ASSESSMENT OF HAND-DUG WELLS IN ATABA COMMUNITY OF ANDONI LOCAL GOVERNMENT AREA, RIVERS STATE, NIGERIA



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Abstract
Uncontaminated potable water is necessary for the existence of humans. However, contaminated water poses threat to the health of consumers. This study assesses the physicochemical and microbial quality of four hand-dug wells (W1, W2, W3 and W4) in Ataba Community of Andoni Local Area, Rivers State, Nigeria. Water samples were taking from these well locations and analyzed for water quality parameters, using standard methods of analysis and results compared with WHO standards. The findings reveal notable spatial variations influenced by natural processes and human activities. All wells exhibited acidic pH levels ranging from 4.68 to 5.97, with W3 and W4 being the most acidic, potentially increasing heavy metal mobility and health risks. While parameters such as TDS (27–123 ppm), salinity (<115 ppm), and turbidity (0 NTU) remained within safe limits, microbial analysis showed high coliform contamination in W2, W3, and W4, and W1 exceeded WHO microbial standards with TCC of ≥2400/100 mL and FCC of 122/100 mL (WHO, 2017). Heavy metals—cadmium, lead, chromium, and nickel—were elevated in W1 and W2, surpassing permissible levels; notably, cadmium was 0.123 mg/L (W1), 0.231 mg/L (W2), and 0.019 mg/L (W3), while lead was 0.24 mg/L (W1) and 0.21 mg/L (W2) (Järup, 2003; WHO,

2017). Statistical analyses confirmed significant differences across wells, with W1, W2, and W3 showing higher pollution levels ($p < 0.001$). The Water Quality Index indicated W1, W2, and W3 are excessively polluted and unsafe for drinking, whereas W4 remains of excellent quality. The extremely high WQI values observed for W1, W2, and W3 indicate that the concentrations of pollutants, such as heavy metals, organic contaminants, and microbial load, are alarmingly high. While W3 and W4 present relatively safer profiles for some parameters, the elevated levels in W1 and W2 warrant immediate attention and remediation to safeguard environmental and public health.

Keywords: *Water quality, physicochemical parameters, microbial content, health risk, potentially toxic elements.*

1.1 Introduction

Clean and potable water is essential for existence and survival of humans (Akinfolarin et al., 2025, Kalagbor & Akinfolarin, 2023, Akinfolarin & Chukwuji, 2016). Physicochemical characteristics of water including pH, conductivity, total dissolved solids (TDS), turbidity, and oxidation-reduction potential serve as vital indicators of water quality. These parameters influence the solubility, mobility, and bioavailability of heavy metals in water (USEPA, 2020; Moyo et al., 2019). For instance, acidic conditions (low pH) can promote the leaching of metals such as lead and copper from surrounding rocks and pipes, thereby increasing their concentrations in water. Elevated levels of conductivity and TDS often suggest high concentrations of dissolved ions, including heavy metals, which may be harmful (Olatunji et al., 2018). Monitoring these parameters is crucial for identifying contamination sources and assessing water safety for human consumption and domestic use. Microbial contamination is another critical aspect of water quality evaluation. The presence of total coliforms and fecal coliforms (such as Escherichia coli) in hand-dug well water indicates fecal pollution, posing substantial health risks (WHO, 2006). Such contamination can result in waterborne diseases like cholera, dysentery, typhoid, and hepatitis. Regular microbial testing is essential to determine the microbiological safety of water, guiding interventions to prevent disease outbreaks and promote safe water handling practices.

Consuming water contaminated with both heavy metals and pathogenic microbes can lead to compounded health effects. Heavy metals like lead and cadmium tend

to accumulate in vital organs such as the kidneys and brain, causing chronic toxicity and neurological damage (Kimbrough et al., 2015; Jaishankar et al., 2014). The presence of fecal coliforms indicates possible exposure to pathogenic bacteria and viruses, which can cause gastrointestinal illnesses and other infections (WHO, 2017; Ahel et al., 2016). The combined exposure to chemical and microbial hazards increases health risks, particularly amo2ng children and immunocompromised individuals.

Therefore, regular assessment of physicochemical parameters, heavy metal levels, and microbial load in hand-dug wells is vital for protecting public health. Such monitoring enables early detection of contamination sources, evaluation of water safety, and the implementation of appropriate treatment and management strategies (Ahel et al., 2016). Compliance with national and international water quality standards, such as those established by the World Health Organization (WHO) and the Standard Organization of Nigeria (SON), is essential to ensure the provision of safe drinking water and minimize health risks (SON, 2015).

Ataba community primarily depends on hand-dug wells as their main source of drinking water. This reliance raises concerns about the safety and quality of the water, especially considering the potential for contamination by heavy metals and microorganisms. Despite the community's dependence on these water sources, there is a lack of comprehensive data on their physicochemical and microbiological quality. This study is essential for evaluating the current water quality in Ataba, identifying potential health risks, and supporting the development of targeted measures to ensure safe and sustainable water access for the community. The findings derived from this study would give insight into the deleterious effect caused by the consumption of water contaminated by heavy metals and microbes in ground water (hand dug wells) in Ataba community of Andoni Local Government Area of Rivers State. The findings derived from this study would give insight into the deleterious effect caused by the consumption of water contaminated by heavy metals and microbial communities in ground water (hand dug wells) in Ataba community of Andoni Local Government Area of Rivers State.

