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Comparative Assessment of Heavy Metals in Well and Borehole Water in Akure, Ondo State, Nigeria

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ABSTRACT

Groundwater sources such as wells and boreholes serve as primary drinking water supplies in many communities especially in developing countries like Nigeria. However, the presence of heavy metals in these sources poses potential health risks. This study evaluates and compares the concentrations of iron (Fe), chromium (Cr), cadmium (Cd), and manganese (Mn) in well and borehole water samples collected from five locations each in Shagari Village, Akure, Ondo State, Nigeria. Water samples were analyzed in the laboratory to determine their heavy metal concentrations. Results showed that Fe levels are higher in well water (0.134–0.163 ppm) compared to borehole water (0.078–0.110 ppm). Chromium concentrations are higher (0.063–0.080 ppm) in borehole water than in well water (0.023–0.030 ppm), with some borehole samples exceeding the WHO limit of 0.05 ppm. Cadmium levels varied slightly, with well water ranging from 0.004–0.009 ppm and borehole water from 0.006–0.010 ppm. Manganese concentrations were similar in both sources, with slight variations. The findings suggest that well water may have higher Fe concentrations due to soil leaching, while borehole water exhibits higher Cr levels, possibly due to geological formations. Continuous monitoring and appropriate treatment methods are recommended to ensure water safety.

Keywords: Heavy metals, groundwater, well, borehole, quality, Shagari Village, Akure

INTRODUCTION

Groundwater serves as an important source of drinking water globally, especially in regions where surface water is limited (Amanambu et al., 2020; Dao et al., 2024). Wells and boreholes are among the most common groundwater sources, but their quality can be influenced by geological formations, anthropogenic activities and environmental factors (Abanyie et al., 2023). Heavy metals are naturally occurring elements that can become contaminants in groundwater due to geological processes, anthropogenic activities, and leaching from surrounding soil and rocks. Their presence in drinking water, even at trace levels, can pose serious health risks, including kidney damage, neurological disorders, and carcinogenic effects (WHO, 2021; Angon et al., 2024). Iron (Fe), chromium (Cr), cadmium (Cd), and manganese (Mn) are heavy metals that can enter groundwater through natural leaching, industrial discharge, agricultural runoff, and improper waste disposal (Nagar et al., 2022; Reddy and Sunitha, 2023). Exposure to these metals, even at trace levels, can pose significant health risks, including organ toxicity, neurological disorders, and carcinogenic effects (WHO, 2021; Akshitha et al., 2022). Given the reliance on groundwater in many developing regions, assessing its quality is essential for ensuring public health and safety.

Heavy metal contamination in groundwater is a growing concern in Nigeria due to rapid urbanization, poor waste management, and industrial activities (Ogbeide and Henry, 2024). Ojo (2023) evaluated the heavy metal content in hand-dug wells at Shasha Market, Southwestern Nigeria and assessed their potential contamination levels and implications for water quality and public health. Elevated levels of Cd and Cr have been reported in well and borehole water in some Nigerian cities, exceeding WHO and Nigerian Standard for Drinking Water Quality (NSDWQ) guidelines (Buba and Maina, 2020; Eluke et al., 2021; Adejuwon and Odusote, 2023, Aluko et al., 2023). While Fe and Mn are essential micronutrients, their excessive concentrations can lead to aesthetic issues (colour, taste, staining) and health complications such as oxidative stress and neurotoxicity (Dorman, 2023).

Therefore, comparing the quality of well and borehole water is critical for understanding contamination patterns and potential health risks.

This study was conducted in Shagari Village, Akure, the capital of Ondo State, Nigeria, to assess the heavy metal concentrations in well and borehole water. Water samples were collected from five different locations for each source in a bid to ensure a comprehensive evaluation of groundwater quality in the area. The research aimed to compare the levels of Fe, Cr, Cd, and Mn in these water sources, identify potential contamination sources, and assess their compliance with international and national drinking water standards. This study is particularly relevant as groundwater remains the primary drinking water source in this region, making its quality assessment vital for public health management.

