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Assessment of Groundwater Quality and Aquifer Vulnerability in Jimeta Metropolis, Adamawa State North-Eastern Nigeria

[1]Timothy Ngbalang Gal and [2]Radeino Maddeino Tanyishi
[1]Department of Agric. & Bio Environmental Engineering
Adamawa State Polytechnic Yola
[2]Department of Mass Communication
Adamawa State Polytechnic Yola

ABSTRACT

The study assesses borehole water quality from the 20 wards of Jimeta Metropolis. This was aimed at evaluating the groundwater quality in the designated area and determine the aquifer's susceptibility to contamination. A total of 40 water samples were taken from boreholes in the 20 wards of Jimeta metropolis, both during the dry and rainy seasons. The obtained levels of the parameters were compared with the World Health Organization (WHO) (World Health Organization, 2011) and the Nigerian Standard for Drinking Water Quality (NSDWQ) (2017) guideline values to establish their conformity with the specified recommended limits. The concentration of each parameter was compared to the permissible norms to determine and compare the acceptability and effect of continued use of such water. The results showed that the mean concentration of contamination for all physiochemical parameters is within the authorized range, with the exception of the bacterial concentration, which exceeds the limit. The sensitivity of groundwater to contamination in the studied area was carried out using the GOD index, and the result shows that the study area has low vulnerability index except for Jambutu, which is moderate.

Keywords: Groundwater, Vulnerability, GOD Index, Aquifer, Jimeta.

Introduction

Groundwater is a significant natural resource for the affordable and secure provision of potable water supply in both urban and rural areas and plays a fundamental role in human well-being, as well as that of many aquatic ecosystems (Subramanya 2008). Groundwater is usually potable under natural conditions and requires almost no treatment before distribution and usage. Good water quality is a result of the preservation of the soil and rocks in the unsaturated zone above the water table. They filter out microorganisms and shield groundwater from surface toxins (AGW-Net, 2015). Though groundwater is not easily contaminated, once it is contaminated, it is difficult to remediate.

Groundwater, as a source of public water supply, has major advantages over surface water in terms of its protection from surface pollution. The occurrence of groundwater pollution is determined by the natural attenuation processes occurring within the zone between the source of contamination (land surface) and target (aquifer). The attenuation of contaminants is regulated by physical processes governed by the physical and hydraulic properties of aquifer media (e.g., thickness and hydraulic parameters that control recharge rate and quantity), chemical reactions that depend on soil properties (e.g., microbial activity, organic matter, presence of roots, etc.), vadose zone characteristics, aquifer characteristics, and geochemical properties of specific contaminants (Machiwal et.al., 2018).

Groundwater vulnerability is a phrase used to reflect the natural ground qualities that impact the ease with which groundwater may be contaminated by human activities (Kurwadkar, 2017). It may be described as the possibility or likelihood of the percolation and diffusion of pollutants from the ground surface into natural water table reservoirs under natural conditions (Qian et al. 2012). It is a concept that is directly related to the aquifer sensitivity to pollution (Chenini et al., 2015) and seen as a relative non-measurable and dimensionless concept where contamination is most likely to occur (Stigter et al., 2006). More scientifically, groundwater vulnerability includes the characteristics of the fundamental geological and hydrogeological aspects of a site that influence the ease of contamination of groundwater. As all groundwater is hydrologically related to the land surface, it is the efficacy of this connection that defines the relative sensitivity to contamination (Falowo and Ojo, 2017).

Metropolitan cities, with their large and dense population, frequently suffer from a variety of intense human influences. Many of the associated processes, like domestic and industrial waste disposal, landfills, and lack of sanitation facilities, can overburden the protection of the unsaturated zone, thereby posing contamination threats to groundwater as the effluent pollutants can be transported to the aquifer by infiltration. Groundwater supplies are threatened by over-pumping and the unsustainable exploitation of aquifers, which are caused by the fast-rising population and agricultural activities.

In order to address the current risks, it is imperative to conduct a scientific investigation that specifically examines the dynamics of the groundwater system. The study's objective is to assess the groundwater quality in the designated area and determine the aquifer's susceptibility to contamination.

