ASSESSMENT OF GROUNDWATER VARIABILITY OVER DIFFERENT GEOLOGIC FORMATIONS ACROSS KEBBI STATE, NIGERIA

By

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ABSTRACT

This study attempts to assess the variability of groundwater composition over three different geologic units in Kebbi State. Nine (9) boreholes were purposively selected and studied. From each bore hole the lithology and water samples were analyzed. Boreholes from Southern Kebbi State (undifferentiated basement complex) were found to be composed of schist and granodiorite with some patches of clay formations. In contrast to this, the lithology of boreholes in Northern and Central Kebbi State is largely composed of sands, inter-bedded by clay formations. In general, lithology was found to differ from northern to southern parts of the study area. In Gwandu Formation, sodium was found to have the highest mean concentration (1081±2 mg/l). Bicarbonates (655l±2 mg/l) was found to be the outstanding parameter under Illo Formation. In undifferentiated basement complex, chloride is the major chemical parameter (498.3±2 mg/l). Sodium, chloride, zinc, magnesium and phosphates were found to be in excess of WHO and national standard for drinking water quality (NSDWQ) reference guidelines across the three geologic units. Whereas mean salinity, TDS, potassium, calcium, copper and iron were found to be within WHO and NSDWQ reference guidelines. The study concludes that the observed variability in physico-chemical composition of groundwater in the study area could be derived from the underlying rock formations, even though, other environmental factors such as climate, and land-use pattern, affect groundwater composition. This could only be explained by detailed studies that compare the effects of geology, climate, and land-use on groundwater quality over a wide range of spatial and temporal scales.

Key words: Geological Formation, Groundwater Composition, Kebbi State, Lithologic Log

INTRODUCTION

Demand for groundwater in Kebbi State has been increasing from a variety of users. Large amount of groundwater is exploited for a variety of uses from boreholes because of the relatively lower costs of construction and maintenance compared to surface water, which requires some forms of treatments. While the demands for groundwater have been increasing, the geochemical mechanism characterizing groundwater is yet to be fully understood (Hirihiko, et al., (2006). Generally, groundwater increases in mineral content as it moves along through the pores and fracture openings in rocks. This is why deeper, older waters can be highly mineralized (Datta, et al., 1987). At some point, the water reaches an equilibrium or balance, which prevents it from dissolving additional substances (Nwankoala, 2014).

Groundwater pollution caused by heavy metals from natural rock has become a serious issue and is widely noticed (Tekehiro, et al 2015). Chemical composition of groundwater is therefore, determined by a number of factors. These include the mineralogy of the rock types forming catchments or aquifers, land use practice, proximity to the coast, source of recharge water, soil type, aquifer structure and the time water has been underground away from atmospheric processes (Mayback, 1987). As groundwater moves along its path from recharge to discharge areas, a variety of hydro geochemical processes altered its chemical composition, (Gibbs, 1970). An understanding of the hydro geochemistry of groundwater is important for a sustainable development of water resources in semi-arid regions, like Kebbi State where groundwater recharge has been altered by changes in land-use and declines in annual rainfall.

Kebbi State, the study area is located within the Sokoto Basin which is mainly sedimentary in character with some outcrops of basement complex rocks in the south (Figure1). This gives Kebbi State two sets of geologic provinces (sedimentary and crystalline). The geologic variability is assumed to be translated in groundwater composition. This study seeks to investigate the spatial variability of groundwater composition as it relates to geologic variability. Many studies on groundwater quality were carried out in Kebbi State including: Labbo and Ogodulunwa (2007); Ojo, et al., (2014); Suleiman, et al., (2014); as well as Mohammed and David (2014). These studies were not hydro geochemical in nature and therefore, justifies the present investigation.

THE STUDY AREA

Location, size and climate

Kebbi State is located between latitudes 10^0 8' and 11^0 67' N; and longitudes 3^0 30'and 4.06' E. The State occupies a total land area of about 36,800 km².The climate is characterized by a long dry season lasting between the months of October and May with a short but intensive wet season between the months of May/June and September/October. Analyses of annual temperature pattern in Kebbi State have shown that for a period of 36 years (1975-2011) the mean maximum temperature in the State is over 30^0 C. Also, the mean minimum temperature for the study area is over 20^0 C (Wali, 2013)

Geology and Hydrogeology

The study area falls within the Sokoto Basin (Figure 1). It is one of the young (Mesozoic-Tertiary) inland cratanozoic sedimentary Basins of West Africa (Suleiman, et al., 2014). The sediments of the northern section of the study area include the Illo, Gundumi and Gwandu formations of cretaceous age. These sediments have been affected by a series of marine transgressions and were deposited during the three main phases of depositions (Kogbe, 1981). The first phase was during the continental period when Illo and Gundumi formations were deposited unconformably on the Pre-Cambrian Basement Complex. The Illo and Gundumi formations are made up of grits and clays, which form part of the Continental Intercalair of West Africa. The second phase began with the Maastrichtian transgression which continued into the Palaeocene (and resulted in the deposition of the Rima Group (Maastrichtian) and the Sokoto Group (Palaeocene). The third and the final phase began in early Eocene with the regression of the sea. Continental conditions prevailed while the Gwandu formation of Eocene to Miocene age was laid down. These Continental conditions continued to prevail until the present (Adeleye, 1979).

