HYDROGEOCHEMICAL CHARACTERIZATION OF SURFACE AND GROUNDWATER AT NASARAWA STATE UNIVERSITY KEFFI, KEFFI SHEET 208 NE, NORTH-CENTRAL NIGERIA

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Abstract

Hydrogeochemical characterization of surface and groundwater at Nasarawa State University Keffi, part of Keffi Sheet 208 NE, North-central Nigeria was carried out. Twenty-five (25) water samples were obtained from hand pumps, hand-dug wells, boreholes and along stream channel in order to ascertain their suitability for human consumption, domestic use and irrigation purposes. Atomic Absorption Spectroscopy (AAS), flame photometry, Macro-Kjeldahl, Turbidimetric, Argentometric and Titrimetric methods were used to analyzed the samples. Results reveal slightly acidic to slightly alkaline water (pH 5.07-8.60), soft to very hard water (TH 28.04-289.32 mg/l), Na^{+} (5.10-80.00 mg/l), K^{+} (2.40-21.00 mg/l), Ca^{2+} (3.54-35.71 mg/l), Mg^{2+} (3.68-53.96 mg/l), Fe (0.00-7.26 mg/l), Cu (0.00-0.07 mg/l), Zn (0.00-0.22 mg/l), As (0.00-1.35 mg/l), Pb (0.00-0.09 mg/l), Cl^{-} (1.50-17.49 mg/l), HCO_3^{-} (0.00-4.00 mg/l), NO_3^{-}(1.96-27.44 mg/l), SO_4^{2-} (1.07-16.87 mg/l). Piper trilinear diagram, Schoeller and Wilcox plot reveal four (4) major water types derived from 13 water facies. The mixed water type, Magnesium Chloride water type, Sodium Chloride water type and Calcium Chloride water type, all of which falls within the alkaline earth water. Na^{+}, K^{+} and Mg^{2+} were above WHO (2011) and NIS (2007) recommended standard for drinking water in some locations, making them the most dissolved cations in the groundwater which added greatly to the TDS. All the water belongs to good-fair water class for irrigation. High concentration of trace elements; Fe, Zn, As and Pb found in some water samples obtained from certain locations make them objectionable for drinking, although can be made suitable for human consumption/ drinking if treated by the addition of coagulants and the use of reverse osmosis. The dominance of cations/anions and trace elements in the water is in an order of $Na^{+}>Ca^{2+}>Mg^{2+}>K>NO_3^{-}>SO_4^{2-}>Cl^{-}>Fe>HCO_3^{-}>As>Zn>Pb>Cu$. The need to continuously monitor, manage, remediate and mitigate against these hydrogeochemical characteristics is called for.

Keywords: Hydrogeochemical, Characterization, Groundwater, Irrigation, Water facies

INTRODUCTION

Water is the world's most essential commodity required by living organisms including human beings, plants and animals, thus, man's sustenance largely depends on its availability and quality. The largest available source of freshwater lies underground and is referred to as groundwater (Ariyo *et al.,* 2005) and it amounts to about 98 % of the world's freshwater (Bouwer, 2002). Groundwater accounts for about one percent of the Earth's water worldwide, or about 100 times more than the total volume of all lakes and rivers (USGS, 2005). The quality of water is very important as its quantity (Abimbola *et al.*, 1999; Tredoux *et al.*, 2000; Adelana & Olasehinde, 2003; Adeyemi *et al.*, 2003;

Anudu *et al*., 2008). Major factors that affect the quality of groundwater includes: the nature of surface run-offs, soil/rock-water interaction during recharge and groundwater flow, prolonged storage in the aquifer leading to dissolution of rock minerals and mineralogical composition of the underlying rocks (Edet, 2009). This implies that the geology of an area plays a vital role in the chemistry of groundwater. Furthermore, groundwater tapped from hand - dug (shallow) wells is most susceptible to contamination compared to does at deeper depths or deep wells, boreholes, etc. The quality required for groundwater supply depends on its intended use or purpose (Ezeigbo, 1998 and Anudu *et al*., 2008). The essential purposes for which water is required domestically include; for drinking, cooking, bathing, general household sanitation such as laundry, flushing of closets and other chores, whereas for agricultural purposes, water is used primarily for irrigation. Hence, a reliable supply of water both qualitatively and quantitatively for these purposes will greatly improve the social, economic and agricultural aspects of the society.

The study area is located at Nasarawa State University Keffi, part of Keffi Sheet 208 NE, North-central Nigeria. It lies within latitudes N08˚50'56" to N08˚49'34" and longitudes E7˚53'40" to E7˚55'00", covering an area of about 4.74 km^2; and can be accessed through the Keffi-Akwanga road (Figure1). The demand for potable water supply for human consumption and other purposes have increased immensely as a result of population growth and development, thus, increasing the need to evaluate groundwater quality in order to ascertain its suitability for human consumption, domestic use and irrigation purposes for healthy living.

Geology of the Study Area

Geological mapping executed showed that the Basement Complex rocks present within the study area comprises of the following rock units; biotite gneiss, granitic gneiss and Schist, where biotite gneiss predominantly occupies 80 % of the study area (Figure 1). The structural features found within the study area are veins (quartz and quartzo-feldspathic) trending NW-SE, joints trending NE-SW and foliations in the NE-SW direction, which corresponds with the major structural trends of the Basement rocks (Mamza, 2018; Jatau *et al.,* 2014; Ancho, 2015).

Hydrogeology of the Basement Complex

Rock outcrops occurring at high elevations within the Basement Complex have experienced and are still undergoing some degree of weathering and fracturing, while superficial deposits derived from the basement rocks that have undergone extensive weathering, transportation and deposition cover the lowlands (or low elevation and/or relief areas). Two major aquifer units or systems are said to exist in the Basement Complex terrains, which are: the weathered aquifer also known as the weathered bedrock (saprolite) aquifer and the fractured aquifer also known as fractured bedrock (saprock) aquifer (Olayinka *et al.,* 1999). The availability of groundwater would

