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Suitability assessment of groundwater for drinking and irrigation use

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Abstract: *The continuous decline in the quality of available surface water resources due to increasing global pollution threats, put pressure on the need for suitability assessment of groundwater resources for drinking and irrigation purposes at the Teaching and Research Farm, Federal College of Horticulture Dadin Kowa, Gombe State. Twelve groundwater samples were collected and Standard methods for physicochemical determinations were employed. Results showed the pH range of 6.5 - 7.5, calcium 0.98 - 1.86 mg/L, magnesium 0.64 - 1.23 mg/L, potassium 0.36 - 1.45 mg/L, sodium 0.02 - 1.01 mg/L, bicarbonate 0.98 - 1.86 mg/L, chloride 0.64 - 1.36 mg/L, iron 0.14 - 0.42 mg/L, Nitrate 16.1 - 42.2 mg/L, sulphate 33.1 - 81.3 mg/L. The ionic dominance for the major cations and the anions respectively were in these order;* $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$ *and* $SO_4^{2-} > NO_3^{-} > HCO_3^{-} > Cl^{-}$ *. Most of the samples analyzed were within the recommended limits set by NWQS (2007) for drinking water. Various determinations such as Electrical Conductivity (EC), Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage, (SSP), Magnesium Adsorption Ratio (MAR) and Permeability Index (PI) were found to be within the safe limits and thus largely suitable for irrigation purposes.*
Keywords: *Aquifers, drinking, irrigation, groundwater quality*

I. Introduction

Water is essential to all forms of life and makes up 50 - 97% of the weight of all plants and animals and about 70% of human body [1] Groundwater occurs almost everywhere beneath the earth surface not only in single widespread aquifers, but also in thousands of local aquifers systems. Rajankar et al [2] pointed out that the presence of dissolved minerals coupled with some special characteristics of groundwater as compared to surface water makes it a preferred choice for many purposes. Groundwater which occurs beneath the earth surface is considered free from contamination, hence usable but anthropogenic as well as natural factors are affecting the quality as well as quantity of these valuable resources. The main source of groundwater contamination is from domestic and a number of industries like woolen and food industries, ceramic industries, bathroom fittings, cotton (in bales) textiles, dairy products, groundnut oil, gypsum, handicraft items, leather footwear, machine tools and parts. These industries pour their effluents directly into open drain, unlined earthen drain and open pits in several places from where polluted water percolate into soil and finally reaches the aquifers. In general, the quality of groundwater depends on the source, the degree to which it has been evaporated, the composition of recharge water, the interaction between the water and the soil, the soil-gas, the rock with which it comes into contact in the unsaturated zone, and the residence time and reactions that take place within the aquifer [3]. Thus, the principal processes that influence the quality of water in an aquifer are physical, geochemical and biochemical. Assessing groundwater quality and developing strategies to protect aquifers from contamination are necessary aspects for proper planning and designing water resources. The importance of water quality in human health has recently attracted a great deal of interest. In developing countries all diseases are directly related to poor drinking water quality and unhygienic conditions [4]. Numerous publications have reported that urban development and agricultural activities directly or indirectly affect the groundwater quality [5- 7].The usage of groundwater has increased substantially in Dadin Kowa of Gombe state. Hence, it is necessary to undergo quality analysis of groundwater in order to assess its suitability for consumption and irrigation activities.

II. Materials and Methods

The study was conducted at the teaching and research farm of Federal College of Horticulture Dadinkowa, Yamaltu Deba Local Government Area, Gombe State and located in the northern guinea savanna zone of Nigeria and lies in latitude 10^{o} 30’ N and longitude 11^{o} 49’ E with an altitude of 195 m above sea level. The study area has a semi arid climate with a single rainy season from June to September and dry season from October to May. The mean annual rainfall is about 850 mm and temperature ranged from 25 to 32°C [8].

