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Groundwater Hydrochemical Characterization in Urban Areas of Southwestern Sokoto Basin Nigeria

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Abstract

Over exploitation of groundwater aquifers and improper sewage disposal in addition to accidental discharge pose risks to groundwater in urban environments. Groundwater under Basement Complex areas of southwestern Sokoto Basin (SWSB) was evaluated to determine its suitability for drinking and agricultural uses. Water samples were drawn from four urban centres – Fakai, Koko, Yauri and Zuru. Results showed that groundwater is slightly acidic to alkaline in nature. The outstanding cations and anions are Mg^{2+}, Fe^{3+}, Zn^{2+}, PO_4^{3-} and SO_4^{2-}. These parameters occur at high concentrations above World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ) reference guidelines. Water samples having higher TDS concentrations also have high Mg^{2+} and SO_4^{2-} concentrations. Groundwater classification showed groundwater in SWSB fall in the category of Ca- Mg-HCO_3, and Mixed Mg-Na-K water types. Most of the groundwater sources fall in low salinity-low sodium class, suggesting water of excellent quality for irrigation use. All the analysed water samples have sodium percent less than 20 and 62.5% have magnesium hazard less than 50. Kelly's index is less than 1 in all the analysed water samples. Although, there is increased urbanization in SWSB, urbanization had negligible impact on groundwater quality. However, results may differ with both the Geography of the Sokoto Basin and land use, particularly in the north (Cretaceous and Tertiary Sediments). Studies evaluating groundwater in Sokoto Basin over wider spatial and temporal scales are therefore recommended.

Keywords: Molar ratio; Scholler index; Sodium adsorption ratio; Sodium hazard; Magnesium hazard, Molar ratio

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Introduction

In Sub-Saharan Africa (SSA), there is increased groundwater extraction driven by urbanization and irrigated agriculture [1]. These coupled with environmental degradation and poor waste disposal pose serious threats to groundwater [2]. According to [3]' at least ¼ urban dwellers in developing countries do not have access to water of excellent quality and improved sanitation.

Similarly, about 90% of municipal wastewater is discharged untreated through drainages and unprotected watercourses, consequently pollute surface and groundwater. Although, the global water crisis tends to be viewed as a water shortages question in SSA countries [4], the fact that some five million people (including children and infants) die annually from water-borne diseases in these countries is sufficient to rally both local and global action about improved sanitation and water supply. Water supply situation in Nigeria is characteristic of underdeveloped regions of the world, reflecting socio-economic and physical factors as well as the level of technological advancement [5]. While not all developing countries and/or regions are facing a crisis of water shortage, all have to a greater or lesser extent some serious problems associated with degraded groundwater quality [4].

The current state of poor water supply is expected to persist because investments required to improved urban water supply are generally very large compared to the budget capabilities of developing economies [1]. While a lot of improvements were recorded by rising the number of urban dwellers having improved water supply, groundwater is threatened by increasing urbanization, poor waste disposal and over exploitation of aquifers, to meet domestic, industrial and agricultural demands. It is an unfortunate fact that the rate of increase in nature and complexity of water supply problems in developing countries like Nigeria, exceed the rate of capacity development for a longer time to come. Of all the environmental problems that Nigeria face, the lack of adequate

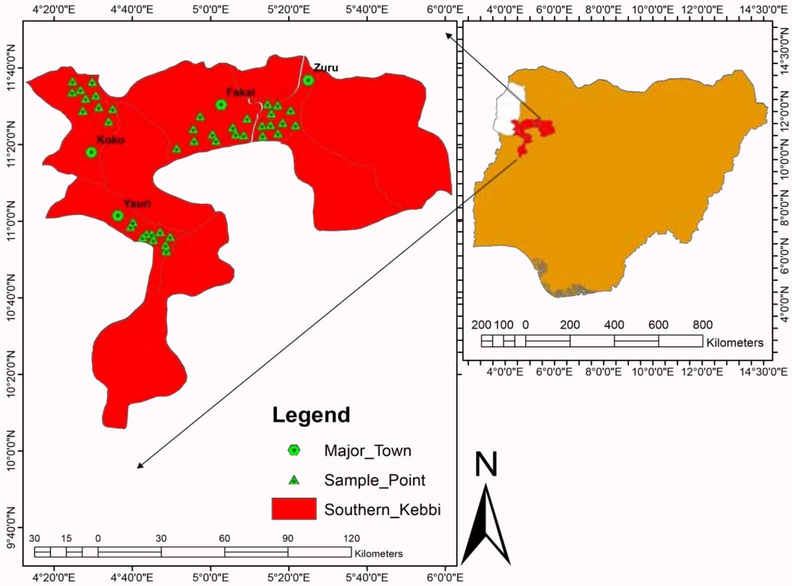

Figure 1: The Study area.

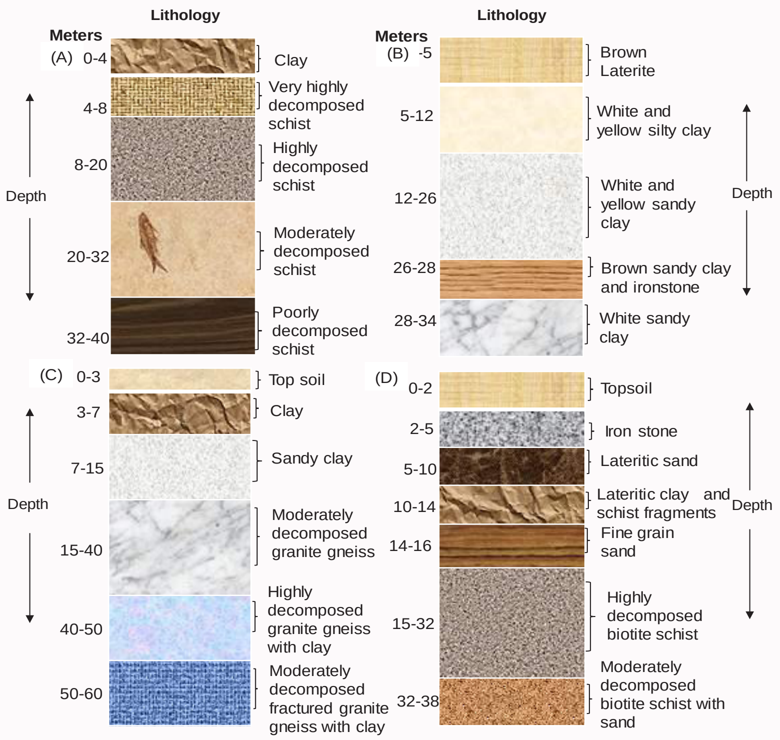

Figure 2: Lithologic section of boreholes in southwestern Sokoto Basin. (A) Fakai, (B) Koko-besse, (C) Yauri and (D) Zuru.

and stable water supply of excellent quality in urban areas is probably the most serious [6]. In 2000, about 1.2 billion or 19 percent of global population live without access to safe drinking water. The SSA ranked second after East Asia and Pacific [7]. This has attracted overwhelming groundwater development in many underdeveloped regions of the world – [8-12] - bordering on the fact that, potable water supply is inadequate and inaccessible by many urban dwellers in developing countries.

Fundamental to the study of groundwater is the Geology of the environment. Because it controls both groundwater quantity and perhaps its quality. The nature and the properties of the underlying rock formations, aquifer specific yield and retention, in addition to the chemical composition of groundwater are all products of the Geology of the environment [13]. The composition of groundwater is therefore, a function of both natural hydrogeochemical processes as well as anthropogenic activities, and that the type, extent and duration of anthropogenic activities may have impact on groundwater quality.

Since groundwater composition is a product of Geology and human activities, many studies including [14-17], have examined groundwater in relation to Geology in urban environments. Findings showed some anthropogenic inputs through variations in TDS, Cl^-, SO_4^{2-}, NO_3^- and Na^+ [18]. While groundwater in sedimentary sections of the Sokoto Basin was intensively studied, we have poor understanding of its physical and chemical properties under Basement Complex areas in SWSB. To highlight this problem, we looked at the major urban areas of southwestern Sokoto Basin (SWSB). Groundwater is generally available in small quantities obtained from fractures and from worn rock (regolith) just below the surface [19]. Except for high iron content, groundwater in SWSB is suitable for most uses. While groundwater is available in small quantities in SWSB, we have poor understanding of impacts of urbanization on groundwater quality in this groundwater poor environment. This study aimed at evaluating groundwater suitability for drinking and irrigation uses.

The Study Area

Location and climate

The study area is in the southwestern Sokoto Basin, North-western Nigeria. It is situated between latitudes 10^0 40' and 11^0 40'N and longitudes 4^o 20'and 5^o 40'E. It occupies a total land area of about 35,516km^2, covering Fakai, Koko-besse, Yauri and Zuru local government areas in Kebbi State (Figure 1). The climate is hot, semi-arid tropical (AW) in Koppen's classification [12]. It is dominated by two contrasting wind systems: The Tropical Maritime and Tropical Continental Air Masses [20]. Owing to the position of the study area in the extreme North-western Nigeria and over 1200 km away from the sea, SWSB remains largely dry for most periods of the year [21]. The mean maximum temperature reaches peak in April (over 40^{o}C). Mean minimum temperature is lowest in December (less than 25^{o}C). Analysis of soil temperature suggests an isohyperthermic soil temperature regime [21]. Relative humidity in the study area reaches peak in August (over 90%) and is lowest in December ranging from 10 – 30% [22]. Annual rainfall is also highly variable and decreases from south to north. It ranges from 500mm in the northern parts, to over 1200mm in the south. Most of precipitation falls in July, August and September [12].

