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Assessment of Shallow Ground Water Quality of Pindiga Gombe Area, Yola Area, NE, Nigeria for Irrigation and Domestic Purposes

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Abstract: The aim of this study is to assess the shallow groundwater quality of Pindiga Gombe area for irrigation and domestic purposes. Fifteen water samples collected from wells tapping shallow aquifer was used. The water samples were analyzed for major cations: Na^+, Ca^{2+}, K^+ and anions: Cl^-, HCO_3^{-1}, SO_4^{2-} and NO_3^-. The important constituents that influence the water quality for irrigation such as Electrical Conductivity (EC), Total Dissolved Solids (TDS), Sodium Adsorption Ratio (SAR), Magnesium Adsorption Ratio (MAR), Permeability Index (PI), Kellys Ratio (KR), and Residual Sodium Bicarbonate (RSBC) were assessed and compared with standard limits. The values of total dissolved solids (<166 mg/L), electrical conductivity (<0.249 ds/m), soluble sodium percentage (2.60 to 38.40%), permeability index (0.19 to 7.40%), magnesium adsorption ratio (37.34 to 66.50%), kellys ratio (0.0004 to 0.029 meq/L), residual sodium bicarbonate (0.35 to 3.02 meq/L) and sodium adsorption ratio (0 to 0.035) were found to be within the safe limits and thus largely suitable for irrigation purposes. The groundwater will thus neither cause salinity hazards nor have an adverse effect on the soil properties of the study area. Furthermore, the water samples also fall within the recommended limits and are found suitable for domestic purposes.

Key words: Electrical conductivity, Gombe, groundwater, Nigeria, water quality

INTRODUCTION

The sources of water supply to the area are through hand-dug wells, boreholes and surface water. These sources of water supply especially from the hand-dug wells and surface water are polluted due to human activities. These activities includes the use of pit latrines by most resident and indiscriminate dumping of house hold solid waste which contribute to the contamination of water from different sources in the study area.

Most of the hand-dug wells are shallow and often left open that renders the well susceptible to contamination by surface water during heavy rainstorms (precipitation) as well as human activities. This unfortunate situation has led to the prevalence of water borne diseases. It is against this background that the physico-chemical assessment of shallow groundwater of Pindiga Gombe area is being carried out. Based on the study recommendation that will serve, as useful guide in arresting the situation will be made.

In order to achieve the above objective different indices for irrigation uses such as Sodium Adsorption Ratio (Sar), Soluble Sodium Percentage (Ssp), Residual Sodium Bicarbonate (RSBC), Electrical Conductivity (EC), Magnesium Adsorption Ratio (MAR), Kellys Ratio (KR), Total Dissolved Solids (TDS) and Permeability Index (PI) were calculated from standard equations and employed to assess the suitability of groundwater for irrigation purposes in the study area.

Location, description and accessibility of the study area: The area of study is part of Futuk sheet 172 NE located in Akko area (Pindiga village) of Gombe state, Northeastern, Nigeria. It is situated at the Southwestern part of Gombe and lies between latitudes N 9º50′ and N10º00′ N and longitudes E 10º50′ and E 10º59′E, (Fig. 1). It covers an areal extent of about 50 km^2 on a map of scale 1:50 000.

Prominent villages within the study area include Sumbe, Garin Dawa, Garin Alkali, Tudun Wada, and Pindiga. The area is accessible by a few Motor able roads and a network of footpaths. The major road to the main town is the Gombe - Kashere, and the road junction along Gombe - Yola main road. The adjoining villages are linked to the main town Pindiga by motorable untarred roads.

The study area is characterized by two prominient topographic features-the highlands that occupy the west to the northwestern part with an elevation of about 420-606 m above main sea level and the low lands. These high topographic expressions correspond to areas underlain by the Gombe Formation. The Pindiga Formation underlies the lowlands, which form Eastern and Northern part of the area.

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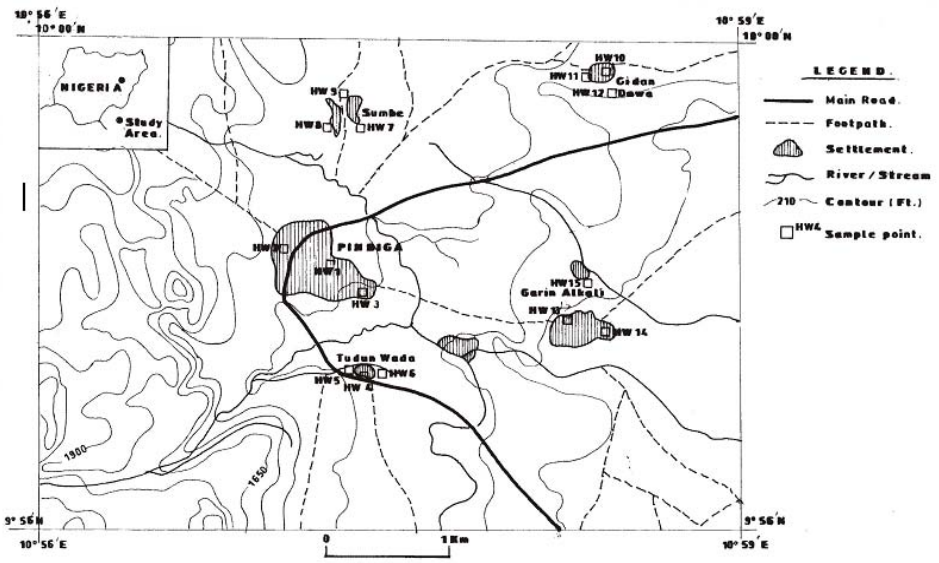

Fig. 1: Topographical map of the study area showing sample locations

The drainage pattern is dendritic with Pindiga as the main channel stream and its tributaries (Sabun Kaura, Sumbe and Garin Alkali tributaries) which all have their sources from the hilly site and subsequently joined the mainstream channel East of Pindiga town. The rivers are virtually seasonal and the general direction of flow is SW, NW-SE (Fig. 1).