2.1 Sampling and Analysis

Groundwater samples were collected randomly from 12 tubewells during dry period in 2012, following the sampling techniques as outlined by Hunt and Wilson [9] and APHA [10]. Each sample was a composite of five sub-samples to minimized error and heterogeneity. The high density PVC bottles were used for sampling. They were thoroughly cleaned by rinsing with $8NHNO_3$ and deionized water followed by repeated washing with water sample. The sample were collected only after the tubewells had pumped for at least 30 minutes to avoid stagnant or contaminated water sampling. After collection of water, the containers mouths were sealed tightly. The containers were kept airtight and labeled properly to avoid complication in identification.

These samples were stored at a temperature below 4°C prior to analysis in the laboratory. Procedures followed for analysis have been in accordance with the standard methods for examination of water and wastewater [11]. Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) were determined titrimetrically using standard EDTA, while sodium (Na) and potassium (K^+) were measured by flame photometry. Chloride was determined by standard $AgNO_3$ titration. Sulfate, Nitrate and iron were determined by spectrophotometer. Bicarbonate (HCO_3^-) was determined by titration with HCl. Other texts such as conductivity (EC) and pH were directly measured in situ using portable measuring device (HANNA instruments, HI9811, portable pH and EC METER, Italy) Note that before each measurement, the pH meter was calibrated with reference buffer solution. Each analysis was carried out in triplicate and then the mean value was taken. Sodium adsorption ratio (SAR), soluble sodium percentage (SSP), Magnesium adsorption ratio (MAR), Permeability index (PI) and Total hardness (TH) was computed as follows:

SAR = $Na^+ / {}^+\sqrt{[(Ca^{2+} + Mg^{2+})/2]}$
SSP = $[(Na^+ + K^+) / (Ca^{2+} + Mg^{2+} + Na^+ + K^+)]\ 100$
MAR = $[(Mg^{2+}) / (Ca^{2+} + Mg^{2+})]\ 100$
PI = $(Na^+ + \sqrt{HCO3^-}) / (Ca^{2+} + Mg^{2+} + Na^+)\ 100$
TH= $(2.5 \times Ca^{2+}) + (4.1 \times Mg^{2+})$

III. Results And Discussion

3.1. Suitability of groundwater for drinking

Groundwater quality assessment was carried to determine its suitability in terms of domestic purposes based on the NWQS [12] standards (Table 2). Chemically, the water used for drinking should be soft, low in dissolved salts and free from toxic constituents. Portability of drinking water is mainly based on recommended permissible limits of certain parameters, when it exceeds the permissible limit, it may be unfit for drinking

3.2. 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 range of 6.5 to 8.5 is generally considered satisfactory. Acid water tends 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 bitter or soda-like taste. In the study area, the concentration of hydrogen ion (pH) ranges between 6.5 to 7.5 with a mean of 6.9 (Table 2) all the water samples analyzed have concentration within the safe limit of 6.5 to 8.5 standard set by the NWQS [12] (Table 3). If pH is not within the permissible limit, it damages mucous membrane present in nose, mouth, eye, abdomen, anus in human beings [1].

3.3 Total hardness as $CaCO_3$

Total hardness (TH) is caused primarily by the presence of cations such as calcium and magnesium and anions such as carbonate, bicarbonate, chloride and sulphate in water. Water hardness has no known adverse effects; however, some evidence indicates its role in heart diseases, [13]. Jain [14] opined that hardness of 150-300 mg/l and above may cause kidney problems and kidney stone formation, as it causes unpleasant taste and reduce ability of soap to produce lather. Hard water is unsuitable for domestic use. In the study area, the total hardness varies between 5.8 - 8.9 mg/l with a mean 7.3 mg/l (Table 2). Most of the samples are soft water and has satisfied the limit of 150 mg/L (Table 3) set by NWQS [12].