Hydrogeological setting

Southwestern Sokoto Basin is underlain by Crystalline Basement Complex Rocks [19]. The topography comprises mainly of Basement rock outcrops varying from 250 to over 400 metres above sea level [22]. Geological work in Sokoto Basin was first carried out in late 1800s and investigations focused on reporting of fossil localities. Not until 1948, when the first stratigraphic study was conducted by Jones. Groundwater resources of Sokoto Basin were first described by [23]. High NO_3^- concentration ranging from 20 to 100 mg/l was reported from shallow aquifers around Sokoto town [24]. It is hard with TDS concentration ranging from 130 and 2,340 mg/l [25]. Sodium and nitrate concentrations vary widely and at some locations, exceed WHO reference limits [26]. It is predominantly of two facies; - calcium– magnesium–bicarbonate and calcium–magnesium–sulphate–chloride [26]. Boreholes yields are generally low. Boreholes tapping weathered granite and gneiss generally produce the highest yield of 3100 gallon per hour (gph). Mean borehole yield in SWSB is about 1400gph. However, there are high drawdowns (63 meters) during pumping [19]. Figure 2, summarized the lithology of SWSB. The swales in the weathered rock sections which lies between fresh rock outcrops are the most suitable sites for borehole construction [19].

Materials and Methods

Field sampling and laboratory analysis

Groundwater samples were drawn from four urban centres - Fakai, Koko-besse, Yauri and Zuru respectively. Groundwater samples were drawn from boreholes which were constructed by Kebbi State Government. Because these are boreholes expected to meet all the requirements for improved water supply. Boreholes were first pumped for at least 15 minutes before taking water samples, so that a representative water sample from the aquifer is taken for analysis.

From each study cluster, 10 water samples were collected. However, physical parameters including temperature (^{o}C), pH, and electrical conductivity (EC) were determined in situ using water quality probes. Water quality probes were first calibrated with deionised water before measurements of pH, Temperature, EC and TDS. Separate groundwater samples were collected in 1 litre polyethylene bottles for Laboratory analysis. Cations (K^+, Na^+, Ca^{2+}, Fe^{3+} Mg^{2+}, Cu^{2+} and Zn^{2+}) were determined using Atomic Absorption Spectrometry following [27]. However, anions (NO_3^- and PO_3^-) were determined using Automated Colorimetry. Cl^- and HCO_3^- were determined using Titration. SO_4^{2-} was determined using Iron Chromatography.

Water samples were stored in insulated containers less than 5^{o}C. Before water samples were taken, polyethylene bottles were rinsed twice; first by deionised water and then with the water from sampled boreholes. Water samples were analysed within 24 hours of collection, as a result no preservative was added. All analyses were carried out in triplicates and results were found reproduceable within error limit of ±5%. Groundwater physical and chemical constituents were compared with World Health Organization [28] and Nigerian Standard for Drinking Water Quality (NSDWQ) (2007) reference guidelines [29], to determine its suitability for drinking (Table 1). Groundwater suitability for irrigation use was determined using chemical indices - Sodium Adsorption Ratio, Sodium Percent, Kelly's index and Magnesium Hazard.

Groundwater data were organized and standardised using basic descriptive statistics (mean, minimum, maximum and standard error). Non-parametric statistics (Kruskal-Wallis test) was employed to test whether there is a significant difference between the four studied clusters. Relationship between studied parameters was further tested using Pearson's correlation (r). All the statistical analysis was conducted using a significant level of $\alpha = 0.5$.

Results and Discussion

Physical properties

Groundwater composition in SWSB showed a marked spatial variability between the four urban clusters (Table 1). Temperature differ significantly ($H=11.77$, $p=0.005$). Major difference was between Zuru and Yauri. Figure 3, presents correlations between physical parameters. Temperature correlates strongly and positively with TDS and EC (Figure 3 A&B). EC level increases with a raised temperature by 2% per 1^{o}C. pH differs significantly ($H=22.11$, $p=<0.001$). Major difference was between Fakai and the three urban clusters. While pH level has less impact on consumers, it is central to understanding groundwater quality. Moderate pH level is therefore required depending on the composition of groundwater and aquifer properties, since pH levels controlled the behaviour of many water quality parameters. TDS differ significantly ($H=27.29$, $p=<0.001$).

Table 1: Physico-chemical composition of urban groundwater in South-western Sokoto Basin, Nigeria (Values in bold do not follow WHO and/or NSDWQ reference guidelines).

Parameter	Fakai				Koko-besse				Yauri				Zuru				**Reference Guidelines**	
Physical	**Mean**	**Max**	**Min**	**SE**	**Mean**	**Max**	**Min**	**SE**	**Mean**	**Max**	**Min**	**SE**	**Mean**	**Max**	**Min**	**SE**	**WHO [28]**	**NSDWQ [29]**
Temper-ature	33	34	31	10.4	32.7	34	31	10.3	31.7	33	31	10	31.7	34	30	10	Ambient	Ambient
pH	7.9	8.4	7.3	2.5	6.5	7	**6**	2	7.9	**8.8**	7.4	2.5	7.8	8.2	7.4	2.5	6.5-8.5	6.5-8.5
TDS	155.1	394	65	49	37	50	24	11.7	**930.9**	**2069**	80	294.4	206.5	330	105	65.3	500	500
EC	312.4	796	136	98.8	74.5	99	51	23.6	**1830.6**	**4146**	163	578.9	414.2	660	212	131	1000	1000
Total Hardness (CaCO3)	118.8	**244.6**	63.4	37.6	109.1	422.7	25.4	34.5	336	**732.9**	67.6	106.2	193.5	**732.9**	25.4	61.2	200	150
Cations																		
K^+	38.7	40.7	33.4	12.2	35.1	39.9	13.3	11.1	32.9	38.4	17.1	10.4	36.8	39.9	32.3	11.6	-	-
Na^+	3.4	9.8	0.1	1.1	5.3	9.8	0.9	1.7	4.6	10.9	0.1	1.5	4.5	9.8	0	1.4	12	12
Ca^{2+}	17.9	56.4	2.7	5.7	32.1	162.5	6.4	10.2	88	228.2	10	27.8	26.7	129.3	2.9	8.4	500	500
Cu^{2+}	0.4	0.6	0.1	0.1	0.4	0.5	0.3	0.1	0.3	0.3	0.1	0.1	0.3	0.6	0.2	0.1	75	75
Fe^{3+}	0.6	1.6	0	0.2	2.2	12.1	0.2	0.7	1	4.6	0.2	0.3	1.2	**3.1**	0.1	0.4	2	1
Zn^{2+}	**0.5**	1	0.3	0.2	0.4	**0.6**	0.3	0.1	0.3	**0.4**	0.2	0.1	**0.5**	**0.7**	0.2	0.2	0.3	0.3
Mg^{2+}	**18**	**26.8**	**8.2**	**5.7**	**7**	**10.4**	**0.7**	**2.2**	**28.3**	**39.6**	**10.4**	**8.9**	**20.9**	**26.3**	**16.2**	6.6	0.3-0.5*	0.2
Anions																		
PO_4^{3-}	**0.4**	**0.6**	0.1	0.1	**0.5**	**2.6**	0.1	0.2	**0.9**	**1.5**	0.2	**0.3**	**0.4**	**0.6**	0.1	0.1	0.2	0.2
Cl^-	2.5	3.5	1.4	0.8	3	4.8	1.3	1	1.8	3.6	0.2	0.6	2.5	3.5	0.6	0.8	200	200
$HC0_3^-$	13.7	33.3	2.7	4.3	20.1	33.4	5.8	6.4	28.5	65.2	11	9	14.3	31.7	0.3	4.5	250	250
SO_4^{2-}	135.7	**214.7**	67.3	42.9	175.4	**241.3**	89.3	55.5	118.8	**246.4**	47.6	37.6	126.6	**245.9**	45.1	40	200	100
NO_3^-	31.6	45.7	12.5	10	27.3	42.3	12.7	8.6	38.5	46.4	18.9	12.2	40.4	46.8	36.3	12.8	50	50

Note: All concentration is in mg/l except Temperature (°C), pH (units) and EC (µS/cm) @ 25°C. * = EPA [27].