Materials and Methods

Groundwater sampling

A total of 20 water samples were taken from boreholes in the 20 wards of Jimeta metropolis, both during the dry and rainy seasons. Water samples were taken from each borehole twice. The initial batch of samples was gathered in August, 2023, coinciding with the rainy season, while the subsequent batch was collected in January, 2024, coinciding with the dry season. A total of 40 water samples were obtained for the investigation. The water was gathered in 1-liter plastic containers, while a sample for bacteriological testing was obtained in pre-sterilized glass bottles.

Every container was clearly labeled based on the sample site to prevent any errors in mixing, and it was handled with care and carried immediately to the laboratory for analysis.

Laboratory Analysis.

Samples were taken to the laboratory for analysis in accordance with the standard methods for physiochemical and bacteriological parameters as prescribed by American Public Health Association (APHA) (1995), which gives standard methods for examination of water and wastewater with reference to the World Health Organization (WHO) (2011) and the Nigerian Standard for Drinking Water Quality (NSDWQ) (2007) guidelines for portable water.

Chlorine was determined by volumetric method, while calcium, potassium, and magnesium were determined by titration using EDTA. Nitrate, was determined using V2000 multi – analyte photometer, while iron concentration was carried out with a Varian model AA240FS Fast Sequential Atomic Absorption Spectrometer. The pH of the water was determined in the laboratory using a digital pH meter, conductivity meter was used in determining the conductivity of the water, direct complexation titration with ethylene diaminetetraacetic acid (EDTA) was used to determine the hardness of the water sample.

Statistical analysis

A mean value test was carried out on data obtained both the dry and rainy seasons. The obtained results were compared with the World Health Organization (WHO) (World Health Organization, 2011) and the Nigerian Standard for Drinking Water Quality (NSDWQ) (2007) guideline values to establish their conformity with the specified recommended limits. The mean value test is based on the estimation of the 95% upper confidence limit (UCL) of the mean concentration of a contaminant and its use as the acceptable value to be compared with the relevant guideline value or site-specific assessment criterion. The 95% UCL provides a reasonably conservative estimate of whether the recorded concentration is acceptable, considering the uncertainty and variability inherent with site investigations. The value is determined using the following procedures (Dean, 2007):

(i) Calculate the arithmetic sample mean (x).

(ii) Calculate the unbiased sample standard deviation (s).

(iii) Select a suitable t value, e.g., the 95th percentile confidence limit; the tabulated "t value" can be acquired from our four-figure mathematical table.

(iv) Calculate the upper 95th percentile bound of the sample as US95 = x + (ts$\sqrt{n}$), where n is the sample points.

(v) Compare the upper bound value (US95) with the guideline values.

Aquifer Vulnerability Assessment

The vulnerability assessment method employed in this paper is the GOD index method. It is a parametric system method that involves selecting representative parameters for groundwater vulnerability assessment. The components in these methods are merged by providing them with a strict range of values known as the raking scale that can be tied to the vulnerability index.

GOD Index Method

The GOD method is characterized by a rapid assessment of the aquifer vulnerability; it was developed by Foster, (1987) for studying the vulnerability of the aquifer against the vertical percolation of pollutants through the unsaturated zone, without considering their lateral migration in the saturated zone. The approach used in this model takes in consideration three parameters, namely, the kind of groundwater confinement (G), the general lithological character of the vadose zone (O), and the depth to the groundwater table (D). The approach is useful when data availability is limited (Rukmana et.al., 2020). The ranges and ratings of the GOD parameters are given in Table 1, while the vulnerability ranges are shown in Table 2.

The GOD index is computed by multiplying the influence of the three parameters using equation (1), and it varies from 0 (negligible vulnerability) to a maximum of 1 (severe vulnerability).

$$G_I = G_R + O_R + D_R \quad (1)$$

Where G_I is GOD vulnerability index, G_R is the rating for groundwater occurrence (type of aquifer, confine or unconfined), O_R is the rating for overlaying lithology of unsaturated zone and D_R is the rating for depth to groundwater.

