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Low level fluoride content in groundwater of the Younger Granite aquifers in parts of the Jos Plateau, Nigeria

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Abstract: Fluoride content in water has received a world-wide attention due to its importance to health. This study attempts to trace the factors responsible for low fluoride levels in the aquifers of the Jos Younger Granites despite the high fluorine content in the rocks. A total of 41groundwater samples (1 mining pond, 2 hand pumps and 38 hand dug wells), 7 rock samples from the various lithological units, and 13 soil sections from two exposed locations were collected and analyzed for their fluorine content. Analysis of major cations was carried out using ICP-OES; the anions were analyzed using the UV multi-ion parameter and bicarbonates by titration method. Fluoride in underground water was determined by multi-ion parameter. Fluorine in rocks and soil were analyzed by the fusion method. The rock samples show variations in their fluorine content (Jos – Bukuru Biotite Granite 6,231, aplo-pegmatic granite-gneiss (basement rock) 4,864, Quartz-pyroxenes-fayalite porphyry 1,280, Dilimi-Biotite Granite 258 and Ngeil Biotite Granite-162 ppm). The soil sections from different locations also show variations of fluorine with depth of sampling. Cumulatively, the fluorine content in the sections and fluoride content in water do not correlate with fluorine in rock in the rock units. The low content in the two media, indicate that: 1. bulk fluorine have not been released from minerals in the host rocks and those retained in soils have not been mobilized to the groundwater. 2. Fluorine have formed complexes with other ions and occurring in compound form rather than ionic form. Apart from low fluoride in about 70% of the water samples all other parameters are within the WHO recommended limit for house hold uses. Although there are no records on the effect of low consumption of fluoride in water, inferences from the data show that most areas with low fluoride level should have dental caries.

Keywords: Fluoride, Groundwater, Younger Granites, Aquifers, Jos Plateau

1. Introduction

Fluoride content in groundwater is of concern because of two reasons – 1. Low content of fluoride (< 0.5 mg/l) may results in the development of dental caries. 2. Concentration levels (> 1.5 mg/l) may result in development of dental fluorosis, skeletal fluorosis, neurological effect, reproductive effect, genetic effect, low intelligent quotient (IQ) (WHO 2004; Hussain et al, 2004). Studies on fluoride in groundwater and effects on health of humans and animal have been reported in different parts of the world both in epidimeological study and the earth sciences for well over a hundred years now. However, in Nigeria, geo-medical studies on fluoride in groundwater and health received attention in the last fifteen years in the earth sciences (Lar and Dibal, 2013). Earlier studies in the area of epidemiology were carried out by Alakija, (1983), Bano et al, (1987) and Wongdem et al, (2002). Before now, data exist as part of water quality parameter, but none has linked the fluoride to source and or health effect. Thompson, 1957 reported fluoride level in waters of the Gombe area to range from 0.0 – 2.1 mg/l. In the Pleistocene sediments of the Chad Formation, Barber, (1965) found fluoride level of 2.0 mg/l. Schoeneich and Mbonu, (1990) reported very low fluoride in groundwater in parts of Jos and Bukuru area. Oteze and Ayegbusi, (2004) recorded value of 5.00 mg/l in the Chad Formation at Maiduguri. The link between fluoride occurrence in groundwater and health was first reported by

Dibal and Lar in 2005. They reported the existence of high fluoride in groundwater in the basement aquifer of (Kaltungo area) as the causal factor for the high incidence of mottled teeth in the area and environs. Lar et al, (2007) linked the source of the high fluoride in groundwater in Dorong area and the Furzi spring on the Jos Plateau, central Nigeria to fluorite minerals in the host granite rocks where it has caused serious dental fluorosis in children. Lar and Tejan, (2008) highlighted the human health effect related to the consumption of fluoride in groundwater particularly in Nigeria. Dibal, et al, (2008) reported the high incidence of dental fluorosis to consumption of high fluoride in groundwater of Langtang area. Dibal and Schoeneich, (2009) reported the occurrence of high fluoride in groundwater in several rural communities in some parts of northern Nigeria. Other studies on fluoride in groundwater are those of Bale and Goni, 2012. Although the Younger Granite lithologies which constitute the major aquifer units in the Jos area have been reported to have high fluorine content (ribeckite and biotite granite) (Bowden, 1965), fluoride in groundwater in these aquifers have been reported to be generally low (< 0.5 mg/l) in many areas (Schoeneich and Mbonu, 1990; Chilota, 2010, Solomon and Piwuna, 2011 and Dibal et al, 2012). Causes of high and low fluoride in Indian groundwater have been reported by Handa in 1975. He found out that the chemical composition of ground water from confined aquifers shows fluoride content below 1.0 mg/l and generally below 0.5 mg/l. He also reported positive correlation between fluoride and silica as well as between fluoride and sodium in groundwater, which indicate a silica-mineral source of fluoride. Hitchon, (1995) found out that fluoride is adsorbed on clay minerals, where ionic exchange takes place, and hence fluoride ions partly replaced which may lead to low fluoride in groundwater. According to (Abu Rukah and Alsokhny, 2004; Jacks et al, 2004), the concentration of fluoride in groundwater depends on the geological, chemical and physical characteristics of aquifers (e.g, porosity and acidity of soils, rocks, temperature and depth).