2.0 Literature Review

Akinfolarin and Ebiana (2016) carried out a study on ground water (Hand dug well water) in the Egunughan community of Emughan, Abua in Abua/Odual Local Government Area of Rivers State. The Hand dug well was assessed for potability purpose by analysing six hand dug wells (W1 to W6) for physicochemical parameters. The results obtained were compared with the permissible limits for drinking water provided by World Health Organization (WHO). The study showed that the groundwater (hand-dug well) in this community area was slightly acidic except for W3 and W5 wells which were within the acceptable limits. Their study did not cover heavy metals and microbial parameters. It was recommended that these hands dug well water (W1–W6) should be monitored regularly to avoid pollution problems that could bring about water borne diseases in the community.

Christian et al. (2024) conducted a study on the management and characteristics of hand-dug wells impact water quality in three suburbs of Kumasi, Ghana, using a combination of qualitative and quantitative research methods. The findings indicated difficulty in establishing a relationship between demographic factors and individual perceptions regarding the management of hand-dug well features. They recommended that the construction and maintenance standards of hand-dug well should be encouraged, it was also stated that properly built wells which are protected from contamination sources should be promoted.

Benefit, (2024) conducted a study on the quality of water between hand dug wells and borehole in Ogbia Local Government Area. The findings indicated that from the three different locations namely Otuoke, Onuebum and Emeyal, the bacteriological water analysis revealed that all the boreholes and hand dug wells were not free from total heterotrophic and coliform bacteria. Their study did not cover heavy metals and human health risk assessment. They concluded that the water samples obtained from hand dug wells in these communities was unsafe for drinking and household usage, they further recommended that these water samples should be properly treated before they are consumed or utilized for cooking purposes.

Kanneh and Lebbie (2023) carried out a study on the assessment of the quality of newly constructed hand-dug well used for drinking and their treatment system at Kenema town, Kenema District, Eastern, Sierra Leone. Standard laboratory

techniques were used in the analysis of the water samples. The finding showed that all the water samples collected and examined were safe and fit for drinking purposes since they were within the WHO permissible limits and also recommended that there should be regular monitoring and treatment of the hand dug wells and other researchers to undertake further studies in different seasons and consider other water quality parameters. Their study did not cover heavy metals and human health risk assessment. Kanneh and Lebbie (2023), concluded that the water samples obtained from hand dug well in Kenema town, Kenema District, Eastern, Sierra Leone posed no carcinogenic threats to the residents of the study location, they however suggested that the presence of the feacal coliform in water samples could lead to water borne diseases and adversely affect the health of residents who depend solely on these hand dug wells as source of their water needs. Ojo (2023) in their study on the assessment of heavy metals content of hand dug wells in Shasha Market, Akure, South Western, Nigeria reported Cd pollution in all the water samples analyzed while some of the well water samples analyzed did not fall within WHO standard for Cr content in water. The study did not cover physicochemical properties and microbial analysis. The study concluded that the presence of heavy metals in potable water could cause serious health issues when consumed by humans.

Akinfolarin, Udo, and Maduelosi (2025) examined the physicochemical characteristics and health risks of toxic elements in surface water from geolocated sites along Ataba Creek near Egwe-Osot Village, Rivers State, Nigeria. The study analyzed water samples collected from upstream, midstream, and downstream between November 2024 and February 2025. Physicochemical parameters, including pH, temperature, electrical conductivity (EC), total dissolved solids (TDS), and salinity, were measured using a multiparameter meter (HACH 1520), while concentrations of arsenic (As), nickel (Ni), chromium (Cr), lead (Pb), and cadmium (Cd) were determined via aqua regia digestion followed by atomic absorption spectrophotometry (AAS).Findings indicated that most water quality parameters were within the acceptable limits recommended by the United States Environmental Protection Agency (USEPA, 2018). However, downstream measurements revealed elevated levels of cadmium (1.53 mg/kg), lead (1.19

mg/kg), and chromium (0.46 mg/kg), exceeding USEPA guidelines and highlighting the anthropogenic impact on water quality. Water Quality Index (WQI) values exceeding 100 suggested that the water at certain locations were unsuitable for domestic use.

3.0 Research Methodology

3.1 Study Area

Ataba is a coastal town situated in Andoni Local Government Area, Rivers State, Nigeria (Gogo et al., 2022). The town is renowned for its abundant coconut and palm kernel shells (Alabi et al., 2020). Located at the western edge of Andoni, Ataba has historically served as a hub for various migration influxes. Its geographical coordinates are approximately Latitude 4.65°N to 4.85°N and Longitude 7.35°E to 7.55°E (Google Earth, 2022). The town is drained by the Ataba River, a tributary of the Bonny River, which stretches about 50 km. The terrain consists of low-lying coastal plains featuring numerous creeks and mangrove swamps. The elevation ranges from 5 to 10 meters above sea level.



