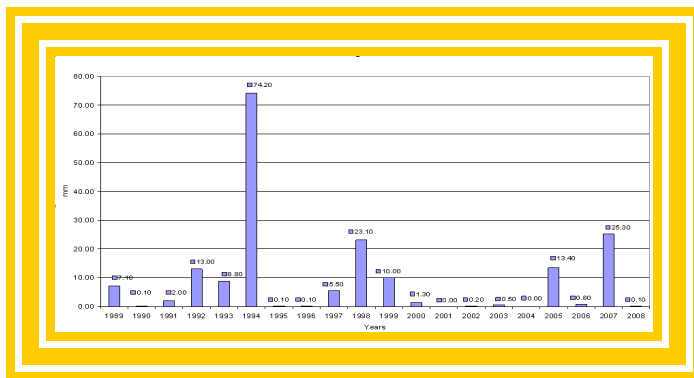| Lowest (mm)	Highest (mm)	Average rainfall (mm)	Standard deviation
0.0	74.2	9.280	17.1223

Figure 2:   Dongula annual average rainfall 1989–2008.

2.3 Geology of the study area

Nubian formation, Wadi El-Melek formation, superficial deposit and basement complex [9].

2.4 Hydrology of the study area

Dongola Sub-Basin;
El- Debba Sub-Basin;
Wadi EL-Mugaddam Sub-Basin.

3   Statement of the problem

Water quality has become one of the important issues for socioeconomic 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 are subjected to mix or interaction by saline water. Salts can be introduced either through complicated chemical processes or by simple addition or mixing from a surface or subsurface saline source. One or many processes may contribute. Regarding this problem, this study will concentrate on salinity problems, the source of saline water, which in specific aquifers, in relation with other water bodies either surface or groundwater, the chemical characteristic of groundwater at the two sides of the river, will be statistically treated to see whether there are significant differences or not.

4   Sampling and analytical procedure

131 and 139 water samples were taken from boreholes on the River Nile at the two sides for chemical analysis (major anions and cations). By using the standard methods (Fig. 3), the physico-chemical parameters were measured in the field (EC, pH and TDS); also TDS was measured in the lab. By the dryness method, carbonate, bicarbonate, chloride, calcium, magnesium total hardness and total alkalinity were measured by titrations method; sulphate, nitrate, nitrite ammonia were measured by spectrometric method.
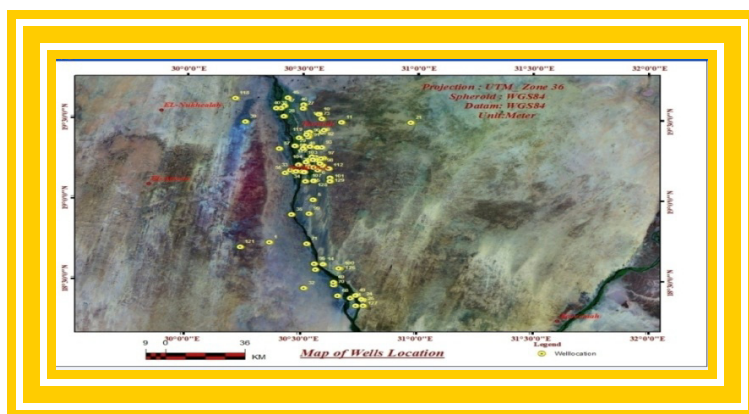

Figure 3:   Location of water samples in the study area.

5   Results and discussion

95.86% of existing groundwater sources at the east river bank and 91.6% at the west river bank have TDS less than 1000 ppm. All of them represent fresh water, according to classifications of water after Corell 1985 [6, 11] the range from 0-100ppm.TDS. Also TDS–EC relationship (= geochemical coefficients).