The sediments further dip gently and thicken gradually towards the northwest, with a maximum thickness of over 1,000 meters near Nigeria's frontier with Niger Republic and this provides a good prospect for possibility of petroleum resources in the area. Highly metamorphosed sediments occur at the boundary between the basement rocks and the cretaceous sediments. These metasediments consist of calc-silicate rocks, quartzite and high grade schist (Labbo and Ugodulunwa 2007). Boulders of rocks of the older granite suite are widespread in this area. Underlying the sedimentary rocks of the Sokoto Basin and rising to the land surface in the uplands to the south and east of the Basin are crystalline rocks of pre-cretaceous age. These include intrusive granite of igneous origin and deformed metamorphic rocks, chiefly gneiss, schist, hyalite, and quartzite. Groundwater in the upland areas of crystalline rocks (southern Kebbi State) is generally available in small quantities from fractures or other tabular partings and from the weathered rock (regolith) just beneath the land surface. The fractures are usually most open above a depth of 300 ft. but, even so, yields to boreholes are relatively low and cause high drawdown. Rocks of the Basement complex outcrop characterized the southeastern extremity of Kebbi state, this area extends from Koko hill through Yauri and Zuru axis (Henry and William, 1979).

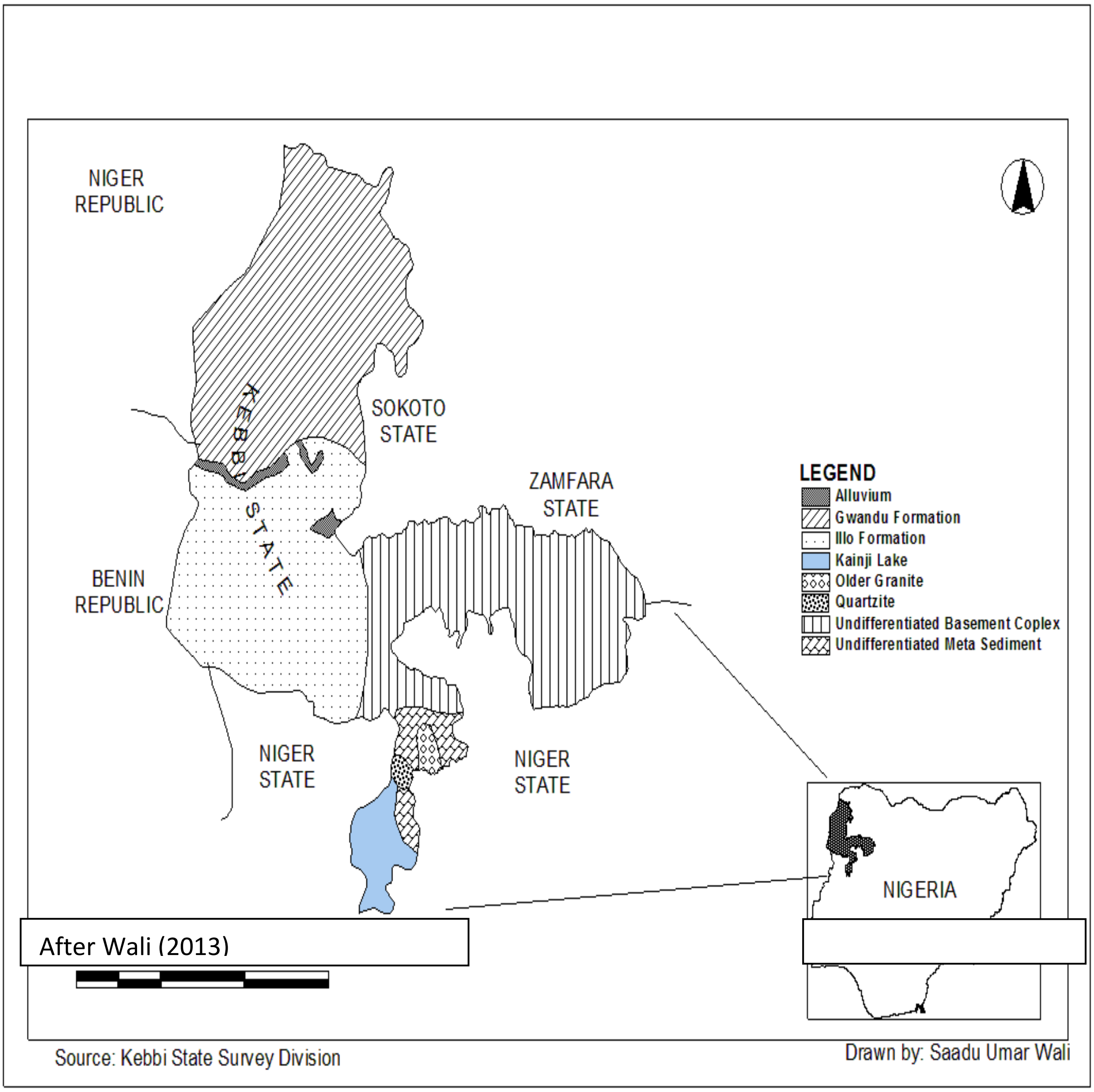


Figure 1: Geological Map of Kebbi State

MATERIALS AND METHODS

Procedure for Sampling and Laboratory Analysis

Three sampling sites were selected from each of the three geologic units, i.e. Gwandu, Illo and Undifferentiated basement complex respectively. Fieldwork/water sampling was carried out: on 15/10/2010in Malisa(BH001), Wuromaliki (Bh002) and Huda(BH003); in Kurugu (BH004), Zagga (BH005) and Kwasara (BH006) on 17/10/2016; and in Kamtu (BH007), Mahuta (BH007) and Amanawa (BH009) on 20/10/2016.The collected water samples (total 9) were analyzed both at the field (in situ) and in the laboratory. Table 1, summarizes field and laboratory methodologies employed in this study. Also contained in the table is WHO (2007) and National Standard for Drinking Water Quality (NSDWQ) 2011 referenced guidelines. Similarly, lithologic data were collected from the Department of Rural Water Supply and Sanitation (RWATSAN) Birnin-kebbi, summarized and presented in Table 2. Water samples were analyzed in Usmanu Danfodiyo University Chemical Laboratory Sokoto (26/10/2016).

Table 1, in this table are probably WHO standards for water for drinking and domestic use

S/NO	Parameters	Methods	Description	Detection limits	Reference Guideline	
					WHO (2007)	NSDWQ (2011)
1	Temperature(^oC)	Field(DKMsG01)	Temp/Salinity-meter	Celsius	Ambient	
2	Conductivity(EC)	Field(DIST)	Conductivity/TDS meter	µS/cm	1000	1000