Fig. 3.0: Map of the Study Area

3.2 Sampling and Data Collection

Water samples were collected from the available four hand dug wells located in Ataba community in Andoni Local Government Area of Rivers State. The four sampling locations are Mission area designated as W1; Orung I as W2; Orung II as W3 and Ibotoka-ama as W4. The study was carried out during the dry season from November, 2024 to January, 2025.

Three (3) water samples were collected into 250ml polyethylene bottles with the aid of drawing bucket from each location with a total of nine samples each for analysis of physicochemical parameters, heavy metals and microbial load. The bottles were rinsed with the sampled water, properly labeled and few drops of HNO3 were added to the water samples for heavy metals analysis. Standard method of analysis (APHA, 2017) was employed for determination of water parameters. On the field insitu measurements were taking for temperature, electrical conductivity, total dissolve solids, pH, dissolved oxygen. Heavy metals were analyzed using aqua regia digestion followed by atomic absorption spectrophotometer (AAS). To ensure research instrument's validity, it was reviewed by professional colleagues for content appropriateness. For reliability, the test-retest method was employed utilizing Spearman's rank correlation coefficient (Igbara, 2014). The resultant correlation coefficient was 0.97 signifying high reliability.

3.3 Statistical and Data Analysis

The SPSS version 23 was used in the analyses of the obtained data; samples were examined in multiplicates (n = 9). The findings were deemed noteworthy when the confidence level was $p<0.05$.

Descriptive Statistics: Mean, standard deviation, minimum, and maximum concentrations were calculated for each water quality parameters at all locations.

Analysis of Variance (ANOVA): One-way ANOVA was used to test for significant differences in pollutant concentrations across the four locations.

Tukey HSD post-hoc tests were applied to identify specific pairwise differences between locations.

Water Quality Index

The assessment of hand-dug wells using the Water Quality Index (WQI) provides an integrative view of their suitability for drinking purposes. It is expressed as:

$WQI = \sum Wi\ Qi / \sum Wi$

Where;

WQI= Water quality index

i = Unit weightage

Wi = Unit Weightage

Qi = Sub index of ith parameter, Qi = Vn/Sn *100

Where Vn = Concentration of ith parameters

Wi = K/Sn

$K = 1/\sum (1/Sn)$

Where;

Sn = Recommended Standard for ith parameter (Akinfolarin et al., 2025)

4. Results and Discussion

4.1 Water Quality Parameters of Hand-Dug Wells

The results of the water quality parameters, physicochemical, microbial and heavy metal levels of hand-dug wells at geolocated sessions (W1 to W4) of Andoni in Ataba Rivers State, are presented in Figures 4.1 to 4.11. Table 4.1 is the Summary of One-Way ANOVA and Tukey HSD Tests for Water Quality Parameters and Heavy Metals. Table 4.2 presents Pearson Correlation Coefficient Matrix of the Water Quality Parameters. Table 4.3 (a) shows Categorization of water quality for

drinking water suitability while Table 4.3 (b) reveals the Water quality index (WQI) of the different hand-dug wells.

