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EVALUATION OF GROUNDWATER QUALITY FROM SHALLOW HAND-DUG WELLS FOR DOMESTIC AND IRRIGATION USES IN TUDUN WADAAND ENVIRONS, PARTS OF ALKALERI SHEET 150 AND YULI SHEET 171, NORTHEASTERN NIGERIA

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ABSTRACT
The study centres on the hydrochemistry of groundwater from shallow hand-dug wells in Tudun Wada and environs intending to evaluate its quality for domestic and irrigation uses. The area is underlain by both basement and sedimentary rocks. The basement rocks in the area include porphyritic biotite granite and granitic gneiss while sedimentary rocks includes and stone, claystone and shale. Ten (10) pairs of water samples (totalling twenty (20) samples –that is, two samples were collected from a point) were randomly collected from hand dug-wells in the study area and analyzed for major cations and anions. The dominant cations and anions were in the order of Mg > Ca > Na > K and HCO_3> Cl > NO_3>SO_4respectively. Results of the water quality analysis were compared with the standards set by the World Health Organization and the Nigerian Standard for Drinking Water Quality. Geochemical values of the water samples analyzed showed that groundwater from hand-dug wells in the area are suitable for domestic uses. Groundwater quality from hand-dug wells in the area was also analyzed for its suitability or otherwise, for irrigation using Sodium Absorption Ratio, Residual Sodium Carbonate, Kelley Index, Magnesium Ratio, Percentage Sodium, Permeability Index, Total Hardness, Total Dissolved Solids, and Electrical Conductivity parameters respectively. The result revealed that groundwater from hand-dug wells in the area is good for irrigation according to Sodium Absorption Ratio, Residual Sodium Carbonate, Total Dissolved Solids, Percentage Sodium, Kelley Index, and Permeability Index; poor according to Magnesium Ratio, and partly good according to Electrical Conductivity. The sources of dissolved chemical constituents of groundwater in Tudun Wada and its environs are rocks (sandstone, claystone, shale, porphyritic biotite granite, and granitic gneiss). This is because all the sample points' fall within the region of rock dominance based on Gibbs' plot.
Keywords*: *Evaluation, Groundwater, Hand-dug Well, Tudun Wada, Domestic, Irrigation, Suitability

INTRODUCTION
Groundwater is a natural resource which occurs in geological formations below the earth surface. Groundwater is used for both domestic and agricultural purposes, especially in tropical areas. Agriculture is the main source of livelihood of the people in the study area and groundwater is one of the major sources of water for irrigation. Groundwater is contaminated with a variety of pollutants generated from different sources. Demand for freshwater has increased over the years due to population growth and intense agriculture activities. Increase in population and growth of industrialization, groundwater quality is threatened by the disposal of urban and industrial solid waste (Raju *et al.*, 2011).Therefore, depletion of groundwater levels and quality deterioration need to be checked periodically. Variation in groundwater quality is a function of physicochemical parameters that are greatly influenced by geological formations and anthropogenic activities. This study aims to investigate the quality of groundwater from shallow hand-dug well for domestic and irrigation uses in Tudun Wada and environs.

METHODOLOGY
Study Area
The study area falls within Northeastern Nigeria, lies within latitudes 9^o 57' N to 10^{o}05' N and longitudes 10^{o}09' E to 10^o 18' E (parts of Alkaleri Sheet 150 and Yuli Sheet 171), and covers a total area of 244 km^2 (Figure 1). The rocks of the area are sedimentary and basement rocks consisting of sandstone, claystone and shale; and porphyritic biotite granite, granitic gneiss with pegmatites and quartz veins as minor intrusions respectively (Figure 2). The eastern part of the area is rich in kaolin which is an industrial mineral used in the manufacturing of drilling mud and paint.