3	pH	Field(pHep)		-	6.5-8.5	6.5-8.5
4	Salinity	Field(DIST)	Temp/Salinity-meter	-	5.0	5.0
5	TDS	"	Temp/Salinity-meter	Mg/l	0.5	0.5
6	Potassium (K^+)	Laboratory	ISEA/SJA	"	500	1000
7	Sodium (Na^+)	"	"	"	12	12
8	Chloride (Cl^-)	"	"	"	200	200
9	Bicarbonate ($HC03^-$)	"	"	"	250	250
10	Calcium (Ca^{2+})	"	"	"	500	500
11	Copper (Cu^{2+})	"	AAS	"	75	75
12	ion (Fe^{3+})	"	"	"	1.0	2.0
13	Zinc (Zn^{2+})	"	"	"	0.3	0.3
14	Magnesium (Mg^{2+})	"	"	"	3.0	4.0
15	Phosphates(PO_4^{3-})	"	"	"	0.2	0.2

Source: (Modified from Liu et al., 2003)

RESULTS AND DISCUSSION

Lithologic logs

Table 2, summarizes lithology of boreholes by geologic units and by sample sites. As can be seen from Bh001 iron stone (3 meters) overlay and extended clay layer (12 meters) [Figure 2a]. The clay was also underlain by sand and clay (8meters), which is separated from coarse sand (12 meters) by another clay layer (15meters). In Bh002, top soils (3meters) overlay a lateritic-clay (9meters), which is underlain by yellow-clay (15meters).

Table 2 Geologic Formations, Boreholes, Logs Interval and Lithology

S/NO	Logs Interval (meters)	Gwandu Formation			Illo Formation			Undifferentiated Basement complex		
		BH 001 Malisa(N12.39285º E004.71899º)	**BH002 W/Maliki (12.39285º E004.30519^{0})**	**BH003 Huda (N12.39285º E00.430519º)**	**BH004 Kurugu(N12.51560º E00.4.23758º)**	**BH005 Zagga(N12.56848º E004.114772º)**	**BH006 Kwasara (N12.52841º E00.41365º)**	**BH007 Mahuta (N11.55002º E005.0096º)**	**BH008 Kamtu (N11.58339º E004.85237º)**	**Bh009 Amanawa (N11.38078º E004.26003)**
1	0-3	Iron stone	Top soils	Top soils	Sandy top soils	Brown sand	Red sandy clay	Laterite	Top soil	Clay
2	4-6	Sandy and clay	Laterite and clay	Laterite	Sands tone and quartzite	"	"	Very highly decomposed schist	Highly decomposed schist	"
3	7-9	"	"	Clay with ironstone	"	Brown sandy clay	"	"	"	"
4	10-12	"	"	"	"	Coarse sand and ironstone	White sandy clay	"	"	Very highly decomposed schist
5	13-15	Clay	Yellow clay	Clay with sand	"	"	"	Highly decomposed granodiodiorite	Moderately decomposed schist	Highly to moderately decomposed schist
6	16-18	"	"	"	"	"	"	"	"	"
7	19-21	"	"	"	"	"	Red coarse sand	"	"	"
8	22-24	"	"	"	"	"	"	Moderately decomposed granodiorite	"	"
9	25-27	Clay and sand	"	Yellowish clay with iron stone	"	"	White coarse sand	" "	Poorly decomposed schist	Moderately decomposed schist
10	28-30	"	Iron stone	"	"	"	"		"	"
11	31-33	"	"	Yellowish c lay	-	-	"	Poorly decomposed granodiorite	"	"
12	34-36	"	Black clay	Coarse sand	-	-	"	"	"	"
13	37-39	"	Sand	"	-	-	-	Fresh granodiorite with soft schist zone	-	Highly decomposed schist with quartz veining
14	40-42	"	"		-	-	-	-	-	-
15	43-45	Soft clay	"	-	-	-	-	-	-	-
16	46-49	"	"	-	-	-	-	-	-	-
17	50-52	"	-	-	-	-	-	-	-	-
18	53-56	"	-	-	-	-	-	-	-	-
19	57-59	"	-	-	-	-	-	-	-	-
20	60-62	Coarse sand	-	-	-	-	-	-	-	-
21	63-65	"	-	-	-	-	-	-	-	-
22	66-68	"	-	-	-	-	-	-	-	-
23	69-71	"	-	-	-	-	-	-	-	-