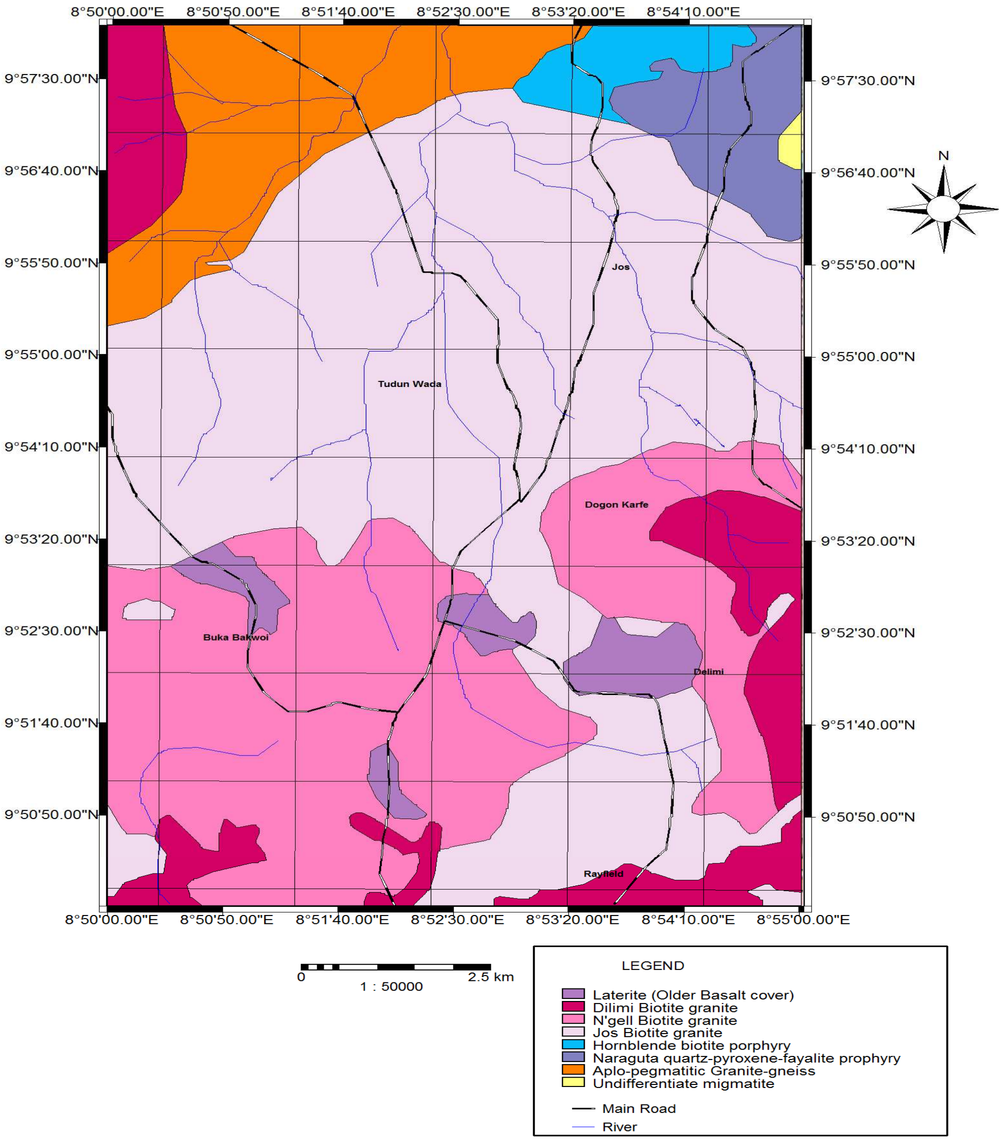


Fig 1. *Geologic Map of the Study Area*

Rock chemistry, groundwater age, well depth, hydrologic condition, residence time and geologic structure are important factors of fluoride rich groundwater (Edmunds, 1994; Kim and Jeong, 2005). The aim of this study is an attempt to trace the factors responsible for low level fluoride content in the Younger Granite Aquifer.

1.1. Description of the Study Area

Geographically the area lies between Latitudes $9^0 48^{'} 9$ and $9^0 58'308"$ and Longitudes $8^0 50'.00"$ and $8^0 55'00.00"$, with aerial extent of about 106 km^2 within the Younger Granite Province of Nigeria. The Younger Granites are characterized by circular intrusions and represent one of the classical areas of occurrences of ring-complexes in the world. They are non - orogenic rocks, which have intruded the Late Precambrian to Lower Paleozioc Basement Complex of Northern Nigeria in a N - S trend (Turner, 1983). Ring faulting and cauldron subsidence are the major tectonic controls governing the emplacement of the Younger Granite (Macleod et al, 1971). These controls have operated during the volcanic and the stages of the emplacement cycles. The pattern of initial volcanism has been determined largely by ring fracturing which have extended to the surface. These fractures controlled the alignment and distribution of the vents and the major cauldron of the same mechanism at greater depth, beneath the lava accumulation, which localized the peripheral ring dykes and the granitic plutons. The Younger Granites exhibit a variety of rock types, which present similar characteristics throughout the whole province. These rock types include; biotite granite, hornblende biotite granites, rhyolite, riebeckite - biotite granite, syenite, gabbro, pyroxene -fayalite granite (Macleod et al. 1971). However, the following rock types characterized the study area; Jos –Bukuru Biotite Granite, N'geil Biotite Granite, hornblende biotite granite, Dilimi Biotite Granite, aplo-pegmatitic granite gneiss (Basement rock), Naraguta Quartz Pyroxene Fayalite Porphyry and the weathered Older Basalt (Laterite) (Fig 1).

2. Methodology

Water samples were collected from different sources (hand dug wells, hand pumps and mining ponds) at intervals of 200 meters depending on availability of sources. 250 ml plastic bottles were used to collect water samples. Two samples each were collected at every sampling point. One sample from each sample point was then acidified with two drops of concentrated pure nitric acid to a pH of <2 for the samples that will be used for the detection of cation. Physical parameters such (temperature, Total Dissolved Solids (TDS), Electrical Conductivity (EC), and pH) for all the samples were determined in the field with the Oakton 5/6 pH/temperature meter and TDS/EC meter. The Inductive Coupled Plasma- Optical Emission Spectrophotometry (ICP-OES) was used to analyse the major cations and trace elements at the ACME Laboratory in Canada. The Multi-Ion Parameter Bench Photometer (HI 83200) was used to determined fluoride at the University of Jos, Faculty of Pharnaceutical Sciences. While the UV Multi-Ion Parameter Model 721 was used to determine SO_4 and bicarbonate and chloride were by titration method at the Univesity of Jos, Department of Geology. Soil samples were collected at intervals of 1 meter from weathered section of the Jos - Bukuru biotite granite the largest rock type which constitutes an aquifer (Plates). Fresh rock samples were also collected from the different rock types. Soil samples were dried at room temperature and both (rock and soil) samples were pulverized with FRITSCH PLANETARY MICRO MILL (Pulverisette 7). 1.5 grammes of each were weighed using AINSWORTH electric balance for analysis. Fluorine in rocks and soils were analysed by the Fusion method at the ACME Laboratory.

3. Results and Discussion

Table1 shows the concentration of fluorine in the rocks sampled at 7 locations on different rock types within the study area (Dillimi-Biotite –Granite, aplo- pegmatitic granite –gneiss, Jos Biotite Granite and Quartz-pyroxene-fayalite porphyry). From the Table 1, The Jos - Bukuru Biotite Granite shows the highest fluorine concentration of 6,231ppm at location 1 and 914 ppm at location 6, this is followed by the aplo-pegmatitic granite –gneiss (basement rock) with 4,864, Dillimi Biotite –Granie, 2,587, Quartz-Pyroxenes-Fayalite Porphyry 1,280. The Ngeil Biotite Granite has the lowest concentration of fluorine of 47ppm.