Table 1: Ratings of GOD Parameters (Kirlas et.al., 2022)

GOD Parameters	Rating	Range
G_R: groundwater occurrence	0	None
	0	Overflowing
	0.2	Confined
	0.4	Semi-confined
	0.6	Uncovered (confined)
	1.0	Unconfined
O_R: lithology of the unsaturated zone	0.4	Residual soil
	0.5	Alluvial silt, loess, glacial till
	0.5	Mudstones
	0.5	Shales
	0.6	Aeolian sands
	0.6	Igneous/Metamorphic formation
	0.6-07	Vulcanic tuffs
	0.7	Alluvial and fluvio-glacial sands
	0.8	Alluvial fan gravels
	0.7-0.8	Sandstones
	0.8	Recent Volcanic lava
	0.9	Chalky limestone calcarenites
	0.9-1.0	Calcretes + Karst limestone
D_R: depth to groundwater	0.9	<5m
	0.8	5-20m
	0.7	20-50m
	0.5	50-100m
	0.4	>100m

Table 2: Vulnerability ranges corresponding to the GOD index (Kirlas et.al., 2022)

Vulnerability	Ranges
0 – 0.1	Negligible
0.1 – 0.3	Low
0.3 – 0.5	Moderate
0.5 – 0.7	High
> 0.7	Extreme

Results and Discussion

Groundwater Quality

The results of the borehole water analysis for samples obtained in the dry and wet seasons are provided in Tables 3 and 4 accordingly. The concentration of each parameter was compared to the NSDWQ and WHO permissible norms to determine and compare the acceptability and effect of continued use of such water.

Water quality evaluation: Parameters within guideline levels

The results showed that all of the boreholes tested were well within the limits given by NSDWQ and WHO both in the wet and dry seasons for: total hardness, Electrical conductivity (EC), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na), Potassium (K), Chloride (Cl^{-}), Nitrate (NO_3), and Iron (Fe^{2+}). The water quality, in terms of the specified criteria, is safe for consumption.

Hardness in water is usually a natural occurrence, indicating that there are a lot of calcium, magnesium, carbonate, hydrogen-carbonate, and sulphate ions present in the water. Water hardness in boreholes in the research area varies from 28 to 62 mg/L in both dry and rainy seasons. None of the samples exceeded the recommended values of 150 mg/L and 500 mg/L for drinking provided by NSDWQ and WHO, respectively.

The electrical conductivity of the water sample in the research area ranges from 630 to 680 Ω/m in the dry season and 690 to 700 Ω/m in the rainy season. The values are often found to be within the permissible limits of 1000 and 2500 Ω/m for drinkable water by NSDWQ and WHO, respectively.

The concentration of calcium was often determined to be within the guideline value of 75 mg/L established by WHO; NSDWQ has no guideline for the element. The value ranged from 40 to 50 mg/L in both the dry and rainy seasons across the research area.

Magnesium content was reported in just seven samples in the research region, with a value of 1 mg/L for both the dry and rainy seasons. The locations are the Federal Secretariat, Mallamre A&B, Karewa Extension, Nassarawo, Jambutu, Nepa, and Old Abbatoir. The value obtained is, however, within the guidelines of 20 and 50 mg/L for drinking water by NSDWQ and WHO, respectively.

Sodium concentration in the research area for both seasons ranged from 16 to 18 mg/L, which is below the recommended guideline threshold of 200 mg/L set by NSDWQ and WHO for drinking water. Concentrations of sodium in excess of 200 mg/L may give rise to an undesirable taste, and there have been reports of a possible relationship between salt in drinking water and the onset of hypertension, although no definite conclusions can be drawn (World Health Organization, 2006).

The concentration of potassium in water samples from our investigation ranged from 3 to 5 mg/L in both seasons. This falls within the criteria of 50 and 55 mg/L established by NSDWQ and WHO, respectively.

The use of chlorine in drinking water as a disinfectant has played a key role in preventing waterborne infections. According to the World Health Organization (1993), the adoption of drinking water chlorination has been one of the most significant advancements in public health protection. However, when the concentration of chlorine in water is over the standard value of 250 mg/L, it could result in irritation of the oesophagus, a burning sensation in the mouth and throat, and involuntary vomiting. In this study, chlorine content varies from 132 to 140 mg/L in the dry season and from 132 to 140 mg/L in the rainy season. The concentration for both seasons is well within the NSDWQ and WHO guideline limits of 250 mg/L.