Source: Department for Rural Water Supply and Sanitation (RWATSAN), Birnin-kebbi (2015) Key: BH=Borehole.

However, black clay (3meters) separates the iron stone from sand (12meters) [Figure 2b]. Similarly, top soil (3meters) overlay a literite (3meters) in Bh003. Clay with ironstone (3meters) occur between the clay-sandstone layer and another extended layer of clay with sand (12meters). Underlying the extended layer of clay and sand is yellowish clay with iron stone (6meters). Below this formation is another layer of yellow clay (3meters) which separates the iron stone with coarse sand (9meters) [Figure 2c]. Lithology of boreholes from Gwandu formation is largely characterized by clay and sand.

Similarly, the Illo Formation like Gwandu is composed of sands and clay. Figure 4d, illustrates the lithologic characteristic of BH004.As can be seen, sand (3meters), overlay sand stone (27meters) in Bh004 (Table 2). In contrast, top soil layer in Bh05 is composed of brown sand (6meters), which overlays coarse sand (21meters) [Figure 2e]. Unlike, in Bh004 and Bh005, in Bh006, the top soil is made up of red sandy-clay (9meters). Below this layer is white sandy-clay (9meters), separating the top soil from a red coarse sand (6meters). The red sand is underlain by an extended layer of white coarse sand (21 meters) [Figure 2f]. The large proportion of sands and clay found in both Gwandu and Illo formations indicates that the two geological formations have similar lithological characteristics. This finding is similar to Offodile (2002) who state that, Gwandu and Illo formations are similar in lithological characteristics, only that the former is a lateral equivalent of Gundumi formation.

In the basement complex zone, of Kebbi State, sands and clay do not constitute any significant portion of the sub surface rocks formation. In Bh007, laterite (3meters) formed the top soil, which overlay very highly decomposed schist (9meters). The decomposed schist was also underlain by highly decomposed granodiorite (9meters). Following the highly decomposed granodiorite is moderately decomposed granodiorite (9meters). Just below the poorly decomposed granodiorite, is fresh granodiorite with soft schist zone (3meters). This is further illustrated in Figure 2g. Unlike Bh007, the surface layer in Bh008, is covered by topsoil (3meters), which separates highly decomposed schist (9 meters) from moderately decomposed schist (12 meters). Underlying the moderately decomposed schist is poorly decomposed schist (12 meters) [Figure 2h]. Clay formation (9 meters) overlay very highly decomposed schist (3 meters) in Bh009 [Figure 2i]. Moderately decomposed schist (12 meters) underlay the very highly decomposed schist. However, these layers are also underlain by 12 meters of moderately decomposed schist. Highly decomposed schist with quartzite veining (3 meters) occur below the schist layers.