Vegetation: The study area falls within the semi-arid zone and is characterized by alternating wet and dry season. The highest daily temperature is about 38ºC which corresponds to the hottest period usually experienced in the months of March to April and the months of December to January are usually very cold with temperature as low as 25ºC. The dry season falls between October and April while the rainy season that is controlled by two contrasting wind systems (A warm and wet wind and dry and cold wind) starts from May to September. The vegetation in the area is a typical guinea savannah characterized by high shrubs intervened with tall trees like mango, nym, local bean etc. These trees are dense in the southwestern part of the area and concentrated mainly along valleys and river/stream channels. The farmlands are very dry and consist of large extent of sand ridges where subsistence agriculture is practiced. The food crops grown in the area include maize, millets, guinea corn, beans, bambaranut and cassava. Another important activity is cattle and sheep rearing practiced by the Fulani. The other inhabitants of the area are Jukun, Kanuri, Hausa and home Fulani who are engaged in farming and trading.

Geology of the area: The study area has a relatively simple geology. The Formations encountered in the area are Pindiga Formation and Gombe Formation (Fig. 2).

The Pindiga Formation covers large area of the study area (about 65%) starting from the Western boundary near the Pindiga hills to the Eastern and Northeastern part of the area. The Pindiga Formation was observed at different locations along the river channels that cross cuts the Pindiga Formation, the stratification displayed is an intercalation of mudstone (shale) and limestone, which are overlain by a thick stratum consisting entirely of shaly mudstone that is dark grey in colour. The member of the Pindiga Formation seen here is the Kanawa member. This member is observed to consist of shales and limestone. Irregular thin lenses and discontinuous layers of diagenetic gypsum also occur in the Formation. Fossils imprints like Ammonites, Bivalves and Ostrea are also characteristics of the Formation. Bioturbated Oolite Ironstone beds lying at the top of the Formation marked the boundary between Pindiga and Gombe Formations.

The Gombe Sandstone formed the rest portion of the study area covering from hilly topography (Pindiga hill) to western border and northwestern part of the area around Sumbe and Garin Dawa, it is also exposed in the eastern part of the area northward of Garin Alkali.

The Gombe Formation is characterized by hilly and rugged terrain due to the high resistance of ironstones to weathering. It shows rapidly alternating sequence of silty shale and fine to medium-grained sand stone at the base with intercalated thin flaggy ironstone (Reyment, 1965). Individual beds vary in thickness between 1.5 to 3.5 m. Around Sumbe stream well bedded Gombe Formation with few intercalations of silty shale. The beds of the Gombe Formation were observed to show variable textures-concave massive beds at the base overlain by thin

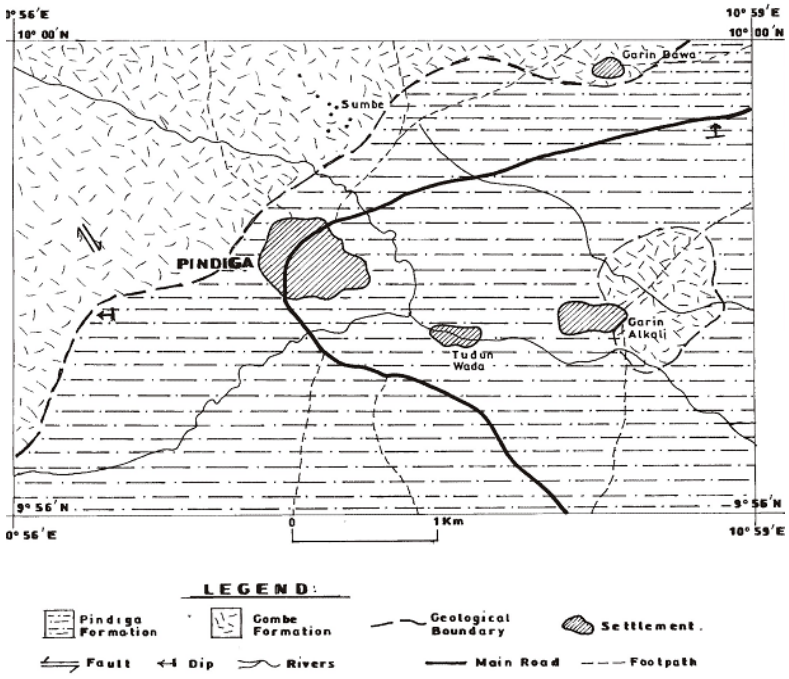

Fig 2: Geological map of study area

Table 1: The depth to static water level of wells in the study area with elevation and grid locations

Location	SWL (m)	Elevation	Longitude	Latitude
Pindiga 1	15.4	480 m	09º59′02.4″	010º57′13.3″
Pindiga 2	8.4	475 m	09º58′53.8″	010º57′ 08.4″
Pindiga 3	7.6	472	09º58′54.7″	010º57′12.2″
Tudun Wada 1	7.3	474 m	09º58′36.9″	010º57′12.8″
Tudun Wada 2	10.6	483 m	09º58′36.1″	010º57′21.0″
Tudun Wada 3	8.2	465	09º58′30.8″	010º57′26.4″
Sumbe 1	25.8	482 m	09º59′33.2″	010º57′23.8″
Sumbe 2	32	487 m	09º59′37.2″	010º57′22.5″
Sumbe 3	27	494	09º59′ 45.4″	010º57′ 15.5″
Garin Dawa 1	9.6	481	09º59′52.6″	010º57′55.5″
Garin Dawa 2	7.2	473 m	09º59′56.1″	010º57′53.8″
Garin Dawa 3	12.4	493	09º59′59.4″	010º57′48.6″
Garin Alkali 1	17	407 m	09º58′48.6″	010º58′18.9″
Garin Alkali 2	5.3	411 m	09º58′51.6″	010º58′10.4″
Garin Alkali 3	8.6	417	09º58′56.3″	010º58′14.8″

The average depth to water table (SWL) in this area is 13.5 m

laminated silty clays that thin out along their lateral extent as an indication of changing conditions in the environment of deposition. The uppermost part of the Gombe Formation is highly ferruginized around Pindiga hill.