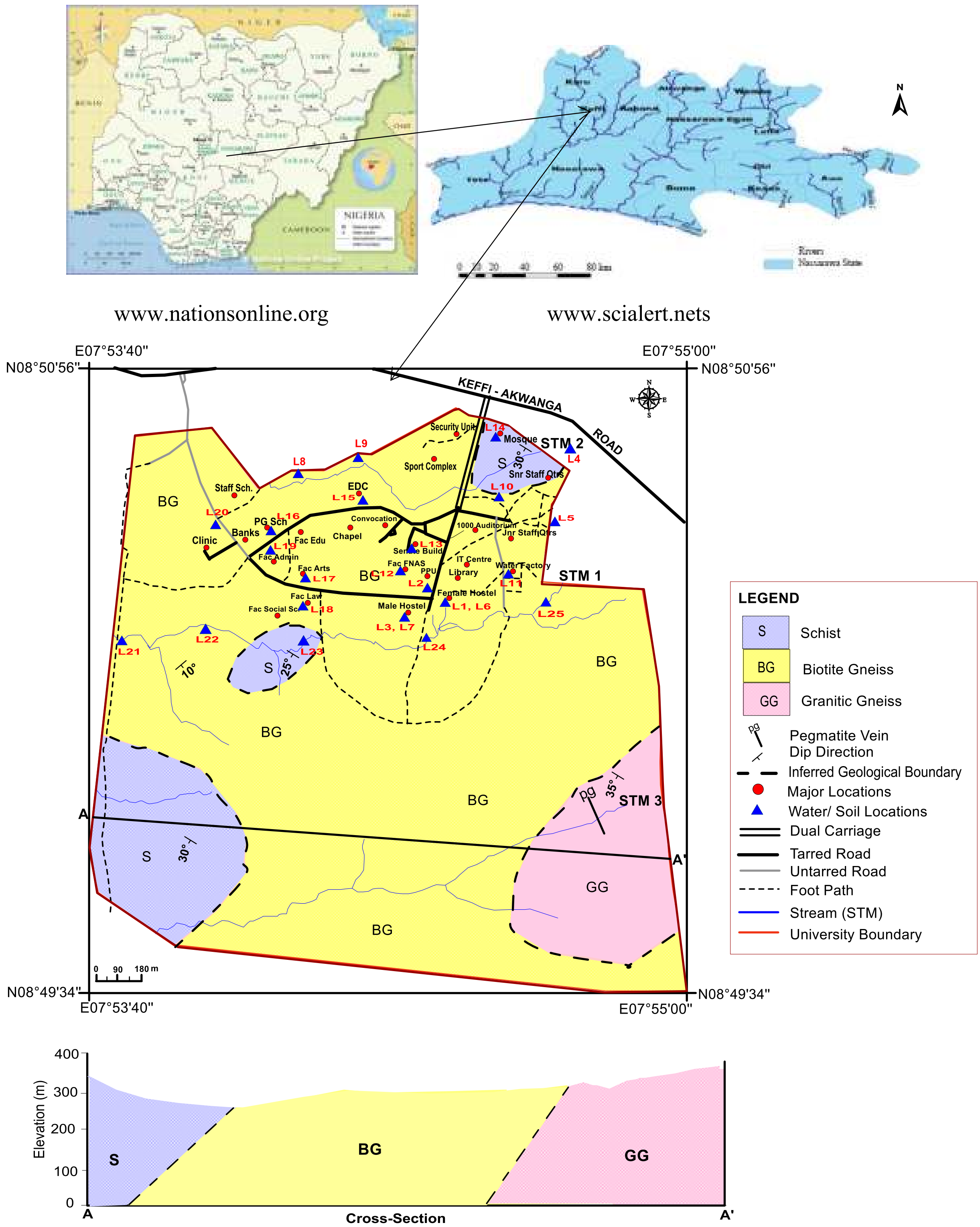

Figure 1: Location, accessibility, hydroeochemical sampling points and geological map of the study area (adopted from Mamza, 2018)

depend on the presence and extent of the weathered overburden and regolith and the presence of faults and fractures in the underlying bedrock, where most hand-dug wells tap their water from the weathered regolith (Olayinka *et al.* 1999).

Highest groundwater yields are obtained where the overburden weathered rock columns overlies the fractured zones (Eduvie *et al.*, 1999, Anudu *et al.*, 2014).

MATERIALS AND METHOD

A total of twenty-five (25) water samples were collected from both surface and subsurface (groundwater), along stream channel (STM), from hand dug wells (HDW), hand pumps (HP) and boreholes (BH) for both physical and chemical analysis. Analysis was conducted in early April, 2017 at the peak of the dry season. The materials used include 50 pieces of 120 ml plastic water bottles where a pair was used per location to collect the water sample, one bottle for anion and the other bottle for cation/trace element chemical analysis at the laboratory; sample containers, Concentrated Nitrate Acid (HNO_3), an acid dropper, Global Positioning System (GPS), masking tape, polythene packs to collect the soil sample, sample bags, field notebook, writing materials, Sartorius potable meter (PT-10), Solinst TLC.

Prior to the chemical analysis, the physical analysis was carried out on each of the sampled water location immediately after collection. Physical analysis employed the use of water kits such as Sartorius potable meter (PT-10) to measure the pH and temperature, while Solinst TLC equally measured temperature, water level/depth and conductivity. Total Dissolved Solids (TDS) was calculated from the values obtained from conductivity (Electrical Conductivity). Elevation and coordinates values were recorded for each sample location using a GPS. The sample containers were rinsed with water from the respective locations, before being proceeding to the next sample location. At the end of the sample collection, the water samples were placed in the refrigerator before being taken to Multi-User Research Laboratory in Chemistry Department and Public Health Laboratory, Department of Water Resources and Environmental Engineering Ahmadu Bello University, Zaria, for chemical analysis, that is, for cations (Mg^{2+}, Ca^{2+}, Na^{+}, K^{+}), anions (NO_3^- , SO_4^{2-}, Cl^-, HCO_3^-) and trace elements (Fe, Cu, Pb, Zn and As). Mg^{2+} and Ca^{2+}, and trace elements were analysed using Atomic Absorption Spectroscopy (AAS, AA240FS model), Na^+ and K^+ were analysed using Flame photometry method while NO_3^-, SO_4^{2-}, Cl^- and HCO_3^- were analyzed using Macro-Kjeldahl, Turbidimetric, Argentometric and Titrimetric methods respectively. Results obtained were used to plot Piper, Schoeller and Wilcox using AquaChem software (version 4.0.254) and contoured using Surfer (version 12) software.

RESULTS AND DISCUSSION

Table 1. Result on the Physical and Chemical parameters of water in the study area