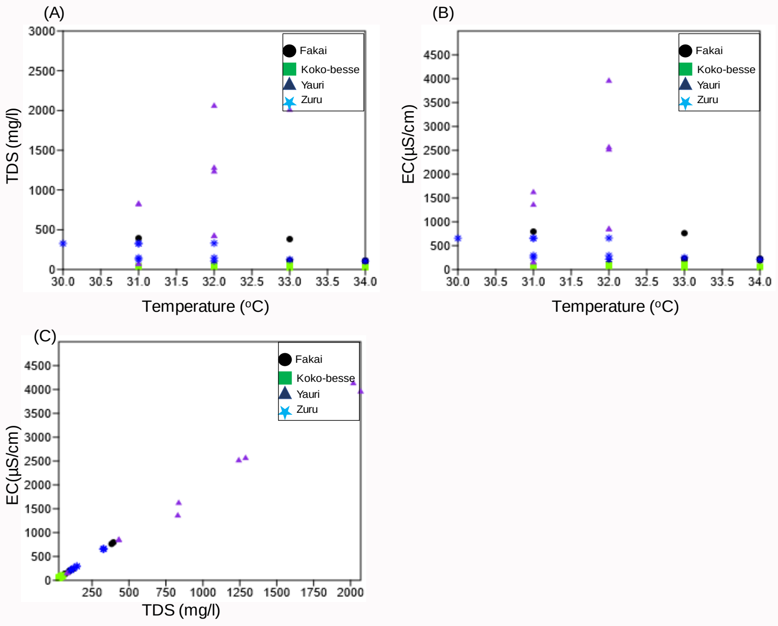

Figure 3: Correlation between physical parameters. (A) Temperature and TDS, (B) Temperature and Electrical conductivity and (C) TDS and Electrical conductivity.

Major difference was between Yauri and the three clusters.

TDS correlates strongly and positively with iron (r=0.95), sulphate (r=0.92) and nitrate (r=0.54). TDS levels rise with increased well depth in the Sokoto Basin [19]. There were weak positive correlations between TDS and temperature (r=0.31), sodium (r=0.38), cupper (r=0.43), zinc (r=0.36) and phosphate (r= 0.29). Groundwater with low-moderate TDS levels <600mg/l is generally considered excellent for drinking. At levels greater than 1000mg/l water becomes increasingly disgusting. David and De Wiest (1966) classified Groundwater based on TDS [30], is presented in Table 2. About 90% of groundwater sources in SWSB have TDS levels less

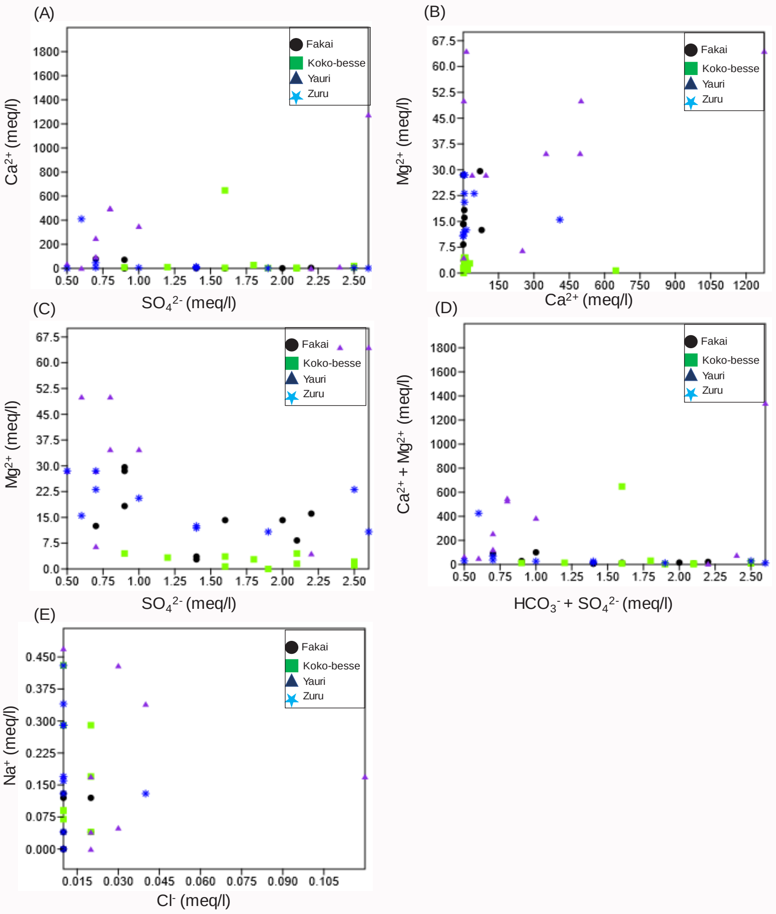

Figure 4: Cationic and anionic relationships.

than 500mg/l, this is particularly required for drinking (Table 2). Five percent have TDS levels ranging from 500 to 1000 mg/l. This is also acceptable for drinking. In addition, 5% have TDS levels ranging from 1000 to 3000 mg/l. Overall, groundwater in SWSB is suitable for drinking base on TDS concentration. Electrical conductivity differs significantly (H=27.29, p=<0.001) between the four clusters. The observed variability in EC and TDS are indications of increased anthropogenic inputs in groundwater [18]. To a water analyst, EC is a parameter of little importance, but is a vital indicator of the range in to which hardness or alkalinity values are likely to fall, as well as to the order of the dissolved solids content of water [27]. Temperature, pH, EC and TDS (Figure 3A, B & C) are often jointly used together to characterise groundwater aquifers. Temperature variation ranging from 5-10˚C in gravity flow water, for instance, may cause detectable changes in TDS level [31]. While both temperature and EC are highly variable in the study area, the former correlates very strongly and positively with EC. Total dissolve solids relate very well with EC (Figure 3C). Current results concur with [31-33].

Cation chemistry

The cation chemistry of groundwater in SWSB is summarised in Table 1. K^+ differ significantly (H=12.19, p=0.006). Although, it has no consequences for toxicity, K^+ is usually restrained on lake waters when an evaluation of nutrient contribution is carried out, since K^+ is an indispensable component of many non-natural fertilizers [35]. There are no indications that elevated K^+ levels in drinking water pose any health risk. Na^+ concentration did not differ significantly (H=2.41, p=0.48). Na^+ is a dietary requirement (common salt) and is always obtainable in natural waters. The major reasons for regulating Na^+ in drinking water, is the combined effects its exercises with sulphate [27]. Excessive intake is often connected to hypertension. Calcium differ significantly (H=9.141, p=0.027). Groundwater, rich in Ca^{2+} tend to be very beneficial and often palatable. Despite the health benefits of elevated Ca^{2+} levels in drinking water, higher concentrations are normally associated with hardness [35]. Another foremost constituent of groundwater is magnesium and like calcium, Mg^{2+} is obtainable in great quantity in natural waters. It is however a key dietary requirement - 0.3 – 0.5 g/day [35].

Mg^{2+} concentration in SWSB differs significantly (H=24.02, p=<0.001). Major difference was between Koko-besse and Zuru. No direct health effects to humans is associated with excessive Mg^{2+} intake but may have some indirect effects in conjunction with sulphate. Mg^+ is an important water quality parameter because it is the second major constituent of hardness ($CaCO_3$) [27]. Table 3, presents groundwater classification based Total Hardness. Groundwater in Yauri and Zuru is relatively harder compared to Fakai and Koko-besse. Copper levels differ significantly (H=8.64, p=0.033). Major difference was between Koko-besse and Zuru clusters. Cu^{2+} is not noxious to humans, rather it is an indispensable nutritional necessity. Therapeutic doses of about 20mg/l are occasionally permitted. But unpleasant tastes can occur at levels greater 1mg/l [27]. It is important to note that Cu^{2+} levels may vary with time the water has been in contact with pipes. This might have accounted for uniform concentration of Cu^{2+} in SWSB, since water samples were drawn from boreholes with little or no extended

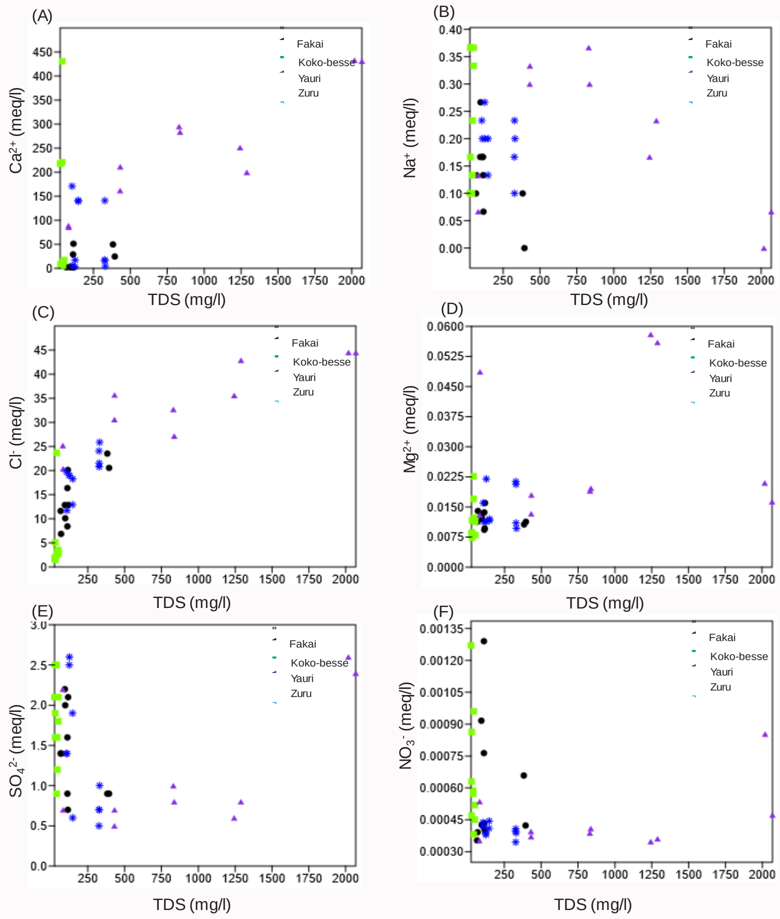

Figure 5: A-F Cationic and anionic relationship with TDS.

pipe networks.

