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Distribution and Risk Assessment of Pollution Levels in Underground Water Sources of Selected Areas of Karu

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Abstract- The problem of underground water quality is a significant concern in many parts of the world, including Nigeria. Therefore, it is essential to assess the quality of underground water in urban areas to ensure its safety. The samples of underground water were collected in duplicates from ten boreholes sources within each of the five areas of Karu LGA studied, such as Mararaba, Ado, New Nyanya, Masaka and Auta. The physical and chemical properties of water, include pH, temperature, turbidity, and conductivity were determined using standard methods. Water quality index and multivariate analysis were carried out to identify pollution sources. Some of the heavy metals (Cr and Cd) were above the permissible limits but didn't pose grave danger to water use. Principal component analysis could account for over 80% of variation and in combination with hierarchical cluster analysis was able to identify the sources of pollution in urban Karu to be a combination of anthropogenic activities and leaching of underlying minerals. Water quality index values were <25, which is considered to be excellent and low risk, hence fit for consumption. The study will help to provide information on the safety of the water for human consumption, agricultural use, and other purposes.

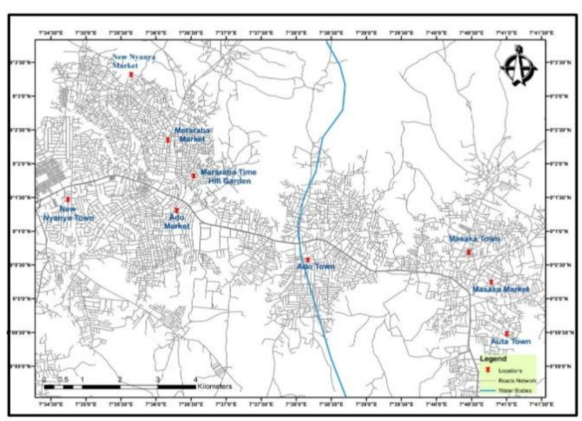
Indexed Terms- Underground water, Principal component analysis, water quality index, water pollution and risk assessment

I. INTRODUCTION

The problem of underground water quality is a significant concern in many parts of the world, including Nigeria (Adekunle & Adetunji, 2019). The increasing population, industrial activities, and agricultural practices in urban areas can contaminate underground water sources, posing a risk to human health and the environment (Ogunwale & Oyediran, 2020). Therefore, it is essential to assess the quality of underground water in urban areas to ensure its safety for human consumption and other uses. Natural occurring groundwater is typical of high quality, but it can deteriorate due to insufficient source protection and poor resource management. Its contamination may be due to improper dwelling of and waste disposal (Allamin et al., 2015; Shawai et al., 2019). Monitoring and evaluating groundwater quality are crucial components in effective water resource management. The traditional groundwater quality assessment method compares individual parameter concentration from generally acceptable standard guidelines data and water samples with parameter concentration values that exceed their limit values are expected to have health implications (Dede et al., 2013). This approach delivers vague information on overall quality but doesn't provide any information on overall quality temporal and spatial scales. (Ibrahim, 2019; Balogun et al., 2020). The Water Quality Index (WQI) in combination with principal component analysis (PCA) technique that provides the composite influence of individual water quality parameters on an area's overall water quality (APHA (2017).

II. MATERIALS AND METHODS

2.1 STUDY AREA



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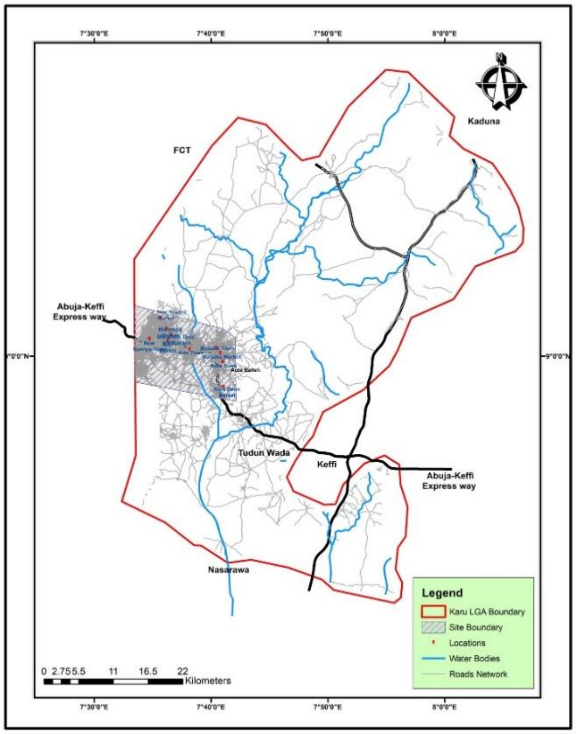