Hydrogeology of the study area: Many people in the area have private hand-dug wells or deep boreholes that tap shallow alluvial aquifers to depth of 1 to 31 m, respectively for drinking and other domestic purposes (Table 1). Figure 1 indicates well locations in the study area.

Irrigation boreholes typically tap both aquifer systems. Deep boreholes are however less common than hand-dug wells especially in rural areas. The shallow aquifer occur in the recent alluvial sediments consisting of gravels, sands, silts and clays whereas the deep aquifers occur in the underlying fine to coarse grained Gombe Sandstone Formation.

To safeguard the long-term sustainability of the groundwater resources the quality of the water needs to be continuously monitored (Raihan and Alam, 2008). In view of this, an attempt has been made to analyze the groundwater quality of the study area to determine the exact level of physicochemical parameters with special emphasis on its irrigation suitability for sustainable crop production.

LITERATURE REVIEW

A few number of literatures are available regarding the assessment of groundwater quality data based on different irrigation indices in different areas of the world (Quddus and Zaman, 1996; Talukder *et al*., 1998; Shahidullah *et al*., 2000; Sarkar and Hassan, 2006; Raihan and Alam, 2008).

Quddus and Zaman (1996) studied the irrigation water quality of some selected villages of Meherpur district of Bangladesh and argued that some of the following ions such as calcium, magnesium, sodium, bicarbonate, sulphate, chloride, potassium, boron and silica are more or less beneficial for crop growth and soil properties in little quantities.

Talukder *et al*. (1998) reported that poor quality irrigation water reduces soil productivity, changes soil physical and chemical properties, creates crop toxicity and ultimately reduces yield.

Shahidullah *et al*. (2000) assessed the groundwater quality in Mymensigh district of Bangladesh and observed a linear relationship between SAR and SSP. They also discovered that the groundwater can safely be used for long-term irrigation. Sarkar and Hassan (2006) investigated the water quality of a groundwater basin in Bangladesh for irrigation purposes and observed that standard water quality indices like pH, EC, SAR, RSBC, MAR, PI, KR, and TDS are within the acceptable range for crop production. Raihan and Alam (2008) presented a pictorial representation of groundwater quality throughout the Sunamganj district that allowed for delineation of groundwater based on its suitability for irrigation purposes.

Finally Obiefuna and Orazulike (2010) carried out similar work in Yola area of Northeast Nigeria which indicated that the groundwater of the area is largely suitable for irrigation purposes.

METHODOLOGY

Water samples (15) which were collected from shallow hand-dug wells of Pindiga Gombe area of Northeastern Nigeria were subjected to chemical analyses between August and September 2010. Sample collection was aimed at covering and representing the lateral and vertical extent of the hydrostratigraphic units within the study area. Sample locations and numbers are plotted in Fig. 1 to display their spatial distribution in the different aquifers.

The samples from the deep wells in which pumps are already installed, were collected after a 2 h of pumping and the screen interval of the well represents the average sample depth. Samples from the shallow hand-dug wells were bailed, using a stainless steel bailer, from a depth of a 2 m below the water table, which more or less indicates the sample depth (Abdalla, 2009). The samples were collected in 1000 mL plastic bottles and field filtration was carried out through filter papers (0.45 μm) to remove suspended solids. They were then carefully sealed, labeled and taken for analyses. Chemical analyses were performed in the laboratory of the Adamawa State Water Board Yola, Nigeria between August and September 2010 employing standard methods, Atomic Absorption Spectrophotometry for cations and conventional titration for anions. Ions were converted from milligram per litre to milliequivalent per litre and anions balanced against cations as a control check of the reliability of the analyses results. The analytical results were compared with the standards specification (WHO, 2006).

The Sodium Adsorption Ratio (SAR) was calculated by the following equation given by Richards (1954) as:

$$SAR = \frac{Na^{+}}{\sqrt{\left(\frac{Ca^{2+} + Mg^{2+}}{2}\right)}} \quad (1)$$

where all the ions are expressed in meq/L.

The Soluble Sodium Percentage (SSP) was calculated by the following equation (Todd, 1995):

$$SSP = \frac{\left(Na^{+} + K^{+}\right) \times 100}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \quad (2)$$

where, all the ions are expressed in meq/L.

The Residual Sodium Bicarbonate (RSBC) was calculated according to Gupta and Gupta (1987):

$$RSBC = HCO_3^{-} Ca^{2+} \quad (3)$$

where, RSBC and the concentration of the constituents are expressed in meq/L.

The Permeability Index (PI) was calculated according to Doneen (1964) employing the following equation:

$$PI = \frac{Na^{+} + \sqrt{HCO_s^{-} \times 100}}{Ca^{2+} + Mg^{2+} + Na^{+}} \quad (4)$$

where, all the ions are expressed in meq/L.

The Magnesium Adsorption Ratio (MAR) was calculated using the following equation (Raghunath 1987):

$$MAR = \frac{Mg^{2+} \times 100}{Ca^{2+} + Mg^{2+}} \quad (5)$$

where, all the ionic constituents are expressed in meq/L.

The Kellys Ratio was calculated employing the following equation (Kelly, 1963) as:

$$KR = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}} \quad (6)$$

where, all the ionic constituents are expressed in meq/L.