However, there is no significant difference in Fe^{3+} concentration (H=3.11, p=0.37). Objections to Fe^{3+} in drinking water are primarily organoleptic, but there has been growing medical concern about elevated Fe^{3+} levels in drinking water [27]. Like Fe^{3+}, there is no significant difference (H=3.36, p=0.33) in Zn^{2+} concentration. It can be toxic to aquatic life, which is dependent on hardness [27]. At Elevated levels (above 4mg/l) in drinking water, can informs an unpleasant taste to water.

Anion chemistry

The anion chemistry of groundwater in SWSB is summarized in Table 1. Phosphate concentration did not differ significantly (H=8.02, p=0.042) between the four urban centres. The unvarying concentrations can be attributed to sewage, since PO_4^{3-} is mainly derived from plants and wastes. There is no considerable health and/or sanitary concerns associated with excessive intake of PO_4^{3-} in drinking water [27]. Like PO_4^{3-}, Cl^- did not differ significantly (H=6.29, p=0.098). Cl in groundwater is derived from soil and rock minerals and does not constitutes health hazard to humans. At levels greater than 250mg/l water will taste salty. What is essential is to understand that Cl^- values are not absolute, rather the comparative levels from one sampling point to another. Elevated Cl^- levels of about 5 mg/l at one-point may lead to the suspicion of groundwater pollution from sewage discharge, particularly if ammonia levels are also raised [27]. Bicarbonate differs significantly (H=8.90, p=0.03). Bicarbonate and carbonate ions joint with Ca^+ or Mg^+ advances as $CaCO_3$ or $MgCO_3$ when the soil solution concentrates in drying solutions. The concentrations of Ca^+ and Mg^+ declines relative to Na^+ and the SAR index rises. This causes an alkalizing effect and elevated pH levels [27]. There is no significant difference (H=4.48, p=0.21) in SO_4^{2-} concentration. Elevated SO_4^{2-} in groundwater can pose health risk, especially when combined with Mg^+ and/or Na^+. At levels above 250mg/l, SO_4^{2-} is reduced to sulphide causing toxic odours. There is a significant difference (H=11.83, p=0.007) in nitrate levels. Major difference was between Koko-besse and Yauri. The observed variability in NO_3^- levels can be attributed to sewage and fertilizer application, since NO_3^- is derived mainly from oxidation of ammonia and agricultural fertilizer. Elevated NO_3^- levels in drinking water may render it hazardous to infants (blue baby syndrome). Elevated nitrite levels in groundwater indicates more recent pollution, since nitrite forms a transitional stage in the ammonia-to-nitrate oxidation [27]. Overall, the cationic and anionic chemistry of groundwater in SWSB pose no serious health risks.

Rock mineral/groundwater interactions

Correlations between dissolved elements in groundwater can indicates the source of solutes and the process that produced the observed groundwater composition. It is assumed that a substantial portion of HCO_3^- is derived from dissolution of carbonate minerals in groundwater aquifer via the action of recharge waters enriched in CO_2, after having contact with atmosphere [18]. CO_2 is then released in to solution by dissolution of carbonate, which produces $Ca^-HCO_3^-$ water type. Therefore, estimation of the slops of HCO_3^- with Na^+,

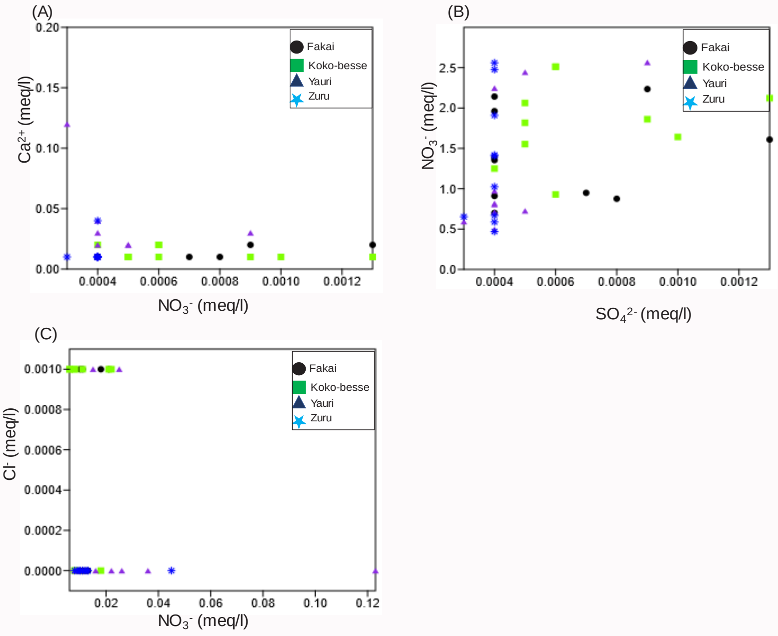

Figure 6: Relationship between NO_3^- and Ca^{2+}, SO_4^{2-} and Cl^-.

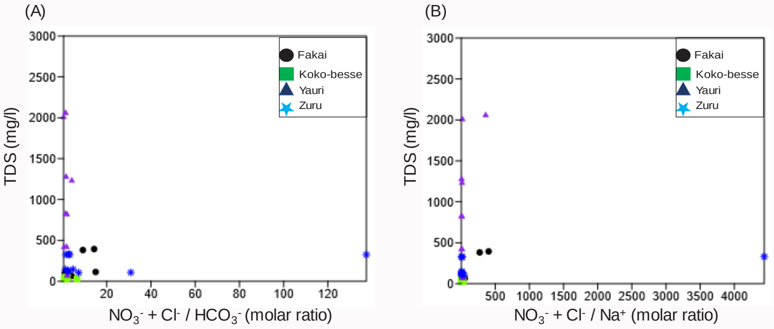

Figure 7: Variation of TDS versus $(NO_3^- + Cl^-)/Na^+$ and $(NO_3^- + Cl^-)/HCO_3^-$

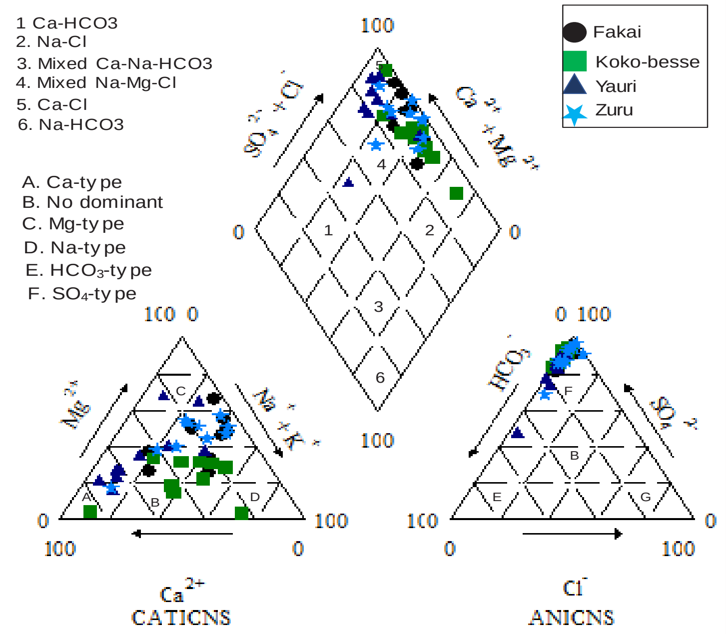

Figure 8: Groundwater classification using Piper diagram.

Table 2: Classification of groundwater based on TDS.

TDS (mg/l)	Classification	No. of Samples	% of samples
Less than 500	Required for drinking	36	90
500-1000	Acceptable for drinking	2	5
1000-3000	Suitable for drinking	2	5
Greater than 3000	Unhealthy for drinking and irrigation	-	-
Total		**40**	**100**

After [41].

Table 3: Groundwater classification based on Total Hardness.

Range (mg/l)	Fakai %		Koko-besse %		Yauri %		Zuru %		Classification
0 - 75	2	20	5	50	1	10	1	10	Soft
75 – 150	5	50	3	30	0	0	5	50	Moderate Hard
150 - 300	3	30	1	10	4	40	2	20	Hard
>300	0	0	1	10	5	50	3	30	Very Hard
Total	**10**	**100**	**10**	**100**	**10**	**100**	**10**	**100**	

After [74].