Methodology
Hand-dugwells were selected for sampling in this study. Water from these hand-dug wells was in used for drinking and domestic purposes throughout the year by the people of the area. A total of twenty (20) groundwater samples were collected from ten (10) hand-dug wells in duplicates and packaged in plastic bottle containers. Sample bottles were cleaned by rinsing them with the water to be sampled. Few drops of a concentrated solution of nitric acid were added to one group of the samples that were used for analyzing anions. The second group of the sample which nothing was added to was used to analyze for cations. Physical parameters such as temperature, pH, total dissolved solids (TDS), and electrical conductivity (EC) were measured by a potable three-in-one digital meter (EC/TDS/temperature) and pH digital meter. Water samples were analyzed for various chemical constituents using standard methods prescribed by the American Public Health Association (APHA, 1995). The chemical parameters analyzed were major cations (Na^+, Mg^{2+}, Ca^{2+} and K^+), major anions (HCO_3^-, Cl^-, SO_4^{2-} and NO_3^-) and also other elements (P, CO_3, DO and NH_4). The techniques for the analysis were Atomic Absorption Spectrophotometry (AAS), Flame Photometry and Titrimetric Methods. The correlation of analytical data and classification for suitability were evaluated by plotting different graphical representations such as Piper (1944), Wilcox (1955), USSL (1954), Gibbs (1970), Doneen (1964) using Arc-GIS 10.3, Rock-Works 15, Aquachem 4.0, and Surfer 11 software.

RESULTS AND DISCUSSION
The hydrochemical properties of water samples collected from hand-dug wells are summarized in Table 1. All the water samples of the area analysed are slightly acidic (pH<7). The order of abundance of the concentration of the cations is Mg^{2+}>Ca^{2+}> Na^+>K^+ while that of the anions is HCO_3^->Cl^->NO_3>SO_4^{2-} (Figure 3).

Groundwater Classification, Hydrogeochemical Facies and their Sources
Interaction of groundwater with the rock types of an aquifer makes the water to assume a characteristic chemical composition. Hydrochemical facies is classified based on the dominant ions using piper trilinear diagram. The concentrations of major ionic constituents of groundwater samples were plotted on the piper trilinear diagram (Piper, 1953) to determine the predominant

water type of Tudun Wada and Environs (Figure 4). Pipertrilinear diagram method is used to classify groundwater based on the basic geochemical characters of the constituent ionic concentrations. The classification for cation and anion facies, in terms of major ion percentages and water type, is according to the domain in which they occur on the diagram segments (Raju *et al.,* 2009). Based on the positions of points on the diagram segment (Figure 4), water-type of Tudun Wada and environs are predominantly Mg-Ca-HCO_3 type.