The Total Dissolved Solids (TDS) was calculated employing the following equation (Richards 1954):

TDS = (0.64 x EC x 106 (Micro-mhos/cm) (7)

Where Electrical Conductivity (EC) and TDS are expresses inμ-mhos/cm and mg/L, respectively.

RESULTS AND DISCUSSION

Assessment of physicochemical qualities of groundwater: Geochemical properties and principles that govern the behavior of dissolved chemical constituents in groundwater are referred to as hydrogeochemistry. The dissolved constituents occur as ions, molecules or solid particles, these constituent not only undergo reactions but also redistribution among the various ionic species or between the liquid and solid phases. The chemical composition of groundwater is related to the solid product of rock weathering and changes with respect to time and space. Therefore, the variation on the concentration levels of the different hydrogeochemical constituents dissolved in water determines its usefulness for domestic, industrial and agricultural purposes.

However, the use of water for any purpose is guided by standard set by the World Health Organization and other related agencies. In this study, the results of the analyzed chemical parameters in the study area were correlated with those of the World Health Organization (WHO, 2006).

The analyzed physical parameters are Temperature, pH, EC and TDS. Results show that the temperature of the sampled water ranged between 23.0 to 31ºC with mean value of 28.34ºC, the least value was recorded in Sumbe (HW8) and the highest value in Garin Alkali (HW15), pH ranged between 5.1 and 8.2, with the mean value of 6.01, the least value was recorded in Garin Alkali (HW15) and the highest value in Tudun Wada (HW5), EC ranged between 67.5 and 249 μs/cm with the mean value 132.42 μs/cm, where the least and high value found in Pindiga (HW1) and Sumbe (HW8) respectively, and TDS ranged between 45 to 166 mg/L with means value 88.25 mg/L where the least and high value were found in Pindiga (HW1) and Sumbe (HW8), respectively.

The chemical parameters analyzed were the major cations and anions. The major cations include Mg^{2+}, Ca^{2+}, Fe^{2+}, Na^{+} and K^{+}. The major anions include Cl^{-}, HCO_3, NO_3^{-} SO_4^{2-} and CO_3^{2-}. Their concentrations vary from one settlement to the other depending on the local geology of the area and other human related factors.

The results of these chemical parameters show that the Mg^{2+}, ranged between 7.78 and 58.98 mg/L with the mean value of 30.13 mg/L, the least value recorded in Sumbe (HW8) and the high value in Tudun Wada (HW5), Ca^{2+}, ranged between 18.07 and 63.76 mg/L with the mean value of 34.17 mg/L, where the lowest value found in Sumbe (HW8) and the highest one in Tudun Wada (HW5), Fe^{2+}, ranged between 0.00 to 1.93 mg/L with the mean value of 0.54 mg/L, the lowest value was found in Garin Dawa and the highest one in Tudun Wada (HW5), total hardness ($CaCO_3$) ranged between 25.41-141.93 mg/L with the mean value of 59.98 mg/L, where the lowest value found in Sumbe (HW8) and the highest one in Tudun Wada (HW5), HCO_3^{-} ranged between 85 to 327 mg/L with mean value of 185.8 mg/L where the lowest value found in Sumbe (HW8) and the highest in Pindiga (HW1), Cl^{-}, ranged between 8.24 to 65.18 mg/L with the mean value of 22.51, where the lowest found in Garin Dawa (HW10) and the highest one in Tudun Wada (HW5), NO_3^{-}, ranged between 0.00 to 93.30 with the mean value of 26.15 mg/L where the lowest value found in Pindiga (HW1 to HW3) and the highest in Tudun Wada (HW6), SO_4^{2-} ranged between 10.06 to 32.01 mg/L with mean value of 21.58 mg/L where lowest value found in Sumbe (HW8) and the highest value in Tudun Wada (HW5) and CO_3^{2-} which ranged between 0.00 to 2.40 mg/L with the mean value of 1.51 mg/L, where the least

Table 2. Result of hydrochemical analysis of water sample from hand-dug wells in the study area

Well no	location	Temp. ºC	PH	EC μS/CM	TDS	NTU	Mg^{2+} Mq/L	Ca^{2+} Mq/L	Na^{+} Mq/L	K^{+} Mq/L	Fe^{2+} Mg/L	TH	Cl^{-} mq/L	HCO_3 mq/L	NO_3 mq/L	$S0_4^{2-}$ mq/L	Co^{-2} mg/L	Cu+	Sio_2	Caliform count.
HW_1	$Pindiga_1$	27.00	6.20	67.5	45.00	2.15	44.93	46.97	0.970	11.00	0.880	92.10	30.03	327	0.00	29.06	2.10	0.031	16.00	7.00
HW_2	$Pindiga_2$	24.00	6.10	79.4	52.90	1.15	38.67	44.00	0.480	6.80	0.510	71.90	30.03	234	0.00	28.11	2.10	0.000	18.90	4.00
HW_3	$Pindiga_3$	25.50	5.80	74.4	49.60	0.65	40.06	40.33	0.610	9.30	0.680	83.78	26.47	302	0.00	23.00	1.80	0.002	20.00	2.00
HW_4	$T/wada_1$	26.50	7.95	92.3	61.50	7.75	48.96	53.67	1.090	7.06	1.600	100.74	26.10	245	63.04	27.11	1.10	0.070	0.00	21.00
HW_5	$T/wada_2$	24.63	8.20	140.0	93.00	10.00	58.98	73.76	1.730	9.80	1.930	141.93	65.18	306	106.0	32.01	2.30	0.021	20.00	32.00
HW_6	$T/wada_3$	24.80	8.00	119.0	79.30	0.75	45.17	64.30	1.120	8.03	0.920	79.30	37.93	217	96.30	30.13	2.10	0.006	16.10	16.00
HW_7	$Sumbe_1$	26.33	5.80	201.0	134.0	4.75	20.93	18.90	0.910	12.10	0.061	31.78	21.11	112	26.11	16.21	2.40	0.000	23.00	46.00
HW_8	$Sumbe_2$	23.00	4.70	249.0	166.0	3.45	7.78	18.07	1.030	8.70	0.034	25.41	10.06	85	17.93	10.06	1.10	0.080	27.00	11.00
HW_9	$Sumbe_3$	27.10	5.40	163.5	109.0	4.00	19.90	24.09	0.930	6.00	0.060	31.75	20.13	136	24.00	18.93	2.00	0.000	31.00	31.00
HW_{10}	$Gartindawa_1$	26.40	5.90	146.0	97.00	0.15	21.77	23.28	0.973	5.60	0.030	44.95	8.24	157	2.10	14.67	0.00	0.000	24.00	3.00
HW_{11}	$Gartindawa_2$	26.90	6.10	137.9	91.90	0.205	22.99	24.41	0.700	6.60	0.000	47.20	9.44	182	16.20	18.83	1.00	0.000	26.00	7.00
HW_{12}	$Gartindawa_3$	29.10	5.30	121.4	80.90	0.065	20.08	19.72	0.152	4.00	0.000	39.00	11.21	208	10.00	13.58	1.40	0.000	20.90	9.00
HW_{13}	$Garin\ alkali_1$	29.00	5.40	128.0	85.00	1.05	19.89	21.67	0.110	4.00	0.220	43.03	14.84	108	4.90	18.04	0.00	0.000	11.00	13.00
HW_{14}	$Garin\ alkali_2$	26.90	4.90	149.0	100	6.603	22.71	18.83	0.029	5.50	1.070	26.73	22.61	124	16.10	22.93	1.60	0.000	12.17	28.00
HW_{15}	$Garin\ alkali_3$	31.00	5.10	117.9	78.60	1.205	19.08	20.57	0.093	5.83	0.097	40.11	10.83	144	9.62	21.01	1.70	0.000	9.00	17.00