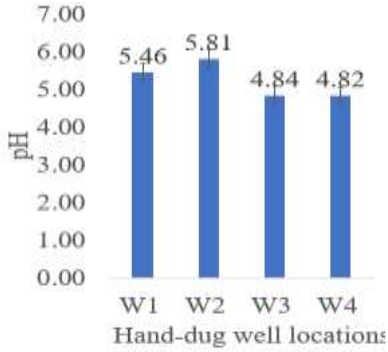

Fig.4.1: pH at all sampling locations

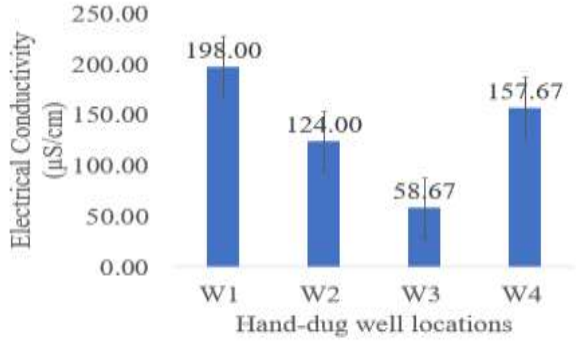

Fig.4.2: Electrical Conductivity at all sampling locations

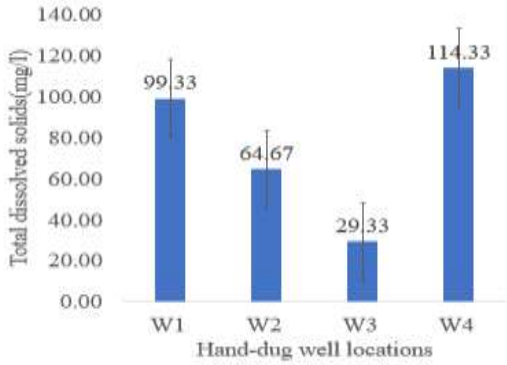

Fig.4.3: Total dissolved solids at all locations

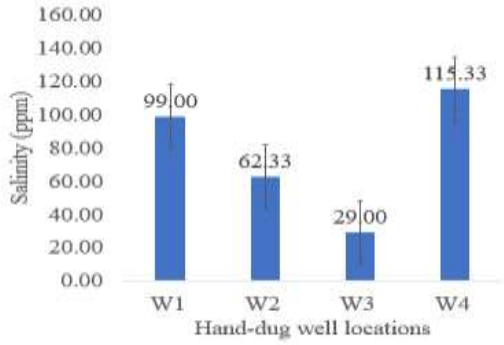

Fig.4.4: Salinity at all locations



Fig.4.5: Temperature at all locations

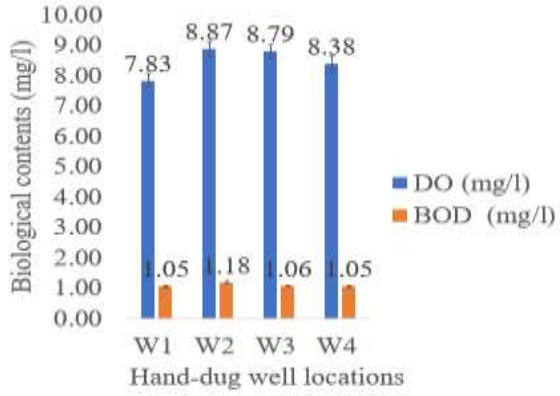

Fig.4.6: Biological contents at all locations

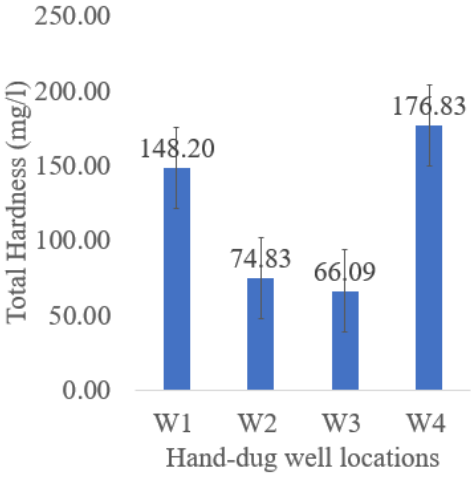

Fig.4.7:Total hardness at all locations

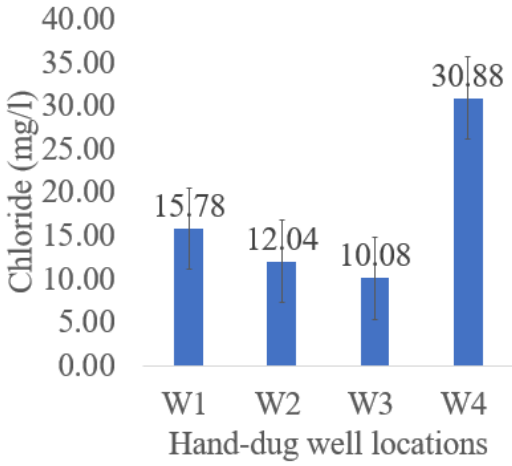

Fig.4.8: Chloride at all locations

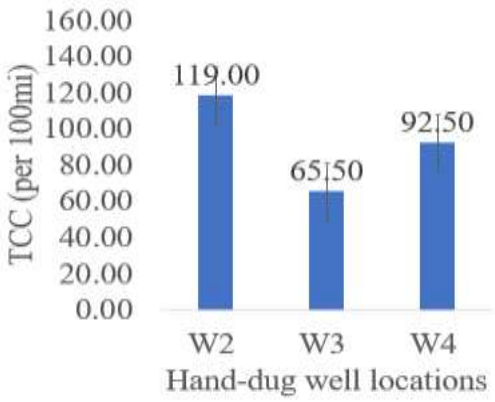

Fig.4.9: Total coliform at all locations

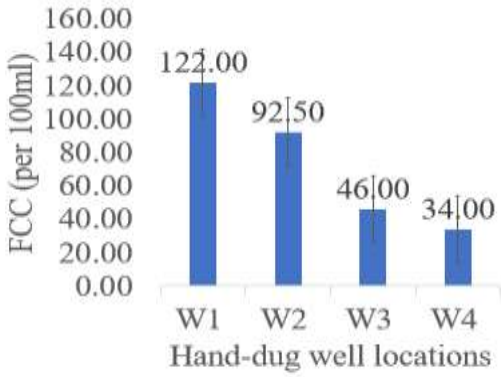

Fig.4.10: Faecal coliform at all locations

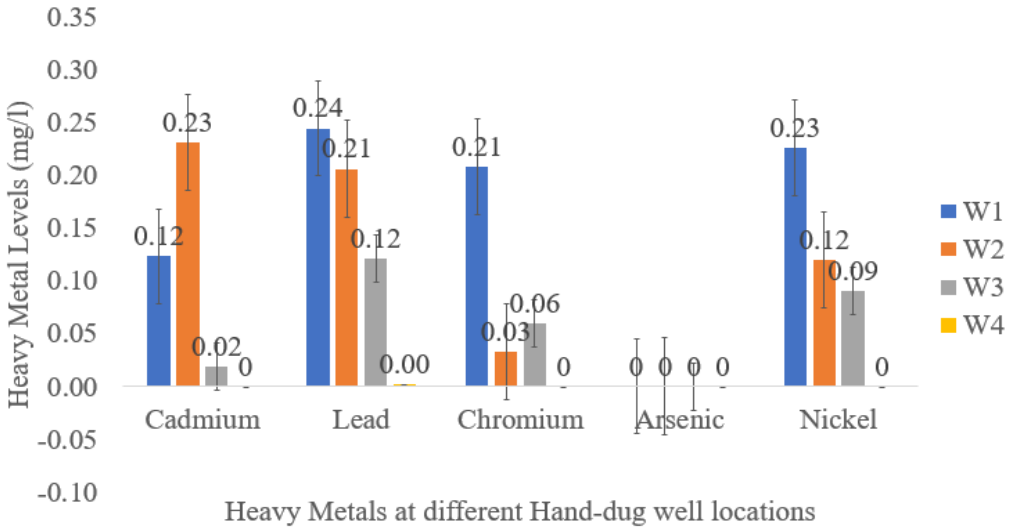

Fig.4.11: Heavy metals levels at all locations

Table 4.1: **Summary of One-Way ANOVA and Tukey HSD Tests for Water Quality Parameters and Heavy Metals**

Parameter	ANOVA	p-value	Significant ($p<0.05$)	Key Tukey Findings
pH	18.70	0.0006	Yes	W2 > W3, W2 > W4, W1 > W3, W1 > W4 ($p<0.05$)
TDS	17.74	0.0007	Yes	W3 < W1 ($p<0.01$), W3 < W4 ($p<0.001$), W2 < W4 ($p<0.05$)
Salinity	16.34	0.0009	Yes	W3 < W1 ($p<0.01$), W3 < W4 ($p<0.001$), W2 < W4 ($p<0.05$)
Chloride (Cl^-)	15.10	0.0016	Yes	W4 > W1, W4 > W2, W4 > W3 ($p<0.01$)
EC	2.31	0.1525	No	No significant differences
Temperature	0.69	0.5830	No	No significant differences
Cadmium (Cd)	81.54	<0.001	Yes	W2 > W1 > W3 ≈ W4
Lead (Pb)	202.78	<0.001	Yes	W1 > W2 > W3 > W4 (except W1 vs W2)
Chromium (Cr)	9.23	0.004	Yes	W1 > W2, W1 > W4
Nickel (Ni)	145.72	<0.001	Yes	W1 > W3 > W4, W2 > W4

Table 4.2: Pearson Correlation Coefficient Matrix of the Water Quality Parameters

Parameter	pH	EC	TDS	Salinity	Temperature	DO	BOD	TH	TA	Cl	Cadmium	Lead	Chromium	Nickel
pH	1													
EC	0.33	1												
TDS	0.02	0.90*	1											
Salinity	-0.01	0.89*	1.00*	1										
Temperature	0.24	0.78	0.5	0.5	1									
DO	0	-0.85	-0.7	-0.7	-0.94	1								
BOD	0.77	-0.19	-0.29	-0.31	-0.43	0.61	1							