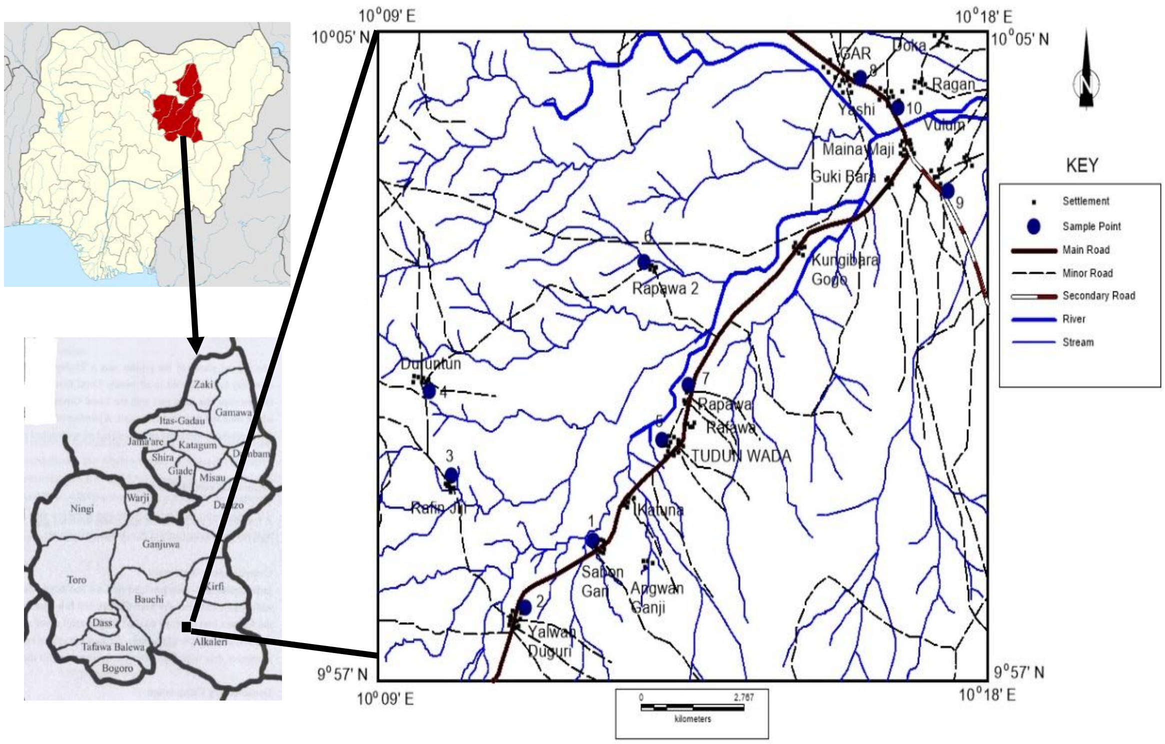


Figure 1: Location Map of Tudun Wada and environs Showing Sample Locations(Extracted and Modified from Topographical Maps of Alkaleri Sheet 150 and Yuli Sheet 171, Produced by Federal Survey Agency, (2012).

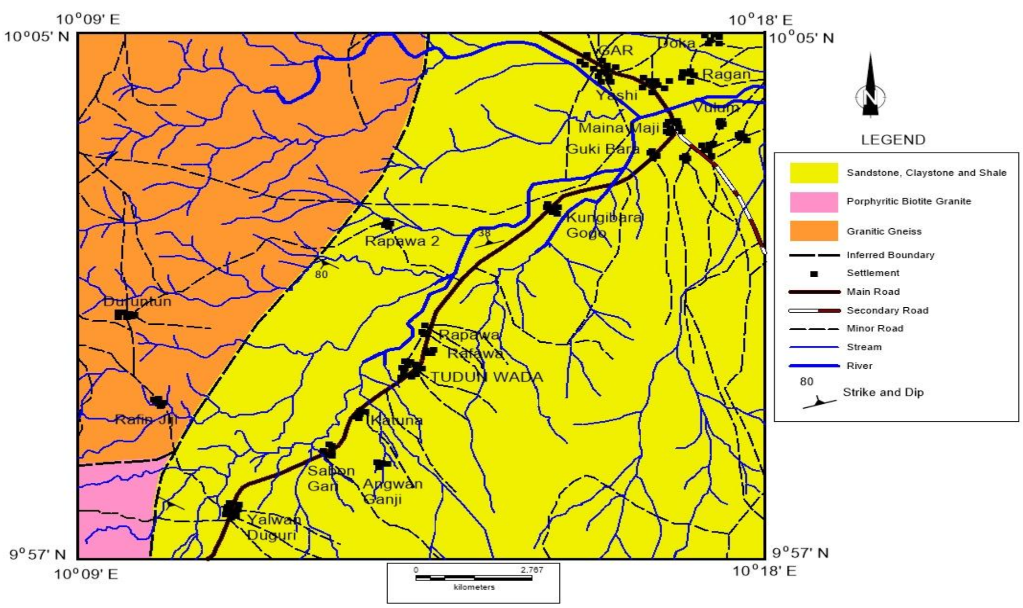


Figure 2: Geological Map of Tudun Wada and environs showing different rock types (Extracted and Modified from Nigerian Geological Survey Agency, 2006)

Table 1: Physico-chemical parameters of groundwater samples (mg/l) of Tudun Wada and environs

S/N	Location	S/I.D	T(^oC)	pH	EC (µS/cm)	TDS	Na	K	Ca	Mg	P	CO_3	HCO_3	Cl	NO_3	NH_4	DO	SO4
1	Sabon Gari	HD1	29	5.7	840	415	9.6	4	8	31.2	0.11	19.67	40	0.7	0.8	0.2	2.8	0.12
2	Yelwan Duguri	HD2	27	6.28	788	388	9.8	1.7	8	30	0.11	13.77	28	1	1.2	0.2	3.1	0.08
3	Rafin Jiji	HD3	29	6.49	655	329	9.8	2	14	31.2	0.11	17.70	36	1	1	0.4	3.1	0.04
4	Duruntun	HD4	30	6	874	433	9.9	0.5	20	27.6	0.11	21.63	44	1	1	0.4	3.3	0.04
5	Tudun Wada	HD5	29	5.62	94	50	0.8	5.5	20	30	0.11	21.63	44	0.8	0.8	0.2	3.1	0.12
6	Rafawa 2	HD6	30	5.92	665	672	6.1	2.2	20	27.6	0.11	19.67	40	0.7	1	0.4	3.3	0.04
7	Rafawa	HD7	31	5.2	685	347	6.3	1.8	14	33.6	0.11	23.60	48	0.7	1	0.4	3.3	0.08
8	Gar	HD8	28	5.75	1025	502	9.9	0	14	31.2	0.11	19.67	40	0.5	1	0.4	3.2	0.08
9	Maina Maji	HD9	30	6.3	254	257	4.2	1	20	32.4	0.11	19.67	40	0.9	1	0.4	3.1	0.08
10	Yashi	HD10	27	6.46	1066	536	9.9	7.5	20	31.2	0.11	13.77	28	0.9	1.2	0.4	3.4	0.12