S/N	Station ID	Sample ID	Location	Coordinates	pH	EC (µS/cm)	TDS (mg/l	Temp °(C)	Na^+ mg/l	K^+ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l	Fe (mg/l)	Cu (mg/l)	Zn (mg/l)	As (mg/l)	Pb (mg/l)	TH (mg/l)	Cl^- (mg/l)	HCO_3^- (mg/l)	NO_3^- (mg/l)	SO_4^{2-} (mg/l)
1	L1	HP 1	Girls' Hostel	8°50'25.2''N 7°54'26.0''E	**6.39**	630	403	29.4	8.70	2.40	4.353	4.930	**7.264**	0.071	**0.193**	0.000	**0.093**	31.09	1.50	2.00	5.04	2.14
2	L2	HP 2	Behind SLT	8°50'25.7''N 7°54'25.3''E	**6.04**	805	515	30.2	15.00	3.10	5.904	6.265	**6.552**	0.054	**0.128**	0.000	**0.076**	40.46	1.50	1.00	5.32	3.88
3	L3	HP 3	Boys Hostel	8°50'24.0''N 7°54'21.2''E	**6.18**	**1312**	839	33.2	27.00	4.80	10.629	8.334	**1.862**	0.003	0.004	**0.355**	**0.075**	60.73	1.50	1.00	3.92	1.74
4	L4	HDW 1	Angwan Lambu	8°50'45.9''N 7°54'43.4''E	**6.43**	**2262**	1448	27.6	34.00	**13.00**	35.707	7.899	**1.430**	0.000	0.000	0.000	0.011	121.67	5.00	2.00	3.64	5.89
5	L5	HDW 2	Angwan Lambu	8°50'34.6''N 7°54'43.7''E	**6.33**	**7477**	**4785**	28.4	**80.00**	**14.00**	27.225	**53.955**	0.000	0.005	0.000	**1.063**	0.000	**289.32**	17.49	0.00	3.08	13.93
6	L6	HDW 3	Girls' Hostel	8°50'24.9''N 7°54'26.3''E	**5.70**	760	486	30.9	26.00	2.70	4.072	10.248	0.049	0.008	0.000	**0.900**	0.000	52.21	4.50	0.00	2.52	6.96
7	L7	HDW 4	Boys' Hostel	8°50'24.1''N 7°54'21.2''E	6.74	**1839**	1177	29.0	38.00	7.50	17.300	9.718	0.154	0.005	0.000	0.000	0.000	83.10	5.00	2.00	4.48	6.43
8	L8	HDW 5	High Court	8°50'43.1''N 7°54'8.3''E	**5.07**	**1497**	958	28.9	36.00	6.50	5.831	3.084	0.092	0.005	0.000	**0.614**	0.000	50.21	5.00	0.00	5.32	1.47
9	L9	HDW 6	High Court	8°50'44.2''N 7°54'15.7''E	**5.99**	**2003**	1282	29.0	32.00	6.40	32.075	3.626	0.000	0.012	0.000	**0.908**	0.000	115.58	5.00	0.00	2.52	7.77
10	L10	BH 1	Pump 5	8°50'38.9''N 7°54'34.6''E	**5.67**	**1076**	689	29.6	24.00	2.60	4.989	9.136	0.000	0.014	0.000	**0.710**	0.000	49.95	3.50	0.00	3.36	2.28
11	L11	BH 2	NSUK Consult	8°50'29.6''N 7°54'35.2''E	**5.86**	**1266**	810	30.0	24.00	5.70	7.754	9.295	0.341	0.009	0.000	**0.185**	0.000	57.51	2.50	0.00	2.80	1.61
12	L12	BH 3	FNAS	8°50'30.6''N 7°54'21.7''E	7.17	494	316	34.2	12.00	4.50	5.932	3.722	0.343	0.015	0.010	**0.556**	0.000	32.58	2.00	0.00	6.72	1.34
13	L13	BH 4	Senate Building	8°50'32.2''N 7°54'23.9''E	7.23	454	290	34.5	6.30	2.90	5.188	3.676	0.000	0.005	0.000	**0.718**	0.000	30.57	1.50	0.00	1.96	1.87
14	L14	BH 5	Central Mosque	8°50'47.9''N 7°54'34.7''E	**5.81**	619	396	34.6	16.00	4.30	3.537	4.682	0.000	0.007	0.000	**0.567**	0.000	28.04	2.50	0.00	2.24	1.21
15	L15	BH 6	EDC	8°50'38.6''N 7°54'16.4''E	6.53	700	448	33.5	20.00	3.40	4.531	6.047	0.020	0.000	0.000	**1.185**	0.000	36.14	1.50	4.00	2.52	1.07
16	L16	BH 7	PG School	8°50'34.5''N 7°54'4.5''E	6.59	638	408	33.0	21.00	3.80	4.327	4.555	0.000	0.000	0.000	**0.756**	0.000	29.53	2.50	0.00	3.36	1.47
17	L17	BH 8	New LT Fac. Arts	8°50'30.5''N 7°54'10.2''E	6.73	**1106**	708	37.6	23.00	4.60	9.370	6.700	0.000	0.009	0.000	**0.541**	0.000	50.90	2.00	2.00	1.96	1.34
18	L18	BH 9	Back of Fac. Law	8°50'26.1''N 7°54'8.6''E	7.25	375	240	35.2	5.10	2.70	5.361	4.640	0.076	0.000	0.000	**0.538**	0.000	32.42	1.50	0.00	2.52	1.47
19	L19	BH 10	Back of Fac. Adm	8°50'30.7''N 7°54'3.4''E	**5.94**	651	417	36.4	22.00	3.70	4.128	5.278	0.042	0.000	0.000	**0.446**	0.000	31.98	2.00	0.00	3.92	1.47
20	L20	BH 11	Front of Clinic	8°50'35.3''N 7°53'56.8''E	**6.10**	797	510	36.7	22.00	3.60	5.378	6.378	0.000	0.000	**0.216**	**1.346**	0.000	39.46	2.50	0.00	3.62	1.47
21	L21	STM 1a	Along Stream 1	8°50'20.5''N 7°53'44.2''E	**8.60**	**1334**	853	32.4	33.00	**14.00**	13.803	6.711	**4.399**	0.000	0.000	**0.424**	0.000	62.01	5.50	0.00	3.36	5.09
22	L22	STM 1b	Along Stream 1	8°50'21.1''N 7°53'57.2''E	6.50	**2408**	**1541**	28.0	**51.00**	**21.00**	22.528	3.270	**3.291**	0.000	0.000	0.000	0.000	90.24	7.50	0.00	27.44	16.87
23	L23	STM 1c	Along Stream 1	8°50'20.4''N 7°54'10.7''E	6.57	**1796**	1149	28.0	36.00	**17.00**	18.051	5.744	**2.202**	0.000	0.000	**0.601**	0.000	68.66	6.00	0.00	3.36	3.88
24	L24	STM 1d	Along Stream 1	8°50'20.7''N 7°54'26.2''E	7.05	**1694**	1084	30.5	31.00	**16.00**	16.711	7.023	**1.190**	0.000	0.000	**0.614**	0.000	70.56	4.50	0.00	3.64	3.21
25	L25	STM 1e	Along Stream 1	8°50'24.8''N 7°54'40.8''E	7.03	**1558**	997	30.6	28.00	**13.00**	20.892	5.201	**1.499**	0.000	0.000	**0.497**	0.000	73.55	4.50	0.00	2.80	3.35
				Range	**5.07-8.60**	**375-7477**	**240-4785**	**27.6-37.6**	**5.10-80.00**	**2.40-21.00**	**3.54-35.71**	**3.68-53.96**	**0.00-7.26**	**0.00-0.07**	**0.00-0.22**	**0.00-1.35**	**0.00-0.09**	**28.04-289.32**	**1.50-17.49**	**0.00-4.00**	**1.96-27.44**	**1.07-16.87**
				Mean	**6.46**	**1422.04**	**910.0**	**31.66**	**26.84**	**7.33**	**11.94**	**8.61**	**1.23**	**0.01**	**0.02**	**0.54**	**0.01**	**65.14**	**3.94**	**0.56**	**4.46**	**3.97**
				WHO (2011) (mg/l)	**6.5-8.5**				**50**	**12**	**100**	**50**	**0.1**	**2.0**	**0.01**	**0.01**	**0.01**		**250**		**50**	**250**
				NIS (2007) (mg/l)	**6.5-8.5**		**500**		**200**			**0.2**	**0.3**	**1**	**3**	**0.01**	**0.01**	**150**	**250**		**50**	**100**
				SON (2007) (mg/l	**6.5-8.5**	**1000**	**500-1000**		**150-200**	-	**75-200**	**39-150**	**0.3-1.0**						**250-600**	-	**50**	**100-400**

Physical Parameters

pH: pH is the degree of acidity or alkalinity of an aqueous solution in a logarithm scale which ranges from 1 to 14. A solution with a pH value of less than 7 has more hydrogen (H^+) activity than hydroxyl (OH^-), and is considered acidic while a solution with a pH value greater than 7 has OH^- activity than H^+, and it is considered alkaline or basic. This implies that a decrease in pH will result in an increase of acidic content of a solution; this will in turn lead to an increase in the ability of the solution to dissolve rock minerals into the water and thus, an increase in the concentration of ions (Tahir, 2015).

pH ranges between 5.07 (HDW 5) to 8.60 (STM 1a). One hand dug well (HDW 4), six boreholes; BH 3, BH 4, BH 6, BH 7, BH 8 and BH 9 and four locations along stream 1 (STM 1b, STM 1c, STM 1d and STM 1e) have pH within World Health Organization (WHO 2011), Nigerian Industrial Standard (NIS, 2007) and Standard Organization of Nigeria (SON, 2007) permissible limit. Furthermore, all the three hand pumps HP 1, HP 2 and HP 3; five hand dug wells such as HDW 1, HDW 2, HDW 3, HDW 5 and HDW 6; five borehole locations, BH 1, BH 2, BH 5, BH 10 and BH 11 have pH below these recommended limit, thereby making them weakly acidic; while one location along stream 1 (STM 1a) have pH above the maximum permissible limit, making it weakly alkaline pH.

Electrical Conductivity: Electrical Conductivity (EC) of water measures the ability of water to conduct electric current. It indicates how ion-free, salt-free or impurity free a water sample is. EC is measured in micro Siemens per centimeter (μS/cm). EC measured in the study area ranges from 375 μS/cm (BH 9) to 7477 μS/cm (HDW 2). Out of the twenty-five samples tested, two hand pumps HP 1 and HP 3; one hand dug well HDW 3; eight boreholes BH 3, BH 4, BH 5, BH 6, BH 7 , BH 9 and BH 11 fall within SON (2007), maximum permissible limit; while one hand pump HP 3, five hand dug wells HDW 1, HDW 2, HDW 4, HDW 5 and HDW 6, three boreholes BH 1, BH 2 and BH 8, and the five sample locations along stream 1 (STM 1a, STM 1b, STM 1c, STM 1d and STM 1e) fall above the maximum permissible limit.

Total Dissolved Solids: Total Dissolved Solids (TDS) is a measure of salinity that has a great effect on the taste of drinking water. TDS comprises of inorganic salts (mainly sodium, potassium, calcium, magnesium, chlorides, bicarbonates and sulphates) and small amounts of organic matter that are dissolved in water; which originates from natural sources, sewage, urban runoff and industrial wastewater. The palatability of water with TDS of 500 mg/l is the maximum permissible limit (NIS, 2007); and a recommended limit of 500 mg/l and maximum permissible limit of 1500 mg/l (SON, 2007), is generally considered to be good for drinking, where at greater levels above these, the water becomes significantly and increasingly unpalatable.

The TDS from in the study area ranges from 240 mg/l (BH 9) to 4785 mg/l (HDW 2). Nine samples HP 1, HDW 3, BH 3, BH 4, BH 5, BH 6, BH 7, BH 9 and BH 10 are within the maximum permitted limit of NIS (2007), with 500 mg/l; while the remaining sixteen samples HP 2, HP 3, HDW 1, HDW 2, HDW 4, HDW 5, HDW 6, BH 1, BH 2, BH 8 and along stream 1 (STM 1a, STM 1b, STM 1c, STM 1d and STM 1e) fall above the maximum permitted limit of NIS (2007). But considering SON (2007), with recommended limit of 500 mg/l and maximum permissible limit of 1,500 mg/l, twenty-three samples are within the maximum permissible limit while two samples HDW 2 (4,785 mg/l) and STM 1b (1,541 mg/l) fall above the maximum permissible limit and therefore not considered safe for consumption.