TH	-0.28	0.79	0.95*	0.95*	0.51	-0.75	-0.57	1						
TA	0.11	0.97*	0.89	0.89*	0.84	-0.94	-0.44	0.87	1					
Cl	-0.47	0.48	0.81	0.83	0.03	-0.35	-0.43	0.88	0.55	1				
Cadmium	1.00*	0.21	-0.08	-0.11	0.11	0.14	0.85	-0.39	-0.03	-0.52	1			
Lead	0.81	0.22	-0.22	-0.24	0.53	-0.22	0.39	-0.39	0.11	-0.75	0.77	1		
Chromium	0.32	0.51	0.14	0.13	0.92	-0.76	-0.32	0.15	0.56	-0.34	0.22	0.74	1	
Nickel	0.76	0.21	-0.24	-0.26	0.55	-0.25	0.32	-0.39	0.11	-0.76	0.72	1.00*	0.77	1

*** denotes statistically significant correlations ($p < 0.05$).**

Table 4.3 (a): Categorization of water quality for drinking water suitability.

WQI rating	Classification
0-25	Excellent
25-50	Slightly polluted (good)
50-75	Moderately polluted (poor)
75-100	Polluted (very poor)
> 100	Excessively polluted (unsuitable)

Table 4.3 (b): Water quality index (WQI) of the different hand-dug wells

Hand-dug wells	WQI
W1	3576.93
W2	6120.49

W3	746.77
W4	3.81

The physicochemical and microbial characteristics of the four hand-dug wells (W1, W2, W3, and W4) were compared against World Health Organization (WHO, 2017) drinking water guidelines (Table 4.1). The results revealed notable spatial variations, indicating influences from both natural processes and anthropogenic activities.

The pH of all wells is in the order W4<W3<W1<W2 (Fig.4.1). It ranged between 4.68 and 5.97 with average values at W1: 5.46, W2: 5.81, W3: 4.84, W4: 4.82 which are below the recommended WHO range (6.5–8.5), indicating acidic water conditions. This acidity could be attributed to leaching of acidic soils or organic matter decomposition in the aquifer zone, particularly in wells W3 and W4 with average pH values of 4.84 and 4.82, respectively. Acidic water can increase the mobility of heavy metals such as cadmium, lead, and chromium, thereby posing health risks to consumers. This agrees with Akoto and Adiyiah, (2007). It can also corrode plumbing materials, leach metals, and pose health risks (WHO, 2017). Well, W3 and W4 are the most acidic, suggesting possible influence from acid rain, industrial emissions, or geogenic sources such as lateritic soils according to Adebowale et al., (2009).