Table 3: Summary of physico-chemical parameters of the shallow groundwater in pindiga area

Parameter	Range	Mean	S.D.	WHO (2006)
PH (unit)	4.70-8.20	6.06	1.13	6-5-8.5
Temperature (ºC)	23-31	26.54	2.07	-
Conductivity (ds/m)	0.068-0.249	0.132	0.0481	1400
Sodium (mg/L)	0.03-97	7.13	24.87	200
Potassium (mg/L)	4-12.10	7.35	2.42	55
Calcium (mg/L)	18.07-73.76	34.17	18.41	75
Magnesium(mg/L)	7.78-58.98	30.13	14.63	50
Iron (mg/L)	0-1.93	0.54	0.63	0.3
Chloride (mg/L)	8.24-65.18	22.95	14.78	250
Sulphlate (mg/L)	10.06-32.01	21.58	6.63	400
Bicarbonate (mg/L)	85-327	192.47	77.95	variable
Nitrate - N (mg/L)	0-106	26.15	34.38	50
Silica (mg/L)	0-31	18.34	7.96	-
TDS (mg/L)	45-166	88.25	32.06	1000
HCO_3 (mg/L)	85-327	192.47	77.95	1000
Total Hardness (mg/L)	25.41-141.93	59.98	33.70	500
CO_3	0-2.40	1.51	0.76	120
Turbidity (NTU)	0.07-10	2.93	3.11	5
Coliform count	2-46	16.47	12.82	10

value found in Garin Dawa (HW1) and the highest in Sumbe (HW1). Coliform count for the bacteriological analyses ranged between 2 to 46 with the mean value of 16.27, where the least value found in Pindiga (HW3) and the highest in Sumbe (HW7). The complete results are presented in Table 2 and summarized in Table 3.

Total hardness as $CaCO_3$ mg/L: The water samples from all the settlements in the study area is very hard with the ranged of between 25 to 141.93 mg/L compare to the maximum allowable limits of WHO (2006) Standards (150 mg/L). This hardness is as the result of the dissolution of limestone deposit that underlies most parts of the settlements, which produce calcium trioxocarbonate ($CaCO_3$), and the excess concentration of calcium makes water hard. The limestone bed found between 6-10 m from the surface is intercalated with shale and gypsum, which corresponds to the depth range of the sampled wells. Therefore, we may probably conclude that this limestone deposits is considered responsible for this Hardness.

Calcium Ca^{2+} mg/L: Calcium contributes to the hardness of water and it is the fifth most common element found in most natural waters. The sources of calcium in ground water especially in sedimentary rocks are calcite, aragonite, gypsum and anhydride. The calcium concentration in the sampled well in the study area is very high 18.07 to 73.76 mg/L with the highest of value found in TudunWada (HW5) and the maximum allowable concentration according to Nigeria standard for drinking water quality 2007 is 75 mg/L. When calcium (Ca^{2+}) and magnesium (Mg^{2+}) occurred in high concentration, they result in the hardness and alkalinity of the water. The possible source of this calcium is limestone or gypsum, which is found between 6 to 10 m from the surface, and average depth of static water level is within such depth.

Magnessium (Mg^{2+}): Magnesium is one of the most common elements in the earth's crust. It is present in all natural waters. It is an important contributor to water hardness.

The sources of magnesium in natural water are dolomites and mafic minerals (amphibole) in rocks. The solubility of dolomite in water depends on the composition. From this, we may conclude that the magnesium source in this area is from the carbonate rock (limestone) deposited in the area which change to dolomite due to dissolution of calcium and thus the source. The carbonate rock (limestone) beds are of 6 to 10 m from the surface and the average depth of the hand dug wells within this area are mostly within this depth, therefore, the dissolution or this carbonate (dolomite) rocks is the most likely source of excess magnesium in the water sample. In study area, magnesium concentration ranged between 7.78 to 58.98 mg/L with the mean of 30.13 mg/L, which is higher than the maximum allowable concentration 30 mg/L based on NWQS 2007/WHO 2006 standard. The high concentration of this magnesium was found mostly in water samples from Pindiga (HW1 to HW3), and Tudun Wada (HW4 to HW6) whose geologic setting has carbonate rock as a component.