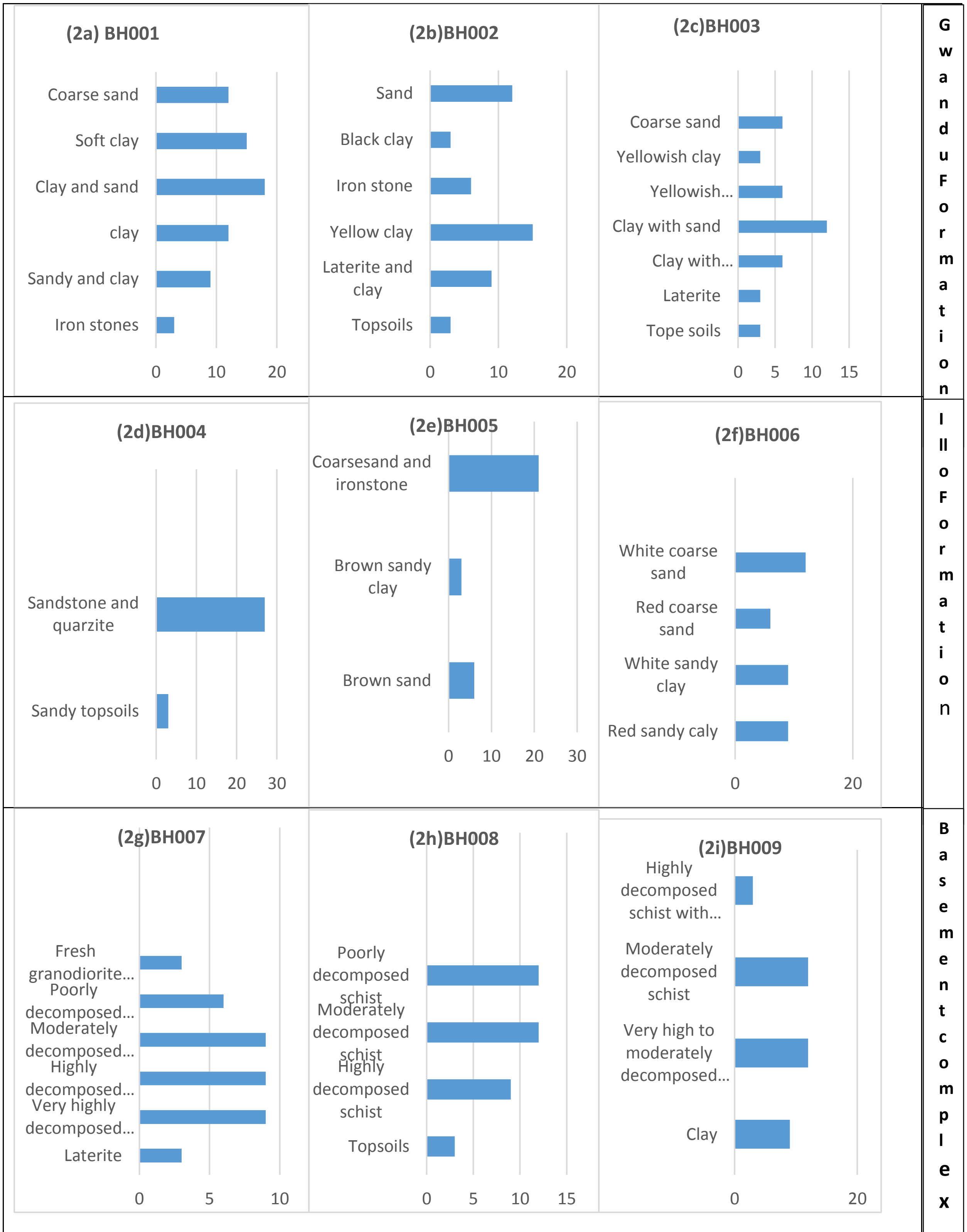


Figure 2a-i Variability of Lithologic logs across Geologic Units in the Study Area
Source: Author(2016) Note: Units are in meters (m)

In general, the lithological characteristics of undifferentiated basement complex is largely composed of granodiorite and schist (Table 2). This finding is similar to Henry and William, 1973(see page 52). As can be seen from Figures 2a-i, while lithologic logs in Gwandu and Illo formations are primarily sandy, logs under undifferentiated basement complex, are mainly composed of poorly to very highly decomposed granodiorite and schist. In the same vein, depth of boreholes reduces from Northern to Southern parts of the study area. This finding is similar to Henry and Williams (1973).

Physico-chemical Parameters

Table 3, summarizes the physico-chemical characteristics of groundwater over three geologic units in the study area. Chloride, sodium, TDS and iron were found to be the major parameters characterizing groundwater in Gwandu formation (Figures 3d, f, g & l). In Illo formation, bicarbonates, calcium, copper and potassium, were found to be the dominant parameters (Figures 3e, h, i& k). In contrast, pH, zinc and phosphates were found to be the major parameters which characterize the groundwater in undifferentiated basement complex (Figures 3c, j & n). These findings showed that, groundwater quality in Kebbi State, shares some degree of similarity in composition despite the State's geologic differences. Table 4 presents mean values of groundwater physico-chemical parameters by geologic formations and by location of boreholes. The outstanding parameters are sodium (1081±2 mg/l), bicarbonates (655±2 mg/l) and chloride (498.3±2mg/l) for Gwandu, Illo and Basement complex respectively.

Chloride concentrations at levels above 250 mg/l, water will begin to taste salty and becomes increasingly objectionable as the concentration rises further. However, external circumstances govern acceptability and in some arid areas waters containing up to 2000 mg/l Cl are consumed, though not by people unfamiliar with such concentrations. High chloride levels may similarly render fresh water unsuitable for agricultural irrigation EPA, 2001(see page 38). Chloride does not pose a health hazard to humans and the principal consideration is in relation to palatability. Therefore, the observed high concentrations of chloride in Gwandu formation present no health or sanitary concern. Bicarbonates in conjunction with calcium and magnesium forms carbonate hardness. Bicarbonate and carbonate ions combined with calcium or magnesium will precipitate as calcium carbonate ($CaCO_3$) or magnesium carbonate ($MgCO_3$) when the soil solution concentrates in drying conditions.Bicarbonates is associated with increases in Copper and Calcium concentrations.

Table 3 Physico-chemical Characteristics of Groundwater samples across the Study Area.