Electrical Conductivity (EC) of all wells is in the order of W3<W2<W4<W1(Fig.4.2). It ranged between 54 to 245 µS/cm, and total dissolved solids (TDS) from 27 to 123 ppm. All EC (W1: 198 µS/cm; W2: 124 µS/cm; W3: 58.67 µS/cm; W4: 157.67 µS/cm) and TDS (W1: 99.33 mg/L; W2: 64.67 mg/L; W3: 29.33 mg/L; W4: 114.33 mg/L) values are well below the WHO limits (1000 µS/cm for EC and 600 mg/L for TDS), indicating low mineralization and salinity. This suggests a relatively fresh groundwater source without significant anthropogenic intrusion according to Bello and Akintola, (2019).

Salinity of all wells is in the order of W3<W2<W1<W4 (Fig 4.4). The salinity levels are also within safe limits (<1000 ppm) across all wells, with the highest average value in W4 (115.33 ppm) and the lowest in W3 (29 mg/L). It ranged from 27 to 123 ppm. The slightly elevated salinity in W1 and W4 indicates possible anthropogenic influence, such as effluents from nearby residential activities or soil leaching during rainfall events. It could also reflect minimal intrusion from seawater or saline formations.

Water temperatures of all wells is in the order of W2=W3<W4<W1 (Fig 4.5). It ranged from 27.0°C to 31.5°C. The recorded average temperatures (W1: 29.77°C; W2: 28.37°C; W3: 28.37°C; W4: 28.47°C) are within and reflect tropical ambient conditions. While temperature does not have a direct health implication, slightly elevated temperatures in W1 could influence the solubility of gases such as oxygen and enhance microbial proliferation (APHA, 2017).

Dissolved oxygen (DO) of all wells is in the order of W1<W4<W3<W2 (Fig4.6). The concentration levels are high across all wells (7.83–8.87 mg/L), exceeding the minimum of 4 mg/L recommended for potable water. High DO indicate good aeration and minimal organic pollution (Chapman, 1996). Biochemical oxygen demand (BOD) of all wells is in the order of W1=W4<W3<W2 (Fig 4.6). The values range from 1.05 to 1.18 mg/L, far below the 6 mg/L guideline. This suggests and absence of significant biodegradable organic contaminants or low organic pollution loads. This is in line with Srinivasamoorthy *et al.,* (2014).

Total hardness of all wells is in the order of W3<W2<W1<W4 (Fig4.7). The concentration varied widely from 66.09 mg/L (W3) to 176.83 mg/L (W4). W1 and W4 approached the WHO upper limit (<200 mg/L), suggesting moderate hardness levels likely from calcium and magnesium-rich minerals in the aquifer geology (Sawyer & McCarty, 1967). Hardness variations are likely due to geological factors, such as the presence of carbonate-bearing rocks (Hem, 1985).

Total Alkalinity levels ranges (5.17–8.00 mg/L) are low, indicating limited buffering capacity. This makes the water more susceptible to pH fluctuations. This agrees with Nkansah et al., (2010).

Chloride of all wells is in the order of W3<W2<W1<W4 (Fig4.8). The levels are very low (10.08–30.88 mg/L), all wells are within the 250 mg/L WHO limit, indicating minimal contamination from saltwater intrusion or sewage sources.

Turbidity was 0.00 NTU across all wells, reflecting clear water conditions and minimal particulate contamination, aligning with WHO standards (<0.2 NTU).

The total coliform count (TCC) and fecal coliform count (FCC) of all wells is in the order of W3<W4 <W2 and W4<W3<W1 (Fig 4.9 and Fig 4.10). This exceeded WHO standards (0 CFU/100 mL) in all wells except W1 for TCC. High microbial contamination is evident, especially in W1 with ≥2400 TCC/100ml and 122 FCC/100ml, which exceeds the WHO standard of zero coliforms. W2, W3, and W4 also show moderate contamination, likely due to infiltration of surface runoff, poor sanitation, or proximity to latrines according to Edokpayi *et al.,* (2018). The presence of fecal coliforms across the wells confirms potential fecal contamination and elevated risk of waterborne diseases such as cholera and typhoid.

Cadmium (Cd) concentration of all wells is in the order of W3<W1<W2 (Fig 4.11). It was detected to be above the permissible limit (0.003 mg/L) in W1 (0.123 mg/L), W2 (0.231 mg/L), and W3 (0.019 mg/L), indicating significant contamination possibly from industrial waste, batteries, or paints according to Järup, (2003). Cadmium poses severe health risks, including kidney damage and carcinogenicity (WHO, 2017).

Lead (Pb) content of all wells is in the order of W3<W2<W1 (Fig 4.11). Lead (Pb) is extremely high in W1 (0.24 mg/L) and W2 (0.21 mg/L), exceeding the 0.01 mg/L WHO limit, indicating significant anthropogenic contamination, possibly from

paints, pipes, or industrial runoff. Chronic exposure can lead to neurological and renal impairments.