Table 2: Range of chemical parameters and their comparison with WHO and NSDWQ standards for drinking water

Parameters	**Ranges of Authors' Results (2019)**	**WHO 2011RecommendedValues**	**NSDWQ2015 Permissible Limit**	**Undesirable Effect**
EC (µS/cm)	94-1066	-	1,000	-
pH	5.2-6.49	6.5-8.5	6.5-8.5	Taste
TH (mg/l)	143.37-183.126	-	150	Scale formation
TDS (mg/l)	50-672	500	500	Gastro-intestinal irritation
K^- (mg/l)	0-7.5	-	-	Bitter taste
Na^+ (mg/l)	0.6-9.8	50	200	High blood pressure
Ca^{2+} (mg/l)	8-20	100	-	Scale formation
Mg^{2+} (mg/l)	27.6-33.6	50	20	Consumer acceptability
Cl^- (mg/l)	0.7-1.0	250	250	Salty taste
SO_4^{2-} (mg/l)	0.04-0.12	250	100	Laxative effect
NO_3^- (mg/l)	0.8-1.2	50	50	Methaemoglobinaemia
HCO_3^-	28-48	-	-	-
CO_3 (mg/l)	13.77-23.60	-	150	-
NH_4 (mg/l)	0.2-0.4	-	-	-
P (mg/l)	0.11	-	-	-
DO (mg/l)	2.8-3.4	-	-	-
Temp (C)	27-31	30-32	-	-

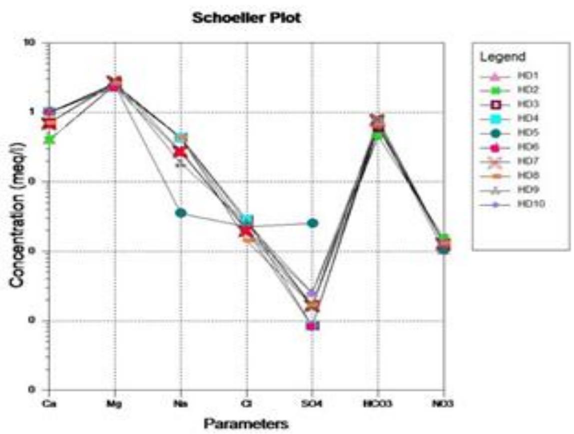


Figure 3: Concentrations of chemical parameters of water samples from Tudun Wada and Wada and environs (Back and Hanshaw (1965).