Temperature: Temperature ranges from 27.6 °C (HDW 1) to 37.6 °C (BH 8). Most of the water samples have temperatures typical of ambient condition. However, three boreholes BH 8 (37.6 °C), BH 10 (36.4 °C) and BH 11 (36.6 °C) show slightly high temperatures which could be due to the inferred depth of groundwater potential from the hybrid Wenner-Schlumberger array data obtained from those areas (Mamza, 2018).

Chemical Parameters

Sodium (Na^+): Sodium, a highly soluble element that is present in surface and groundwater, can be sourced from dissolution of sodium bearing rocks, irrigation and leached through soils that are rich in sodium or groundwater pollution by sewage effuent (Hassan, 2009). The concentration of sodium from the study area ranges from 5.10 mg/l (BH 9) to 80.00 mg/l (HDW 2). Twenty-three water samples fall within the WHO Standard (2011) with permissible limit of 50 mg/l; while two samples at HDW 2 and STM 1b fall above the maximum permissible limit for drinking water. Whereas all twenty-five-sampled water fall within the maximum permissible limits; and are safe for drinking and other purposes when compared with NIS (2007) and SON (2007) whose maximum permissible limit and recommended-maximum permissible limit is 200 mg/l and 150-200 mg/l respectively. The contour map of Sodium concentration reveals its distribution in the study area, where it is generally less than 30 mg/l. Areas with low-moderate concentration of 5-30 mg/l are depicted by the light to dark brown colour towards the north, northcentral, northwest, west and south of the study area; while the white to blue colour with 35-80 mg/l towards the northeast, east, southeast and southwest depict high concentration (Figure 2).

Potassium (K^+): Potassium occurs naturally in rock and soil minerals. High concentration levels in surface water could indicate the application of fertilizer (composed mostly of potassium) from surrounding farmlands (Hassan, 2009). The concentration of potassium within the study area ranges from 2.4 mg/l (HP 1) to 21.00 mg/l (STM 1b). From the water samples analyzed, eighteen samples fall within the WHO (2011) maximum permissible limit of 12 mg/l; while the remaining seven samples at HDW 1, HDW 2 and along stream 1 channel STM 1a, STM 1b, STM 1c, STM 1d and STM 1e fall above the maximum permissible limit; and therefore, not safe for consumption (Table 1). High dosage of potassium chloride can interfere with nerve impulses, thereby affecting almost all body functions including the heart. Excess potassium in water may be removed by reverse osmosis (Ahmed *et al.,* 2016).

The contour map of Potassium concentration (Figure 3), reveals the Potassium distribution in the study area, where it is generally less than 7 mg/l. Areas with low-moderate Potassium concentration of 2-10 mg/l, with light to dark brown colour are towards the north, northcentral,

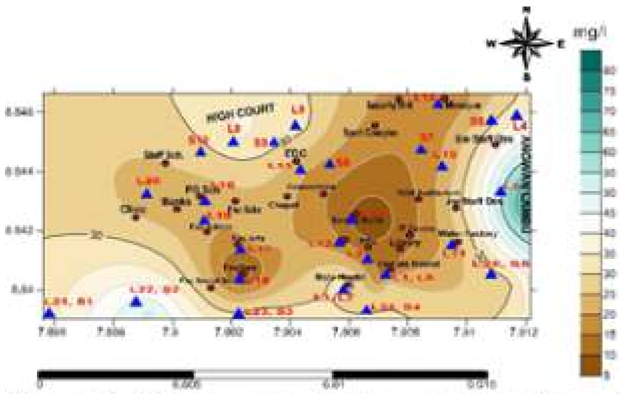

Figure 2: Contour map showing concentration of Sodium (Na^+)

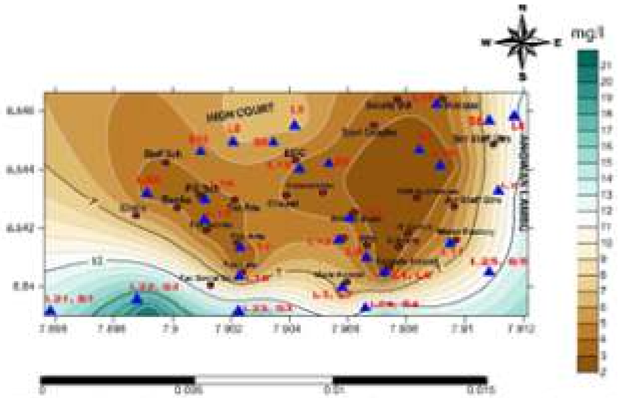

Figure 3: Contour map showing concentration of Potassium (K^+)

northwest and west of the study area; while the white to blue colour with 11-21 mg/l towards the southwest, south, southeast, east and northeast have high Potassium concentration.

Calcium (Ca^{2+}): Calcium occurs naturally in rocks where it is dissolved and carried into surface and groundwater. Calcium and magnesium are the major cause of water hardness when derived from high weathering/dissolution of calcium containing rocks or from limestone and dolomite; and also, acts as a pH stabilizer due to their buffering qualities (Ahmed *et al.,* 2016). The concentration of calcium within the study area ranges from 3.54 mg/l (BH 5) to 35.71 mg/l (HDW 1). WHO Standard (2011) has 100 mg/l as its maximum permissible limit, while SON (2007) gave a recommended and maximum permissible limit of 75-200 mg/l. This indicates that calcium concentration in all the twenty-five-sampled water are within WHO (2011) and SON (2007) maximum permissible limits; and are safe for drinking and other uses (Table 1).

The contour map of Calcium concentration (Figure 4), reveals its distribution in the study area, where it is generally less than 12 mg/l. Areas with low-moderate concentration values of 2-16 mg/l are depicted with light to dark blue colour towards the north-northeast, northcentral, northwest, west, southwest and south of the study areawhile the yellow to red colour with 18-36 mg/l towards the north, northeast, east, southeast and south-southwest depict high concentration levels.

Magnesium (Mg^{2+}): The concentration of magnesium within the study area rangesfrom 3.68 mg/l (BH 4) to 53.96 mg/l

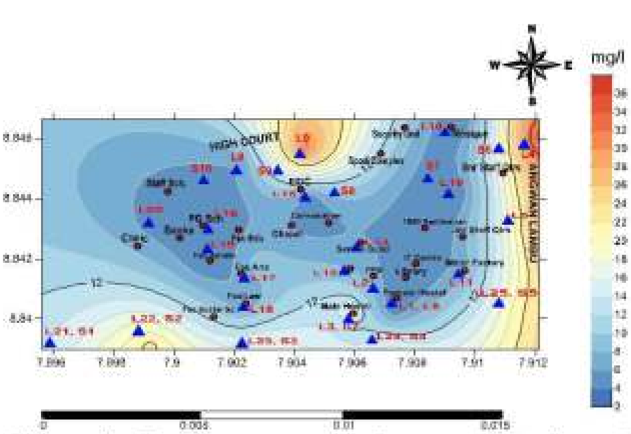

Figure 4: Contour map showing concentration of Calcium (Ca^{2+})

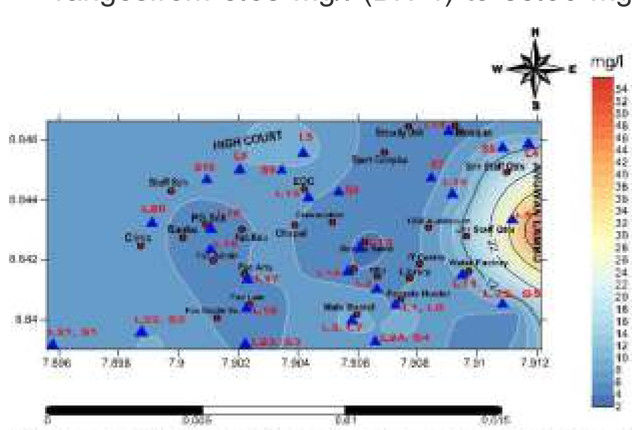

Figure 5: Contour Map showing concentration of Magnesium (Mg^{2+})

(HDW2). WHO (2011) and NIS (2007), has 50mg/l and 0.2 mg/l respectively as their maximum permissible limit, while SON (2007) gave a recommended and maximum permissible limit of 39-150 mg/l. This indicates that magnesium concentration in twenty-four sampled water are within WHO (2011) maximum permissible limits except for one hand dug well, at HDW 2 (53.96 mg/l); all twenty-five-sampled water fall above NIS (2007) maximum permissible limit; while all twenty-five sampled water are within SON (2007), recommended - maximum permissible limits; and are safe for drinking and other uses (Table 1).