Table 1. *Concentration of fluorine in rocks at various locations in the study area*

SID	Longitude	Latitude	Date	Rock type	F(ppm)
LR1	8 54 38	9 48.9	11/4/2012	Dillimi-Biotite -Granite	2,587
LR2	8 50 39.3	9 56 49.6	12/4/2012	Aplo-pegmatitic granite-gneiss	4,864
LR3	8 51 53.2	9 55 49.7	12/4/2012	Jos - Bukuru Biotite Granite	6,231
LR4	8 50 06.7	9 51 53.1	12/4/2012	Ngell Biotite Granite	162
LR5	8 54 30.8	9 56 27.6	13/4/2012	Quartz -pyroxene-fayalite pophyry	1,280
LR6	8 53 28.6	9 54 15.6	13/4/2012	Jos - Bukuru Biotite Granite	914
LR7	8 50 25.3	9 51 53.2	13/4/2012	Ngell Biotite Granite	47

The concentration of fluorine in the soil samples taken from weathered sections of the Jos-Bukuru Biotite Granite at two locations (only rock type with exposed weathered section) is shown in Table 2. From (Table 2), it shows that the soils generally have moderate concentration of fluorine however; there are variations of fluorine content in the different sections with the bottom layers from the two locations having the highest concentrations and the top have the list concentration. The sample LS1-4 a sample collected at the bottom of the soil section at location 1 has fluorine concentration of 598 ppm. The sample LS2-5 a sample taken at the bottom of the soil section at location 2 has fluorine concentration of 375 ppm. The top soils represented by samples LST-2 and LST-1 from locations 2 and 1 respectively have fluorine concentrations of 155 ppm and 188 ppm probably indicating leaching of fluorine from the top to bottom. The samples LLSM-1 and LSV1 are soils from weathered pegmatite vein with fluorine concentration of 246 and 263 ppm respectively. Generally it can be observed that all the soil sections have lower fluorine content compared to the parent rock. The top soils appear to have lower fluorine concentration than those at the bottom which could probably explains the high concentration at the bottom. Probably this is because they are friable and have acted as a sink for the fluorine to be leached down to the bottom.

Table 3, shows the concentrations of major cations, anions and fluoride in water samples of the study area and their physical parameters and Table 4 shows the summary of the data. Temperature ranges from 23 to 25.50 °C with a mean of 24.5°C. pH, ranges from 7 to 11.1 with an average pH of 8.2 indicating neutral to alkaline water in the area .Total Dissolved Solids (TDS) ranges from 3 to 598 mg/l with few wells having TDS > 500 mg/l indicating such hand dug wells may probably have been affected by residential pollution. Calcium level is relatively high except at locations 1 an 2 which have 0.57 and 0.81 ppm respectively. Magnesium ranges from <0.05 to 14.18 ppm on average 2.15 ppm. Sodium concentration is relatively high except at locations 1 and 50 which recorded 0.63 and 1.09 ppm respectively. Potassium is generally low except at location 30 where the concentration is 44.9 ppm. Sulphate concentration is generally low ranging from 6.5 to 42.5 on average 12.68, chloride ranges from 0.00 to 206 on average 30.95. The absence of chloride in some locations could only be explained on the basis of analytical error, since it conservatively behaves in the geochemical environment. Bicarbonates concentration ranges from 8.8 to 328 ppm on average 68.27. Fluoride concentration level is very low; it ranges from 0.01 to 1.56. 97% of the locations have fluoride level of less than 1.5. These areas include Rayfield, Zaramaganda, Baza Bakwoi and Tudun Wada

Table 2. *Concentration of fluorine in the soil samples at two locations in the study area: Location: Ray Field Weathered Sections*

SID	Date	Depth (m)	Texture	colour	Soil type	F ppm
LST2	11/4/2012	surface	coarse-grained	Reddish-Brown	lateritic	155
LS37	11/4/2012	0 - 1	fine- grained	Brownish	clay	288
LS1-3	11/4/2012	1 - 2	Medium grained	Reddish-Brown	lateritic	170
LS1-4	11/4/2012	2 – 3	fine- grained	Reddish-Brown	clay	598
LSM-1	11/4/2012	3 - 4	Medium grained	Brownish	clay	246
LS2-3	11/4/2012	4 - 5	fine- grained	Pinkish white	clay	202
LS1-2	11/4/2012	5 - 6	fine- grained	Brownish	clay	302
Location: Air Force Base Weathered Sections						
LS2-4	11/4/2012	surface	fine- grained	Pinkish white	clay	212
LSV1	11/4/2012	0 – 1	Medium grained	Pinkish white	clay	263
LST1	11/4/2012	1 - 2	fine- grained	Reddish-Brown	lateritic	188
LS15	11/4/2012	2 - 3	fine- grained	Reddish-Brown	clay	231
LS2-2	11/4/2012	3 - 4	coarse-grained	Brownish	clay	200
LS2-5	11/4/2012	4 - 5	fine-grained	Brownish	clay	375