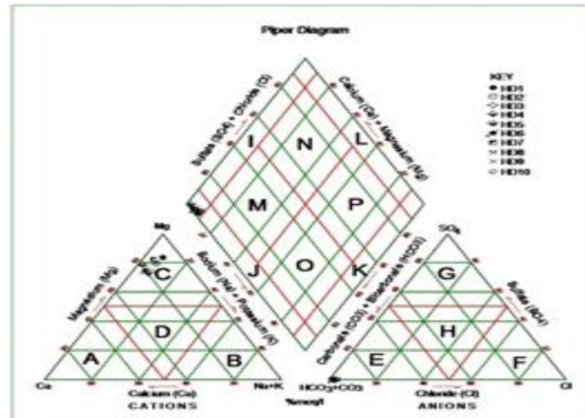
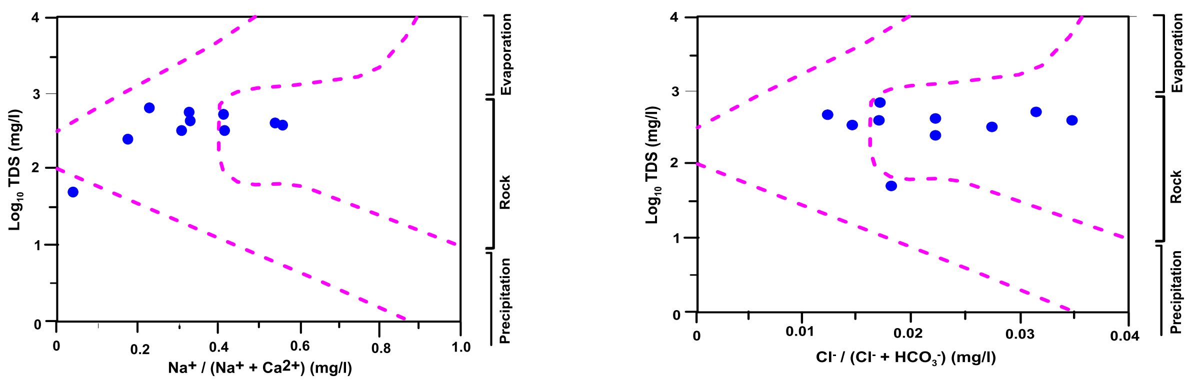


Figure 4: Type classification for water samples from Tudun environs (after Schoeller, 1967).

Gibbs's diagrams are plots of $[Na^+ :(Na^+ + Ca^{2+})]$ for cations and $[Cl^- :(Cl^- + HCO_3^-)]$ for anions against TDS. These plots are used to assess the functional sources of dissolved chemical constituents as precipitation dominance, rock dominance and evaporation dominance (Gibbs, 1970). Based on the Gibbs' plot, the sources of dissolved chemical constituents of groundwater of Tudun Wada and Environs are from the rocks of the study area (Figures 5 a and b).



(a) (b)

Figure 5 (a and b**):** Controlling mechanisms for groundwater quality in Tudun Wada and environs (after Gibbs, 1970)

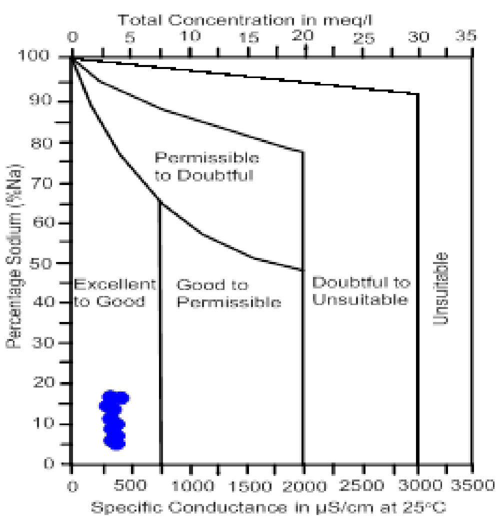


Figure 6: Classification of irrigation waters based on %Na (after Wilcox, 1948).

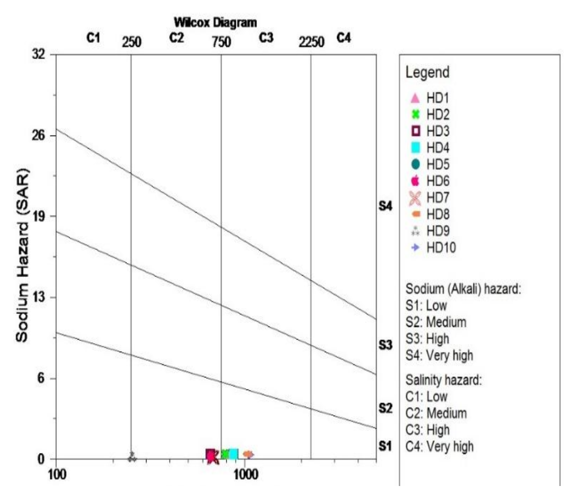


Figure 7: Classification of irrigation waters based on SAR (after Wilcox, 1962)

Evaluating Groundwater Quality for Drinking and Domestic Purposes

The adequacy of groundwater for drinking and domestic use is directly related to different physicochemical parameters and their concentrations. The physicochemical parameters obtained from groundwater of Tudun Wada and environswere compared with the guidelines prescribed by World Health Organization (WHO, 2011) and Nigerian Standard for Drinking Water Quality (NSDWQ, 2015- Table 2). All the physical and chemical parameters except for three sampling points for TDS are below recommended values set by WHO 2011 standards for drinking water quality. Comparing the same parameters (Table 2) with NSDWQ, 2015 standard for drinking water quality, Most of the physical parameters except for two sampling points for EC, and three sampling point for TDS, are below NSDWQ, 2015 Standards for drinking water quality. The pH values of groundwater samples range between 5.2 and 6.49 which indicate that the groundwater is slightly acidic.