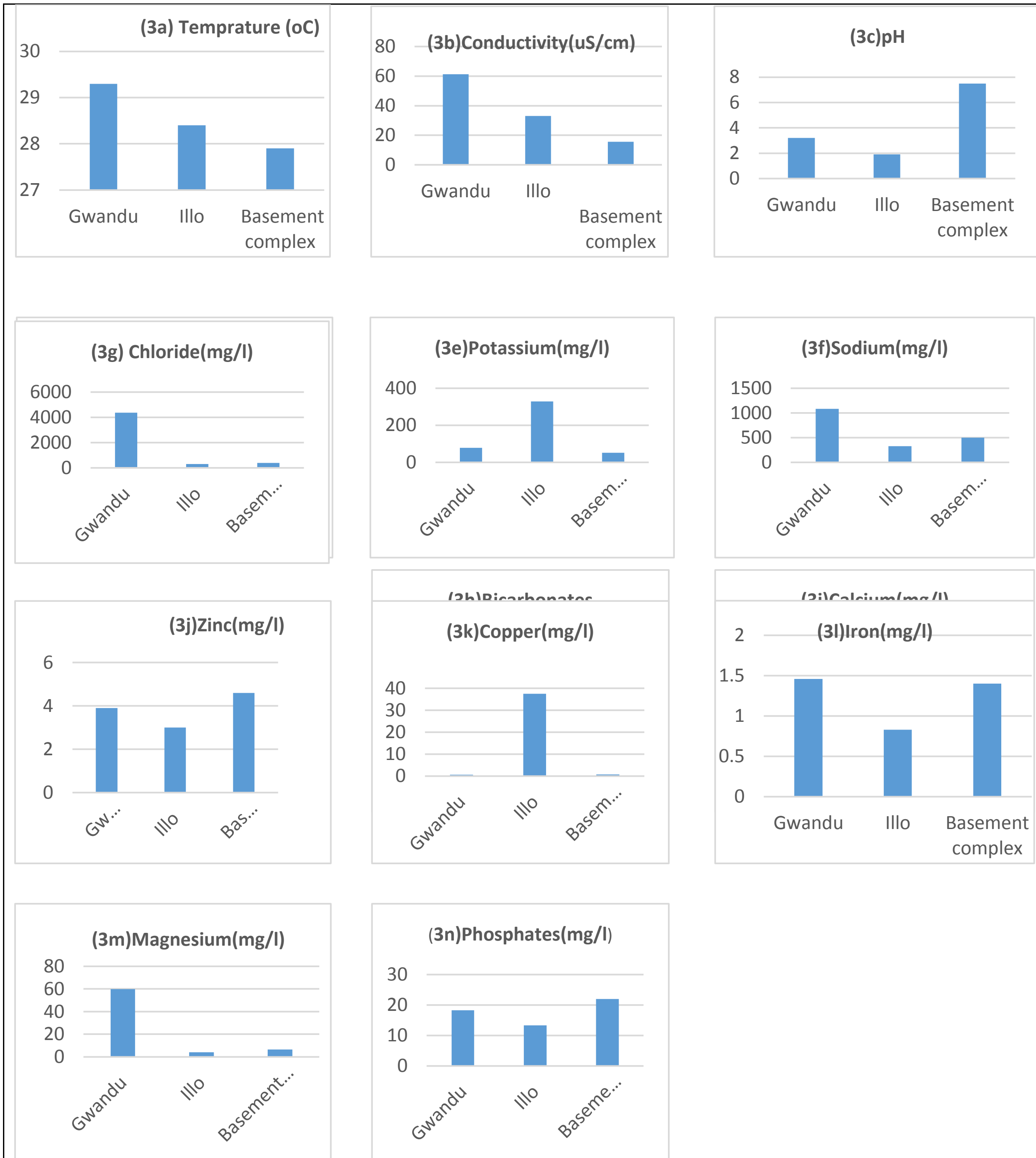
S/NO	Formation	Location	WD (meters)	Temp. ºC	EC (uS/cm)	pH	SAL. (mg/l)	TDS (mg/l)	K^+ (mg/l)	Na^+ (mg/l)	Cl^- (mg/l)	HCO_3^- (mg/l)	Ca^{2+} (mg/l)	Cu^{2+} (mg/l)	Fe^{3+} (mg/l)	Zn^{2+} (mg/l)	Mg^{2+} (mg/l)	SO_4^{3-} (mg/l)
001		**Malisa**	71	30.1	167	5.2	3.0	174	39	851	9159	244	210	0.3	1.0	3.1	6.0	24
002	**Gwandu Formation**	**Wuromaliki**	49	27. 9	15.0	1.9	0.2	220	78	437	355	122	17	1.1	1.3	4.3	23	11
003		**Huda**	39	28.5	2.0	2.5	0.0	10.0	117	1955	3586	61	4.0	0.3	2.1	4.2	150	20
004		**Kurugu**	30	29.4	82.0	0.00	9.2	0.7	910	39	460	1598	244	111	0.4	2.1	3.2	3.0
005	**Illo Formation**	**Zagga**	30	26.7	3.4	2.8	0.1	370	39	529	213	244	16	1.1	1.0	6.2	5.0	1.0
006		**Kwasara**	36	29.1	14.0	2.8	0.0	150	39	414	213	122	17	0.5	1.1	0.7	4.0	36
007		**Kamtu**	39	28.0	24	7.7	0.2	270	78	598	888	61	51	0.3	0.5	6.3	14	22
008	**Undifferentiated Basement Complex**	**Mahuta**	36	30.7	16	7.8	0.1	220	39	552	249	244	30	1.6	2.0	4.1	3.0	22
09		**Amanawa**	39	25.1	7.0	7.0	0.1	150	39	345	71	244	28	0.4	1.7	3.2	3.0	22