Table 1: Classification of water hardness

Hardness range (mg/l of $CaCO_3$)	Water classification
0 – 75	Soft
75 – 150	moderately hard
150 – 300	Hard
>300	Very hard

Source: Sawyer and Mc Carty [15]

3.4 Chloride (Cl^-)

Chloride is present in all natural waters, usually in relatively small amounts; however, chloride also can be derived from human sources. Chloride is a major ion that is associated with Individual Septic Disposal System (ISDSS) [16] . In the study area, the concentration of chloride is low and range between 0.64 to 1.36 mg/L, with a mean of 0.96 mg/L (Table 2) which is below the maximum allowable concentration of 250 mg/L [12]. Excess chloride above the background levels may be due to groundwater contamination as a result of seepage from septic systems, landfill, fertilizers or animals. Excess concentration of chloride in drinking water gives a salty taste and has a laxative effect on people not accustomed to it [17]. Chloride imparts a salty taste and some times higher consumption causes the crucial for the development of essential hypertension, risk for stroke, left ventricular hypertension, osteoporosis, renal stones and asthma in human beings [18]. Although, the chloride plays an important role in balancing the level of electrolyte in blood plasma, but higher concentration can produce some physical disorders.

3.5 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 in the study area is low and ranged between 16.1 to 42.2 mg/L with a mean of 25 mg/L (Table 2) which is below the maximum allowable concentration of 50 mg/L according to NWQS [12] standard. Nitrate concentration that exceeds 50 mg/l in drinking water have the potential of causing health disorders such as methemoglobinemia, goiter, hypertension, cyanosis, and asphyxia (blue baby syndrome) in infants less than 3 months [19-20].

3.6 Sulphate (SO_4^{2-})

Sulphate occurs in water as the inorganic sulphate salts as well as dissolved gas. The concentration of sulphate ($SO4^{2-}$) in the present study the values are very low and ranged between 33.1 - 81.3 with the mean value of 57.5 mg/L (Table 2) and the values are within the maximum allowable limits of 100 mg/L according to NWQS [12] standards. The high concentration of sulphate in some places is likely due to the dissolution of gypsum, which underlies the area. According to Raghunath [21], sulfate causes gastrointestinal irritation if it exceeds 250 mg/l level. The excess of sulfate (more than 250 mg/l) may also be the reason for bitter taste and may have laxative effect to human beings and livestock at further higher level [22]. Very high levels of sulfates have been associated with some brain disorders in livestock.

3.7 Iron (Fe^{2+})

Iron is a very common element found in many of the rocks and soils of the earth's crust. In the study area, the concentration of iron is between 0.14 - 0.42 mg/L with a mean of 0.24 mg/L (Table 2) with the highest concentration value being 0.42 mg/L and the maximum allowable concentration based on NWQS [12] standard is 0.3 mg/L. The source of this iron is probably due to the presence of ironstone, which dissolved into the ground water. Three of the twelve samples had Fe values greater than 0.3 mg/l (Table 3). Iron is biologically an important element which is essential to all organisms and present in hemoglobin system. High concentration causes slight toxicity, inky flavour, bitter and astringent taste. Iron contained water makes the teeth and nail black and weak, stickiness of hair and water. The shortage of iron causes a disease called anaemia and prolonged consumption of drinking water with high concentration of iron may lead to liver disease called as haermosiderosis [23].

3.8 Calcium (Ca^{2+})

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. In the study area, the concentration of calcium in groundwater is low and ranged between 0.98 to 1.86 mg/L with the mean of 1.44 mg/L (Table 2) which is below the maximum allowable concentration of 75 mg/L [12]. From health point of view, the content of calcium in groundwater is unimportant. Its concentration in natural waters is typically <15 mg/l. When calcium (Ca^{2+}) and magnesium (Mg^{2+}) occurred in high concentration, they result in the hardness and alkalinity of the water.

3.9 Magnesium (Mg^{2+})

Magnesium contributes to the hardness of water and it is one of the most common elements found in the earth's crust. It is present in all natural waters. 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. In the study area, magnesium concentration ranged between 0.64 to 1.23 mg/L with the mean of 0.90 mg/L (Table 2). Some of the samples had Mg values slightly exceeding a set standard of 0.2 mg/l by NWQS, [12] with highest record of 1.23 mg/l.