Evaluating Groundwater Quality for Irrigation Purposes

Irrigated agriculture depends on a sufficient supply of good quality water. Water quality refers to the characteristics of a water supply which influences its suitability for a specific use (Kumar *et al.* 2007). The important chemical parameter for judging the degree of suitability of water for irrigation are Percentage Sodium (%Na) or Soluble Sodium Percentage, Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), Permeability Index (PI), Magnesium Ratio (MR), Kelley Ratio (KR), Total Hardness (TH), Electrical Conductivity (EC), and Total Dissolved Solids (TDS).

Percentage Sodium (%Na): Sodium serves as essential nutrients necessary for some biochemical functions. It is found in natural waters because of its high solubility and frequent association with salinity problems when linked to chloride and sulfate ions. Percentage of sodium is utilized to evaluate the suitability of water for irrigation purposes (Wilcox, 1948). The %Na is computed concerning the relative proportions of cations present in water and calculated using the following formula: Na% = Na + K x 100 / (Ca + Mg + Na + K) (meq/l)

The calculated values of %Na ranged from 5.38 – 14.91 (Tables 3 and 4) which fall within the categories of water that range from good to excellent for irrigation purposes (Figure 6).

Sodium Absorption Ratio (SAR): SAR is used to evaluate water quality for irrigation purpose because it is responsible for the sodium hazard in irrigation water. The proportion of sodium (Na^+) to calcium (Ca^{+2}) and magnesium (Mg^{+2}) ions in the water sample is expressed as SAR. Higher concentration of SAR results in the breakdown in the physical structure of the soil. Sodium is adsorbed and become attached to soil particles. Thenthe soil becomes hard and compact when dry and impervious to water penetration. SAR is computed using the following equation: SAR = Na^- / {(Ca + Mg) / 2} 0.5 (meq/l)

The calculated values of SAR range from 0.02 to 0.33 (Tables 3 and 4) which fall within the categories of water that is excellent for irrigation purposes (Figure 7).

Residual Sodium Carbonate (RSC): Is an important parameter to evaluate the quality of water for irrigation purpose (Raju *et al.*, 2009). Higher carbonate and bicarbonate in water increase the sodium hazard of the water to a level greater than that indicated by the SAR. The excess sum of carbonate and bicarbonate in groundwater over the sum of calcium and magnesium influences the quality of groundwater for irrigation. RSC is calculated using the formula: RSC = [(HCO_3 + CO_3) – (Ca + Mg)] (meq/l)

The RSC values in groundwater sample of Tudun Wada and Environs range from -2.65 to -1.66. This shows that the RSC values are much less than 1.25 meq/l, indicating that the water is within safe quality categories for irrigation (Tables 3 and 4).

Permeability Index (PI): Doneen (1964) proposed a model for evaluating water quality for irrigation based on the PI (Figure 7).Soil permeability is affected by long-term use of irrigation water with high salt content as influenced by Na^+, Ca^{2+}, Mg^{2+}, and HCO_3 contents of the soil. PI is calculated using the formula (Doneen, 1962; Raghunath, 1987): PI = Na + $(HCO_3)^2$ / (Ca + Mg + Na) x 100 (meq/l). The calculated PI value in the study area ranges from 25.25 – 36.27, which shows that the water of Tudun Wada and Environs falls within excellent categories of water for irrigation (Figure 8; Tables 3 and 4).

Magnesium Ratio (MR): MR was introduced by Paliwal (1972) to evaluate water quality for irrigation. Calcium and magnesium in most water maintain equilibrium (Hem, 1985). In the equilibrium state, Mg^{2+} in water will negatively affect crop yield (Nagaragu *et al.*, 2006). MR is calculated using the formula: MR = Mg / (Ca + Mg) x 100 (meq/l)

The calculated values of MR in the study area range from 71.21 - 86.55% indicating that water in the study area falls within the categories of water that is poor for irrigation (Tables 3 and 4). Continual use of water with high magnesium content will adversely affect crop yield.