Table 3. *Compositions of groundwater in the study area*

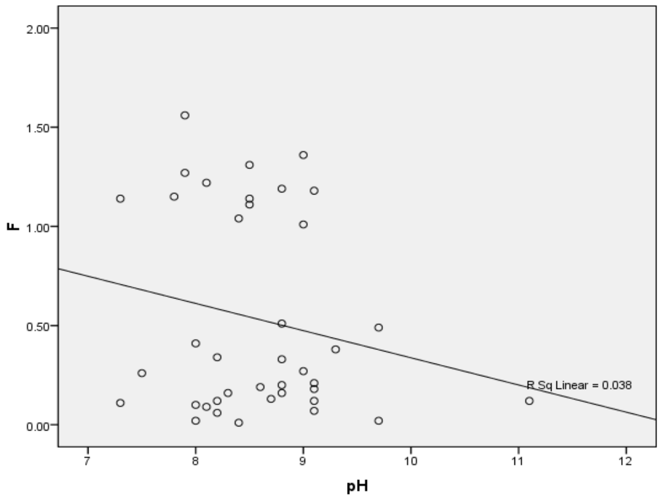
SID	Longititude	Latitudes	Date	Source	Depth	Elev(m)	EC	T (°c)	pH
SD1	08°54'41.7"	9°49'6"	11/4/2012	MP	1.5m	4241	6	22.5	11.1
SD2	08°54'38"	09°48'9"	11/4/2012	well	3.5m	4218	17	23.2	9.7
SD3	08°53'17.6"	09°52'37.1"	11/4/2012	well	3.5m	4241	203	23	9.1
SD4	08°53'17.3"	09°52'42.0"	11/4/2012	well	5m	4152	11	26	9.1
SD5	08°52'51.4"	09°52'57"	11/4/2012	HP	None	4204	40	27	8
SD6	08°52'49.5"	09°53'04.9"	11/4/2012	well	7m	4172	149	23	8.4
SD7	08°53'06.4"	09°53'03.2"	11/4/2012	well	6m	4208	437	25	7.9
SD9	08°54'11.9"	09°52'33.6"	11/4/2012	well	10m	4218	136	24	8.2
SD10	08°53'58.1"	09°52'38.1"	11/4/2012	well	1.3m	4214	40	24.5	9.1
SD11	08°53'36.4"	09°53'53.5"	11/4/2012	well	0.5m	3985	289	24	8.1
SD12	08°51'25.9"	09°57'22.6"	12/4/2012	well	7m	4142	351	24.2	8.3
SD13	08°50'27"	09°58'17.8"	12/4/2012	HP	10.6m	3850	67	25	9.1
SD14	08°50'42.2"	09°56'50.6"	12/4/2012	well	10m	3808	86	24	9.1
SD15	08°50'52.3"	09°56'54"	12/4/2012	well	5.5m	3781.8	146	23.2	8.8
SD16	08°51'15.2"	09°56'53.4"	12/4/2012	well	8m	3768.7	102	24	8.8
SD18	08°50'47.5"	09°57'57.8"	12/4/2012	well	7.8m	3693	68	23.5	8.8
SD19	08°51'32.9"	09°56'28.6"	12/4/2012	well	8.8m	3775	72	24	8.8
SD20	08°51'53.2"	09°55'49.7"	12/4/2012	well	3.8m	3857	284	25	8.1
SD21	08°50'51.5"	09°55'38.4"	12/4/2012	well	3.7m	3873	387	25	8.2
SD22	08°53'21.9"	09°55'04.2	12/4/2012	well	3m	3988	415	24	8.5
SD23	08°50'06.7"	09°51'53.1"	12/4/2012	well	10m	4283	7	25	9.3
SD24	08°52'14.3"	09°54'21.5"	13/4/2012	well	5m	4063	81	24	9.7
SD27	080 5140.6	090 54 05.3	13/04/2012	well	5m	4080	1138	24	7.5
SD29	08°51'48.1"	09°54'23.1"	13/4/2012	well	4.2m	4001	408	24.5	8
SD30	08°59'30.4"	09°54'32.1"	13/4/2012	well	4.2m	4044	1178	24	7.3
SD31	08°51'57.9"	09°53'53.7"	13/4/2012	well	1m	4077	126	25.5	8.2
SD32	08°51'10.6"	09°53'10.6"	13/4/2012	well	6.4m	4100	79	23.5	8.6
SD33	08°50'57.8"	09°52'02.6"	13/4/2012	well	3m	4296.8	76	23.5	8.5
SD36	08°50'09.3"	09°50'29.5"	13/4/2012	well	5.8m	4319.7	9	24	9
SD37	08°50'25.2"	09°50'53.7"	13/4/2012	well	8.9m	4303	12	24.5	9
SD38	08°50'32.6"	09°50'50.0"	13/4/2012	well	3.2m	4286	8	25	9
SD41	08°50'48.0"	09°52'57.3"	13/4/2012	well	5.5m	4346	29	23	8.4
SD43	08°52'11.3"	09°52'54.0"	13/4/2012	well	6.8m	4195	81	25	8.7
SD45	08°54'42.5"	09°54'15.2"	14/4/2012	well	4.4m	4031	94	23	8.5
SD46	08°50'51.9"	09°55'00.6"	14/4/2012	well	5.7m	4011	339	24	8
SD47	08°54'53.6"	09°56'00.2"	14/4/2012	well	5.2m	3919.6	235	25	7.8
SD48	08°54'30.8"	09°56'27.6"	14/4/2012	well	5.9m	3880	166	25	7.3
SD49	08°54'16.1"	09°57'14.2"	14/4/2012	well	6.1m	3922.8	30	25	7.9
SD50	08°53'28.6"	09°54'15.6"	14/4/2012	well	5m	4096.7	117	24.5	8.7
SD29	08°51'48.1"	09°54'23.1"	13/4/2012	well	4.2m	4001	408	24.5	8
SD30	08°59'30.4"	09°54'32.1"	13/4/2012	well	4.2m	4044	1178	24	7.3
SD31	08°51'57.9"	09°53'53.7"	13/4/2012	well	1m	4077	126	25.5	8.2
SD32	08°51'10.6"	09°53'10.6"	13/4/2012	well	6.4m	4100	79	23.5	8.6
SD33	08°50'57.8"	09°52'02.6"	13/4/2012	well	3m	4296.8	76	23.5	8.5
SD36	08°50'09.3"	09°50'29.5"	13/4/2012	well	5.8m	4319.7	9	24	9
SD37	08°50'25.2"	09°50'53.7"	13/4/2012	well	8.9m	4303	12	24.5	9
SD38	08°50'32.6"	09°50'50.0"	13/4/2012	well	3.2m	4286	8	25	9
SD41	08°50'48.0"	09°52'57.3"	13/4/2012	well	5.5m	4346	29	23	8.4
SD43	08°52'11.3"	09°52'54.0"	13/4/2012	well	6.8m	4195	81	25	8.7
SD45	08°54'42.5"	09°54'15.2"	14/4/2012	well	4.4m	4031	94	23	8.5
SD46	08°50'51.9"	09°55'00.6"	14/4/2012	well	5.7m	4011	339	24	8
SD47	08°54'53.6"	09°56'00.2"	14/4/2012	well	5.2m	3919.6	235	25	7.8
SD48	08°54'30.8"	09°56'27.6"	14/4/2012	well	5.9m	3880	166	25	7.3
SD49	08°54'16.1"	09°57'14.2"	14/4/2012	well	6.1m	3922.8	30	25	7.9
SD50	08°53'28.6"	09°54'15.6"	14/4/2012	well	5m	4096.7	117	24.5	8.7