Iron (Fe^{2+}): Iron is a very common element found in many of the rocks and soils of the earth's crust. It is also an essential trace element for animal growth. Soluble ferrous iron is present in natural water with a low Eh. Some ground water, hypolynnitic water from some thermally stratified lakes and water from the marshed may be devoid of oxygen and thus contain ferrous iron. When such water becomes oxygenated, the ferrous iron oxidizes to ferric iron and precipitate well-oxygenated surface waters normally contain no dissolve iron. In some cases, iron is found where ground water containing ferrous iron is discharging into a lake through spring.

In the study area, the concentration of iron is between 0.00-1.93 mg/L with the mean of 0.73 mg/L with thehighest concentration value being 1.93 mg/L from Tudun Wada (HW5) and the maximum allowable concentration based on NWQS 2007/WHO 2006 standard is 0.3. The source of this iron is probably due to present of ironstone in Gombe Formation, which dissolved into the ground water. The iron is high in Tudun Wada because Gombe Formation, which contains much of these ironstones, underlies it.

Sulphate (SO_4^{2-}) mg/L: Sulphate occurs in water as the inorganic sulphate salts as well as dissolved gas (H_2S). sulphate is not a noxious substance although high sulphate in water may have a laxative effect.

The concentration of sulphate (So_4^{2-}) in study area is between 10.06-32.01 with the mean value of 21.58 mg/L, the highest value was recorded in Tudun Wada (HW5). The concentration in samples from Sumbe, Garin Dawa and Garin Alkali are within the maximum allowable limits of NWQS (2007), WHO (2006) standards. The high concentration of sulphate in the other settlements is likely due to the dissolution of gypsum, which underlies the settlements. The gypsum is found within the shales fracture that occurs at a depth of between 6 to 10 m from the surface and the average depth of the sampled wells within the areas is about 12 m, hence the groundwater has contact with the gypsum. However this is not the same in other two settlements i.e., Sumbe, Garin Dawa and Garin Alkali because from the result, the sulphate is very low compare to NWQS (2007), WHO (2006) standards, this is due to the absence of gypsum lenses within the depth penetrated by the sampled wells as they are underlain by the Gombe Formation.

Bicarbonate (HCO_3^-): Bicarbonate combines with calcium carbonate and sulphate to form heat retarding, pipe clogging scale in boilers and in other heat exchange equipment. The source of bicarbonate irons in ground water is from the dissolution of carbonate rocks and from carbonate species present and the pH of the water is usually between 5 and 7 (Taylor, 1958). It was observed that below pH of 6, especially all dissolved carbonate species are in the form of H_2CO_3 and above 7, the ratio of CO_3 and H_2CO_3 increases (Drever, 1988).

In the study area, the concentration of bicarbonate (HCO_3^-) is high in Pindiga and Tudun Wada up to 217 mg/L compare to WHO Standard, which is 100 mg/L, meanwhile in the other settlements the concentration is within the acceptable limit i.e. about 112 to 208 mg/L. This high concentration of HCO_3 is as the result of carbonate rocks which are found between 6 to 10 m within the study area and the depth of carbonate rocks correspond to the depth of sampled well.

Nitrate (NO_3^-): Sources of nitrate in water include human activity such as application of fertilizer in farming practices, human and animal waste (which relate to population). The concentration of nitrate (NO_3^-) is high in Tudun Wada (HW4-HW6) with the range between 63 to 106 mg/L and the maximum allowable concentration of NWQS (2007), WHO (2006) standard is 50 mg/L, the high NO_3^- in samples HW4, HW5 and HW6 has been related to two possible sources. Tudun Wada is highly populated and the human waste management system is poor (shallow pit toilets and open defecation in the bushes) and also the use of nitrogenous fertilizer and animal dung in farming is a likely source of input into the ground water of this chemical.The migration of the chemical in these location is facilitated by sandy nature of the superficial geology (Gombe Formation).

Chloride (Cl^-): A major ion that may be associated with Individual Septic Disposal System (ISDSS) is chloride (Canter and Knox, 1985). Chloride is present in all natural waters, usually in relatively small amounts; however, chloride also can be derived from human sources. Chloride is not effectively removed by the septic systems and therefore, remains in their effluent high concentration of chloride in water is known to cause no health hazard, hence, its readily available in almost all potable water.

In the study area, the concentration of chloride is low and range between 8.24 to 65.18 mg/L, which is below the maximum allowable concentration of 250 mg/L (WHO, 2006). The highest concentration was recorded in the Tudun Wada (HW5).

Total Dissolved Solid (TDS): Total Dissolved Solid (TDS) generally reflects the amount of minerals content that dissolved in the water, and this controls its suitability for use. High concentration of total dissolved solid may cause adverse taste effects. Highly mineralized water may also deteriorate domestic plumbing and appliances.

In the study area, the concentration value of TDS ranged between 45 to 166 mg/L with the mean value of 88.25 mg/L and the highest value from Sumbe (HW8). The TDS of the study area falls within the WHO (2007) Standard of 1000 mg/L. the water is thus good for human consumption (domestic) and agricultural purposes.