Nitrate concentration in boreholes in the city is between 16 and 18 mg/L in both seasons. Therefore, borehole sources in our study area can be regarded as being within the range of 50 mg/L recommended by NSDWQ and WHO.

The concentration of iron was confirmed to be within the guideline levels of 0.3 mg/L by NSDWQ and WHO. The value over the research area ranges from 0.02 mg/L to 0.16 mg/L during both the dry and rainy seasons.

Water Quality Evaluation: Parameter outside guideline levels

The pH and bacterial analysis in a portion of the study area have been found to be outside the guidelines set by the NSDWQ and WHO.

pH is a measure of the relative concentration of free hydrogen and hydroxyl ions in water. The pH scale spans from 0 to 14, with 7 signifying neutrality, pH less than 7 indicating acidity, and pH greater than 7 indicating base. Because pH may be influenced by chemicals in water, it is a valuable marker of chemical change. The pH values of 18 of the 20 sample locations recorded during the rainy season are below the NSDWQ and WHO's acceptable standard of 6.5 - 8. These areas are: Karewa, GMMC, Police Barracks, Malamre A, Malamre B, Karewa Extension, Legislative Quarters, Nassarawo, Demsawo, Damilu, Jambutu, Old GRA, Bye-pass, Nepa Ward, and Old Abattoir. The spots had values ranging from 6 to 6.3. This means that groundwater at these places is corrosive during the rainy season. The pH value for samples collected during the dry season all falls within the permissible guideline values, with the exception of Nassarawo and Bye-pass, which both had a value of 6.3. pH is widely regarded as having no direct effect on humans. However, long-term ingestion of acidic water can usually lead to mineral shortages (Fairweather, Tait and Hurrel, 1996). Prolonged exposure to such acidic water will only invalidate the numerous efforts of governments to boost the nutrition of the people. Non-health implications are cosmetic, because acidic water tends to be destructive to pipes and faucets (Abubakar and Adeokola, 2012).

Coliforms are dangerous bacteria whose presence in water can lead to major health consequences. It should not be present in water used for drinking purposes. The bacterial study confirms the presence of this bacteria in both dry and wet seasons for water samples at: Police barracks, Mallamre A&B, Nassarawo, Demsawo, Damilu, Jambutu, Bye-pass, Nepa Ward, and Anwan Tana. During the wet season, the sample analysis at Demsawo and Damilu revealed no indication of the bacterium.

Table 3: Physio-chemical concentration of water samples in rainy season

Sample Point	PH	Total hardness ($CaCO_3$) (mg/L)	EC (Ω/m)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Na (mg/L)	K (mg/L)	Cl^- (mg/L)	NO_3 (mg/L)	Fe^{2+} (mg/L)	E-coli
Karewa	6	47	690	45	0	160	3	140	18	0.02	0
Federal secretariat	6.7	48	700	43	1	120	4	136	16	0.04	0
GMMC	6.1	62	690	45	0	160	3	140	18	0.01	0
Police barracks	6.1	50	700	42	0	160	4	138	18	0.1	1
Maskare	6.7	43	700	45	0	140	3	132	16	0.06	0
Mallamre A and B	6	64	690	41	1	145	4	140	17	0.03	1
Karewa Extension	6.1	58	690	41	1	160	3	138	18	0.01	0
Legislative Quarters	6.7	55	700	43	0	160	4	140	16	0.16	0
Nassarawo	6.3	38	690	45	1	150	3	140	16	0.06	1
Luggere	6.8	30	700	42	0	153	4	132	18	0.1	0
demsawo	6.1	62	700	43	0	156	3	134	17	0.03	0
Damilu	6.1	47	690	41	0	160	4	140	16	0.03	0
Jambutu	6.1	47	700	45	1	156	3	140	17	0.01	1
Old GRA	6.8	48	690	40	0	160	4	136	18	0.1	0
Bye-Pass	6.3	34	690	45	0	141	3	138	18	0.04	1
Nepa ward	6.1	47	700	45	1	150	4	140	17	0.1	1
Old Abbatior	6	38	690	42	1	160	3	138	18	0.02	0
Anguwan Tana	6.8	47	700	45	0	160	4	140	18	0.06	1
NSDWQ	6.5 - 8.5	150	1000		20	200	50	250	50	0.30	0
WHO	6.5	500	2500	75	50	200	55	250	50	0.30	