Figure 1. Map of study area

The study area is Lower-Urban Karu Local Government Area in Nasarawa State, Nigeria (Adekunle & Adetunji, 2019). The area was assessed using geospatial mapping, (Smith et al., 2018) and it is made up of settlements such as; Mararaba, Ado, New nyanya, Masaka, and Auta. The majority of the study area is dominated by residential land use. Commercial, agricultural, institutional, and educational activities are all part of the study area. Commercial activity can be found throughout the areas, with several major markets including Mararaba market, Ado market, New nyanya market, Masaka market and Auta bean market. The climate is tropical wet and dry, with the wet season lasting 4 to 6 months between April and October (Olofin and Tanko, 2002).

2.2 Sample Collection and preparation

The water samples were collected in duplicates from ten individual boreholes within each of the five areas of Karu LGA studied, to include; Mararaba, Ado, New-nyanya, Masaka and Auta. Geo-spatial analysis was carried out with the aid of digital compass and spatial maps. The pH and temperature for the samples was immediately measured and recorded after collection in-situ while the other physicochemical parameters were determined in the laboratory using standard procedures and precautions. The digested filtrate using HNO_3 and HCl aua regia was analyzed for heavy metals using Atomic absorption spectroscopy (AAS) in duplicate determinations to minimize error. (Adelana & Olasehinde, 2018).

2.3 Determination of physicochemical properties

Some selected physical and chemical parameters were determined in groundwater samples. The parameters include; temperature, pH, Chloride (Cl), alkalinity, dissolved oxygen (DO), chemical oxygen demand (COD), Sulfate ($PO4^{2-}$), and some heavy metals like Iron (Fe), lead (Pb), chromium (Cr) and cadmium (Cd) were also determined using standard methods (WHO, 2011). All determinations were done in duplicates.

III. RESULTS AND DISCUSSION

Table 1. Descriptive analysis of physicochemical properties for wet season

3.1 Physicochemical Properties

The physicochemical parameters were analyzed and reported in Table 1. Below

Table 1. Physicochemical properties

	N	Min	Max	Mean	Std. Dev.	(NSDWQ, W.H.O 2007)
Temp	10	26.90	28.16	27.7280	0.48618	Ambient
pH	10	6.01	6.81	6.3840	0.32786	6.5 - 8.50
DO	10	1.50	1.90	1.8100	0.12867	4.0 – 6.0 mg/L
COD	10	17.00	21.10	18.9000	0.37032	<20 mg/L
Alkalinity	10	37.60	45.20	40.7800	0.81101	<200mg/L
Chloride	10	0.01	0.32	0.1490	0.10354	250 mg/L
PO42-	10	0.21	0.91	0.4770	0.24878	0.3 – 0.5 mg/L
Pb	10	0.48	0.60	0.5130	0.03401	0.01 mg/L
Cr	10	0.001	0.008	0.0010	0.01201	0.05 mg/L
Cd	10	0.001	0.009	0.0011	0.00804	0.003 mg/L
Fe	10	0.01	0.21	0.0830	0.07181	≤ 0.3 mg/L