The findings from this study will contribute to the growing body of research on groundwater contamination in Nigeria and inform policymakers and water resource engineers on potential health risks. Additionally, this research provides baseline data that can support future water treatment interventions and groundwater management strategies. By identifying variations in heavy metal concentrations between well and borehole water, this study will offer understanding of the influence of geological and environmental factors on water quality, thereby aiding in the development of mitigation measures.

MATERIALS AND METHODS

Study area and sample collection

This study was carried out in Shagari Village, Akure, a Federal Government Low-Cost Housing Estate situated in Akure South Local Government Area (LGA) of Ondo State, Nigeria. Shagari village covers a land area of 11.14 hectares and is geographically positioned at approximately latitude 7.25000 and longitude 5.19000. Shagari village, Akure, is predominantly inhabited by the Yoruba ethnic group, the major tribe in southwestern Nigeria. According to the National Population Commission (2006), Akure South LGA had a projected population of 453,731, with Shagari Village alone housing approximately 12,000 residents (Enisan and Unum, 2020).

The study was conducted by collecting water samples from two groundwater sources—wells and boreholes—at five different locations in Shagari village, Akure. The sample collection locations were randomly selected to ensure a representative assessment of groundwater quality in the area. Plates 1 and 2 shows a sampled well and borehole respectively in the study area.

Plate 1. A sampled well in the study area.

Plate 2. A sampled borehole in the study area.

Sample location and coordinates

To ensure precise location tracking, the coordinates of the sample collection sites were recorded using GPS.

Materials used

The collection of groundwater samples was carried out systematically to minimize contamination. The materials used for sample collection included funnels, clean plastic bottles, and buckets, all of which were thoroughly rinsed before use. The plastic bottles were specifically chosen to prevent interactions between the container material and the water samples, which could alter the concentration of heavy metals.

For well water collection, samples were obtained early in the morning before any water was fetched or disturbed, reducing the likelihood of surface contamination and ensuring that the samples reflected the true groundwater quality. Similarly, borehole water samples were collected under the same conditions to maintain consistency in sampling procedures. Each sample was carefully transferred into labeled plastic bottles, sealed tightly, and stored under controlled conditions to prevent oxidation or contamination before analysis.

After collection, all samples were immediately transported to the laboratory for comprehensive testing. The analyses focused on heavy metal concentrations, including Fe, Cr, Cd, and Mn. Standard laboratory procedures, as outlined by the American Public Health Association (APHA, 2017) and World Health Organization (WHO, 2021) guidelines, were followed to ensure accuracy and reproducibility of results.

RESULTS AND DISCUSSION

Well and borehole water locations

Tables 1 and 2 present the coordinates and altitudes of the well and borehole water sampling points in Shagari Village, Akure, Ondo State, Nigeria. The tables reveal variations in elevation that may influence groundwater quality. Well water sampling locations range in altitude from 87.12 m to 101.12 m, while boreholes have a slightly higher range of 88.04 m to 107.50 m which signifies differences in water depth and potential contamination sources. The spatial distribution of these points allows for a comparative assessment of groundwater quality while considering factors such as surface influence on wells and deeper geological interactions in boreholes.

Heavy metal concentrations in well and borehole water

The concentrations of iron (Fe), chromium (Cr), cadmium (Cd), and manganese (Mn) in well and borehole water samples collected from Shagari Village, Akure, Ondo State, Nigeria, are discussed in relation to the World Health Organization (WHO) standards for drinking water quality. The results are presented in Table 3.

The standard deviation values presented in Table 3 show the variability in heavy metal concentrations in well and borehole water samples. Fe concentrations show higher variability in borehole water (±0.0136 ppm) compared to well water (±0.0106 ppm), suggesting greater fluctuations in borehole water quality, possibly due to differences in geological formations or external contamination sources. Cr exhibits significantly higher variation in borehole water (±0.0071 ppm) than in well water (±0.0027 ppm), with some borehole samples exceeding WHO limits, indicating potential industrial or geogenic influences. Cd concentrations have a relatively low standard deviation in both sources, but the values exceed WHO limits, raising health concerns. Mn levels show minimal variation, with well and borehole water standard deviations at ±0.0024 ppm and ±0.0016 ppm, respectively, suggesting stable concentrations within safe limits. The observed variations affirm the need for regular groundwater monitoring to ensure water quality consistency and safety.