   East river bank and west river bank – demonstrated by Figures 4 and 5 – were 0.6826 (east side) and 0.7066 (west side); the coefficients at the two sides are the same when it becomes to one decimal (0.7). About 4% of east river bank water and 8% of west river bank water represents brackish water. Because there
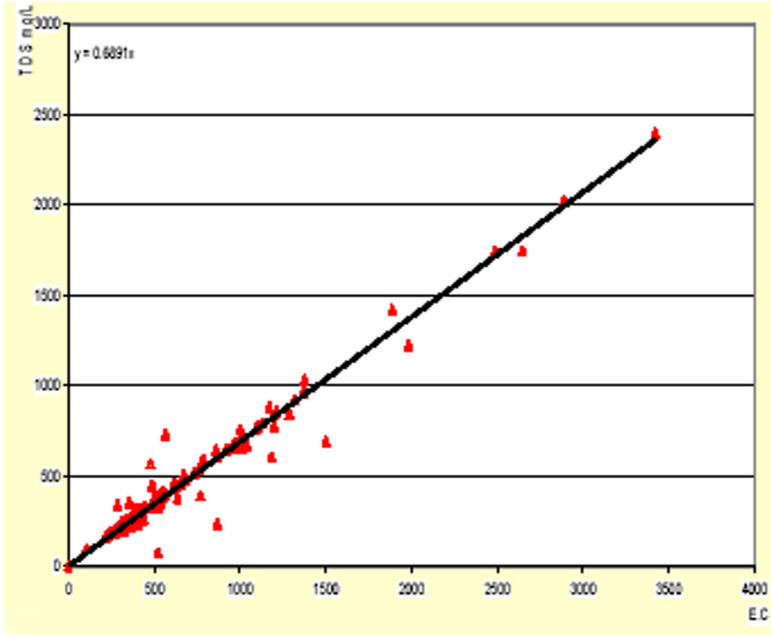
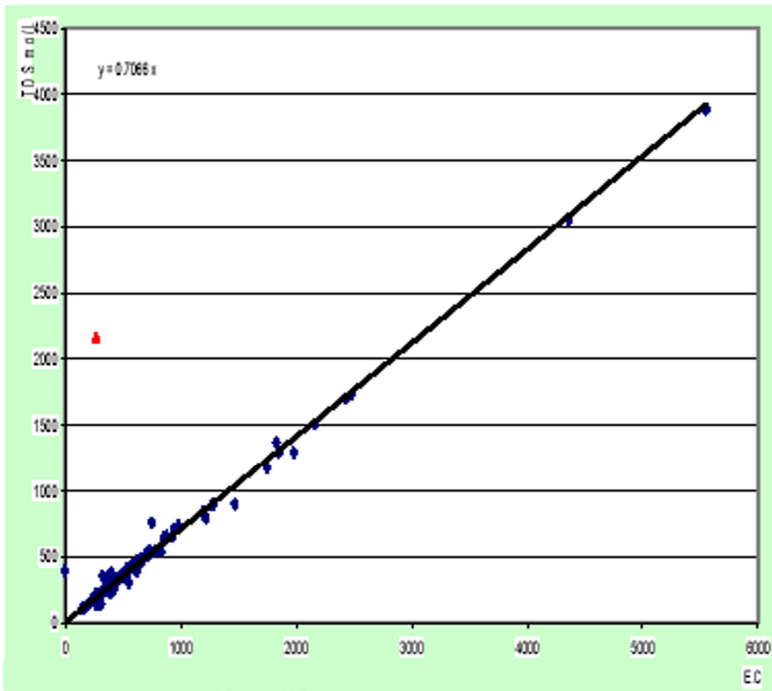Figure 4:   TDS vs. EC in the study area, east river bank.

Figure 5:   TDS vs. EC in the study area, west river bank.

are seven samples at the west river bank that 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 those are for samples 2, 62, 66, 75, 109, 117 and 119 respectively; 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.

6 Suitability for drinking

There were some water samples at the east river bank which were unsuitable for human consumption because there were one or more parameters greater than WHO and Sudanese Level standards. For example, sample No. 75 with high concentrations of sodium and chloride, this water resembles a feature of sea water (NaCl). Sample No. 44 recorded high calcium, magnesium chloride, and sulphate concentrations. Then there were $CaCl_2$ $MgCl_2$–$CaSO_4$–$MgSO_4$ rocks type in the locations. The majority of water samples were moderately hard water, and temporarily hard (carbonate and bicarbonate hardness). It is to be assumed that groundwater having pH values above 8.4 are usually associated with sodium carbonate–bicarbonate water; moderately high pH values are commonly associated with high bicarbonate concentrations. Also, we can say the main rocks in the aquifer are calcium and magnesium carbonate and bicarbonate type (dolomite). The other type of hardness is the permanent hardness (sulphate, chloride, salts). Magnesium ion concentration at east river bank varied from 0 mg/l to 167 mg/l. All samples were within the WHO range except for sample No. 44 (167 mg/l). At the west river bank the minimum concentration was 0 mg/l (sample No. 37) but there were three samples with values greater than standards (samples Nos. 75, 117 and 119). It is to be 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 dissolved ions and biological influences. Also, according to my 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 both west and east banks at the study area is 120mg/l: The similarities of concentration are due to simulations of chemical composition of calcium ions in the rocks. It is possible that the same rocks or basalts maybe among the igneous rocks and in carbonate rocks (limestone, dolostone) among sedimentary rocks. Calcium is also a dominant cation in most river waters.