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The physicochemical properties for underground water sources (bore holes) in urban Karu were investigated and results obtained were compared with water standards (NSDWQ and W.HO 2011) as shown in Table 1. as descriptive statistical analysis of the measured parameters. The temperature range in the study area was from 26 °C to 28 °C with Masaka (M1) sample having the lowest temperature while Ado (AD2), Maraba (MR1 and MR2) and New Nyanya (NY2) had the highest temperature. The mean temperature was obtained as 27 ± 0.48 °C. This mean temperature for ground water was also reported by Umana et al. (2022) in the assessment of ground water in bore holes in parts of Lagos. They reported temperatures in acceptable range (27.6 ^{O}C) as specified by NSDWQ. pH defines the hydroxonium ion concentration in solution which expresses the degree of acidity and alkalinity. In the study area, the pH ranged from 6.01 to 6.81 and the mean pH was 6.38 ± 0.33. Maraba (MR1) sample had the lowest pH of 6.01 while New Nyanya (NY1) had the highest pH of 6.81, all others also had pH lower than the acceptable values specified by NSDWQ. The limit set by NSDWQ is ranged (6.5–8.5) (Standard organization of Nigeria, SON, 2015). This implies that the ground water in urban Karu is slightly acidic. Similar observation was also reported by (Shawai et al., 2018). The possible reasons for the acidic level maybe as a result of dissolution of the high amount of carbon dioxide emitted in the area from atmosphere and soil giving carbonic acid, sometimes it could be the breaking down of organic matter which may lead to humic or fulvic acids, also the leaching of minerals into the underground water sources from mineral rich-rocks since the area is geographically rich in underlying solid minerals. Dissolved oxygen (DO), shows concentration of oxygen gas that is dissolved in water. In the area under study, the measured DO ranged from 1.50 mg/L to 1.90 mg/L. the water source from Auta (A2) had the lowest value while sources from Masaka (M1), New Nyanya (NY2), and Maraba (M1 and M2) had the highest DO values. The obtained mean DO value of 1.81 ± 0.12 mg/L for the study area was below ideal values of 4-6 mg/L. Low value of DO may be associated with high level of organic matter decomposition, high bacteria activity and bacterial contamination (Abatyough et al., 2016). Alkalinity is the degree of buffering of acidity in water. Alkalinity in water is due to the presence of carbonate ions CO32−, bicarbonates HCO3−, hydroxide OH−. The mean value from the study area was 40.78 ± 2.81 mg/L alkalinity values from the study area are within the acceptable limit of 200 mg/L set by NSDWQ. Chemical oxygen demand (COD) in underground water refers to the concentration of organic matter that can be oxidized by chemical agents. It's a measure of water quality, indicating the degree of pollution from organic substances. High COD levels in groundwater can lead to reduced dissolved oxygen, potentially harming aquatic life and affecting water potability, the Water samples in the study area had the lowest COD value of 17.10 mg/L at New yanya (NY1) and Ado (AD1) samples while the highest value 0f 21.10 mg/L was obtained at Maraba (MR1) sample. The mean value of 18.9 ± 0.37 mg/L was determined, this value is within the acceptable standard for portable water but it also indicates reasonable chemical activities in the water source. Phosphate (P042-) contents in the samples were determined with the lowest value obtained as 0.21 at Ado (AD1) while the highest value of 0.91 at Auta (A2). Samples from Ado (AD1) and Maraba (MR2) fall within the acceptable limits, all others were above. Similar report was observed by Arthur et al. (2023) in Latosa of Ondo state, Nigeria. They reported that the accumulation of excess nutrients over a period of time could also lead to eutrophication. Chloride levels were reported to range from 0.01 at Masaka (M1) to 0.32 at Auta (A2). The mean value of 0.14 ± 0.10 was recorded. The measure values are within standards.

3.2 Heavy Metal Analysis

The heavy metals like, Iron, Lead, Cadmium and Chromium in the water samples were analyzed and results are presented in Table 2. Some heavy metals have the potential of being deadly and metabolic dysfunction. According to NSDWQ, High concentration of Iron affects the colour and taste of water. In the study area, the mean value for Iron was 0.08 ± 0.07 mg/L. The permissible limit for Iron is 0.3 mg/L. Lead is implicated in serious health issues like cancer, interference with vitamin D metabolism, toxic to central, peripheral nervous system and obstruction of proper infant mental development (Hammoumi, et al., 2024), measured mean value for Lead was 0.51 ± 0.03 mg/L, all the samples had values above permissible limits of 0.01 mg/L. Cadmium is a heavy metal known for its toxicity to kidney (Ali et al.,

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2024), mean measured value of Cadmium in the water sources was 0.0011 ± 0.008 mg/L, this value was lower than the acceptable limit of 0.003 mg/L set by NSDWQ. Chromium is known to be carcinogenic especially Cr^{+6}, mean measured range of chromium in the study area was 0.0010 ± 0.0012 mg/L, all the samples had Chromium values within acceptable limit.

Table 2. Total Variance Explained for dry season

	Initial Eigenvalues		
Component	Total	% of Variance	Cumulative %
1	2.787	39.814	39.814
2	1.861	26.582	66.396
3	1.197	17.097	83.494
4	.679	9.699	93.193
5	.219	3.133	96.326
6	.197	2.821	99.147
7	.060	.853	100.000

Extraction Method: Principal Component Analysis.