Table 1. Coordinates of well water locations

ID	Coordinate X	Coordinate Y	Altitude (m)	Point Name
0410	806309.2850	742026.6610	100.0000	FGPS 41 ODY
WELL 1	806805.2658	742270.4874	92.4582	Well A
WELL 2	806860.0341	742210.3884	98.8015	Well B
WELL 3	806624.3113	742262.5671	87.7513	Well C
WELL 4	806609.9170	742522.6837	87.1247	Well D
WELL 5	806991.3673	742358.4285	101.1154	Well E

Table 2. Coordinates of borehole water locations

ID	Coordinate X	Coordinate Y	Altitude (m)	Point Name
0410	806309.2850	742126.3660	100.0000	FGPS 041 ODY
B100	806614.7120	742602.2137	88.0416	Borehole A
B200	806628.0433	742604.9534	88.3260	Borehole B
B300	806751.5749	742729.2105	99.0707	Borehole C
B400	807070.2831	742495.3087	105.4719	Borehole D
B500	807165.3708	742464.1895	107.5034	Borehole E

Table 3. Variability in heavy metal concentrations in well and borehole water samples.

Heavy Metal	Well Water (ppm)	Borehole Water (ppm)	WHO Limit (ppm)
Iron (Fe)	0.149 ± 0.0106	0.093 ± 0.0136	0.3
Chromium (Cr)	0.026 ± 0.0027	0.072 ± 0.0071	0.05
Cadmium (Cd)	0.006 ± 0.0019	0.008 ± 0.0016	0.003
Manganese (Mn)	0.041 ± 0.0024	0.037 ± 0.0016	0.1

Iron (Fe) concentration

Figure 1 shows that Fe concentrations in well water ranged from 0.134 to 0.163 ppm, while borehole water contained between 0.078 and 0.110 ppm. The WHO permissible limit for Fe in drinking water is 0.3 ppm. Fe levels were higher in well water, likely due to soil leaching, sediment dissolution, and oxidation-reduction reactions that occur within the shallow aquifer (van Beek et al., 2021). Fe is one of the most abundant elements in groundwater, particularly in areas with iron-rich lateritic soils, which are common in southwestern Nigeria (Ngah and Nwankwoala, 2013; Moyosore et al., 2014). While Fe is an essential micronutrient, excessive amounts in drinking water can cause aesthetic issues such as metallic taste, reddish-brown staining of plumbing fixtures, and discoloration of water (Hu et al., 2018). The relatively lower iron levels in borehole water suggest deeper aquifer sources where the presence of iron-bearing minerals is reduced due to filtration through geological layers.

Chromium (Cr) concentration

Cr concentrations in well water ranged from 0.023 to 0.030 ppm, whereas borehole water exhibited higher levels between 0.063 and 0.080 ppm as presented in Figure 2. The WHO permissible limit for Cr is 0.05 ppm, some borehole water samples exceeded this threshold thus indicating potential contamination from industrial runoff or geological formations (Aralu et al., 2023; Okorie et al., 2024). Cr exists in water primarily as trivalent chromium (Cr^{3+}) and hexavalent chromium (Cr^{6+}), with Cr^{6+} being highly toxic and carcinogenic (Monga et al., 2022). Elevated Cr levels in borehole water could indicate leaching from underground rock formations containing Cr-rich minerals or contamination from nearby anthropogenic activities such as metal plating, tanneries, or improper disposal of industrial waste (Singh et al., 2022). Prolonged exposure to high Cr concentrations has been associated with dermatological conditions, respiratory disorders and increased cancer risks (Hessel et al., 2021; Shin et al., 2023; Katsas et al., 2024).