3.10. Potassium (K^{+})

Potassium is an essential element for humans, plants and animals, and derived in food chain mainly from vegetation and soil. The main sources of potassium in ground water include rain water, weathering of potash silicate minerals, use of potash fertilizers and use of surface water for irrigation. In study area, potassium concentration ranged between 0.36 to 1.45 mg/L with the mean of 0.79 mg/L, which is lower than the maximum allowable concentration of 10 mg/L based on The European Economic Communities (EEC) [24] standards for drinking water. As per European Economic Community 5 (EEC) criteria, all the 12 samples fall within the guideline level of 10 mg/l. Though potassium is extensively found in some of igneous and sedimentary rocks, its concentration in natural waters is usually quite low. This is due to the fact that potassium minerals offer resistance to weathering and dissolution.

3.11. Sodium (Na^{+})

Sodium is common constituents of natural waters. Sources of sodium are halite, sea spray, some silicate and rare minerals such as plagioclase, plagioclase variety of albite and nepheline. Most sodium results from natural ion exchange. In the study area, the concentration of sodium in groundwater is low and ranged between 0.02 to 1.01 mg/L with a mean of 0.70 mg/L (Table 2) which is below the maximum allowable concentration of 200 mg/L [12]. From health point of view sodium have negative effects on people with heart disease. Sodium hydrogen carbonate mineral waters are important for treatment of gastric and biliary tract diseases.

3.12. Suitability of groundwater for irrigation

Chemical quality of water is a significant factor to evaluate the suitability of water for irrigation [25]. Suitability of water for irrigation purposes depends on the effect of some mineral constituents in the water on both the soil and the plant. Good qualities of waters for irrigation are characterized by acceptable range of:

- The Electrical conductivity (ECw)
- The Sodium Adsorption Ratio (SAR)
- The Soluble Sodium Percentage (SSP)
- The Magnesium Adsorption Ratio (MAR)
- The Permeability Index (PI)

The results of the different irrigation indices for rating irrigation water quality are presented in Table 4.

3.14. Electrical conductivity (ECw)

The total concentration of soluble salts in irrigation water can be expressed in terms of electrical conductivity for purposes of diagnosis and classification. In the study area, EC ranged from 133 to 1200 μS/cm with a mean value of 467μS/cm (Table 4). The large variation in EC is mainly attributed to lithologic composition and anthropogenic activities prevailing in the area. Table 5 showed that out of twelve groundwater samples, 8 samples fall into C1 category, showing low salinity hazard and 4 samples fall into C3 category indicating high salinity hazard. Normally, irrigation water with an EC of < 700 μS/cm causes little or no threat to most crops while EC > 3000 μS/cm may limit crops growth [26]. Groundwater that falls in the low salinity hazard class (C1) can be used without any special practices for salinity control. However, water samples that fall in the high salinity hazard class (C3) may have detrimental effects on salt sensitive crops and adverse effects on many plants. Such areas with high salinity require careful management practices. Very high salinity water (C4) is not suitable for irrigation under ordinary conditions but may be used for salt tolerant plants on permeable soils with special management practices.

3.15 Sodium Adsorption Ratio (SAR)

The sodium adsorption ratio gives a clear idea about the adsorption of sodium by soil. Sodium adsorption ratio (SAR) specifies the degree to which irrigation water tends to enter into cation-exchange reactions in soil. It is the proportion of sodium to calcium and magnesium, which affect the availability of the water to the crop and it causes harm to the soil composition and becomes compact and impervious. The sodium adsorption ratio of shallow groundwater obtained in the present study varies from 0.000 to 0.035% with a mean of 0.020%, Table 4 indicates that the values are generally low. Based on the US Salinity Laboratory classification (1954) the sodium hazard for groundwater samples in the study area is classified as low (Table 5). All the groundwater samples belong to low sodium hazard (S1) as per the sodium hazard classification. Water having SAR < 10 is good for irrigation. It was observed that all the sites studied were good for irrigation [27]. Continuous use of water having high SAR leads to breakdown in the physical structure of the soil particles.