The contour map of Magnesium Concentration (Figure 5), reveals its distribution in the study area, where it is generally less than 12 mg/l. Areas with low - moderate Magnesium concentration of 2-24 mg/l with light to dark blue colour, covering above 90 % are towards the north, northwest, northeast, southeast, south, southwest and northcentral of the study area; while the yellow to red colour with 26-54 mg/l towards east have high Magnesium concentration.

Iron (Fe): Iron is one of the most abundant metal found on the Earth's crust. The concentration of ferrous irons (Fe^{2+}) in groundwater does not cause any discolouration but on exposure to the atmosphere, it oxides into ferric iron (Fe^{3+}) which gives rise to reddish-brown colouration of the water (Tahir, 2015; Oleka & Olalekan 2011). Odour, taste and staining of laundry/plumbing fixtures sets in when iron concentration exceeds NIS (2007), maximum permissible limit of 0.3 mg/l. WHO (2011) and SON (2007), have a maximum permissible limit and recommended-maximum permissible limits of 0.1 mg/l and 0.3-1.0 mg/l respectively (Table 1).

The concentration of Iron from the study; area ranges from 0.00 mg/l (HDW 2, HDW 6, BH 1, BH 4, BH 5, BH 7 and BH 8) to 7.26 mg/l (HP 1). From the water samples analyzed, thirteen samples which comprises of four hand dug wells at HDW 2, HDW 3, HDW 5 and HDW 6; nine borehole at BH 1, BH 4, BH 5, BH 6, BH 7), BH 8, BH 9, BH 10 and BH 11, are within WHO (2011), maximum permissible limit of 0.1 mg/l; while all the three hand pumps at HP1, HP 2 and HP 3, two hand dug well at HDW 1 and HDW 4, two boreholes at BH 2 and BH 3 and the five sampled locations along stream 1 channel (STM 1a, STM 1b, STM 1c, STM 1d and STM 1e), fall above WHO (2011), maximum permissible limit for drinking water. When compared with NIS (2007), with 0.3 mg/l and SON (2007), with 0.3-1.0 mg/l, sixteen water samples comprising of five hand dug wells at HDW 2, HDW 3, HDW 4, HDW 5 and HDW 6 and all the eleven boreholes (BH 1-BH 11), are within NIS (2007) and SON (2007), maximum permissible limit; while all the three hand pumps at HP 1, HP 2 and HP 3, one hand dug well at HDW 1and the five sampled locations long stream 1 channel (STM 1a, STM 1b, STM 1c, STM 1d and STM 1el), fall above NIS (2007) and SON (2007) maximum permissible limit for drinking water.

Copper (Cu): The presence of copper in drinking water results from corrosive action of copper pipes on water. Concentration of copper above 5 mg/l can lead to colouration and an undesirably bitter taste to the water, thereby rendering such water unfit for drinking (Tahir, 2015).

The concentration of copper from the study area ranges from 0.00 mg/l (HDW 1, BH 6, BH 7, BH 9, BH 10 and BH 11; and the five sampled locations long stream 1 channel, STM 1a, STM 1b, STM 1c, STM 1d and STM 1e) to 0.07 mg/l (HP1). This indicates that copper concentration in all the twenty-five-sampled water are within WHO (2011) and NIS (2007), maximum permissible limits of 2.0 mg/l and 1.0 mg/l respectively for drinking water; and are safe for drinking and other use.

Zinc (Zn): The concentration of zinc in the study area ranges from 0.00 mg/l (HDW 1-HDW 6, BH 1, BH 2, BH 4-BH 10 and the five sampled locations along stream 1 channel, STM 1a, STM 1b, STM 1c, STM 1d and STM 1e) to 0.22 mg/l (BH 11) (Table 4.5). WHO (2011) and NIS (2007), has 0.01 mg/l and 3 mg/l respectively as its maximum permissible limit while SON (2007), did not record any value for zinc concentration. From the water samples analyzed, two samples which comprises of HP 3 and BH 3 are within WHO (2011), maximum permissible limit for drinking water; while three samples which comprises of HP 1, HP 2 and BH 11, fall above WHO (2011), maximum permissible limit. When compared with NIS (2007), with maximum permissible limit of 3 mg/l, all the twenty-five-sampled water are within the maximum permissible limits; and are safe for drinking and other uses.

Arsenic (As): The concentration of arsenic in the study area ranges from 0.00 mg/l (HP 1, HP 2, HDW 1, HDW 4, and STM 1b) to 1.35 mg/l (BH 11). WHO (2011)and NIS (2007), both have 0.01 mg/l as maximum permissible limit. This indicates that arsenic concentration in five sampled water with 0.00 mg/l (HP 1, HP 2, HDW 1, HDW 4 and STM 1b) are within WHO (2011) and NIS (2007), maximum permissible limit; while the remaining twenty, fall above WHO (2011) and NIS (2007), maximum permissible limit for drinking water; and are unsafe for drinking.

Lead (Pb): Lead hardly dissolves from its natural source for it to be present in surface or ground water except where the household plumbing system such as pipes, fittings contain lead in them (Tahir, 2015). In such scenario, the concentration of lead in water will also depend on the pH, temperature, duration and how soft/hard the water is; because the more acidic and soft the water is over a period of time, the more plumb-solvent the plumbing system will be. Lead is toxic to the nervous system, leading to neurological and behavioural defects (Tahir, 2015). The concentration of lead ranges from 0.00 mg/l (HDW 2-HDW 6, BH 1-BH 11 and the five sampled locations long stream 1 channel, STM 1a, STM 1b, STM 1c, STM 1d and STM 1e) to 0.09 mg/l (HP 1). WHO (2011) and NIS (2007), both have 0.01 mg/l as maximum permissible limit. This indicates that lead concentration at HDW 1 (0.01 mg/l) and twenty-one sampled water at HDW 2-HDW 6, BH 1-BH 11 and the five sampled locations long stream 1 channel (STM 1a, STM 1b, STM 1c, STM 1d and STM 1e), (0.00 mg/l) are within WHO (2011) and NIS (2007), maximum permissible limit; while the remaining three samples comprising of the three hand pumps, HP 1, HP 2 and HP 3, fall above WHO (2011) and NIS (2007), maximum permissible limit for drinking water, which sources may be from the plumbing fixtures of those hand pumps and therefore are unsafe for drinking. This is an indication that Pb might have leached from the fittings and plumbing system of the installed hand pumps, to correlate with work of (Tahir, 2015).

Chloride (Cl^-): The taste threshold of chloride anion depends on the cation that is gets associated/bonded with; such as sodium, potassium or calcium. Concentrations above 250 mg/l are likely to be detected by taste (WHO, 2011 and SON, 2007). The concentration of chloride ranges from 1.50 mg/l (HP 1, HP 2, HP 3, BH 4, BH 6 and BH 9) to 17.49 mg/l (HDW 2). This indicates that chloride concentration in all the twenty-five sampled water are within WHO (2011) and NIS (2007), maximum permissible limits and SON (2007), recommended limit of 250 mg/l for drinking water; and are safe for drinking and other uses (Table 1).The contour map of Chloride concentration (Figure 6), reveals the Chloride distribution in the study area, where it is generally less than 6 mg/l. Areas with low-moderate Chloride concentration of 1-10 mg/l with dark to light purple colour, covering above 90 % are towards the north, northwest, northeast, southeast, south, southwest and north-central of the study area; while the light to dark brown colour with 11-18 mg/l towards the east have high Chloride concentration in the study area.

Bicarbonate (HCO_3^-): The concentration of bicarbonate ranges from 0.00 mg/l (HDW 2, HDW 3, HDW 5, HDW 6, BH 1, BH 2, BH 3, BH 4, BH 5, BH 7, BH 9, BH 10, BH 11) and the five sampled locations along stream 1 channel (STM 1a, STM 1b, STM 1c, STM 1d and STM 1e) to 4.00 mg/l (BH 6), (Table 1). This indicates that bicarbonate concentration in all the twenty-five-sampled water are within WHO (2006), maximum permissible limit of 200 mg/l for drinking water; and are safe for drinking and other uses. The contour map of Bicarbonate concentration (Figure 7), reveals the Bicarbonate distribution in the study area, where it is generally less than 0.4 mg/l. Areas with low-moderate Bicarbonate concentration of -0.6-1.8 mg/l with dark to light purple colour, covering above 90 % are towards the north, northwest, northeast, east, southeast, south, southwest and west of the study area; while the light to dark brown colour with 2-4 mg/l towards northcentral have high Bicarbonate concentration in the study area.