Ca^+ and Mg^{2+} stretches vital information relating to the process of stoichiometry [18]. HCO_3^- and Ca^{2+} were not significantly related (r=0.36), indicating that Ca^{2+} does not originate from calcite rocks. Perhaps, dissolution of gypsum is the source of Ca^{2+} and SO_4^{2-}. Weak correlation between Ca^{2+} and SO_4^{2-} (r=0.29) indicates that most of the analysed water samples are closer to 1:1 line (Figure 4A), suggesting that Ca^{2+} was derived from gypsum [51]. Ca^+ correlates weakly with Mg^+ (r=0.03) (Fig 4B) indicating that the two chemical constituents might not have been derived from the same source. There was negative correlation (Figure 4C) between SO_4^{2-} and Mg^+ (r= -0.31), suggesting that the two ions might not have been produced by the weathering of magnesium sulphate minerals. The negative correlations did not concur with [18].

When Ca^{2+}, Mg^{2+}, SO_4^{2-}, and HCO_3^- + SO_4^{2-} are derived from simple dissolution of gypsum, dolomite and calcite, a charge balance exists between cations and anions [18]. There is no lack of (Ca^{2+} + Mg^{2+}) relative to (HCO_3^- + SO_4^{2-}) and (HCO_3^- + SO_4^{2-}) relative to (Ca^{2+} + Mg^{2+}) in SWSB (Figure 4D). As a result, no need for balance by major ions since there was no excess positive charge of Ca^{2+} and Mg^{2+}. Therefore, Ca^{2+}, Mg^{2+}, HCO_3^-, SO_4^{2-} may not be sources of gypsum, dolomite and calcite. In semi-arid regions, Na^+ - Cl^- relationship has frequently being used as mechanism for determining salinity in groundwater [18]. Na^+ correlates strongly (r=0.63) with Cl^- (Figure 4E), indicating that halite may be the major source of Na^+. Meybeck (1987) used Na^+/Cl^- molar ratio to study silicate weathering reactions. Most of groundwater sources (80%) in SWSB have Na^+/Cl^- molar ratio greater than 1, suggesting that parts of Na^+ in SWSB was derived from silicate weathering. However, cation exchange between Na^+, Ca^{2+} and Mg^{2+} indicates elevated levels of Na^+. Aquifers with Na^+/Cl^- molar ratio less than 1, are deficient in Mg^{2+} + Ca^{2+} which corresponds with Ca^{2+} - Na^+ cation exchange process. This result into softened of water. In some aquifers having clay formations, Ca^{2+} + Mg^{2+} is exchanged with Na^+ derived from the exchange sites, causing a decrease of Ca^{2+} + Mg^{2+} and elevated levels of Na^+ [18].

Anthropogenic contributions

Correlations between TDS and sodium, chloride, sulphate and nitrate, can be used as an indicator of how human activities contributes to changes in groundwater chemistry (Figure 5). TDS variations in groundwater can be attributed to pollution and land use [18]. Ions (sodium, chloride, sulphate and nitrate) in groundwater are derived from human activities- fertilizer application, municipal and industrial sewage as well as organic wastes. TDS correlates positively with Ca^{2+}, Mg^{2+} and Na^+. Rising Na^+ levels with elevated TDS levels (Figure 5B), is an indication of silicate weathering

Table 4: Summary of chemical indices of groundwater.

Clusters	S/no	SAR	Si	Ki	SP	MH	Vi	MR
Fakai	Sp 001	6.4	12.8	0.1	4.1	60.8	0.1	1
	Sp 002	4	13.4	0.1	5.6	23.6	0.1	1.9
	Sp 003	7.6	15.6	0	0.1	33.2	0	0
	Sp 004	6	18.5	0	0.1	90.8	0	0
	Sp 005	1.9	13.8	0	1.6	48	0	0.3
	Sp 006	1.8	18.9	0.3	9.6	36	0.2	2.7
	Sp 007	7.3	30.8	0.1	4.4	85.3	0.1	2.1
	Sp 008	3.2	13.4	0.2	4.7	79.7	0.1	0.9
	Sp 009	6.6	24.8	0	1.3	58.1	0	0.6
	Sp 010	4.3	20.9	0.4	12.9	72.7	0.3	4
Koko-besse	Sp 011	0.2	11.1	1	16.5	6.8	0.5	2.2
	Sp 012	1.4	11.8	0.2	8.8	15.3	0.2	1.8
	Sp 013	2.6	13.1	0.4	14	45	0.3	2.7
	Sp 014	1.9	14	0.2	10.9	19.7	0.2	2.8
	Sp 015	1.9	11	0.1	8.3	30.1	0.1	2.5
	Sp 016	3.2	15.3	0.1	3.2	41	0.1	0.8
	Sp 017	2.2	7.6	0.2	4	48.9	0.1	0.4
	Sp 018	1	10.6	0	0.7	2.4	0	0.4
	Sp 019	1.9	35.3	0.3	9.6	30.3	0.2	5.1
	Sp 020	2.8	28	0	1.4	35.9	0	0.7
Yauri	Sp 021	12.8	32.2	0	0.4	14.8	0	1
	Sp 022	9.4	9.5	0	0.1	62.8	0	0.1
	Sp 023	2.1	9.5	0.2	7.1	51	0.2	1.1
	Sp 024	3.2	21.2	0	0.6	11.2	0	0.5
	Sp 025	7.2	177.1	0.1	4.5	77.2	0.1	16.9
	Sp 026	7.3	56.9	0	3.5	19.6	0	9.8
	Sp 027	5.6	11.8	0	3.1	29.6	0	1.3
	Sp 028	5.8	14.9	0.2	9.8	40.1	0.1	3.5
	Sp 029	6.3	28	0	2.1	19.6	0	3
	Sp 030	6.5	41.4	0.1	4.5	17	0.1	9
Zuru	Sp 031	3.9	16.4	0.2	9.4	59.6	0.2	2.6
	Sp 032	3.9	15.2	0	1.3	55.1	0	0.4
	Sp 033	3.6	19.9	0.3	10	74.9	0.2	2.9
	Sp 034	4.5	20.1	0	1.5	13	0	1.4
	Sp 035	5.4	13.4	0.1	4.7	60.3	0.1	1.3
	Sp 036	4.9	11.2	0	0	60.4	0	0
	Sp 037	5.8	15.2	0.3	12.2	85.6	0.2	3
	Sp 038	5.3	61.9	0	2.7	35.2	0	4.6
	Sp 039	3.5	12.2	0.2	5.8	85	0.2	1
	Sp 040	5.2	19.3	0.2	9.8	62.5	0.2	3.6

Note: Si: Scholler Index; Vi: Versluys Index; Ki: Kelly's Index; SAR: Sodium Adsorption Ratio; MH: Magnesium Hazard and Molar Ratio from literature. ND: No data.

Table 5: Groundwater classification based on sodium percent.

Sodium (%)	Classification	No. of Samples	% of samples
Less than 20	Excellent	40	100
20-40	Good	0	0
40-60	Permissible	0	0
60-80	Doubtful	0	0
Greater than 80	Unsuitable	0	0
Total		**40**	**100**

After [70].

reactions. However, correlations may result from anthropogenic inputs, including industrial and municipal sewage, melting road salt and effluents from engineering works [34]. Elevated levels of Ca^{2+} and Mg^{2+} with increasing TDS levels (Figure 5A&C) indicate anthropogenic inputs from municipal and industrial sewage. There is a positive trend between TDS and Cl^-, SO_4^{2-} and NO^- (Figure 5D-F), suggesting pollution from anthropogenic sources. Positive correlation between TDS and SO_4^{2-} (Figure 5E), also suggests pollution from anthropogenic sources. Positive correlations between SO_4^{2-} and NO_3^- (Figure 5F), suggest the same source of the two ions [34]. Correlations between Cl^- and NO_3^- below 0.35, suggests different source [18]. Positive correlations between Ca^{2+} and NO_3^- (r=0.93) and Cl^- and NO_3^- (r=0.44) indicates that the two ions might have being derived from the same source (Figure 6). TDS correlates positively with $(NO_3^- + Cl^-)/Na^+$ (r=0.78) and $(NO_3^- + Cl^-)/HCO_3^-$ (r=0.85). The molar ratio backs the anthropogenic contributions (Figure 7).

Ion exchange process

The process of ion exchange can be evaluated using Scholler index. Indices tend to be positive when Ca^{2+} and Mg^{2+} exchange with K^+ and Na^+ (chloro-alkaline equilibrium). Chloro-alkaline disequilibrium is indicated by negative Scholler indices [35]. Groundwater in SWSB have positive Scholler index, suggesting chloro-alkaline balance (Table 4). In aquifers where alkaline rock minerals are replaced with Na^+ ions ($HCO_3 > Ca + Mg^+$), for instance, denotes base exchange softened water. In contrast, when Na^+ is exchanged with alkaline rocks ($Ca + Mg > HCO_3$), denotes base exchange hardened water [35]. While Scholler index is more widely used base exchange index, Versluys (1916, 1931) was the first to used Na/(Na + Ca + Mg) ratio as index of base exchange [36,37]. Like Scholler index, values of Versluys index are positive in SWSB. This further confirmed chloro-alkaline balance base exchange reaction in the study area.