3.16. Soluble Sodium Percent (SSP)

The soluble sodium percentage (SSP) of all twelve groundwater samples varied from 31.7 to 51.6% with mean value of 38.8% (Table 4). Based on the classification after Wilcox [28] out of twelve samples, seven samples fell under 'Good' class (SSP 20 to 40%) and five samples fell under 'permissible' class SSP 40 to 60%. Water with SSP greater than 60% may result in sodium accumulations that will cause a breakdown of the soils physical properties. The agricultural yields are observed to be generally low in fields irrigated with water belonging to unsuitable category. This is probably due to the presence of Na salts, which cause osmotic effects in soil plant system. Hence, air and water circulation is restricted during wet conditions and such soils are usually hard when dry [29]. In the study area, the ground waters might safely be used for irrigating agricultural crops.

3.17. 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 [30]. In the study area MAR varies from 25.6 to 51.0% with a mean of 38.5%. According to the MAR classification proposed by Khodapanah et al [31], eleven samples were classified as 'suitable' (MAR< 50%), one sample were rated as 'unsuitable' (MAR >50%) (Table 4). High MAR causes a harmful effect to soil when it exceeds 50%. But in the present study, MAR was less than 50% causing no harmful effect to soil.

3.18 Permeability Index (PI)

The soil permeability is affected by the long term use of irrigation water as it is influenced by Na^+, Ca^{2+}, Mg^{2+} and HCO^{3-} content of the soil. The PI value of irrigation water of the study area ranges from 54.0 to 78.1% with an average value of 63.2% (Table 4). The result show that all samples have PI greater than 25% and are good and suitable for irrigation purposes. According to Domenico and Schwartz [32] water can be classified based on permeability index as class I, class II and class III orders. Class I and class II waters are categorized as good for irrigation with 75% or more maximum permeability. Class III water are unsuitable with 25% of maximum permeability.

IV. Conclusions

The results revealed that the water is suitable for drinking and domestic uses. The ionic dominance for the major cations and the anions respectively were in these order; $Ca^{2+} > Mg^{2+} > K^+ > Na^+$ and $SO_4^{2-} > NO_3^- > HCO_3^- > Cl^-$. However, the water samples are low in EC, SAR, SSP, RSC and MAR values; the water is good for irrigation purposes and could be used on almost all soils with little danger of sodication and salinization of the soils.

V. Recommendations

This study emphasizes the need for regular groundwater quality monitoring to assess pollution activity from time to time for taking appropriate management measures in time to mitigate the intensity of pollution activity. The remedial measures include: i) encourage the framers to use biofertilizers and biopesticides to avoid the soil, surface water and groundwater contamination. ii) A short term and long term management action plan should be formulated for the efficient use of groundwater resources and other natural resources after taking into account the population distribution, agricultural activities etc.

Table 2: Results of physico-chemical analysis of groundwater

S/No.	PH	TH	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	HCO_3^-	SO_4^{2-}	NO_3^-	Cl^-	Fe^{2+}
1	7.5	7.7	1.42	1.01	1.23	0.02	1.67	36.5	18.2	0.81	0.18
2	7.1	6.7	1.25	0.87	1.45	0.33	1.86	33.1	16.1	0.82	0.21
3	6.8	6.6	0.98	1.02	1.26	0.2	1.42	68.1	25.1	1.36	0.27
4	6.5	5.8	1.03	0.78	1.17	0.76	0.98	61.8	19.3	1.29	0.31
5	6.6	7.3	1.86	0.64	0.43	0.73	1.67	53.8	31.6	0.97	0.37
6	6.9	8.3	1.68	0.99	0.63	0.83	1.73	60.1	28.7	1.01	0.42
7	7.1	8.9	1.53	1.23	0.73	0.86	1.24	72.2	42.2	0.64	0.22
8	7.3	8.2	1.41	1.14	0.65	0.82	1.14	64.1	36.9	0.75	0.17
9	6.7	8.3	1.77	0.94	0.69	0.92	1.38	81.3	17.3	1.09	0.14
10	7.0	7.3	1.63	0.79	0.44	0.78	1.23	70.2	19.2	0.96	0.19
11	6.6	6.3	1.49	0.64	0.44	1.01	1.73	42.6	24.2	1.03	0.19
12	7.1	5.9	1.21	0.69	0.36	0.97	1.62	46.2	21.4	0.87	0.21
SD	0.30	1.03	0.28	0.19	0.38	0.31	0.28	15.1	8.30	0.21	0.08
Mean	6.9	7.3	1.44	0.90	0.79	0.70	1.47	57.5	25.0	0.96	0.24