Table 3. *Continued*

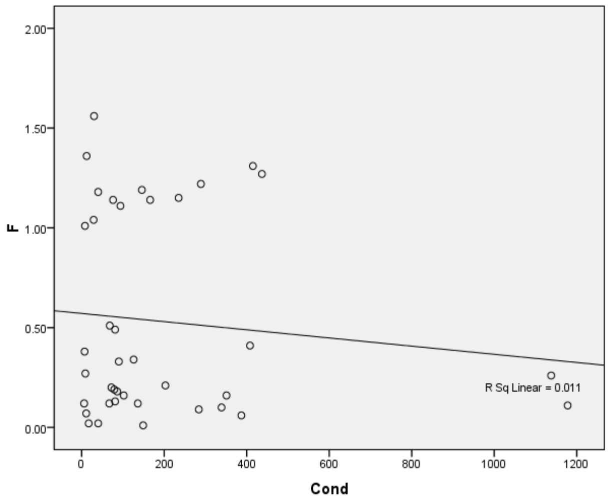
SID	TDS	Ca	Mg	Na	K	SO4	Cl	HCO3	F
SD1	3	0.57	0.07	1.09	0.44	6.5	ND	8.8	0.12
SD2	8	0.81	0.09	2.66	1.72	7.9	0	10.1	0.02
SD3	104	11.09	1.38	26.51	7.25	10.7	21.27	64	0.21
SD4	6	1.06	0.08	2.34	0.61	7.5	7.09	120	0.07
SD5	20	4.36	1.24	2.18	1.22	8	21.27	18.18	0.02
SD6	75	10.87	1.87	13.58	6.93	12.2	14.18	40.4	0.01
SD7	221	31.50	5.01	39.26	12.96	11.8	63.81	30.3	1.27
SD9	68	25.96	0.21	2.72	2.91	19.6	92.17	44.44	0.12
SD10	20	2.48	0.47	4.40	2.82	12.1	0	62.62	1.18
SD11	149	34.02	14.18	7.60	1.87	14	14.18	144	1.22
SD12	177	33.03	5.11	28.29	6.16	16.3	14.18	141.4	0.16
SD13	33	3.14	1.54	10.62	2.07	14.8	28.36	76.76	0.12
SD14	43	9.53	0.33	7.90	3.20	8.45	2.5	42.42	0.18
SD15	72	16.40	0.55	5.93	11.36	9	4.2	38.38	1.19
SD16	52	15.93	0.48	3.50	3.21	13.5	0	58.58	0.16
SD18	34	4.13	1.30	8.72	2.83	9.2	49.63	50.5	0.51
SD19	36	4.98	0.83	6.84	5.00	13	14.18	54.54	0.2
SD20	145	22.52	3.68	25.11	7.05	18.6	28.36	84	0.09
SD21	191	25.63	2.55	39.95	10.42	9.75	7.09	200	0.06
SD22	208	14.83	1.61	51.50	10.03	19.4	35.45	52.52	1.31
SD23	3	0.27	<0.05	1.68	0.74	37.5	42.54	60.6	0.38
SD24	41	6.67	0.68	6.49	4.56	8.9	42.54	12.12	0.49
SD27	181	73.95	12.92	127.73	27.34	8.0	42.54	480	0.26
SD29	206	27.04	3.17	29.81	25.47	11.5	42.54	158	0.41
SD30	598	71.51	10.14	113.05	44.97	12.6	77.99	328	0.11
SD31	61	8.02	1.44	11.56	6.68	42.5	205.6	129.28	0.34
SD32	38	5.56	0.50	6.48	6.30	8.8	42.54	10.1	0.19
SD33	38	4.18	0.81	8.70	2.79	10.5	42.54	14.14	1.14
SD36	4	0.55	<0.05	2.11	0.24	20.5	184.3	20.2	0.27
SD37	7	L.N.R.	L.N.R.	L.N.R.	L.N.R.	15.3	21.27	20.2	1.36
SD38	4	0.37	0.05	1.28	0.56	14.4	7.09	20.2	1.01
SD41	14	2.92	0.27	2.58	1.48	12.8	21.27	20.2	1.04
SD43	41	2.67	0.48	10.57	7.45	8.1	21.27	20.2	0.13
SD45	47	7.50	0.63	9.18	4.38	9.7	77.99	10.1	1.11
SD46	173	16.28	3.11	34.42	9.78	8.8	56.72	14.14	0.1
SD47	118	10.75	1.18	30.73	8.22	8.9	56.72	16.16	1.15
SD48	84	6.70	1.15	21.50	8.90	8.49	63.81	10.1	1.14
SD49	15	1.91	0.31	2.81	3.42	9.75	28.36	18.18	1.56
SD50	48	1.38	0.12	0.63	0.24	7.98	63.81	14.14	1.42
SD29	206	27.04	3.17	29.81	25.47	11.5	42.54	158	0.41
SD30	598	71.51	10.14	113.05	44.97	12.6	77.99	328	0.11
SD31	61	8.02	1.44	11.56	6.68	42.5	205.6	129.28	0.34
SD32	38	5.56	0.50	6.48	6.30	8.8	42.54	10.1	0.19
SD33	38	4.18	0.81	8.70	2.79	10.5	42.54	14.14	1.14
SD36	4	0.55	<0.05	2.11	0.24	20.5	184.3	20.2	0.27
SD37	7	L.N.R.	L.N.R.	L.N.R.	L.N.R.	15.3	21.27	20.2	1.36
SD38	4	0.37	0.05	1.28	0.56	14.4	7.09	20.2	1.01
SD41	14	2.92	0.27	2.58	1.48	12.8	21.27	20.2	1.04
SD43	41	2.67	0.48	10.57	7.45	8.1	21.27	20.2	0.13
SD45	47	7.50	0.63	9.18	4.38	9.7	77.99	10.1	1.11
SD46	173	16.28	3.11	34.42	9.78	8.8	56.72	14.14	0.1
SD47	118	10.75	1.18	30.73	8.22	8.9	56.72	16.16	1.15
SD48	84	6.70	1.15	21.50	8.90	8.49	63.81	10.1	1.14
SD49	15	1.91	0.31	2.81	3.42	9.75	28.36	18.18	1.56
SD50	48	1.38	0.12	0.63	0.24	7.98	63.81	14.14	1.42

Table 4. *Minima, maxima, mean and standard deviations of analyzed water samples in the study area.*

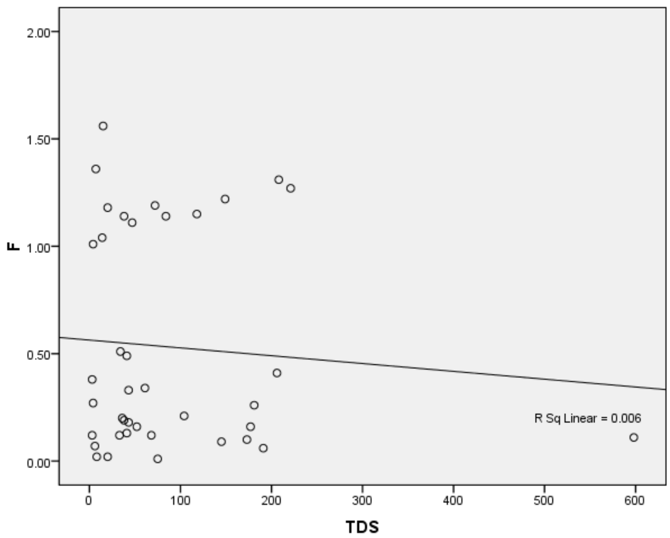
	N	Minimum	Maximum	Mean	Std. Deviation
EC	41	6	94	35.68	27.595
Temp	41	23	27	24.25	.923
pH	41	7	11	8.20	.782
TDS	41	3	598	85.98	105.487
Ca	40	0	74	13.36	16.899
Mg	38	0	14	2.15	3.318
Na	40	1	127	18.35	26.880
K	40	0	44	6.48	8.476
SO4	40	7	42	12.69	7.138
Cl	39	0	92	30.95	23.943
HCO3	40	9	480	68.27	92.913
F	40	0	1	.35	.483
Valid N (listwise)	36				



2a



b



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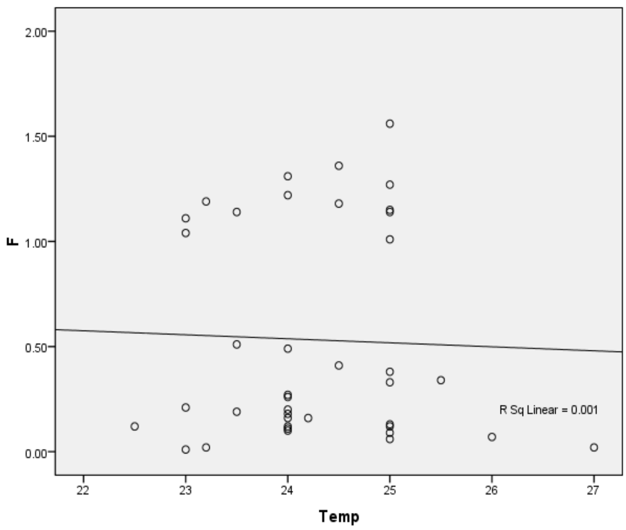