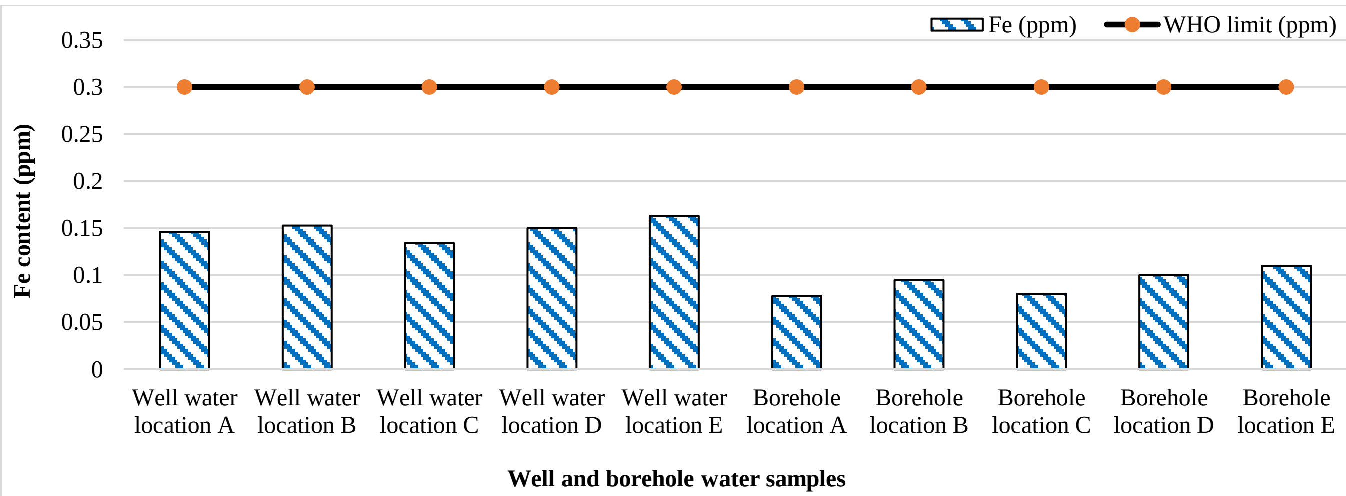

Figure 1. Fe content of well and borehole water samples

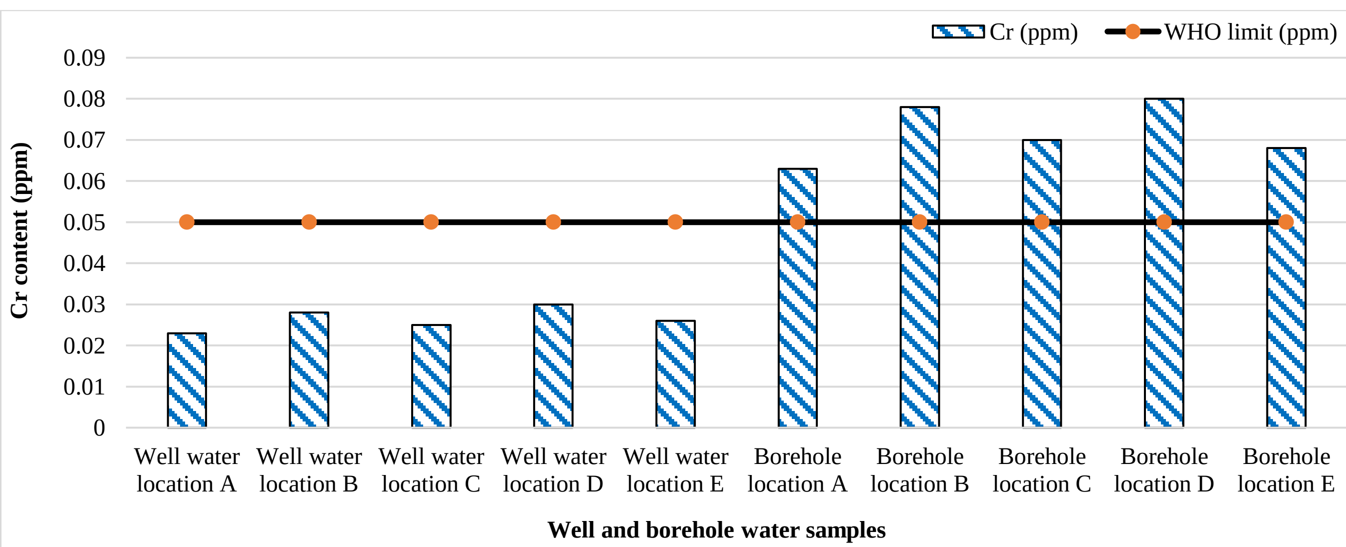

Figure 2. Cr content of well and borehole water samples

Cadmium (Cd) concentration

As presented in Figure 3, Cd concentrations in well water ranged from 0.004 to 0.009 ppm, while borehole water contained between 0.006 and 0.010 ppm. Both sources exceeded the WHO permissible limit of 0.003 ppm, raising serious health concerns. Cd is a highly toxic heavy metal with no known biological function in humans, and chronic exposure can lead to kidney dysfunction, bone demineralization (Itai-Itai disease), cardiovascular diseases, and cancer (Charkiewicz et al., 2023, Rasin et al., 2025). The higher Cd levels in borehole water compared to well water suggest possible leaching from deep geological formations, industrial pollution, or contamination from agricultural runoff (Kubier et al., 2019; Balaram et al., 2023; Abanyie et al., 2023). In Nigeria, several studies have reported elevated Cd levels in groundwater, particularly in areas with intensive agricultural activities where phosphate fertilizers (which contain Cd as an impurity) contribute to contamination (Grema et al., 2022). The presence of Cd in well water may also be attributed to corroding galvanized pipes or nearby waste dumpsites.

Manganese (Mn) Concentration

Mn concentrations in well water ranged from 0.038 to 0.044 ppm, while borehole water contained levels between 0.035 and 0.039 ppm as shown in Figure 4. The WHO permissible limit for manganese in drinking water is 0.1 ppm, this indicates that all measured values were within safe limits.

Mn is an essential trace element required for enzymatic reactions, but excessive intake can lead to neurological impairment, particularly in children (Miah et al., 2020). The slight variations in Mn levels between well and borehole water may be influenced by geochemical interactions, natural mineral dissolution, and redox reactions within the aquifer (Liu et al., 2023; Jolaosho et al., 2024). Mn contamination is more common in acidic and oxygen-deficient environments, where it dissolves readily from surrounding rocks (Wu et al., 2022). While the current levels are within safe limits, long-term exposure to even low concentrations of Mn in drinking water has been linked to cognitive deficits and neurodevelopmental disorders (Khan et al., 2012; Iyare 2019). Therefore, continuous monitoring and appropriate water treatment strategies are recommended to prevent potential health risks.