Nitrate (NO_3^-): Nitrates are mainly used in inorganic fertilizers, which imply that nitrate concentration will be negligible in surface and ground water except in situations where leaching or run off occurs from agricultural land or contamination from animal or human wastes due to oxidation of ammonia, then, such will warrant high

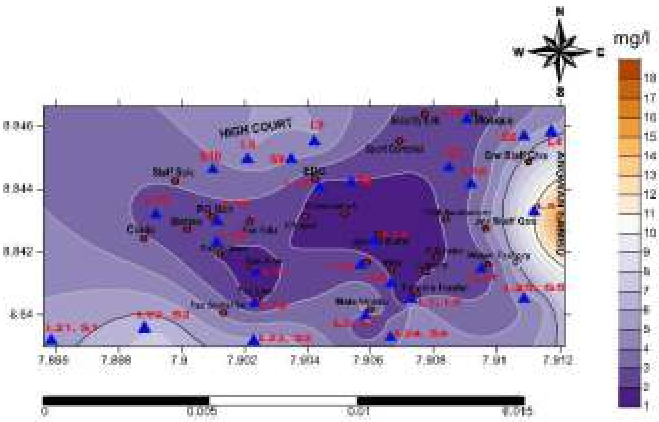

Figure 6: Contour map showing concentration of Chloride (Cl-)

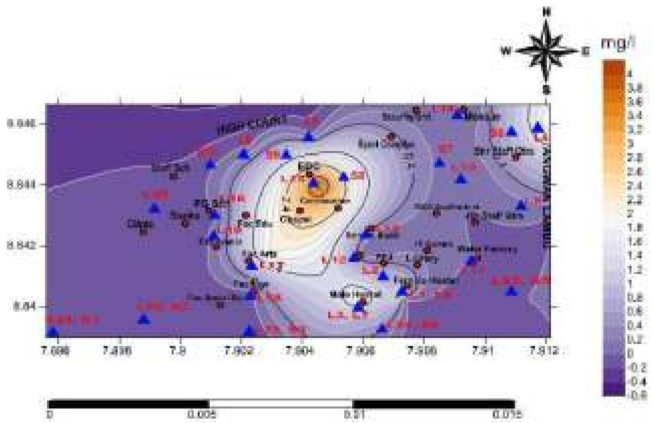

Figure 7: Contour Map showing concentration of Bicarbonate (HCO_3^-)

concentration of nitrate (Obrike *et al.,* 2011; Tahir, 2015).

The concentration of nitrate ranges from 1.96 mg/l (BH 4 and BH 8) to 27.44 mg/l (STM 1b) due to agricultural activities going on very close to that sample location. This indicates that nitrate concentration in all the twenty-five-sampled water are within WHO (2011), NIS (2007) and SON (2007), maximum permissible limit of 50 mg/l for drinking water; and are safe for drinking and other uses. The contour map of Nitrate concentration (Figure 8), reveals the Nitrate distribution in the study area, where it is generally less than 6 mg/l. Areas with low-moderate Nitrate concentration of 1-11 mg/l with dark to light blue colour, covering above 85 % are towards the north, northwest, northeast, northcentral, east, southeast, south, and west of the study area; while the yellow to red colour with 12-27 mg/l towards southwest have high Nitrate concentration in the study area.

Sulphate (SO_4^{2-}): Sulphate in water is likely from decaying organic matter, which means that sulphate is an indicator of organic pollution in water especially in hand dug well or surface water bodies such as along the stream channel (Brian, 2010; Tahir, 2015). The concentration of Sulphate ranges from 1.07 mg/l (BH 6) to 16.87 mg/l (STM 1b). This indicates that sulphate concentration in all the twenty-five sampled water are within WHO (2011) and NIS (2007), maximum permissible limit and

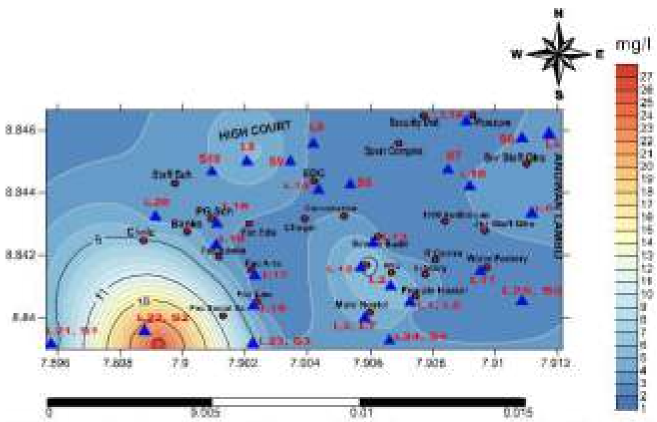

Figure 8: Contour Map showing concentration of Nitrate (NO_3^{2-})

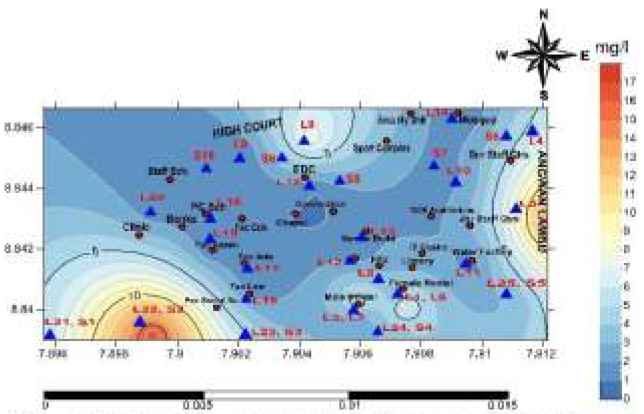

Figure 9: Contour map showing concentration of Sulphate (SO_4^{2-})

SON (2007), recommended limit of 250 mg/l, 100 mg/l and 100 mg/l respectively for drinking water; and are safe for drinking and other uses (Table 1) . The contour map of Sulphate concentration (Figure 9), revealed that the sulphate distribution in the study area is generally less than 5 mg/l. Areas with low-moderate sulphate concentration of 0-7 mg/l with dark to light blue colour, covering above 85 % are towards the north, northwest, northeast, northcentral, southeast, south, and west of the study area; while the yellow to red colour with 8-17 mg/l towards east and southwest have high Sulphate concentration in the study area. The total hardness (TH) ranges from 28.04 mg/l (BH 5) to 289.32 mg/l (HDW 2), with a mean value of 65.14 mg/l. NIS (2007), has a permissible limit of 150 mg/l, which implies that twenty-four (24) water samples are within the permissible limit except HDW 2 with 289.32 mg/l. Based on Hem (1970) water hardness classification, sixty percent (60 %) of the water are soft, thirty-two percent (32 %) of the water are moderately hard, four percent (4 %) are hard and the remaining four percent (4 %) are very hard (Table 2).The total hardness in the water samples were calculated using Todd (1980) equation:

$$TH\ (CaCO3)\ (mg/l) = 2.5(Ca^{2+}) + 4.1(Mg^{2+}) \ ...1$$

Table 2. Percentage of hardness in the study area (After Hem, 1970)

Hardness (Ca + MgCO3) mg/l	Water classification	Result of Study (%)
0 – 60	Soft	60
61 – 120	Moderately hard	32
121 – 180	Hard	4
➢ 180	Very hard	4

Water Facies

The study area revealed thirteen (13) water facies, which include Mg-Na-Ca-SO_4 (HP 1), Mg-Na-Ca-Cl (HDW 2), Na-Mg-Ca-SO_4 (HP 2 and HP 3), Na-Mg-Ca-Cl (HDW 5, BH 1, BH 2, BH 5, BH 7, BH 8, BH 10 and BH 11), Na-Mg-Ca-HCO_3 (BH 6), Ca-Na-Mg-SO_4 (HDW 6), Ca-Na-Mg-Cl (HDW 1), Na-Mg-SO_4 (HDW 3), Na-Ca-Mg-SO_4 (STM 1b), Na-Ca-Mg-Cl (HDW 4 and BH 3), Ca-Mg-Na-SO_4 (BH 4), Mg-Ca-Na-Cl (BH 9), Na-Ca-Mg-K-Cl (STM 1a, STM 1c-STM 1e).