Hydrogeochemical faeces

The Piper trilinear diagram is used to classify groundwater (Figure 8). The classification is based on the basic geochemical character of dissolved ionic absorptions (Piper, 1964). Groundwater in SWSB fall in the category of Ca-Mg, Mg-HCO_3 and Mixed Ca-Na-SO_4-Cl water types and is probably suitable for all uses. This finding agrees with

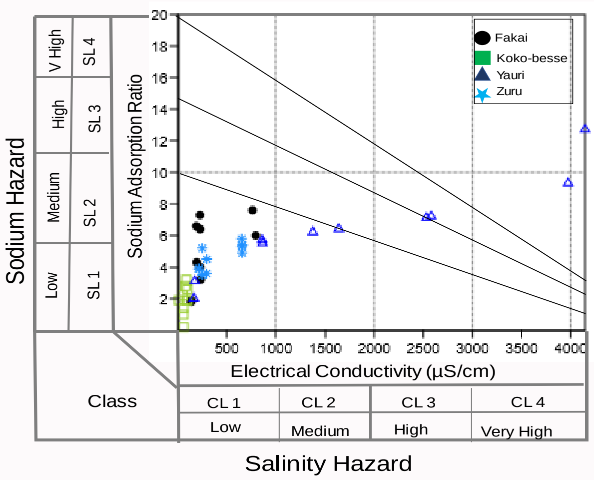

Figure 9: Irrigation water classification Using USDA Diagram.

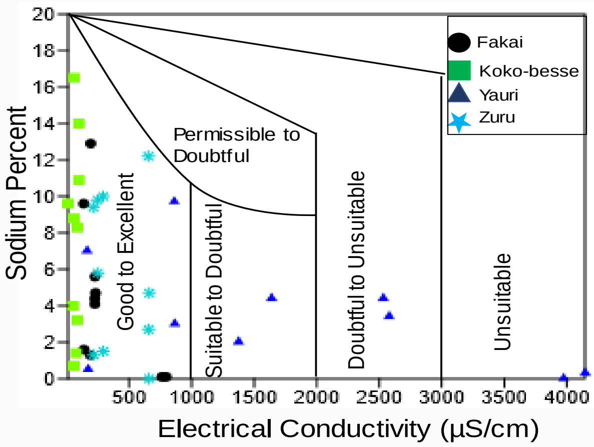

Figure 10: Wilcox plot of groundwater classification in SWSB.

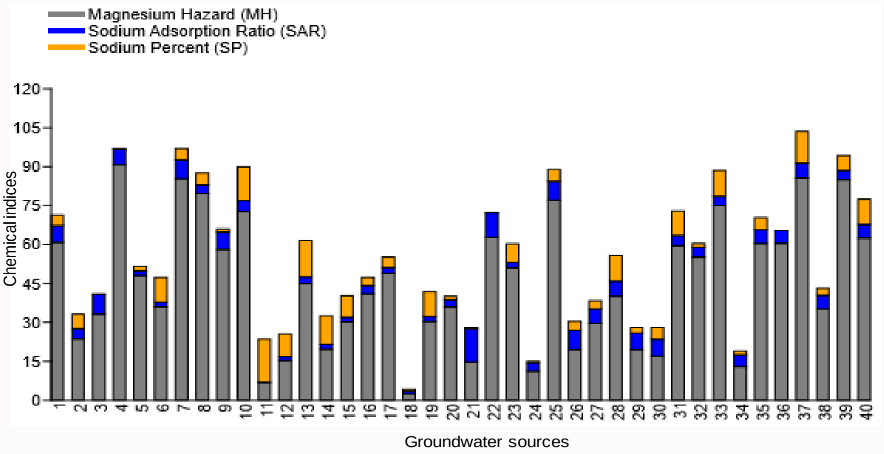

Figure 11: Variability of Magnesium hazard, Sodium adsorption ratio and Sodium percent in SWSB.

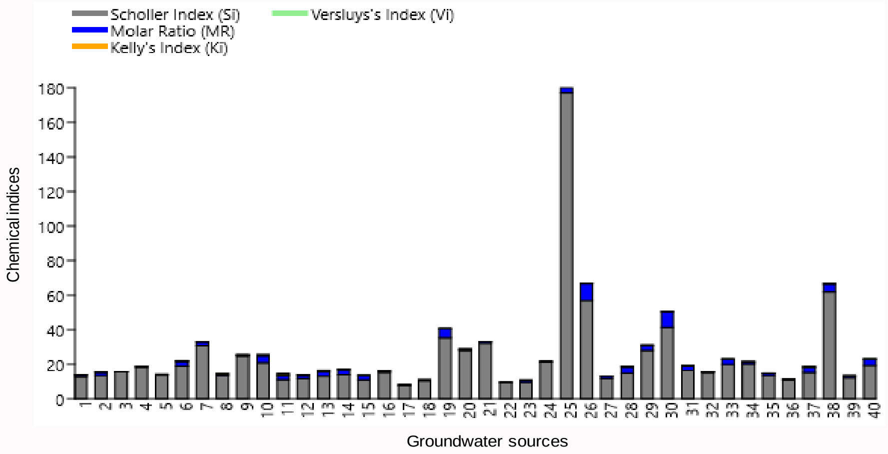

Figure 12: Variability of Scholler ratio, Kelly's index and Molar ration in Groundwater in SWSB.

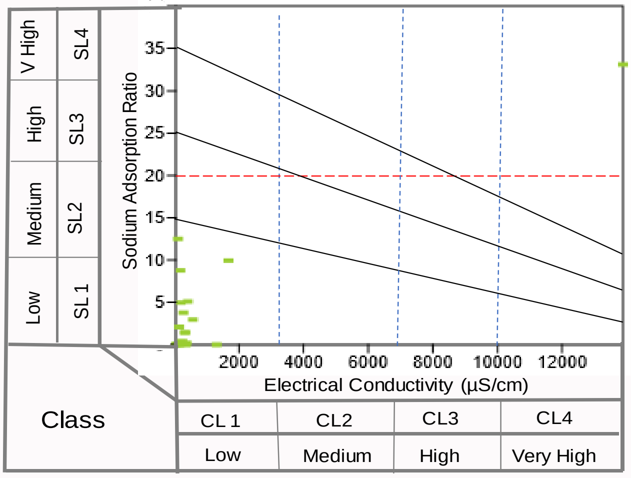

Figure 13: Irrigation water classification in Nigeria using USDA diagram.

[19,26]. Groundwater in Sokoto Basin is predominantly of two facies; - calcium– magnesium–bicarbonate and calcium–magnesium–sulphate–chloride.

Suitability for irrigation use

The suitability of groundwater for irrigation use depends on the mineralization of water and its effects on soil and plants [38]. It also depends on Na^+ and EC levels. High salinity decreases plant's osmotic activity and subsequently affects water and nutrients intake by plants from the soil. Aquifers with elevated levels of dissolved ions such as HCO_3^-, CO_3^- and Na^+ affects groundwater-fed crops by reducing crop yields. Major effect of these ions includes the lowering of osmotic

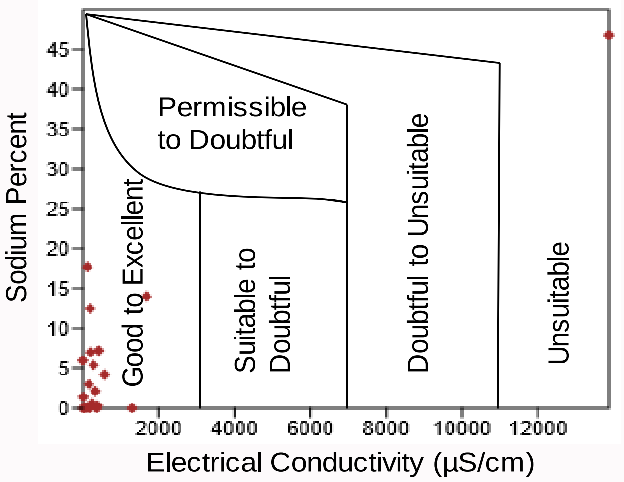

Figure 14: Wilcox plot of irrigation water classification in Nigeria.