Table 3: Nigeria Standard for Drinking water Quality (NIS, 2007)

Parameter	Unit	Maximum Permitted	Health Impact	Notes
Mercury (Hg)	mg/L	0.001	Affects the kidney and central nervous system	
Nickel (Ni)	mg/L	0.02	Possible carcinogenic	
Nitrate (NO_3)	mg/L	50	Cyanosis, and asphyxia ("blue-baby syndrome") in infants under 3 months syndrome") in infants under 3 months	
Nitrite (NO_2)	mg/L	0.2	Cyanosis, and asphyxia ("blue-baby syndrome") in infants under 3 months	
pH	-	6.5-8.5	None	
Sodium (Na)	mg/L	200	None	
Sulphate (SO_4)	mg/L	100	None	
Total Dissolved Solids	mg/L	500	None	
Zinc (Zn)	mg/L	3	None	

Parameter	Unit	Maximum Permitted	Health Impact	Notes
Aluminum (Al)	mg/L	0.2	Potential Neuro-degenerative disorders	Note 1
Arsenic (As)	mg/L	0.01	Cancer,	
Barium	mg/L	0.7	Hypertension	
Cadmium (Cd)	mg/L	0.003	Toxic to the kidney	
Chloride (Cl)	mg/L	250	None	
Chromium (Cr^{6+})	mg/L	0.05	Cancer	
Conductivity	µS/cm	1000	None	
Copper (Cu^{+2})	mg/L	1	Gastrointestinal disorder,	
Cyanide (CN^-)	mg/L	0.01	Very toxic to the thyroid and the nervous system	
Fluoride (F^-)	mg/L	1.5	Fluorosis, Skeletal tissue (bones and teeth) morbidity	
Hardness (as $CaCO_3$)	mg/L	150	None	
Hydrogen Sulphide (H_2S)	mg/L	0.05	None	
Iron (Fe^{+2})	mg/L	0.3	None	
Lead (Pb)	mg/L	0.01	Cancer, interference with Vitamin D metabolism, affect mental development in infants, toxic to the central and peripheral nervous systems	
Magnesium (Mg^{+2})	mg/L	0.20	Consumer acceptability	
Manganese (Mn^{+2})	mg/L	0.2	Neurological disorder	

Table 4: Different parameter indices for rating groundwater quality and its sustainability in irrigation ECw in µS/cm

Serial No	ECw	PI (%)	MAR (%)	SAR	SSP (%)
1	146	54.0	41.6	0.000	33.9
2	160	69.1	41.0	0.009	45.6
3	180	63.2	51.0	0.006	42.2
4	192	68.1	43.0	0.023	51.6
5	140	63.0	25.6	0.018	31.7
6	133	61.2	37.1	0.019	35.4
7	162	55.0	44.6	0.021	36.5
8	176	56.0	44.7	0.024	36.6
9	1000	58.0	34.7	0.026	37.3
10	960	59.0	32.6	0.024	33.5
11	1200	74.0	30.0	0.035	40.5
12	1160	78.1	36.3	0.032	41.2
SD	457	7.7	7.2	0.01	5.7
Mean	467	63.2	38.5	0.020	38.8

Table 5. Salinity and Alkali Hazard Classes after Richard [33]

Quality of water	Electrical conductivity (µS/cm)	Sodium adsorption ratio
Excellent	<250	<10
Good	250-750	10-18
Doubtful	750-2250	18-26
Unsuitable	>2250	>26

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