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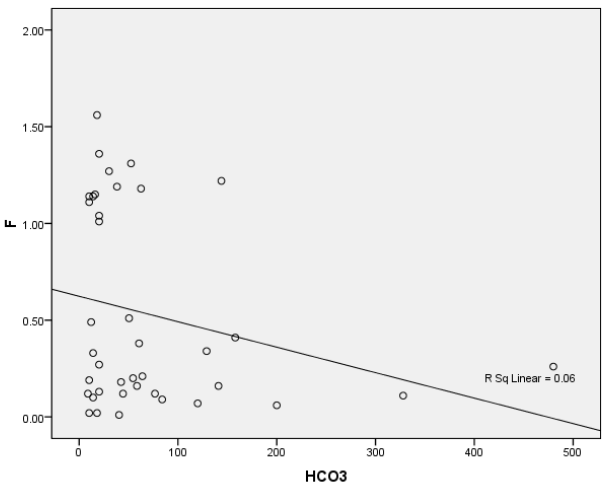
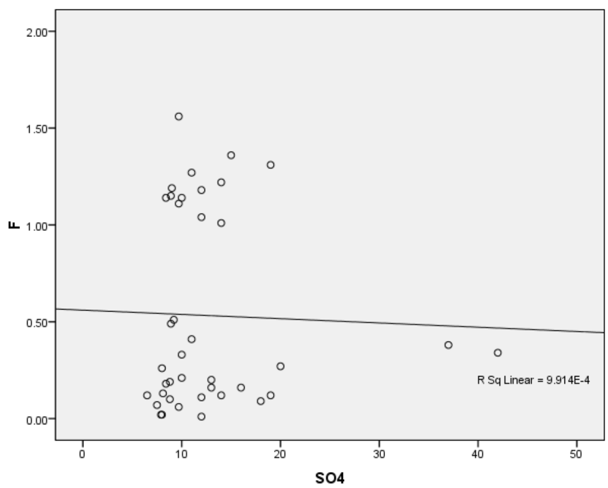
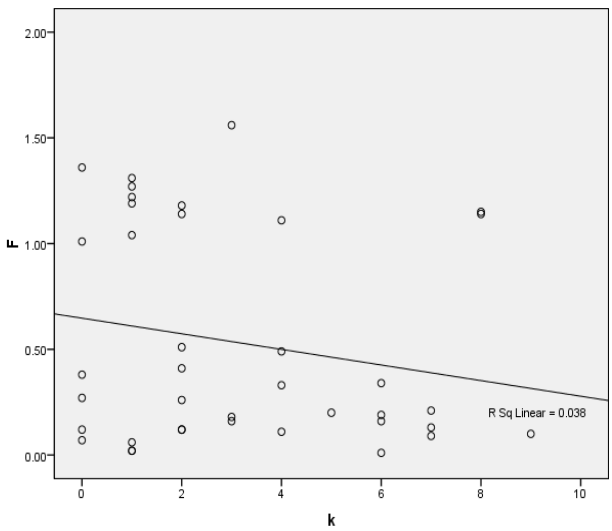

2.00
1.50
1.00
0.50
0.00
F
R Sq Linear = 0.06
0
100
200
300
400
500
HCO3

e


2.00
1.50
1.00
0.50
0.00
F
R Sq Linear = 9.914E-4
0
10
20
30
40
50
SO4

f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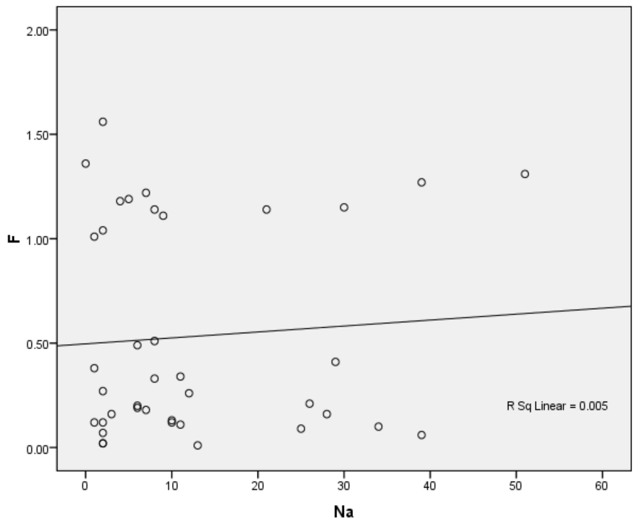
1.50
1.00
0.50
0.00
F
R Sq Linear = 0.038
0
2
4
6
8
10
k

g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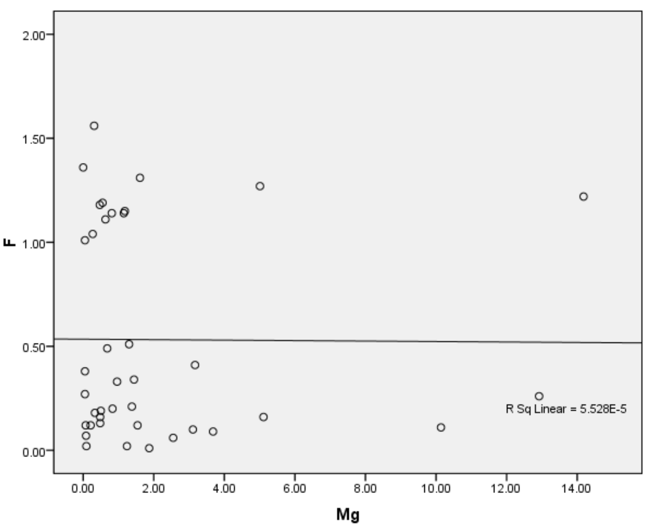
1.50
1.00
0.50
0.00
F
R Sq Linear = 0.005
0
10
20
30
40
50
60
Na

h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1.50
1.00
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0.00
F
R Sq Linear = 5.528E-5
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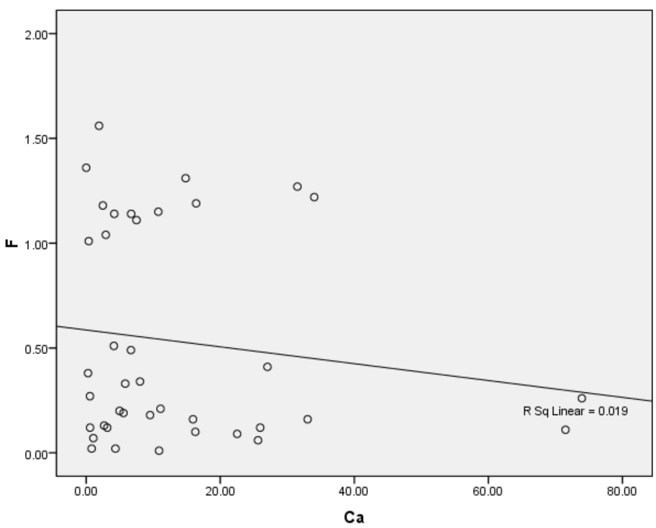
2.00
4.00
6.00
8.00
10.00
12.00
14.00
Mg