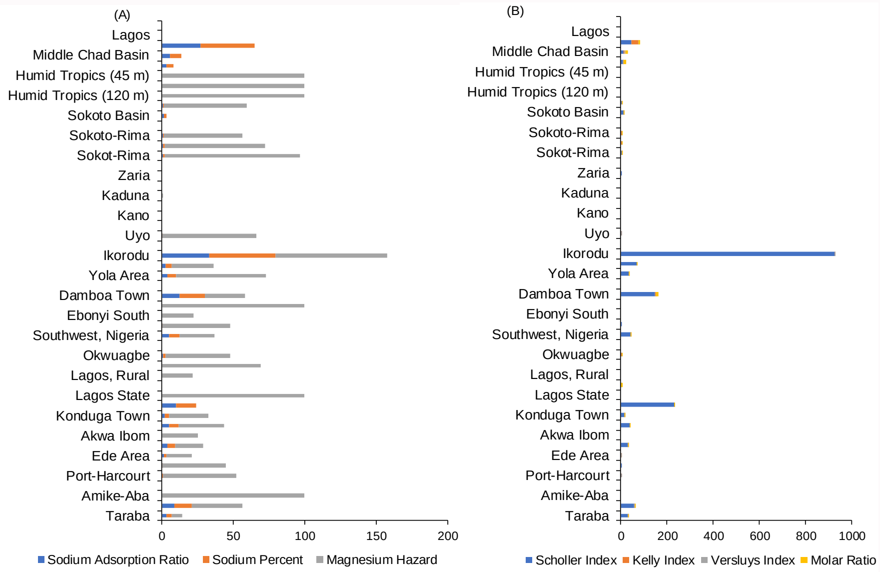

Figure 15: Variability chemical indices in Groundwater in Nigeria (A) Sodium adsorption ratio, Sodium percent and Magnesium hazard (B) Scholler index, Kelly's index and Molar ratio.

compression in the plant structural cells. This chemical upshot disturbs plant metabolism, by preventing water from reaching the leaves and branches. High salinity affects soil aeration, permeability and soil structure all of which affects plant growth indirectly [18].

Groundwater suitability for irrigation is normally evaluated and classified using total concentration of soluble salts which is express in terms of specific conductance [39]. Table 4 summarised chemical indices used to evaluate groundwater suitability for irrigation use.

Sodium adsorption ratio: Sodium Adsorption Ratio is used for determination of alkali and/or sodium hazard to crops.

SAR is defined thus:

$$SAR = Na^{+}/\sqrt{[Ca^{2+} + Mg^{2+})/2]},$$

Most of groundwater samples (97.5%), fall in low sodium-low EC class (Figure 9), suggesting groundwater of low sodium and low salinity type. This water type has no danger of exchangeable Na^+ [40]. About 2.5% of groundwater samples fall in high salinity-medium sodium water type. Under favourable drainage conditions, this water type can be used to irrigate salt tolerant and semi-salt tolerant crops [40]. Current result concurs with [33]. However, irrigation water with low salinity and low SAR can lead to problems relating to water infiltration [33]. Evaluation of sodium percent and permeability index is required.

Sodium percent: Sodium reacts with soil to decrease soil permeability [38]. Elevated sodium levels cause cation exchange between Mg^{2+} and Ca^{2+} from soil, which eventually reduces water and air circulation in the soil under wet conditions. Sodium percent is defined thus:

$$Na^{+} (\%) = [(Na^{+})\times 100/(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})]$$

In SWSB sodium percent is less than 20, this is especially required for irrigation use. Wilcox diagram [94] relating electrical conductivity and sodium percent (Figure 10), showed that, about 80% of groundwater samples fall in good-excellent class, 10% suitable, 5% doubtful to unsuitable and 5% unsuitable. Low sodium in SWSB

Table 6: Compilation of Literature Report of physico-chemical Properties of Groundwater in Urban Nigeria (Values in bold do not follow WHO and NSDWQ reference guidelines).

S/no.	**Location**	**ºC**	**EC**	**pH**	**TDS**	**K$^+$**	**Na$^+$**	**Cl$^-$**	**HC0^{3-}**	**Ca^{2+}**	**Cu^{2+}**	**Fe^{3+}**	**Zn^2**	**Mg^{2+}**	**NO3$^-$**	**SO$_4^{2-}$**	**PO$_4^{3-}$**	**Source**
L1	Akure		284.6		142	1.6	**31.6**	43.5	223	27.3				**6.7**				[41]
L2	AkwaIbom	29.2	10.5	**4.6**	4.5			0.2		72	0.1	0.1	BD	**24**	BD	3	BD	[86]
L3	Alimosho										2.1	**1.8**	**18.1**					[26]
L4	Amike-Aba	26.3	11.9	**6.4**							BD	0.2		0.1				[60]
L5	Calabar	27.5		6.9			2.1	0.3								1.7		[34]
L6	Damboa	28	120	6.8	140		**150**	0.2		52	BD	0.1	BD	**20**	**65**	0.7	BD	[79]
L7	Dareta	29.1	370.8	**6.3**	174.3									2.5				[84]
L8	Dass Town	27.9	**1483**	6.8	**733.8**													[43]
L9	Ebonyi South	27.7	52	**5.1**	27.4			8		3.6	0.2	0.3	BD	1	12.6	10.7	**0.3**	[8]
L10	Ede Area		330	**5.8**		4.8	11.6			26				**5.5**		7.2		[3]
L11	Humid Tropics (120 meters)	27.4	17	**5.85**	11.05						1.5	0.5		1.1	0.6	11		[25]
L12	Humid Tropics (45 meters)	28	17.3	**5.01**	12.78						2.72	**3.5**		4	0.9			[25]
L13	Humid Tropics (60 meters)	27.6	16.8	**5.32**	12.5						2.5	**2.4**		3.6	0.8	16		[25]
L14	Ibadan	27.6	207.2	6.2	349.3	12.5	**37.5**	79.5	69.8	19.5		0.3		**9.1**	14	29.5	0.2	[10]
L15	Ibadan City	34		8	**11925**			**1151**			0.1		**6.1**				**164**	[64]
L16	Ibadan,	28.5	1230	7.2	610						0.6		**0.7**					[6]
L17	Ikorodu	28.1	**13880**	6.9	**8883**	45.5	**926**	**326845**		86.3				**3060**			**1.6**	[19]
L18	Jada		141.3	6.2	95.9	2.9	0.6	20.9	205.2	20.8				**19.2**	9.2	14.9		[42]
L19	Jimeta			6.9	**550**	6	**69.4**	**289**	**486**	201		0.9		**83**				[4]
L20	Kaduna		357		**1670**													[54]
L21	Kaduna	22.1	5	6.5	500					200	0.1	1	**5**	0.2			**5**	[54]
L22	Kaduna		351	6.5	0.3			50			0.6	**1.7**					**3.9**	[85]
L23	Kaltungo		387.6	7.9	221.5	5.4	3.6	74	**342.6**	62		**4.7**		**49.8**	**103.6**	23.2		[1]
L24	Kano	302.5	82.8	7.3	156			9.1		55.6							**28.1**	[56]
L25	Konduga		160	7.1	80	11	8.9	2	218.3	6.5		0.2		2.5	2.3	1.2		[24]
L26	Lagos	28		6.5	**2320**			2			0.02	0.1			5.6	0	0.06	[48]
L27	Lagos State		628.6	6.5	321.9			70.8				0.6	**8.6**	**25.1**				[79]
L28	Lagos, Rural		172.6	6.7	88.7			31.1		49.1				**13.4**	4.2	8.7		[20]
L29	Lagos, Urban		**1305.8**	8.5	614.9			**285.4**		60.7				**136**	23.1	15.4		[20]
L30	Landfill Ondo			**5.68**	342			122		83		**1.2**	**5.4**		**61**			[23]
L31	Lokoja						3.7	16		6.6				**9.1**		9.2		[5]
L32	Lower Chad Basin						**45**	7.5		1.4		0.11			<0.3	<0.5		[32]
L33	Middle Chad Basi						**13**	1		2.7		<0.02			<0.02	<0.5		[32]
L34	Nassarawa										0.4	0.1	0.1					[78]
L35	Odeda										0.2	0.9	**1.5**					[15]
L36	Okwuagbe	28	10.2	6.5	7.6	0.2	1.5	0.3	14.6	0.6		0.1	BD	0.5		0.6		[33]
L37	Patigi	32	**1678**	6.7	460	312	**230**	**260**		268	0.9	0.4	**2**	0	0.3	**500**		[55]
L38	Port Harcourt	27.7	245.8	7.7	145.5	0.5	1.6	161.5	16.7	3	0.1	0.3	**0.7**	3.2	3.2	68.8	**0.3**	[61]
L39	Sokoto			6.7	125.2			8.1							4.6			[41]
L40	Sokoto Basin	30	351	7	296	4.3	**12.1**	8.3	118	35		BD						[5]
L41	Sokoto-Rima, BH					0.6	2.5	3.7	10.9	2.7				3.3	4.5		**3.8**	[33]
L42	Sokoto-Rima, OW					4	4	3.7	6.4	0.64				**11.3**	12.2		**23.5**	[33]

L43	Sokoto-Rima, TW					1.1	2.1	3.7	4.4	0.8				1.9	8.3		**6.4**	[33]
L44	Southwestern Nigeria	26	427.4	6.4	329	8.6	**42.6**	62.3	11	26		0.5		**8.6**	3.5	53.7	**0.5**	[63]
L45	Taraba	31.2	576	6.9	280	1.2	**29.6**	123.5	35	46.4		0.2		3.5	**94.3**	0.7		[18]
L46	Taraba	32.5	194.8	7.3	93.2	12.6	**56.4**	143	6.1	13.2		BD		**7.2**	**72.4**	1.8		[18]
L47	Upper Chad Basin						7.1	0.5		2.2		<0.2			<0.4	<0.5		[32]
L48	Uyo	26.9	99.7	**4.2**	47.3		0.1	8.7		0.5	0.3	0.1	BD	1				[7]
L49	Yola Area		0.1	7.1	59.6	4	**34.4**	68.2	93.4	12.2		0.4		**20.8**	4.4			[36]
L50	Zaria					2.4		6.3		9.5	-	**1.3**	0.1					[2]
Reference Guidelines		Ambient	1000	6.5-805	500	-	12	200	250	500	75	2	0.3	4	50	200	0.2	[93]
Reference Guidelines		Ambient	1000	6.5-8.5	500	-	12	200	250	500	75	1	0.3	3	50	100	0.2	[29]

Note: All concentrations are in mg/l, except Temperature (°C), Electrical conductivity (µS/cm) and pH (Units), BD= Below detection limits.