From the 13 water facie types from the study area, four (4) major water types were derived from the 25 water locations. Mg-Na-Ca-SO_4, Na-Mg-Ca-HCO_3, Ca-Na-Mg-SO_4, Na-Mg-Ca-SO_4, Na-Mg-SO_4, Na-Ca-Mg-SO_4, Ca-Mg-Na-SO_4 are the mixed water type in eight locations, Mg-Na-Ca-Cl, Mg-Ca-Na-Cl are the Magnesium Chloride water type in two locations, Na-Ca-Mg-Cl, Na-Ca-Mg-K-Cl, Na-Mg-Ca-Cl are the Sodium Chloride water type in fourteen locations and Ca-Na-Mg-Cl is the Calcium Chloride water type in one location. Furthermore, all the 13 water facie types belong to the alkaline earth water due to the presence of Na in them, with higher alkaline proportion, which correlates (Anudu *et al.*, 2011a & 2011b), (Figure 10).

Piper trilinear diagram

In plotting the Piper (1944), trilinear diagram, the major ion concentrations in milli- equivalent per litre (meq/l) were calculated from the obtained milli-gram per litre (mg/l); where the cations and anions in meq/l are being expressed in percentages. The cations and anions were plotted in the lower triangles, and the resulting two points are extended into the central field (diamond shaped) to represent the total ion concentration, which gave rise to the 13 water facie types in the study area and all fall within the alkaline earth water, which correlates (Anudu *et al.,* 2011a & 2011b), (Figure 10).

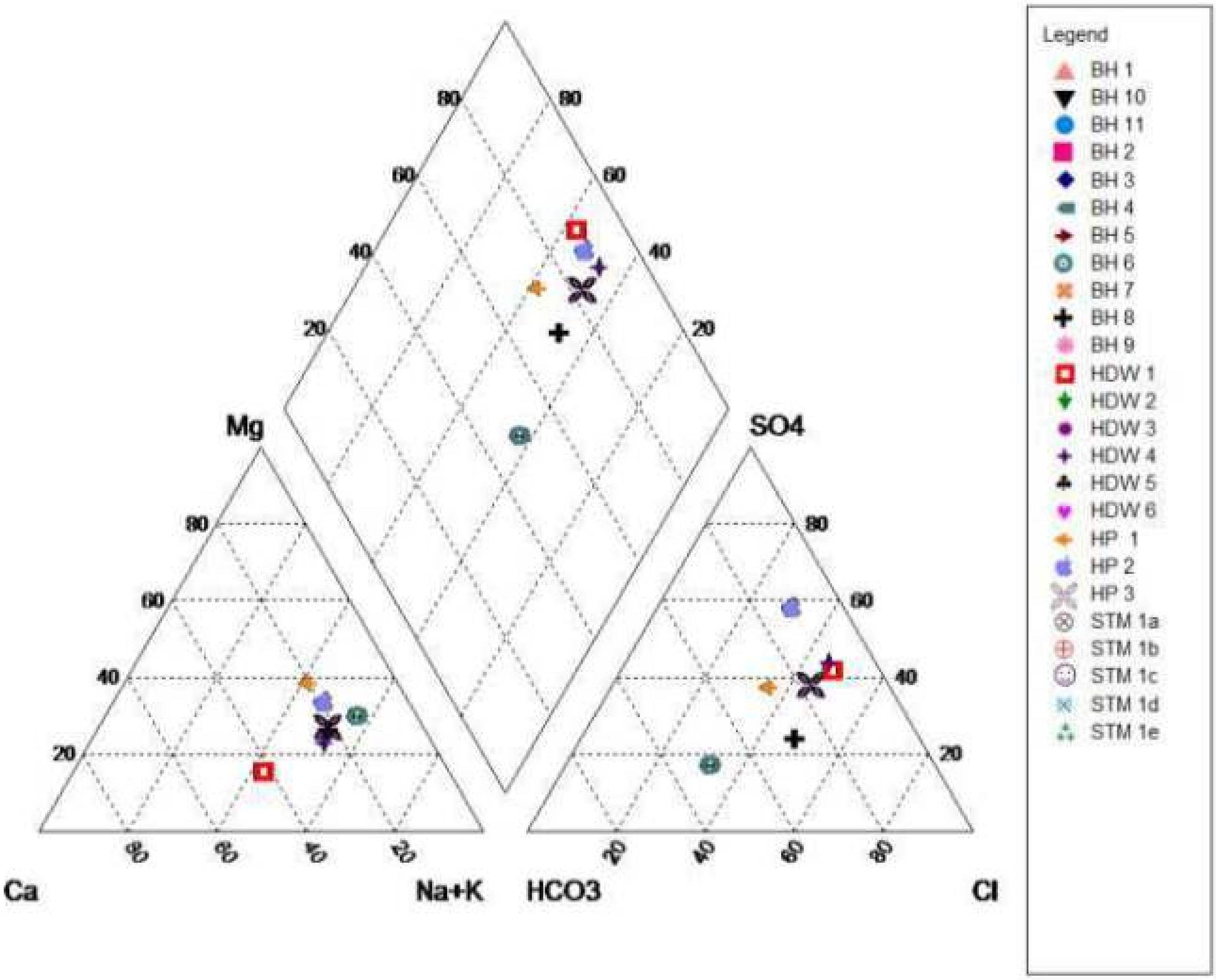

Figure 10: Piper plot showing concentration of major ions and water facies in the study area

Schoeller plot

The Schoeller plot was plotted using major ions concentration in meq/l. From this research, it shows that Ca and Na are the major cations, while Cl and SO_4 are the major anions. An offset of Mg can be observed on HDW 2, to have high concentration above other water locations. But in the absence of that, Na has the highest concentration ranging from 0.2-<3.0 meq/l, followed by Ca, which ranges from >0.2-2.0 meq/l, Mg ranges from <0.2-0.9 meq/l, Cl ranges from 0.04-0.6 meq/l, SO_4 ranges from 0.02-0.5 meq/l and HCO_3 ranges from >0.02-0.08 meq/l. (Figure 11).