Source: Author (2015) Key: WD = Well depth.

Table 4 Mean Concentrations of Groundwater Physico-chemical Parameters across the Study Area.

Parameter / Formation	Temp. ºC	EC (us/cm)	pH	SAL. (mg/l)	TDS (mg/l)	K^+ (mg/l)	Na^+ (mg/l)	Cl^- (mg/l)	HCO_3^- (mg/l)	Ca^{2+} (mg/l)	Cu^{2+} (mg/l)	Fe^{3+} (mg/l)	Zn^{2+} (mg/l)	Mg^{2+} (mg/l)	SO_4^{3-} (mg/l)
Gwandu	29.3±1	61.3±2	3.2±0.5	1.066±0.1	656.6±2	78±2	1081±2	4366.6±2	142.33±2	77±2	0.56±0.5	1.46±0.1	3.86±0.5	59.66±1	18.33±2
Illo	28.4±1	33.13±2	1.86±0.5	3.1±0.1	173.56±2	329.3±2	327.3±2	295.3±2	654.6±2	92.3±2	37.5±0.5	0.83±0.1	3.0±0.5	4.06±1	13.33±2
Basement complex	27.9±1	15.6±2	7.5±0.5	0.1±0.1	213±2	52±2	498±2	402±2	183±2	36±2	0.7±0.5	1.4±0.1	4.5±0.5	6.6±1	22±2

Source: Author (2015)



Figures 3a – n Variability of Groundwater Physico-chemical Parameters across the Study Area (Temperature, Electrical conductivity, pH, TDS, Potassium, Sodium, Chloride, Bicarbonates, Calcium, Zinc, Copper, iron, Magnesium and Phosphates) across Gwandu, Illo and Basement Complex Formations
Source: Author (2016)

Despite the potential benefits of calcium abundance there are problems associated with hardness. Bicarbonates in combination with calcium and magnesium forms carbonate hardness. Hardness is a natural characteristic of water which can enhance it palatability and consumer acceptability for drinking purpose. Health studies in several countries in recent years indicate that mortality rates from heart diseases are lower in areas with hard water (EPA, 2001). Sodium on the other hand is always present in natural waters, it is an essential dietary requirement and normal intake is as common salt (sodium chloride) in food. The reason for limiting it is the joint effect which it exercises with sulphates. In addition, too excessive intake of sodium chloride is associated with hypertension (EPA, 2001).

Compliance with WHO and NSDWQ Reference Guidelines

Groundwater in Gwandu and Illo formations were found to be acidic. Mean pH is thus: 3.2±0.5; and 1.86±0.5 for Gwandu and Illo formations respectively and the concentration levels fall below WHO and NSDWQ reference guidelines. pH concentrations value of 7 for instance, represents neutral conditions, while pH values greater than 7 indicate basic (or alkaline) conditions and pH values less than 7 indicate acidic conditions (EMER, 2016). Acidity in water is may cause gastro-intestinal problems to humans. In contrast to this, in the Basement complex the mean pH (7.5±0.5) was found to be within WHO and NSDWQ reference guidelines. In the same vein, the concentrations levels of sodium, chloride, zinc, magnesium and phosphates were found to be to in excess of WHO and NSDWQ reference guidelines for drinking water quality across the three geologic units (Tables 1&2). Similarly, Bicarbonates was found to be in excess of WHO and NSDWQ reference guidelines in Illo formation. While, mean salinity, TDS, potassium, calcium, copper and iron were found to be within WHO and NSDWQ reference guidelines, the observed high concentrations of some of these physico-chemical parameters, in the study area presents no health or sanitary problems. Only that a continuous rise in concentrations of some certain parameters e.g. chloride is indication of pollution from sewage. Because an increase of 5 mg/l in at one point may give rise to suspicions of sewage discharge, especially if the free ammonia levels (q.v) are also elevated (EPA, 2001)