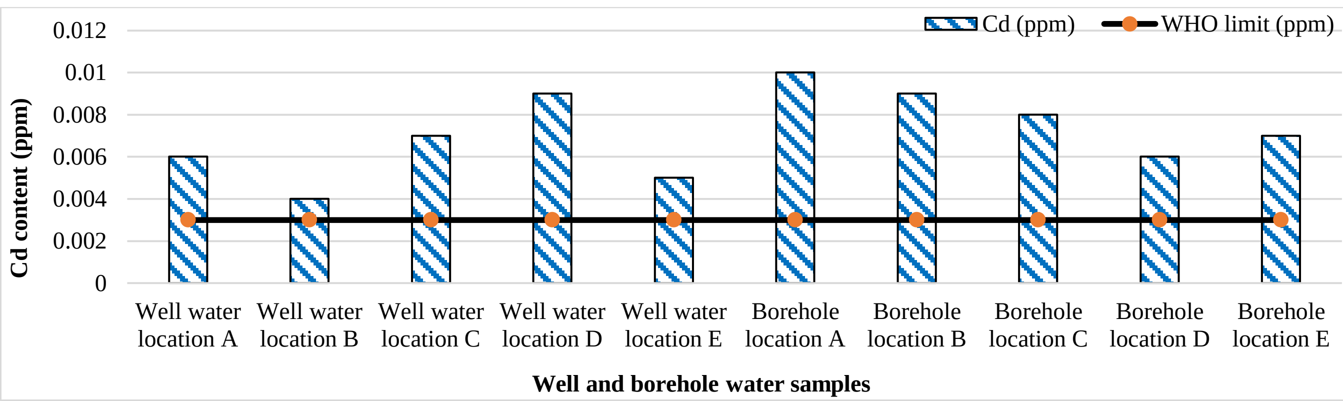

Figure 3. Cd content of well and borehole water samples

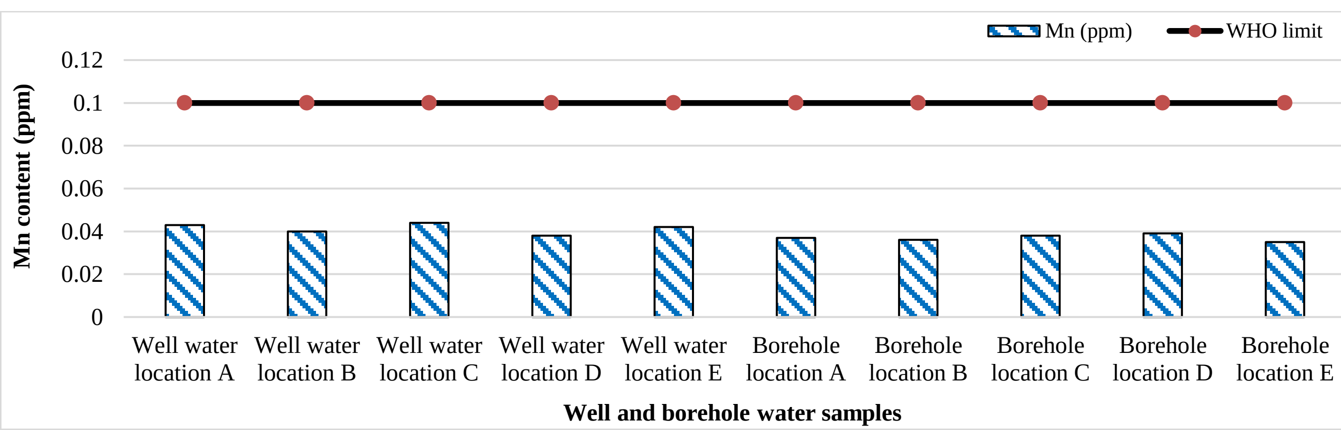

Figure 4. Mn content of well and borehole water samples

Comparative assessment of well and borehole water quality

The results of this study show that well water generally had higher Fe levels, whereas borehole water exhibited higher Cr and Cd concentrations. These variations highlight differences in aquifer depth, geological influences, and potential contamination sources. The higher Fe concentration in well water suggests greater interaction with lateritic soil and oxidation of iron-bearing minerals, while the elevated Cr and Cd levels in borehole water may indicate leaching from deep geological formations or anthropogenic pollution (Hoque et al., 2024; Farinloye and Smith, 2024). From a public health perspective, the presence of cadmium at concentrations exceeding WHO limits in both well and borehole water is a major concern. Cd exposure has been linked to renal dysfunction, osteoporosis, and cancer, necessitating immediate intervention measures such as improved water treatment, community awareness, and regulatory enforcement (Ugwu et al., 2022). The exceedance of WHO limits for chromium in borehole water also raises concerns, particularly if the toxic hexavalent chromium form (Cr^{6+}) is present, which is known for its carcinogenic properties (Sharma *et al*., 2022).

CONCLUSION AND RECOMMENDATION

The comparative assessment of well and borehole water quality in Shagari Village, Akure, revealed varying heavy metal concentrations, with well water exhibiting higher Fe levels, while borehole water contained elevated Cr and Cd concentrations. Although Fe and Mn were within WHO permissible limits, Cr exceeded the standard in some borehole samples, and Cd levels were above the allowable threshold in both sources, thus posing significant health risks. These findings suggest potential contamination from geological formations, industrial activities, and agricultural runoff. There is a need for urgent intervention through regular water quality monitoring, effective treatment methods and community awareness programs. The findings of this study emphasize the need for continuous groundwater monitoring, proper waste management and enhanced water treatment techniques to mitigate contamination risks. Further research on identifying specific pollution sources and assessing seasonal variations in heavy metal concentrations is recommended.

DECLARATIONS

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Data availability

The datasets used and/or analysed in this study can be obtained from the corresponding author upon a reasonable request.

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Authors' contribution

Ojo, O. M. was responsible for designing the study and writing the manuscript. Obiora-Okeke, O. A. contributed to data interpretation and the literature review, while Adeniran, D. O. participated in laboratory analysis and data collection.

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Competing interests

The authors declare that there is no competing interests whatsoever with any third party.

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