Sodium ion concentrations of groundwater samples taken in the study area were 0 mg/l Na^+ at the west bank samples 2, 10 and 11. Here it may be that the chemical composition of aquifer rocks at these wells is without sodium, like anhydrites, calcium carbonate, dolomite and sylvite. As for sample 119, the concentration of sodium is 1537mg/l and the concentration of bicarbonate is 285 mg/l so the water type at this well is sodium bicarbonate water having pH values above 8.4. Also high sodium with high chloride suggests solution of halite; if considerable sulphate and calcium are also present.

Table 2:   The drinking water problems of the study area – east river bank.

Parameters	Within the range of WHO standard		Greater than WHO range		
	Wells	%	Wells	%	Remarks
pH	94	67.63	45	32.37	Many samples over the range.
TDS	135	97.83	3	2.17	75,81,102 and 122
TH	136	98.55	2	1.45	44 and 102 ;122
K^+	139	100	-	-	All samples within the WHO range
Na^+	133	95.68	6	4.32	75,77,81,85,133 and 135
Ca^{++}	135	97.12	4	2.88	44,102,122 and 133
Mg^{++}	138	99.28	1	0.72	44
Cl^-	135	97.12	4	2.88	44,75,81 and 102
$SO_4=$	129	92.81	10	7.19	27,44,77,81,93,102,121,122,133 and 138
F^-	138	99.28	1	0.72	27 has 2 mg/l
NH_3	139	100	0	0	All samples within the WHO range
NO_{2-}	139	100	0	0	All samples within the WHO range
NO_{3-}	139	100	0	0	All samples within the WHO range

Table 3:   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	%	Wells	%	Remarks	
pH	94	71.76	37	28.24	About 30% of samples	6.5-8.5
TDS	124	94.66	7	5.34	2,62,66,75, 117 and 119	1000mg/l
TH	127	96.95	4	3.05	75,98,100 and 119	
K	130	99.24	1	0.76	66	
Na	121	92.37	10	7.63	Ten samples	
Ca	125	95.42	6	4.58	Six samples	
Mg^{++}	128	97.71	3	2.29	75, 117 and 119	
Cl^-	123	93.89	8	6.11	59,66,72,75,109,112,117 9	
$SO_4=$	118	90.08	13	9.92	Thirteen samples	
Fluoride	126	96.18	4	3.82	23, 117, 118 and 119	1.5 mg/l
NH_3	131	100	0	0	No sample	
NO_{2-}	131	100	0	0	No sample	
NO_{3-}	131	100	0	0	No sample	

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

All groundwater samples at the east side were suitable for livestock (because the quality factors of all of them are within the range of the Guidelines of the California Control Board (1963), while at the west side there were three water samples unsuitable for livestock because the quality factor of bicarbonate was above 500mg/l.

7   Suitability for livestock

Table 4:   The Guidelines of the California Control Board (1963).

Quality Factor	Threshold Conc. mg/l	Limiting Conc. mg/l	Maximum Conc^n in the study area	
			East river bank	West river bank
TDS	2500	5000	2394 mg/L (No. 81)	3885mg/L (No. 109
Ca^{++}	500	1000	120 mg/L (No.122)	149mg/L. (Nos. 117, 119)
Mg^{++}	250	500	167 mg/L (No. 44)	196mg/L (Nos. 117, 119)
Na^+	1000	2000	524 mg/L (No.81)	1553.7 (No. 110)
HCO_3^-	500	500	469 mg/L (No. 86)	1464mg/L (No. 130)
Cl^-	1500	3000	550 mg/L (No.81)	1314mg/L (No. 109)
$SO_4^=$	500	1000	387 mg/L (No.133)	1225mg/L (No. 109)

Table 5:   Irrigation problems in the study area, east river bank.

Irrigation problems		No problems		Increasing problems		Severe problems	
		Wells	%	Wells	%	Wells	%
Salinity		100	71.94	37	26.62	2	1.44
Permeability	Adj. SAR	5	3.60	12	8.62	122	87.78
Specific Ion	Adj. SAR	5	3.60	12	8.62	122	87.78
Toxicity	Cl^-	125	89.93	11	7.91	3	2.16
Miscellaneous	NO_3^-	88	63.31	49	35.25	2	1.44
	HCO_3^-	5	3.60	133	96.68	1	0.72
	pH	0	0	0	0	139	100

8   Suitability for irrigation

Most water samples in the study area indicated that there were 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 classification mentioned above for suitability for irrigation.

Table 6:   Irrigation problems in the study area, west river bank).