Sources: Field work (Aug – Sept, 2023)

Table 4: Physio-chemical concentration of water samples in dry season

Sample Point	PH	Total hardness ($CaCO_3$) (mg/L)	EC (Ω/m)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Na (mg/L)	K (mg/L)	Cl^- (mg/L)	NO_3 (mg/L)	Fe^{2+} (mg/L)	E-coli
Karewa	7	45	680	45	0	160	4	140	18	0.02	0
Federal seceretariate	6.7	46	680	43	1	120	4	136	16	0.04	0
GMMC	7.1	60	670	45	0	160	3	140	18	0.01	0
Police barracks	7.1	48	660	42	0	160	4	138	18	0.1	1
Maskare	6.7	41	680	45	0	140	3	132	16	0.06	0
Mallamre A and B	7	62	630	41	1	145	3	140	17	0.03	1
Karewa Extension	7.1	56	680	41	1	160	4	138	18	0.01	0
Legislative Quarters	6.7	53	650	43	0	160	4	140	16	0.16	0
Nassarawo	6.3	36	640	45	1	150	3	140	16	0.06	1
Luggere	6.8	28	680	42	0	153	5	132	18	0.1	0
demsawo	7.1	60	680	43	0	156	4	134	17	0.03	1
Damilu	7.1	45	650	41	0	160	4	140	16	0.03	1
Jambutu	7.1	45	680	45	1	156	5	140	17	0.01	1
Old GRA	6.8	46	670	40	0	160	4	136	18	0.1	0
Bye-Pass	6.3	32	680	45	0	141	3	138	18	0.04	1
Nepa ward	7.1	45	660	45	1	150	4	140	17	0.1	1
Old Abbatior	7	36	680	42	1	160	4	138	18	0.02	0
Anguwan Tana	6.8	45	680	45	0	160	3	140	18	0.06	1
NSDWQ	6.5 - 8.5	150	1000		20	200	50	250	50	0.30	0
WHO	6.5	500	2500	75	50	200	55	250	50	0.30	

Sources: Field work (Jan – Feb. 2024)

Mean value test

The mean value test was done using data from each season, and the average value for the two seasons is shown in Table 4. The goal of the mean value test is to determine the level of water contamination with respect to guideline values. The test to assess the risk to human health from water contamination in the study area finds that the mean concentration of contamination for all physiochemical parameters is within the authorized range, with the exception of the bacterial concentration, which exceeds the limit. Using the mean value test, it is possible to establish that action is required to reduce these contaminants in the area.

Table 4: Mean value test for water sample

	Upper Bond Values			Guideline values	
Parameters	Dry season	Rainy season	Mean	NSDQW	WHO
PH	7.00	7.01	7.01	6.5 -8.5	6.5
TDS (mg/L)	335	338	336.50	500	1000
Total hardness (mg/L)	50.47	52.29	51.38	150	500
EC (Ω/m)	675.81	697.47	686.64	1000	2500
Ca (mg/L)	44.05	43.88	43.97		75
Mg (mg/L)	0.62	0.63	0.63	20	50
Na (mg/L)	157.77	157.01	157.39	200	200
K (mg/L)	4.08	3.75	3.92	50	55
Cl (mg/L)	139.18	138.96	139.07	250	250
N (mg/L)	17.63	17.55	17.59	50	50
Fe (mg/L)	0.07	0.07	0.07	0.3	0.3
E-Coli	0.74	0.62	0.68	0	

Result for aquifer vulnerability

Groundwater Occurrence.

Groundwater occurrence is one of the criteria utilized in the investigation of groundwater vulnerability (Rukmana, 2020). It can be interpreted based on subsurface conditions utilizing vertical electrical sounding (VES). The research region's groundwater occurrence type is an unconfined aquifer. Table 2 shows that the parameter's rating is given a value of 1.