CONCLUSION

An investigation of groundwater variability from different geologic units in Kebbi State revealed that groundwater composition across the study area showed a wide range of spatial variability over the three geologic units. In Gwandu formation the mean concentration of chloride is (1081±2mg/l), while bicarbonates (655±2mg/l) have highest concentration level under Illo formation. However, in undifferentiated basement complex, sodium is outstanding parameter (498±2mg/l). Although, the mean concentrations of these outstanding parameters are relatively high, it presents no health or sanitary problem in the study area. In the same vein, mean concentrations of sodium, chloride, zinc, magnesium and phosphates were found to be to in excess of WHO and NSDWQ reference guidelines for drinking water quality across the three geologic units. In contrast, mean salinity, TDS, potassium, calcium, copper and iron were found to be within WHO and NSDWQ reference guidelines. While salinity is an indicator of TDS, the former varies with type of aquifer materials, solubility of minerals and contact time. Where TDS are high, water may be saline, but salinity however, increases with decreased groundwater movement and rises with depth of water table, (Todd and Larry 2005). The study concludes that, the observed variability in physico-chemical composition of groundwater in the study area could be derived from the variability of the underlying rock formations, across the study area. The observed excessive concentrations of physico-chemical parameters, also present no health or sanitary concern. However, the observed variability in groundwater composition in the study area, could be influenced by climate, land-use and time, and this could only be explained by detailed studies that compare the effects of climate, land-use and geology on groundwater composition over wide range of spatial and temporal scales.

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REFERENCES

Adeleye, D. R. (1979). A review of Maastritchian paleogeography of the southern Iullemmeden and Nupe Basins. *Nigeria Journal of Mining and Geology*.1, pp. 10-14.

Artimes, G.D., Ramin, S., and Ngaraju, D. (2011). Hydro geochemical and rock water interaction in East of Kurdistan, N-W of Iran. *International Journal of Environmental Research.* 1, (1), pp16-22.

Datta, P.S. and Tyagi, S.K. (1996). Major ion chemistry of groundwater in Delhi area: Chemical weathering processes and groundwater flow regime. *Journal of Geological Society.* India. 47, pp179–188.

EPA (2001). Parameters of water quality: Interpretation and standards. The Environmental Protection Agency. Johnstown Castle, Co. Wexford, Ireland.

EMER (2016). Environmental monitoring, evaluation and reporting Agency.*Water Quality Indicators: Temperature and Dissolved Oxygen.* Alberta: Alberta.

Gibbs, R. J. (1970). Mechanism controlling world water chemistry. *Science*.17, pp 1088–1090.

Henry, A. and William, O. (1973). Aquifers in the Sokoto Basin, Northwestern Nigeria, with a description of the general hydrogeology of the region. Geological Survey of Nigeria under auspices of the USAID. Paper 1757-L.

Hirohiko, K., Naotatsu, S., Yasumasa, O., Yasunori, H., Makiko, T., and Yuko, T. (2006). Mineral and biological Influences on groundwater chemistry of the Boso Peninsula, Chiba, central Japan: Implications for the origin of groundwater in sedimentary basins. *Geochemical Journal*. 40, pp 345-361.

Kogbe, C. A. (1980). Cretaceous and tertiary of the Iullemmeden Basin in Nigeria (West Africa) *Cretaceous Research*. 2, pp 129-186.

Labbo, A.Z. and Ugodulunwa, F.X.O. (2007). An Interpretation of total intensity of aeromagnetic maps of sart of Southern Sokoto Basin. *Journal of Engineering and Applied Sciences.* 3, (1), pp 15-20.

Liu, W., Lin, K. and Kuo, Y. (2003). Application of factor analysis in the assessment of groundwater quality in a Blackfoot disease area in Taiwan. *The Science of the Total Environment.* Elsevier Science B.V. Vol. 313 pp 77-89.

Mayback, M., (1987). Global chemical weathering of surficial rocks estimated from river dissolved loads. *American Journal of Science.* 28, (7), pp 401–428.

Mohammed, N. B. and David, N.J. (2014). Analyses of flood risk inundation hazard Birnin-kebbi Town, Kebbi State, Nigeria. *International Journal of Geomatics and Geosciences.*5 (1), pp 119-131.

Nwankoala, H.O. (2014). Hydrogeology of and groundwater resources of Nigeria. *New York Science Journal*. 8, No. 1, pp 89-100.

Offodile, M.E. (2002). *Groundwater Study and Development in Nigeria*. Mecon Geo &Eng., Ltd, Nigeria.

Ojo, O.I., Graham, W.B.R. and Pishiria, I.W. (2014). Environmental implications of groundwater quality in Irrigated agriculture in Kebbi State Nigeria. *Civil and Environmental Research*. 6 (9), pp 21-28.

Suleiman, T., Udeni, E.E., and Muhammed, S.B. (2014). Analyses of aeromagnetic data across Kebbi State, Nigeria. *International Journal of Marine, Atmospheric and Earth Sciences.* 2, (1), pp 41-51.

Takehiro, O., Shuichi, H., Yohihiro, K., and Dai, S. (2015). Influence of mineral assemblage to form the groundwater quality in altered rock area. Conference Paper, Presented at 10th Asian Regional Conference of IAEG.

Todd D.K., and Larry, M. (2005). *Groundawter Hydrology.* Third Edition, River street Hoboken: John Welle and Son inc. USA.

Wali, S.U. (2013). *Impact of physiography on groundwater levels in Kebbi State, Nigeria*. Unpublished MSc Dissertation. Department of Geography, Usmanu Danfodiyo University Sokoto. Nigeria.