Electrical conductivity (ds/m): Conductivity is a measure of the ability of water to conduct an electric current. It is used to estimate the amount of dissolved solids. It increases as the amount of dissolved mineral (ions) increases. In the study area, the value of conductivity ranged between 676.5 to 249 μS/Cm with the highest value from Sumbe (HW8) and the lowest from Pindiga (HW1). The maximum concentration of electrical conductivity (EC) in the study is 250 μS/Cm (0.25 ds/m) which is below WHO (2006) value of 1000 μS/Cm (Table 4). The sample with the highest value (HW8)

Table 4: Quality of irrigation water in relation to Electrical Conductivity (EC) after Richard (1954)

S.No.	Electrical conductivity (μmhos/cm)	Type of water	Suitability for irrigation	Remarks
1	Below 250	Low saline water	Entirely safe	All samples in the study area fall within this zone
2	250-750	Moderately saline (2)	Safe under practically all conditions	Nil
3	750-2250	Medium to high salinity (3)	Safe only with permeable soil and Moderate leaching	Nil
4	Above 2250			
(i)	2250-4000	High salinity	Unfair for irrigation	Nil
(ii)	4000-6000	Very high salinity	Unfair for irrigation	Nil
(iii)	Above 6000	Excessive salinity class	Unfair for irrigation	Nil

Table 5: Different parameter indices for rating groundwater quality and its sustainability in irrigation

S.No.	LOCATION	Hw1	SAR	SSP (%)	MAR (%)	KR meq/L	PI (%)	TDS mg/L	RSBCmeq/L	EC (ds/m)
1	Pindiga	HW1	0.024	37.497	61.194	0.0070	3.813	45.00	3.016	67.50
2	Pindiga	HW2	0.013	3.490	59.232	0.0040	3.626	52.90	1.639	79.44
3	Pindiga	HW3	0.014	4.149	63.225	0.0050	4.051	49.60	2.973	74.40
4	Tudun Wada	HW4	0.022	2.611	37.339	0.0070	2.974	61.50	1.337	92.30
5	Tudun Wada	HW 5	0.030	2.837	56.863	0.0090	2.611	93.00	1.335	140.0
6	Tdun Wada	HW 6	0.026	3.540	53.662	0.0070	2.712	79.30	0.348	119.0
7	Sumbe	HW 7	0.035	11.84	59.817	0.0152	0.194	134.0	0.791	201.0
8	Sumbe	HW 8	0.045	14.775	41.512	0.0290	7.145	166.0	0.472	249.0
9	Sumbe	HW9	0.034	18.380	57.659	0.0150	5.199	109.0	1.027	163.5
10	Garin Dawa	HW10	0.035	38.370	38.370	0.0140	5.371	97.00	1.412	146.0
11	Garin Dawa	HW11	0.024	6.070	60.820	0.0090	5.511	91.90	1.765	137.9
12	Garin Dawa	HW12	0.005	3.360	52.670	0.0020	5.883	80.90	1.926	121.4
13	Garin Alkali	HW13	0.004	3.790	60.210	0.0020	4.889	85.00	0.689	128.0
14	Garin Alkali	HW14	0.001	4.770	66.500	0.0000	5.076	100.0	1.093	149.0
15	Garin Alkali	HW15	0.003	5.370	58.220	0.0020	5.692	78.60	1.234	117.9

recorded a high value of TDS and this could be related to a slightly acidic condition (pH 6.65).

Hydrogen ion concentration (pH): The pH is a measure of the hydrogen ion concentration in water. The pH value of water indicates whether the water is acidic or alkaline. Drinking water with a pH between 6.5 to 8.5 is generally considered satisfactory. Acid water tend to be corrosive to plumbing and faucets, particularly, if the pH is below 6. Alkaline waters are less corrosive; water with a pH above 8.5 may tend to have a biter or soda-like taste. In the study area, the concentration of hydrogen ion (pH) ranges between 5.1 to 8.2, all the water samples analyzed have concentration within the safe limit of 6.5 to 8.5 standard set by the WHO (2006).

Assessment of ground water quality for irrigation purposes: Assessment of the groundwater quality of the study area was done to determine its suitability for for domestic and agricultural purposes water for each of these purposes is require meeting certain safety standard that have been set by either World Health Organization or agencies.

Domestic use: Portability of water for human consumption is determined by factor such as TDS, the World Health Organisation (WHO, 2006) has set pH, odour, colour, and temperature standard by world Health Organization Standards, only nitrate in three locations exceeded the World Health Organization recommended limit of 50 mg/L. The locations are Tudun Wada (HW, HW5 and HW6). These locations can be treated for nitrates. Hence, the water in the study area could be said to be portable for human consumption.

Agricultural use: Water for agricultural purposes should be good for both plant and animals. Good quality of waters for irrigation are characterized by acceptable range of:

- The Soluble Sodium Percentage (SSP)
- The Residual Sodium Bicarbonate (RSBC)
- The Magnesium Adsorption Ratio (MAR)
- The Kellys Ratio (KR)
- The Total Dissolved Solids (TDS)
- The Permeability Index (PI)

The results of the different irrigation indices for rating irrigation water quality are presented in Table 5 and summarized in Table 6.

Sodium Adsorption Ratio (SAR): The sodium adsorption ratio gives a clear idea about the adsorption of sodium by soil. It is the proportion of sodium to calcium and magnesium, which affect the availability of the water to the crop. The sodium adsorption ratio of shallow groundwater obtained in the present study are generally

Table 6: Summary statistics of different indices of shallow groundwater

	Concentration			
Parameter	Minimum	Maximum	Mean	S.D.
SAR	0.000	0.050	0.020	0.140
SSP (%)	2.610	38.37	10.72	12.14
EC (ds/m)	0.068	0.249	0.132	0.048
MAR (%)	37.34	66.50	55.15	9.020
KR (meq/L)	0.000	0.030	0.009	0.007
P1 (%)	0.190	7.150	4.320	1.720
T.D.S (mg/L)	45.00	166.0	88.25	32.06
RSBC (meq/L)	0.350	3.020	1.40	0.790

Table 7: Limits of some parameter indices for rating groundwater quality and its sustainability in irrigation (Ayers and Westcot, 1985; Eaton, 1950; Wilcox, 1950)

Category	EC (μmhos/cm)	RSC (meq/L)	SAR	SSP (%)	Sustainability for Irrigation
I	< 117.509	< 1.25	< 10	<20	Excellent
ii	117.509 -	1.25 – 2.5	10-18	20-40	Good
iii	508.61	> 2.5	16-26	40-80	Fair
iv	> 503.61	-	>26	>80	Poor

less than 9 and fall under the category of C2SI indicating low alkali hazards and excellent irrigation water (Fig. 3; US Salinity Laboratory Staff, 1954).