i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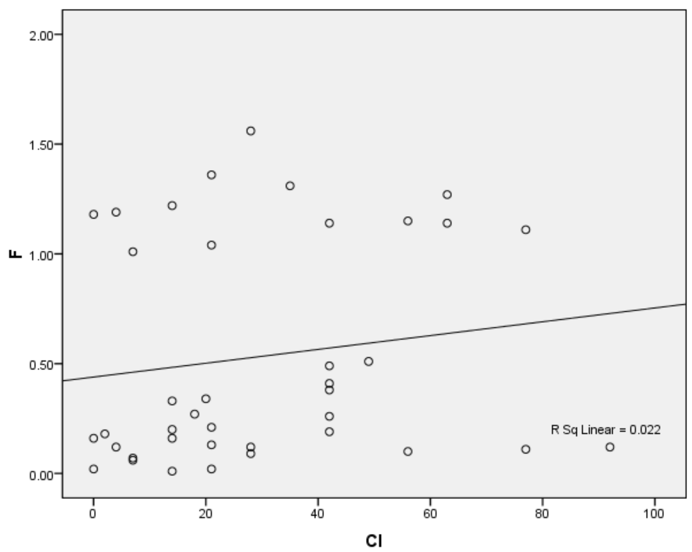
1.50
1.00
0.50
0.00
F
R Sq Linear = 0.019
0.00
20.00
40.00
60.00
80.00
Ca

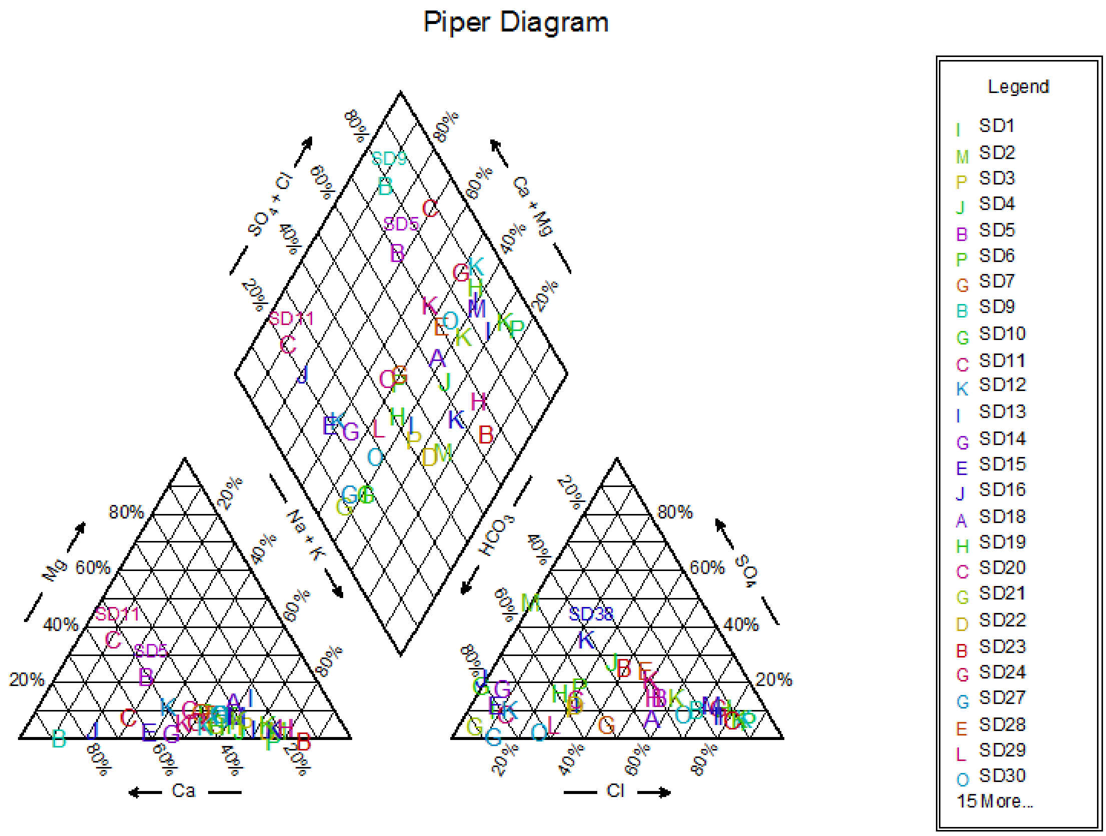
j



k

Fig 2 (a – k). *Relationship between Fluoride and some Parameters in the Study Area*

The Figures 2 (a -k) show scatter plots between F^-, and the physical parameters and other ionic constituents in the study area. There seem not to be a clear relationship between F and Temperature, TDS, Conductivity, Mg and SO_4 in the water. However, F exhibit negative relationship with pH, Ca, K and HCO_3 and a poor but positive relationship with Na and Cl.



90%

Fig 3. *Piper Diagram showing Major Ion Chemistry of Groundwater in the Study Area.*