Chromium (Cr) levels of all wells is in the order of W2<W3<W1 (Fig 4.11). Chromium (Cr) had Elevated amount in W1 (0.21 mg/L), surpassing the 0.05 mg/L guideline, but lower in W2 (0.03 mg/L) and W3 (0.06 mg/L), suggesting anthropogenic inputs such as corrosion of plumbing systems or industrial discharges.

Nickel (Ni) content of all wells is in the order of W3<W2<W1 (Fig 4.11). Nickel (Ni) was detected in W1 (0.18 mg/L), W2 (0.14 mg/L), and W3 (0.094 mg/L), all above the 0.07 mg/L limit, raising concerns about chronic exposure risks. Contamination is possibly from geological sources or anthropogenic waste.

Arsenic (As) was not detected (Nd) in all wells, which aligns with safe water conditions for this parameter.

The physicochemical parameters suggest that the water from the four hand-dug wells is generally soft to moderately hard, with low mineralization, with TDS, salinity, and chloride within safe limits, but high acidity. However, the microbial and heavy metal contamination (Pb, Cd, Cr, Ni), especially in W1 and W2, renders the water unsafe for direct human consumption without treatment. Wells W3 and W4 showed lower heavy metal contamination but still failed microbial safety standards. The presence of high coliform counts suggests fecal contamination from anthropogenic activities, and the elevated heavy metals may indicate industrial, agricultural, or geogenic sources (Adebowale *et al*., 2009; Edokpayi *et al.,* 2018).

4.2 One-Way ANOVA and Tukey HSD Tests for Water Quality Parameters and Heavy Metals

One-Way ANOVA is a parametric statistical test used to determine if there are statistically significant differences between the means of more than two groups.

In this case, the groups are the four wells (W1, W2, W3, W4). The response variables are each water quality parameter (e.g., pH, TDS, Salinity, etc.). The test assumes that data within each group are approximately normally distributed, variances are roughly equal across groups and samples are independent.

The pH values exhibited significant spatial variation ($F(3,8) = 18.70$, $p < 0.001$). Tukey's HSD showed that W2 recorded higher pH levels compared to W3 and W4, while W1 also displayed higher values than W3 and W4. These results suggest that W3 and W4 are more acidic, likely influenced by industrial effluents or natural acidification (APHA, 2017).

Total dissolved solids (TDS) and Salinity both demonstrated significant differences ($p < 0.01$) across locations. The W3 showed the lowest concentrations, whereas W4 consistently recorded the highest values, suggesting localized anthropogenic influences or increased mineral dissolution (Srinivasamoorthy et al., 2014). Elevated chloride levels in W4 ($p<0.01$) further indicate possible saline intrusion or wastewater discharge, aligning with WHO (2022) standards that highlight health risks from prolonged consumption of chloride-rich water.

No significant differences ($p > 0.05$) were observed in Electrical Conductivity (EC) and Temperature, implying relatively stable background conditions across the sampled sites (Adebowale et al., 2009).

Significant spatial variation was observed in all heavy metals analyzed. Cadmium (Cd) was highest in W2, followed by W1, while W3 and W4 recorded the lowest concentrations ($p<0.001$). This pattern suggests contamination from industrial waste, batteries, or paints near W2 (Järup, 2003). Lead (Pb) recorded elevated levels were observed in W1 and W2, significantly higher than in W3 and W4 ($p<0.001$). These findings point to vehicular emissions, battery recycling activities, or industrial effluents as probable sources (WHO, 2022). Chromium (Cr) Levels were significantly higher in W1 compared to W2 and W4, indicating possible contributions from metal plating industries or tannery effluents (Adebowale *et al.,*

2009). Nickel (Ni) concentration trend (W1 > W2 > W3 > W4) reflects the influence of industrial wastewater and corroded infrastructure (Srinivasamoorthy et al., 2014). W4 consistently had the lowest metal levels, suggesting minimal contamination.

The elevated levels of TDS, salinity, and chloride in W4, along with significant heavy metal contamination in W1 and W2, indicate anthropogenic activities as key contributors to water quality degradation. According to WHO (2022), cadmium levels exceeding 0.003 mg/L and lead levels above 0.01 mg/L pose serious health risks, including kidney dysfunction, neurological disorders, and carcinogenic effects.

Pearson Correlation Coefficient Matrix of the Water Quality Parameters
The correlation analysis reveals several significant relationships between water quality parameters and heavy metal concentrations that can inform environmental status and pollution sources.

Strong positive correlations between Electrical Conductivity (EC), Total Dissolved Solids (TDS), Salinity, and Total Hardness (TH) imply these parameters co-vary, reflecting mineral content and salinity levels typical of water chemistry (e.g., EC-TDS: 0.90*, Salinity-TDS: 1.00*), consistent with findings in water chemistry studies (Wetzel, 2001).

Negative correlations between Dissolved Oxygen (DO) and parameters indicating mineralization (EC: -0.85, TDS: -0.70) suggest increased mineral content may be associated with lower oxygen solubility or biological activity in these waters, aligning with ecological observations (Wetzel, 2001).