Kelley Index (KI): Kelley's ratio can be used to determine the suitability of water for irrigation. It is the measurement of the concentration of Na^+ against Ca^{2+} and Mg^{2+} (Kelley, 1963). KI is calculated using the formula: KI = Na^+ / Ca^{2+} + Mg^{2+} (meq/l)

The calculated values of KI in the study area range from 0.01 – 0.15. Based on KI classifications (Kelley, 1946), all samples collected from the study area are excellent for irrigation (Tables 3 and 4).

Total Hardness (TH): The summation of temporary and permanent hardness is known as Total hardness. Dissolved calcium and magnesium from soil and aquifer containing limestone or dolomite are the main sources of water with high hardness. Hardness of water limits its uses for domestic, industrial and agricultural activities. Total Hardness is calculated by the formula: TH = 2.497 Ca^{+2} + 4.115 Mg^{+2} (mg/l)

The calculated values of TH in the study area range from 143.43 – 183.27, indicating that all the samples collected from the study area are excellent for irrigation (Tables 3 and 4).

Electrical Conductivity (EC): Is a decisive parameter in determining the suitability of water for a particular purpose. It is an indication of the concentration of total dissolved solids and major ions in a given water source which is simply defined as an indicator of the total salinity or salinity hazard. EC values in water of the study area range from 94 – 1066 µS/cm. This shows that 50% of the water samples fall within the categories of water that is good to moderately good for irrigation, while the remaining 50% fall within the categories of water that is poor for irrigation purposes (Tables 1 and 3).

Total Dissolved Solids (TDS): Salts of calcium, magnesium, sodium and potassium present in irrigation water may be injurious to plants (Obiefun and Sheriff, 2011). 60% of the water samples collected from the study area fall within the categories of water that is excellent for irrigation. The remaining of the water samples have values slightly below and slightly above 200 – 500 mg/l respectively, which is the limit of the categories of water that is excellent for irrigation (Tables 1 and 3).

Table 3: Classification of groundwater for agricultural purposes (Doneen, 1964; Sawyer and McCarthy, 1967; Lloyed and Heathcote, 1985; Nagaraju *et al.*, 2006; Vasanthavigar *et al.*, 2010; Tiri and Boudoukha; 2010)

Parameter	Range	Suitability for irrigation	No. of Samples	% of Sample
SAR (meq/l)	0 – 10	Excellent (suitable for all types of crops and soil except for those crops sensitive to Na)	10	100%
	10 - 18	Good (suitable for coarse-textured soil with permeability	-	-
	18 - 26	Fair (harmful for almost all soils)	-	-
	>26	Poor (unsuitable for irrigation)	-	-
RSC (meq/l)	<1.25	Good	10	100%
	1.25-2.5	Medium	-	-
	>2.5	Bad	-	-
EC (μS/cm)	<250	Good (low salinity hazard)	1	10%
	250-750	Moderate (medium salinity hazard)	4	40%
	750-2250	Poor (high salinity hazard)	5	50%
	>2250	Very Poor (very high salinity hazard)	-	-
TH (mg/l)	0-75	Excellent	-	-
	75-150	Good	2	20%
	150-300	Fair	8	80%
	>300	Poor	-	-
TDS (meq/l)	200-500	Excellent	6	60%
	1000-2000	Good	-	-
	3000-7000	Fair	-	-
%Na (%)	<20	Excellent	10	100%
	20-40	Good	-	-
	40-60	Permissible	-	-
	60-80	Doubtful	-	-
	>80	Unsuitable	-	-
KI (meq/l)	<1	Excellent	10	100%
	>1	Poor	-	-
PI (meq/l)	Class I	Excellent (Ma ility)	10	100%
	Class II	Good (75% of Max. permeability)	-	-
	Class III	Fair (25% of Max. permeability)	-	-
MR (%)	<50	Excellent	-	-
	>50	Poor	10	100%

Table 4: Parameter used for the evaluation of groundwater quality for irrigation practice (Na throughSO_4 are in meq/l)