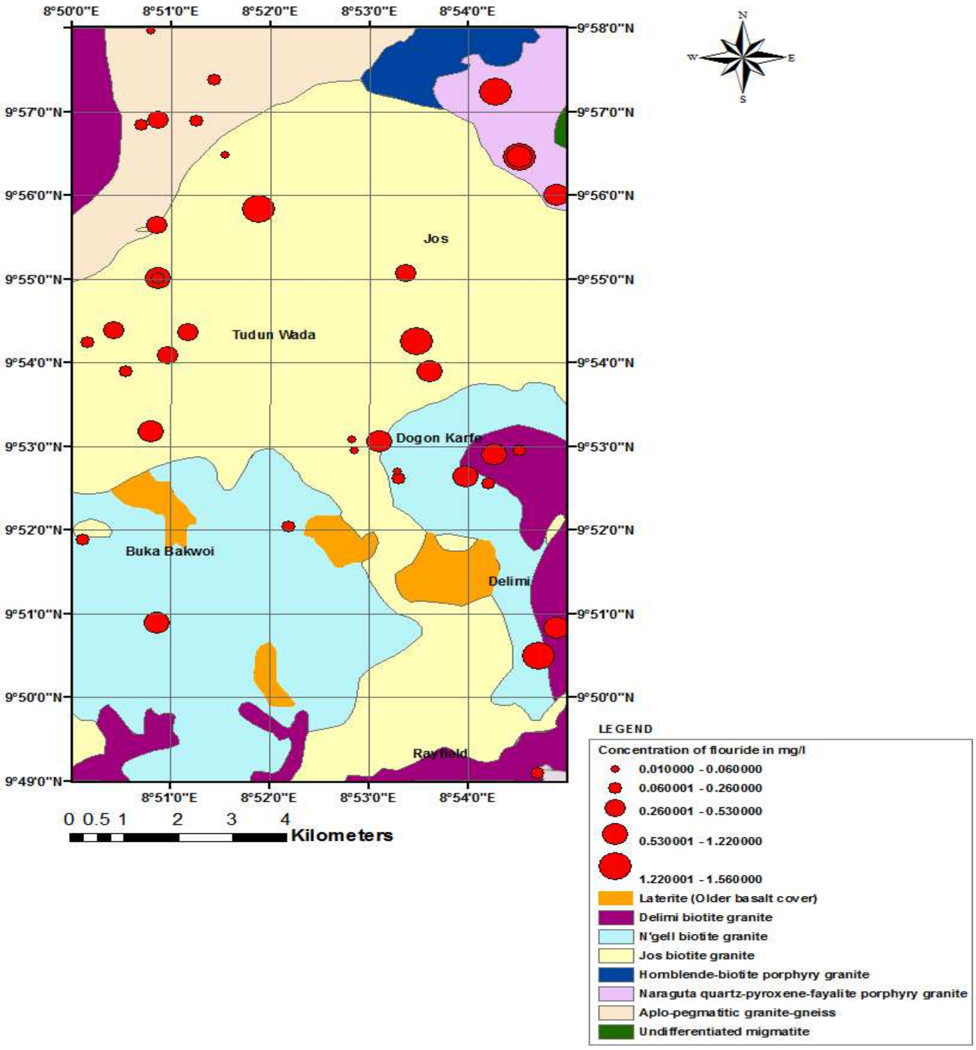


Fig 4. *Fluoride symbol map of the study area*

3.1. Groundwater Types

Groundwater type is useful in determining groundwater flow history, groundwater contact time and residency. High fluoride groundwaters have been associated to the Na-HCO_3 water type (Handa, 1975, Gaciri and Davies, 1993; Edmunds, 1994 Ampambire et al, 1997; Fordyce, 2007). Low level fluoride groundwaters have been associated to Ca-HCO_3 water type (Handa, 1975, Gaciri and Davies, 1993; Edmunds, 1995). The ionic concentration of major cations and anions in groundwater of the study area are plotted in Piper's Trillinear Diagram (Fig. 3). The analysis of Piper diagram suggests the majority of groundwater samples belong to the Na-Ca-HCO_3-Cl (mixed) water type with very few which is of the SO_4-Cl water type.

In order to examine the relationship between F^- levels in groundwater and geology, the fluoride values were plotted on geological map of the study area in the form of symbol map (Figure 4). It is observed that, of the 40 wells located on the different lithological units which make up the aquifer in the area, 13 (32%) have F^- concentration between 0.53 and 1.56 mg/l and 5 (38%) out of these 13, are located on the Jos-Bukuru Biotite Granite, 3 (23%) are located on the applo – pegmatitic granite terrain, 2 (15%) in the Dilimi Biotite-Granite area and 3 (23%) are located on the Naraguta quartz-pyroxene-fayalite-porphry granite terrain. The wells with lower F^- content occur mostly in the Ngeil-Biotite Granite. High concentration of F^- in groundwater occurs in the Jos-Bukuru -Biotite granite, Naraguta quartz –pyroxene-fayalite-porphry granite and applo-pegmatitic granite as earlier mentioned. The highest concentration of F- in groundwater occurs in the Jos-Bukuru -Biotite granite. It appears that the concentration of F^- in groundwater is proportional to the concentration of fluorine in the rocks (Fig 2).

4. Discussion of Results

The fluorine content in rocks of the study area is high except that of the Ngeil Biotite Granite area. The soils from the different sections of the weathered Jos - Bukuru Biotite Granite show variations in the content of fluorine, but appear to have higher fluorine content at the sections at the bottom. Cumulative (from top to bottom) value of fluorine collected from a section in the Ray Field area show slightly lower than half the value obtained in the rock mass and around the Air Force Base it has almost the same value in the rock mass. There is a clear indication that fluorine has been leached, evidenced from the low values obtained from the top soil. However, the values obtained from the different sections and the cumulative value especially that of the Ray Field areas do not correlate with the values obtained in the rock units. The high pH, low TDS, High bicarbonate and Na, low Ca content of the water are factors which favour the accumulation of fluoride in groundwater (Handa, 1975; Edmunds, 1994, Gaciri and Davies, 1993). However, the existence of these factors does not justify the content of fluoride in the groundwater of the study area. We therefore believe that apart from fluorine that have been adsorbed to the bodies of clay, bulk of the fluorine have not been leached from the biotite and other variety of minerals in the soils (Pickering, 1995) or probably fluorine may have formed complexes with other ions in soils or in the waters, rather than occurring in ionic form.

4.1. Groundwater Quality

The groundwater quality of the study area is evaluated by comparing the range of values of different geochemical parameters with the standard of the World Health Organization (WHO 1984). Physico-chemical properties of analysed water samples show considerable variation in the water quality with respect to their chemical composition. The waters in the study area are neutral to alkaline in nature. Nine (22%) out of 40 water samples from the study area have pH values above the WHO standard of 6.5 to 8.5 for human consumption. The electrical conductivity (EC) values are found to be within the range of 6 to 94 with mean value of 35.68. 91% of the samples were found to have EC values less than the maximum of 1,400 ppm at 25^0C specified by WHO (2004). With the concentrations of Total Dissolved Solids (TDS) ranging from 3 mg/l to 598 mg/l most of the samples are classified as soft as mean values for TDS is 85.98 less than the prescribed limit of 500 mg/l WHO, (2004) for drinking water. All the other ions found in the groundwater of the study area are within the WHO (2004) standard for house hold uses. With only 38% of water in the study area having fluoride level between 0.5 – 1.5 mg/l, most areas are imbibing water with fluoride below the recommended level of 0.5 mg/l (WHO 2004). Although there is no record to show the manifestation of dental caries in the study area, inferences can be drawn for the occurrence of dental caries owing to the low level of fluoride in the waters.

5. Summary and Conclusion

The Younger Granites rocks of the Jos, particularly the biotite granites as revealed in the study area, have considerable amounts of fluorine, but generally, fluoride levels in the groundwater is low. There is clear indication that fluorine has been leached as evidenced from the low content in the top soils. Also, factors which favour the accumulation of fluoride in groundwater in the study area have been satisfied, but it seems they have not been mobilized to the water. This low level fluoride in the waters may probably be due non release of fluorine in the biotite minerals and other minerals which fluorine may be residing in, apart from those that have been adsorbed to the bodies of clays. Probably also, fluorine may have formed complexes with other ions in the water and the soils and may be occurring in compound from rather than in ionic form.

About 90% of the concentration of cations, anions are within the permissible standard limit prescribed by WHO (2004) for drinking water..

38% of the F^- content in the water samples are within the permissible standard limit prescribed by WHO (2004) for drinking water. Some locations, particularly the Rayfield area, have F^- levels below the prescribed permissible standard limit by WHO 2004 for drinking water. People living in these areas may likely suffer from dental carries.

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