Irrigation problems		No problems		Increasing problems		Severe problems	
		Wells	%	Wells	%	Wells	%
Salinity		105	802	23	17.6	3	2.29
Permeability	Adj. SAR	118	90.1	7	5.3	6	4.58
Specific Ion	Adj. SAR	103	78.6	22	16.8	6	4.58
Toxicity	Cl⁻	121	92.4	7	5.3	3	2.29
Miscellaneous	NO_3^-	74	56.5	55	42	2	1.53
	HCO_3^-	7	5.3	121	92.37	3	2.29
	pH	0	0	0	0	131	100

On the two sides of the river there were three dominant anion water types divided as follows:

1-	(HCO_3+CO_3) type	(1)
2-	$(HCO_3+CO_3) - (SO_4-Cl)$ type	(2)
3-	$(SO_4 - Cl)$ type	(3)

East side was dominated by:
1- (HCO_3+CO_3) type, included the majority of samples. This water type is divided into the following subgroups: (Piper Diagram (Fig. 6) showed bicarbonate water type).

- $(Na+K)-(HC O_3+CO_3)$ type   (4)
- $(Na+K)+ (Ca + Mg)-(HC O_3+CO_3)$ type   (5)
- $(Ca+Mg)-(HC O_3+CO_3)$ type   (6)

2- $(HCO_3+CO_3) + (SO_4-Cl)$ type includes only one subgroup (Fig. 7).

- $(Na+K)-(HCO_3+CO_3)+(SO_4-Cl)$ type   (7)

3- This group was dominated by (SO_4-Cl) type; was divided into the following subgroups (Fig. 8).
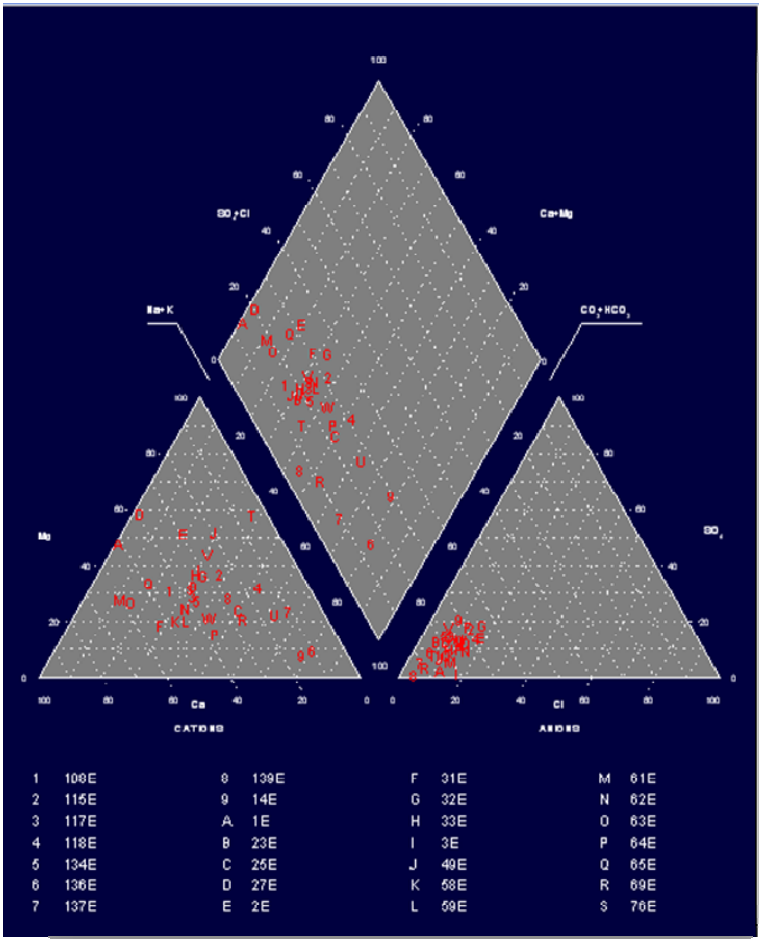
- $(Na+K)-(SO_4-Cl)$ type   (8)

1	108E	8	139E	F	31E	M	61E
2	115E	9	14E	G	32E	N	62E
3	117E	A	1E	H	33E	O	63E
4	118E	B	23E	I	3E	P	64E
5	134E	C	25E	J	49E	Q	65E
6	136E	D	27E	K	58E	R	69E
7	137E	E	2E	L	59E	S	76E

Figure 6:   Bicarbonate water type east side of the river.