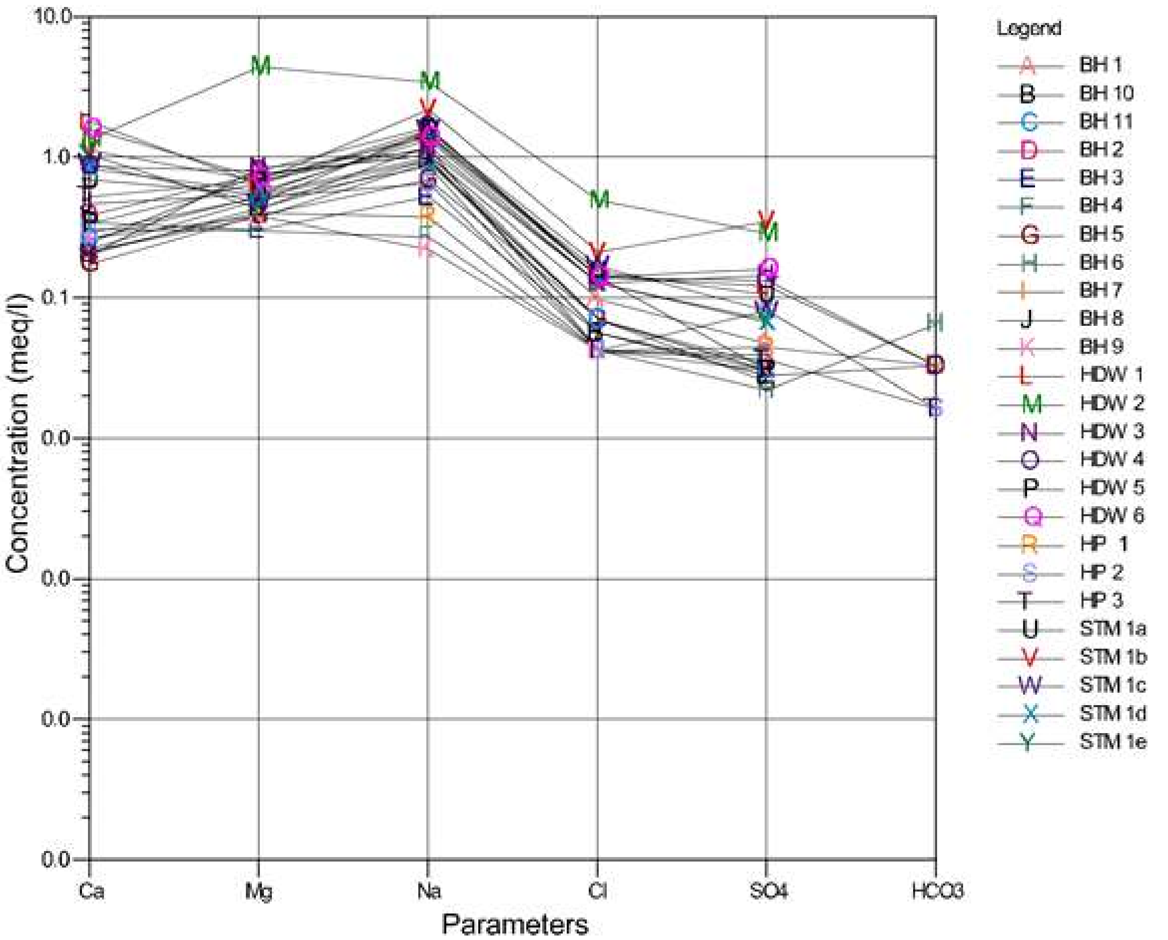

Figure 11: Schoeller plot showing concentration of major ions in the study area

Wilcox plot

A Wilcox plot can be used to determine how variable the water is for irrigation purpose. The major criteria for any water to be suitable for irrigation purposes are conductivity (salinity) and Sodium Absorption Ratio (SAR). The conductivity concentration of water for most agricultural purposes should not exceed 3000 µS/cm (Hamill & Bell, 1986). From this research, conductivity ranges between 375-7477 µS/cm with high values of 2003 µS/cm, 2262 µS/cm and 2408 µS/cm at HDW 6, HDW 1 and STM 1b respectively. Using Wilcox diagram (Figure

12), we can see the suitability of the analysed water for most crops. All the water belongs to good-fair water class with SAR of S1 (low) and salinity hazard falling within C2 (medium),

C3 (high) and C4 (very high) except HDW 2 with 7477 μS/cm, which was not reflected on the Wilcox diagram because the salinity hazard exceeded C4. The following sections are represented on the Wilcox plot:
C1: low (0-249) – Excellent for irrigation
C2: Medium (250-749) – Good for irrigation
C3: High (750-2249) – moderately good for irrigation
C4: Very high (2250-5000) – Fair for irrigation

This implies that the salinity hazard of the samples from the study area can be classified as follows:

1. C2: BH 9, BH 3, BH 4, BH 5, BH 10, BH 6, BH 7 and HP 1 are considered good for irrigation.
2. C3: HDW 3, BH 11, HP 2, BH 1, BH 8,BH 2, HP 3, HDW 4, HDW 5, HDW 6, STM 1a, STM 1c, STM 1d and STM 1e are considered moderately good for irrigation.
3. C4 : HDW 1 and STM 1 b are considered fair for irrigation (Figure 12).

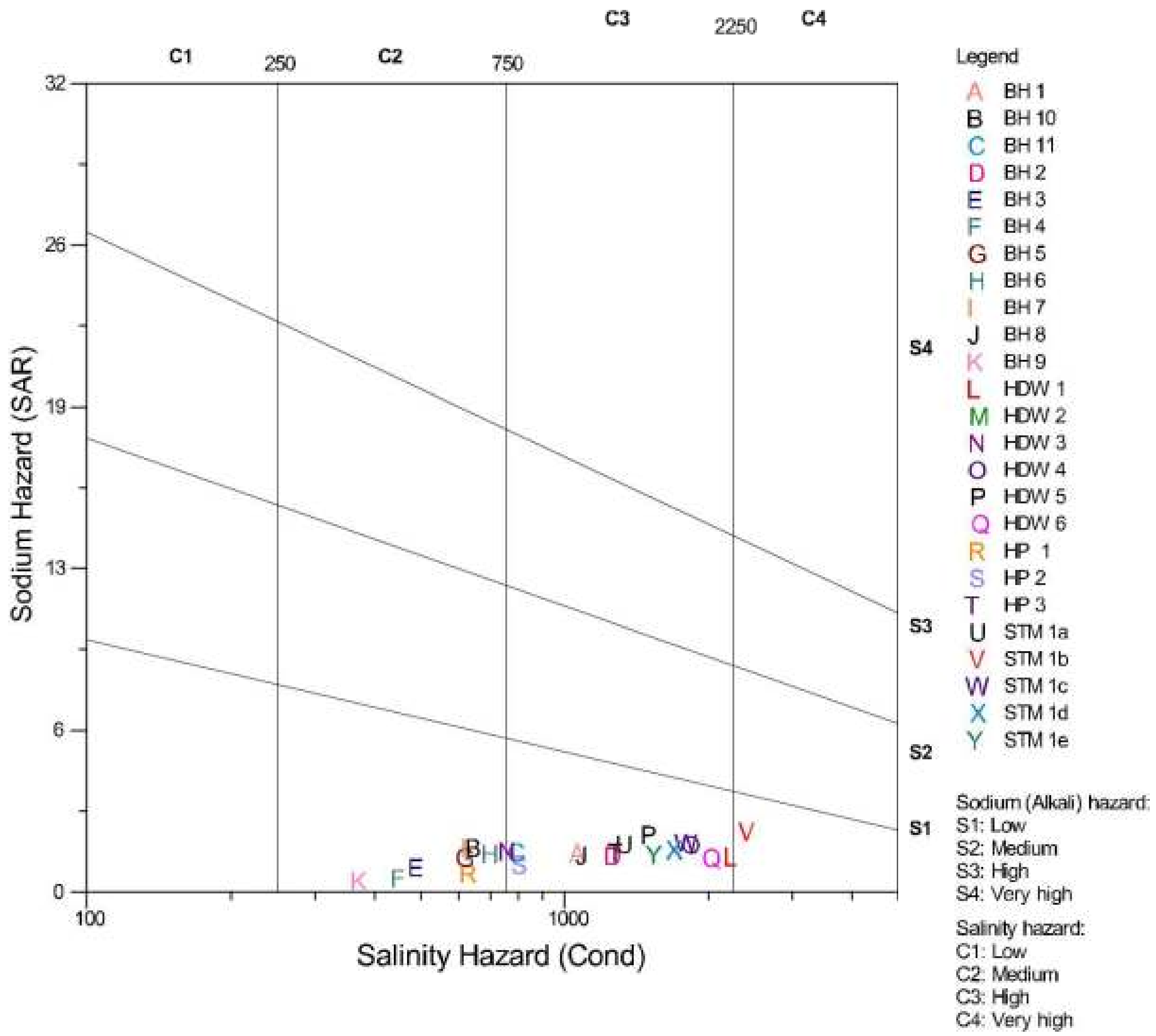

Figure 12: Wilcox Diagram showing suitability of water for irrigation in the study area

CONCLUSION

This study reveals the hydro geochemistry and quality of surface and groundwater from hand pumps, hand-dug wells, boreholes and along stream channels located within Nasarawa State University Keffi, main campus. Results show slightly acidic to slightly alkaline water, soft to very hard water. Na^+, K^+ and Mg^{2+} were above (WHO 2011; NIS 2007) recommended standard for drinking water in some locations, making them the most dissolved cations in the groundwater which added greatly to the TDS. Ca^{2+}, Cu, Cl^-, NO_3^- and SO_4^{2-} fall within (WHO 2011; NIS 2007; SON 2007) recommended standard for drinking water. These anions (nitrate and sulphate) pose no threat during this research but could lead to certain health effects in the future if indiscriminate use of fertilizers or pesticides for agricultural purposes continues in the study area, due to bio-magnification of these ions. The alkaline earth water was deduced from the 13 water facies, to result from the concentration of cations being geogenic in origin, due to the interaction between water and rock weathering of ions into the water. All the water belongs to good-fair water class for irrigation purpose. High concentration of trace elements; Fe, Zn, As and Pb in some water sample locations has made such water to be objectionable for drinking, although can be suitable for drinking when treated using precipitation and filtration methods by the addition of coagulants and the use of reverse osmosis. The dominance of cations and anions in the water is in an order of $Na^+ > Ca^{2+} > Mg^{2+} > K > NO_3^- > SO_4^{2-} > Cl^- > Fe > HCO_3^- > As > Zn > Pb > Cu$.

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