Table 7: Summary of chemical indices of groundwater in Urban Nigeria.

S/no.	**Location**	**SAR**	**Si**	**Ki**	**Vi**	MR	SP	MH
L 1	Akure	3.8	31.6	0.9	0.5	0.7	5.4	19.8
L 2	Akwa Ibom	0	0	0	0	0	0	25
L 3	Alimosh	ND	ND	ND	ND	ND	ND	ND
L 4	Amike-Aba	0	ND	0	0	ND	0	100
L 5	Calabar	ND	2.1	ND	ND	8.4	ND	ND
L 6	Damboa Town	12.5	150	2.1	0.7	10	17.7	27.8
L 7	Dareta Village	0	ND	0	0	ND	0	100
L 8	Dass Town	ND	ND	ND	ND	ND	ND	ND
L 9	Ebonyi South	0	0	0	0	0	0	22.4
L 10	Ede Area	1.5	ND	0.4	0.3	ND	2.1	17.5
L 11	Humid Tropics (120 m)	0	ND	0	0	ND	0	100
L 12	Humid Tropics (45 m)	0	ND	0	0	ND	0	100
L 13	Humid Tropics (60 m)	0	ND	0	0	ND	0	100
L 14	Ibadan	ND	ND	ND	ND	ND	ND	ND
L 15	Ibadan City	ND	0	ND	ND	0	ND	ND
L 16	Ibadan Metropolis	5	37.7	1.3	0.6	0.5	7	31.9
L 17	Ikorodu	33.1	926	2.4	0.7	0	46.8	78
L 18	Jada	0.1	0.8	0	0	0	0.1	47.9
L 19	Jimeta Metropolis	2.9	69.4	0.2	0.2	0.2	4.1	29.2
L 20	Kaduna	ND	ND	ND	ND	ND	ND	ND
L 21	Kaduna	0	ND	0	0	ND	0	0.1
L 22	Kaltungo	0.2	3.7	0	0	0	0.3	44.5
L 23	Kano	0	0	0	0	0	0	0
L 24	Konduga Town	2.1	14.4	1	0.5	4.5	3	27.8
L 25	Lagos	ND	0	ND	ND	0	ND	ND
L 26	Lagos State	ND	ND	ND	ND	ND	ND	100
L 27	Lagos, Rural	0	0	0	0	0	0	21.5
L 28	Lagos, Uran	0	0	0	0	0	0	69.1
L 29	Landfill Ondo	0	0	0	0	0	0	0
L 30	Lokoja	0.7	3.7	0.2	0.2	0.2	0.9	58
L 31	Lower Chad Basin	26.9	45	32.1	1	6	38	0
L 32	Middle Chad Basin	5.6	13	4.8	0.8	13	7.9	0
L 33	Nassarawa State	ND	ND	ND	ND	ND	ND	ND
L 34	Odeda region	ND	ND	ND	ND	ND	ND	ND
L 35	Okwuagbe	1	2.4	1.4	0.6	5.8	1.4	45.6
L 36	Patigi	9.9	231.2	0.9	0.5	0.9	14	0
L 37	Port-Harcourt	0.4	1.6	0.3	0.2	0	0.6	51.1
L 38	Sokoto	ND	0	ND	ND	0	ND	ND
L 39	Sokoto Basin	1.4	12.6	0.3	0.3	1.5	2	0
L 40	Sokoto-Rima	0.7	2.7	0.4	0.3	0.7	1	55
L 41	Sokoto-Rima	0.8	5.1	0.3	0.3	1.1	1.2	94.6
L 42	Sokoto-Rima	0.9	2.4	0.8	0.4	0.6	1.3	70.4
L 43	Southwest, Nigeria	5.1	42.7	1.2	0.6	0.7	7.2	24.8
L 44	Suleja,	ND	0	ND	ND	0	ND	ND
L 45	Taraba	3	29.6	0.6	0.4	0.2	4.2	7
L 46	Taraba	8.8	56.5	2.8	0.7	0.4	12.5	35.3
L 47	Upper Chad Basin	3.4	7.1	3.2	0.8	14.2	4.8	0
L 48	Uyo	0.1	0.1	0.1	0.1	0	0.1	66.2
L 49	Yola Area	4.2	34.4	1	0.5	0.5	6	63
L 50	Zaria	0	0.4	0	0	0	0	0

Note: Si: Scholler Index; Vi: Versluys Index; Ki: Kelly's Index; SAR: Sodium Adsorption Ratio; MH: Magnesium Hazard and Molar Ratio from literature. ND: No data.

can be attributed to the ion exchange reaction between Ca^{2+} and Na^+ perhaps caused by residence time and sluggish sub-surface flows, since the aquifers underlying SWSB receive recharge from Fadama (floodplain) areas in north-eastern Sokoto Basin. Groundwater classification based on sodium percent is further illustrated in Table 5.

Kelly's index: In Kelley's index, Ca^{2+} and Mg^{2+} are measured against Na^+. It is defined thus:

$$KI = [Na^+/(Mg^{2+} + Ca^{2+})].$$

Indices less than 1 indicates water of excellent quality. In contrast, indices greater than 1, indicate water which is unsuitable for irrigation, because of alkali hazards [49]. Kelly's index is less than 1 in 97.5% of analysed water samples.

Magnesium hazard: Often Ca^{2+} and Mg^{2+} are found in a state of equilibrium in aquifers. Mg^{2+} concentrations in groundwater at levels greater than Ca^{2+} accelerates the degree of Mg^{2+} saturation which destroys soil structure and consequently reduces its productivity [39]. Elevated Mg^{2+} in groundwater affects the soil quality by converting it to alkali which eventually lessen crop yield [49]. Magnesium Hazard [41] is defined thus:

$$MH = [Mg^{2+} \times 100/(Ca^{2+} + Mg^{2+})]$$

About 62.5% have MH less than 50 (Table 4), indicating water suitable for irrigation use. The variability of chemical indices is further illustrated in Figures 11 and 12 respectively.

Implications for Groundwater Quality in Urban Nigeria

To better understand groundwater quality in urban areas, data from 50 locations from the literature was compiled (Table 6). About 94.7% of groundwater sources in urban Nigeria fall in low sodium-low salinity class (Figure 13). Kelly's index is less than 1 in 86.8% of groundwater sources. Similarly, about 97.4% have sodium percent less than 20 (Figure 14). Low sodium in groundwater across Nigeria suggest ion exchange reaction between Ca^{2+} and Na^{2+}. Scholler index was positive in all the 50 locations (Table 7) and Versluys indices were less than, suggesting overall base-exchange reactions in groundwater aquifers in Nigeria. Na^+/Cl^- molar ratio suggest that some parts of Na^+ in groundwater across Nigeria was consequent of silicate weathering, because all the 50 locations have molar ratio less than 1. Groundwater in Nigeria is therefore, deficient in $Mg^{2+} + Ca^{2+}$ which is equivalent to Ca^{2+} - Na^+ cation exchange process.

As a result, groundwater may be soft in most locations. Further, about 38.5% have MH greater than 50. The implication is that some groundwater sources in Nigeria may not be suitable for irrigation because of possibility of magnesium hazard. The variability of chemical indices in groundwater across Nigeria is further illustrated in Figure 15.

Conclusion

Characterization of groundwater in SWSB showed Fe^{3+}, Mg^{2+}, PO_4^{3-} , SO_4^{2-} and Zn^{2+} concentrations are above WHO and NSDWQ reference guidelines. Groundwater in SWSB is slightly acidic in nature. The alkaline earths (Ca^{2+} and Mg^{2+}) significantly exceed alkali (Na^+ and K^+) and the strong acids (Cl^- and SO_4^{2-}) significantly exceed weak acid (HCO_3^- and CO_3). This results in to $Ca^-Mg^-HCO_3$ and mixed Mg-Na-K water types. Correlations between TDS and other ions, in addition to variations in TDS are indications of anthropogenic contributions to groundwater pollution. NO_3^- is the major contaminant of groundwater and it is derived from the River-Rima lying on the sedimentary section of the Sokoto Basin. Most of groundwater recharge in to the aquifers underlying SWSB comes from the Fadama areas where effluents are collected. Groundwater is suitable for irrigation use owing to low SAR and sodium percent. But there could risk of magnesium hazard in some locations. Overall, groundwater quality in urban SWSB is suitable for both domestic and irrigation uses.

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