Overlying lithology of the vadose zone.

It is the lithological property and degree of consolidation of the vadose zone that influence pollutant attenuation processes. This depends on the porosity and particle size of the constituent materials. In general, when toxins reach the water table, they spread into groundwater and get diluted (Jesudhas et al. 2021). The main constituents of the aquifer lithology in the research area were laterite, clay, and shale, all having a value of 0.5 based on the GOD parameter categorization value (Table 2).

Depth to Groundwater.

This characteristic is thought to have a substantial effect on groundwater quality decline. It depicts the real depth from the ground surface to the water table, and its thickness functions as a barrier for pollution until it reaches the saturated aquifer. Higher depths in groundwater suggest a decreased likelihood of pollution and consequently less sensitivity due to the increased potential for natural attenuation (Kirlas et.al., 2022). The groundwater depth data is acquired by measuring the boreholes in the research area. Table 5 indicates the groundwater depth in the study area as well as GOD's classification rating.

Table 5: Groundwater depth and GOD classification rating.

Location	Depth to groundwater (m)	D_R
Karewa	135	0.4
Federal Secretariat	150	0.4
GMMC	130	0.4
Police Barrack	100	0.5
Maskare	80	0.5
Malamre A & B	140	0.4
Karewa Extension	120	0.4
Legislative Quarters	150	0.4
Nassarawo Luggere	80	0.5
Demsawo	65	0.5
Damilu	70	0.5
Jambuto	45	0.7
Old GRA	125	0.4
Bye-Pass	75	0.5
Nepa Ward	135	0.4
Old Abattoir	80	0.5
Angwan Tana	85	0.5

The GOD index is calculated using Eq. 1, and according to the technique of classification (Table 2), the groundwater index (GI) in the research region varies between 0.2 and 0.35, as indicated in Table 6. The findings suggest that the sensitivity of groundwater to contamination in the studied area is low except for Jambutu, which is moderate. This means that the migration of pollutants in the subsurface materials down to groundwater in most of the research region is low and moderate in just Jambutu.

Table 6: GOD Vulnerability Index of the Study Area

Location	GOD Vulnerability Index
Karewa	0.20
Federal Secretariat	0.20
GMMC	0.20
Police Barrack	0.25
Maskare	0.25
Malamre A & B	0.20
Karewa Extension	0.20
Legislative Quarters	0.20
Nassarawo Luggere	0.25
Demsawo	0.25
Damilu	0.25
Jambuto	0.35
Old GRA	0.20
Bye-Pass	0.25
Nepa Ward	0.20
Old Abattoir	0.25
Angwan Tana	0.25

Conclusion and Recommendations

The results of the analysis and evaluation of groundwater from twenty locations in Jimeta metropolis during the dry and rainy seasons for domestic purposes revealed that the groundwater quality is safe for physio-chemical parameters in both seasons based on the comparative analysis made with the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ) guidelines for portable water using the mean value test. The bacterial analysis of water sample across the study area confirms the presence of coliform in both dry and wet seasons in sample obtained in some part of the study area. The study further investigated the sensitivity of groundwater aquifer to contamination and found that the index of sensitivity of the aquifer in the study area to contamination is low, except for Jambutu which is medium.

Based on the findings of this research, the following recommendations were made:

Continue monitoring: Although the physio-chemical parameters meet WHO and NSDWQ guidelines for portable water, it's crucial to continue monitoring the water quality regularly, especially regarding bacterial contamination. This will help identify any changes or areas with recurring issues.

Targeted interventions: The presence of coliform bacteria indicates potential fecal contamination and poses a risk to public health. Implementing measures to reduce bacterial contamination, such as; promoting household water treatment methods like boiling or chlorination in vulnerable areas. Investigating and addressing potential sources of bacterial contamination in those specific areas. This might involve identifying and managing sewage leaks, improper waste disposal, or agricultural practices that could be introducing bacteria.

Collaboration with Stakeholders: Collaboration among stakeholders, including government agencies, local authorities, researchers, and community groups, is essential for implementing effective water quality management strategies.

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