S/N	Na	K	Ca	Mg	SO4	Cl	NO_3	HCO_3	CO_3	%Na	RSC	MR	KI	TH	PI	SAR
1	0.418	0.102	0.399	2.57	0.0025	0.020	0.013	0.66	0.65	14.91	-1.66	86.55	0.14	148.36	36.27	0.32
2	0.426	0.044	0.399	2.47	0.0017	0.028	0.019	0.46	0.45	14.07	-1.95	86.08	0.15	143.43	33.51	0.33
3	0.426	0.051	0.699	2.57	0.0008	0.028	0.016	0.59	0.58	12.75	-2.09	78.61	0.13	163.35	32.35	0.30
4	0.431	0.013	0.998	2.27	0.0008	0.028	0.016	0.72	0.71	11.94	-1.83	69.48	0.13	163.51	34.60	0.29
5	0.035	0.141	0.998	2.47	0.0025	0.023	0.013	0.72	0.71	4.82	-2.03	71.21	0.01	173.39	25.25	0.02
6	0.265	0.056	0.998	2.27	0.0008	0.020	0.016	0.66	0.65	8.96	-1.96	69.48	0.08	163.51	30.42	0.18
7	0.274	0.046	0.699	2.77	0.0017	0.020	0.016	0.79	0.78	8.46	-1.90	79.83	0.08	173.22	31.07	0.19
8	0.431	0.000	0.699	2.57	0.0017	0.014	0.016	0.66	0.65	11.65	-1.96	78.61	0.13	163.35	33.56	0.31
9	0.183	0.026	0.998	2.67	0.0017	0.026	0.016	0.66	0.65	5.38	-2.36	72.77	0.05	183.27	25.80	0.12
10	0.431	0.192	0.998	2.57	0.0025	0.026	0.019	0.46	0.45	14.87	-2.65	72.01	0.12	178.33	27.73	0.29

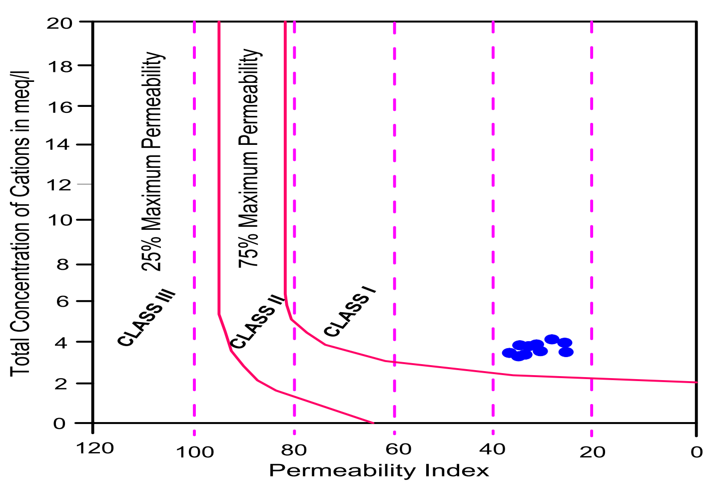


Figure 8: Classification of irrigation water based on permeability index (PI) (Doneen, 1964).

CONCLUSION

The quality of water from hand-dug wells of Tudun Wada and Environs, Northeastern Nigeria has been surveyed for its chemistry and suitability for the human utilization and agricultural purpose. The area is underlain by both basement and sedimentary rocks. The request of plenitude of cations fixation are found in the diminishing order of Mg^{2+}> Ca^{+}> Na^{2+} > K^{+} while those of the anions are HCO_3^{-}> Cl^{-}> NO_3^{-}> SO_4^{2-}.The analyzed chemical parameters were compared with standards set by WHO, 2011 and NSDWQ, 2015 to determine its suitability for drinking and other domestic uses. Most of the parameters are within the standards indicating that the water in the area is suitable for drinking and other domestic uses. The outcome demonstrate that groundwater quality status in the area is good for irrigation given SAR, RSC, TDS, %Na, KI, and PI; while poor for irrigation given MR. The groundwater quality of the area in terms of EC is only slightly good for irrigation purposes. The sources of dissolved chemical constituents of groundwater in Tudun Wada and environs are from rocks. This is because all the sample points' fall within the region of rock dominance based on Gibb's plot.

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