Soluble Sodium Percentage (SSP): Sodium percent is an important factor for studying sodium hazard. It is also used for adjudging the quality of water for agricultural purposes. High percentage sodium water for irrigation purpose may stunt the plant growth and reduces soil permeability (Joshi *et al*., 2009).

The soluble sodium percentage values of shallow groundwater in the study area ranges between 2.61 and 38.37 indicating low alkali hazards and fair (ClassIII) to excellent (ClassI) irrigation quality (Wilcox, 1950).

Residual Sodium Bicarbonate (RSBC): The concentration of bicarbonate and carbonate influences the suitability of water for irrigation purpose. The water with high RSBC has high pH. Therefore, land irrigated with such water becomes infertile owing to deposition of sodium carbonate (Eaton, 1950). The residual sodium bicarbonate values of water samples from the study area vary from 0.37 to 3.02 meq/L.

The residual sodium bicarbonate values are less than 3.0 meq/L and are therefore considered safe for irrigation purposes (Table 7).

Magnesium Adsorption Ratio (MAR): Magnesium content of water is considered as one of the most important qualitative criteria in determining the quality of water for irrigation. Generally, calcium and magnesium maintain a state of equilibrium in most waters. More magnesium in water will adversely affect crop yields as the soils become more saline (Joshi *et al*., 2009).

The values of The magnesium adsorption ratio of shallow groundwater in present study varies from 37.34 to 66.50% indicating that they are above the acceptable limit of 50% (Ayers and Westcot, 1985). The waters are

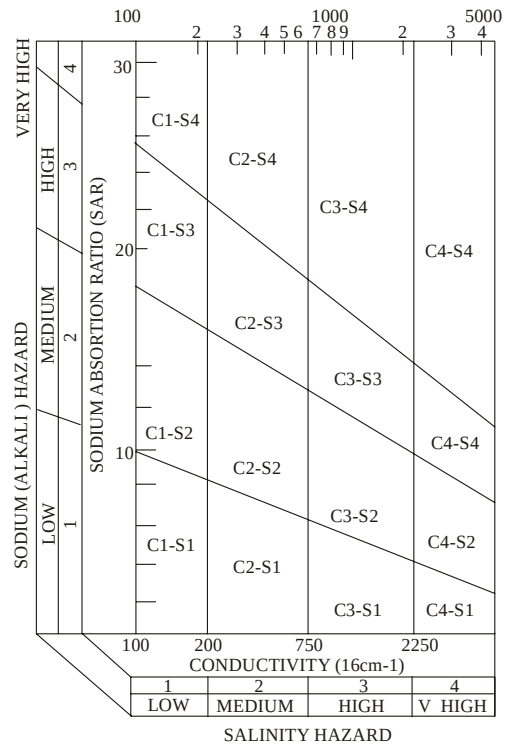

Fig 3: Classification of the analyzed water sample with respect to sodium adsorption ration and salinity hazard (After us salinity lab, 1954)

therefore, considered unsuitable. This is because high magnesium adsorption ratio causes a harmful effect to soil when it exceeds 50%.

Kellys Ratio (KR): The kellys Ratio (KR) values of the study area ranged between 0 and 0.03% .These indicate that Most of the KR for the shallow groundwater samples however fall within the permissible limit of 1.0 and are considered suitable for irrigation purposes.

Total Dissolved Solids (TDS): Salts of calcium, magnesium, sodium, potassium present in the irrigation water may prove to be injurious to plants. When present in excessive quantities, they reduce the osmotic activities of the plants and may prevent adequate aeration.

The TDS value of the study area ranges from 45 to 166 mg/L They are generally less than 200 mg/L and can be classified as excellent irrigation water according to Robinove *et al*. (1958) (Table 8).

Permeability Index (PI): The soil permeability is affected by the long-term use of irrigated water and the influencing constituents are the total dissolved solids, sodium bicarbonate and the soil type. In the present study, the permeability index values range between 0.19 to 7.15. The above result therefore suggests that water samples fall within ClassI and ClassII and can be categorized as good irrigation water (Doneen, 1964).

CONCLUSION

The groundwater quality of Pindiga Area of Northeast Nigeria was assessed for its irrigational and domestic suitability.

The values of total dissolved solids (<250 mg/L), electrical conductivity (<3 ds/m), soluble sodium percentage (2.22 to 85%), permeability index (28.7 to 131.36%), residual sodium bicarbonate (<1.0) and sodium adsorption ratio (<9) obtained for most of the water samples were found to be within the safe limits. In addition, most of the other irrigation indices of the sampled water also fall within the permissible level indicating low sodic waters. The groundwater will neither cause salinity hazards nor have an adverse effect on the soil properties and are thus largely suitable for irrigation purpose.

The results of the analysis indicate nitrate pollution in five locations (Hw4, Hw5, Hw6, Hw7 and Hw9 with values ranging from 24 to 106 mg/L) which are attributed to fertilizer applications. The results of hydrochemical analyses also indicate that all the other parameters fall within the recommended limits of World Health Organisation (WHO, 2006) and thus largely suitable for irrigation and domestic purposes.

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Table 8: Range of total dissolved solids for irrigation use (Robinove *et al*., 1958)

Classification	Total dissolved solids (mg/L)	Remarks
Non saline	< 1000	All samples in the study area fall in this zone
Slightly saline	1000-3000	Nil
Moderately saline	3000-10,000	Nil
Very saline	> 10000	Nil

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