While the west side of the river, dominated by (HCO_3+CO_3) type, included the majority of samples, this water type is divided into the following subgroups: (Piper Diagram (Fig. 9) showed bicarbonate water type).

- (Na+K)-(HCO_3+CO_3) type   (9)
- (Na+K)+ (Ca + Mg) -(HCO_3+CO_3) type   (10)
- (Ca+Mg)-(HCO_3+CO_3) type   (11)

2- Dominated by (HCO_3+CO_3)+(SO_4-Cl) type, it includes two subgroups (Fig. 10)

- Na+K)+ (Ca+Mg)-(HCO_3+CO_3)+(SO_4-Cl) type   (12)
- (Ca+Mg)-(HCO_3+CO_3)+ (SO_4-Cl) type   (13)

3- This group, dominated by the (SO₄-Cl) type, was divided into the following subgroups (Fig. 11).

- ((Na+ K)-(SO₄-Cl) type (14)
- (Na+K)+(Ca+Mg) (SO₄-Cl) type (15)
- (Ca+Mg) (SO₄-Cl) type (16)

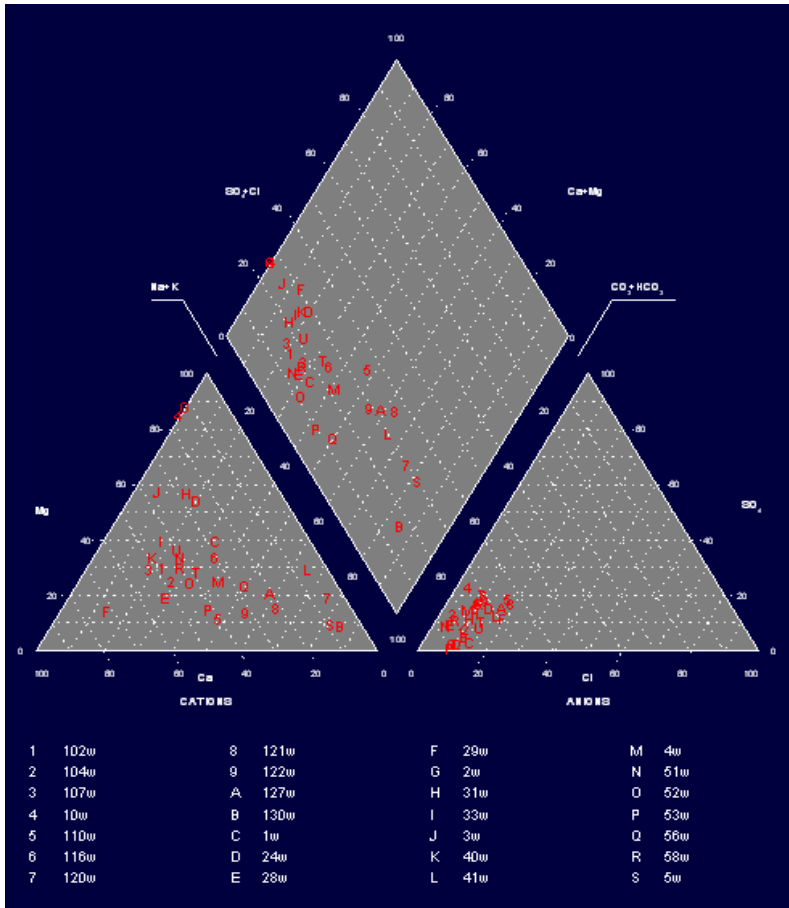| 1 | 102w | 8 | 121w | F | 29w | M | 4w |
2	104w	9	122w	G	2w	N	51w
3	107w	A	127w	H	31w	O	52w
4	10w	B	130w	I	33w	P	53w
5	110w	C	1w	J	3w	Q	56w
6	116w	D	24w	K	40w	R	58w
7	120w	E	28w	L	41w	S	5w

Figure 7:   Bicarbonate water type, west side of the river.

9   Conclusion

According to the investigation and interpretation of the chemical results, the majority of water samples in the study area are dominated by bicarbonate water types. This bicarbonate water type is divided into three subgroups as sodium-potassium bicarbonate type, calcium-magnesium bicarbonate water type and sodium-potassium-calcium-magnesium bicarbonate type. All groundwater

samples were taken in the study area within the range of permissible limits for livestock, except for three water samples on the west side of the river which were very high bicarbonate (above the permissible limit 500 mg/l). In addition, all groundwater samples were taken within the nitrogen component range as ammonia, nitrite and nitrate – this means there is no nitrogen pollution. In addition, all water samples vary from suitable to unsuitable for irrigation purposes while most of them are fit for human consumption.

Acknowledgements

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