Table 3. Component Scores for dry season

	Component		
	1	2	3
Temp	.843	-.095	-.073
pH	-.710	-.537	.310
DO	.295	-.009	.857
COD	.686	.487	-.294
Alkalinity	.649	-.717	.016
Chloride	.504	.520	.518
PO42-	-.584	.736	.071

Extraction Method: Principal Component Analysis.

a. 3 components extracted.

3.3 Principal Component Analysis (PCA)

Principal component analysis (PCA) was applied to sets of parameters obtained from underground water sources from the study area. Principal components (PC's) were extracted with their corresponding component plot rotated in spac as shown in Tables 3 and 4 and Figures 2 and 3. PC3 having a cumulative variance of 83.494 meaning it could explain up to 83% of the total variance been observed among the studies samples. High factor loadings were observed on DO, Chlorides and PO42-. This indicates presence of organic matter which could be from sewage leakage or prolong use of fertilizer for agricultural purpose. Therefore, the source of pollution is mainly anthropogenic. PC2 having cumulative variance of 66.396 meaning it could account for about 66% of the total variance been observed in the study area PC2 has high factor loadings on COD, Alkalinity and PO42- The source of these pollutants is mainly from leaching of rock bearing minerals from the ground, hence a more natural pollution source. Figure 4. shows the cluster plots for hierarchical cluster analysis (HCA) carried out to check for similarities within the locations for water sources. A total of ten source locations were clustered into three (3) main clusters. The first cluster has Mararaba (MR1 and MR2), Auta (A2) and Masaka (M1) and also New Nyanya (NY2), these are locations of high human populations and markets hence pollution here is likely due to anthropogenic activities. The second cluster contains the locations, Ado (AD1 and AD2), Masaka(M2) and New Nyanya (NY1). These are mainly residential areas and pollution here is attributable to leaching of minerals and waste disposal. While the last cluster contains site 5 referring to Auta (A1) clustered alone linked to all other clusters is relatively sparsely habited area comprising of several rocks. pollution here is largely due to natural leaching of underlying mineral rocks. These similarities observed among the studied locations of water sources would be useful in mitigating water quality in Karu.

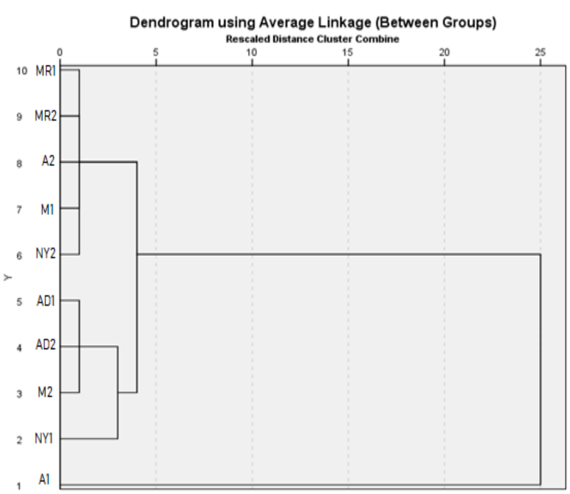

Figure 2. Dendrogram of Clusters

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3.4 Water quality index

Calculated results of water quality index (WQI) for underground water sources is presented in Table 4. The WQI was determined as 1.55 which is within the range of 0-25 that is considered to be excellent, therefore the underground water sources in the studied area are good enough for daily use and industrial activities.

Table 4. Water quality parameters

AP	IP	S	W	QP	QXW
27.728	0	28	0.035714	27.728	0.990286
6.384	7	6.5	0.153846	-1.69292	-0.26045
1.81	14.6	5	0.2	-15.71	-3.142
88.9	0	30	0.033333	88.9	2.963333
40.78	0	44.1	0.022676	40.78	0.924717
0.149	0	250	0.004	0.149	0.000596
1.477	0	0.1	10	1.477	14.77
		SUM	10.44957	SUM	16.24648

$$\boldsymbol{WQI = \frac{QW}{W}} = 1.55$$

IV. CONCLUSION

The study of pollution distribution and risk in Karu was identified to be caused by both anthropogenic activities or leaching of underlying mineral sources as suggested by principal component analysis with component 3 having high scores for DO, pH, chlorides and $PO4^{2-}$, Similarities were also observed among the studied locations from principal component analysis (PCA). These causes are attributable to the huge markets and population in the study area, furthermore the large amounts of underlying rocks and minerals could also be responsible. Overall, the water quality index (WQI) suggests that the water in Karu area of Nasarawa state can be classified as safe for consumption.

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