Cadmium correlates positively with Biochemical Oxygen Demand (BOD) (0.85*) and pH (1.00*), indicating that cadmium contamination may be linked to organic pollution and neutral to slightly alkaline pH conditions (Alloway, 2013). Lead correlates strongly with nickel (1.00*), chromium (0.74*), and cadmium (0.77*),

reflecting common pollution sources or geochemical associations (Kabata-Pendias, 2011). Chromium shows strong positive correlation with Temperature (0.92), highlighting possible temperature-dependent mobilization or industrial discharge (US EPA, 2020).

Chloride negatively correlates with heavy metals, cadmium (-0.52), lead (-0.75), and nickel (-0.76*), indicating different sources or dilution effects for chloride relative to these metals.

The pH shows very strong positive correlation with cadmium (1.00) and nickel (0.76), suggesting that metal solubility and speciation may be influenced by pH, consistent with geochemical behaviour of metals in water (WHO, 2022).

The correlations underscore the interlinked nature of water quality parameters and heavy metal contaminants. The mineral constituents (TDS, EC, salinity) act as indicators of ionic strength and pollution. Their inverse relationship to DO aligns with water quality degradation trends. Heavy metals correlate with increased organic load (BOD) and alkaline pH, suggesting anthropogenic pollution inputs and geochemical controls affecting their mobility and bioavailability.

The differentiated correlations of chloride compared to metals signal diverse contamination sources, likely from agricultural or saline intrusion distinct from metal pollutant origins. Temperature effects on chromium highlight the influence of environmental factors on contaminant behaviour. These findings provide insight into both pollution sources and physicochemical processes affecting water quality and metal contamination levels, informing pollution management strategies.

4.3 Water Quality Index of the different Hand-dug Wells

The assessment of hand-dug wells using the Water Quality Index (WQI) provides an integrative view of their suitability for consumption purposes. Table 4.3 (a) presents the categorization scheme, while Table 4.3 (b) shows the computed WQI values for the different wells (W1–W4).

According to the classification in Table 4.3 (a), WQI values below 25 indicate excellent water quality, while values exceeding 100 signify excessive pollution, rendering the water unsuitable for consumption. The results from Table 4.3 (b) show that wells W1 (3576.93), W2 (6120.49), and W3 (746.77) fall far above the threshold of 100, suggesting that these sources are excessively polluted and highly unsuitable for human consumption. This implies that the water in these wells may pose significant health risks if consumed without treatment (Sahu & Sikdar, 2008; Tyagi et al., 2013).

Interestingly, well W4 recorded a WQI of 3.81, which falls within the "excellent" category. This suggests that W4 is largely free from pollution and is suitable for consumption purposes. Such stark variation in WQI between wells within the same study area could be attributed to differences in hydrogeological conditions, depth of the wells, proximity to pollution sources such as latrines, refuse dumps, and abattoirs, and anthropogenic activities around the well sites (Ramakrishnaiah et al., 2009; Adebowale et al., 2009).

The extremely high WQI values observed for W1, W2, and W3 indicate that the concentrations of pollutants, likely including heavy metals, organic contaminants, and microbial load, are alarmingly high. Previous studies have shown that hand-dug wells located in densely populated or industrialized areas often exhibit elevated contamination due to leaching from waste dumpsites, infiltration of sewage, and agricultural runoff (Akinbile & Yusoff, 2011; Rao et al., 2012). This finding aligns with reports by Akoteyon et al. (2011), who observed similar excessive WQI values in hand-dug wells in Lagos, Nigeria, suggesting poor protection of groundwater sources.

The implication of these findings is critical for public health. Consumption of water from W1, W2, and W3 could lead to serious waterborne diseases and long-term health effects due to toxic contaminants. On the other hand, the excellent quality of W4 could provide a safer alternative, but continuous monitoring is necessary to ensure sustainability (WHO, 2017).

Overall, the results highlight the urgent need for improved management of hand-dug wells, proper sanitary protection, and regular monitoring to safeguard public health. Additionally, treatment methods such as filtration, chlorination, and boiling should be encouraged for communities relying on contaminated wells before consumption.

5. Conclusion and Recommendation

The physicochemical parameters suggest that the water from the four hand-dug wells is generally soft to moderately hard, with low mineralization but high acidity. However, the microbial and heavy metal contamination (Pb, Cd, Cr, Ni), especially in W1 and W2, renders the water unsafe for direct human consumption without treatment. Wells W3 and W4 showed lower heavy metal contamination but still failed microbial safety standards. The extremely high WQI values observed for W1, W2, and W3 indicate that the concentrations of pollutants, such as heavy metals, organic contaminants, and microbial load, are alarmingly high.

The integrated statistical analysis underscores significant spatial heterogeneity in both basic water quality parameters and heavy metals across the study sites. While W3 and W4 present relatively safer profiles for some parameters, the elevated levels in W1 and W2 warrant immediate attention and remediation to safeguard environmental and public health.

Continuous and seasonal monitoring is necessary to assess trends in heavy metal contamination and water quality dynamics. The findings highlight the need for effective treatment such as boiling, or neutralization of acidity through lime dosing. installation of filtration and disinfection systems. Communities relying on these water sources should be educated on potential health risks and the importance of water treatment before consumption.

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