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Determination of Heavy Metals, Physicochemical and Bacteriological Profile in Water from Selected Bore Holes within Karu, Nasarawa State, Nigeria

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Heavy metal, physicochemical and bacteriological profile of borehole water from selected locations in Karu LGA of Nasarawa State was carried out. Borehole water which was collected from three locations in Mararaba, New Karu, Masaka, Auta Balefi and Uke were subjected to atomic absorption spectroscopy (AAS) to determine the heavy metal level and their physicochemical and bacteriological status. While the mean concentration of chromium was higher than the world health organization (WHO) standard for drinking water, the levels of copper, arsenic, cobalt and nickel were lower than the standard. The result also revealed that manganese, cadmium, lead and zinc were not within the detectable region of AAS in the borehole water. Iron concentration was within the WHO specification. Chromium levels which are above the WHO standard for drinking water may be adduced to surface contamination arising from pollution, environmental and topographical sources. Iron, copper and nickel levels which were below WHO standard may not predispose to renal failure. Physicochemical analysis indicated that all parameters assessed were either below or within the WHO standard. Microbiological analyses showed no visible presence of bacteria except for traces of *E. coli* and total coliform observed in Masaka as well as those of *S. typhi* in New Karu and *V. cholerae* observed in Uke. The alterations in metal and physicochemical parameters showed that the sample may not have deleterous effect. The lack of visible presence of bacteria in most locations and little traces in few locations are not sufficient enough to cause tyhoid and cholera.

Keywords: Borehole water, Heavy metals, Karu, Bacteriological, Physicochemical.

1. Introduction

Heavy metal, physicochemical and bacteria contaminations are among the major challenges affecting borehole water in most Nigerian communities. Access to safe bore hole water is therefore crucial for maintenance of health in any community. The need for accessible and safe borehole water is on the increase due to population explosion, shortage of government interventions coupled with the contamination of the aquatic ecosystem with contaminants such as heavy metals, physicochemical materials, bacteria, personal care products, pesticides, herbicides, amongst a plethora of biological contaminants. The availability of borehole water with reasonable quantity of heavy metal and physicochemical matters as well as bacteria load for drinking and domestic purposes is a huge challenge in most communities (Gao *et al*., 2023). This challenge is captured for attention in the Sustainable Development Goal (SDG) Target 6.1 which calls for universal and equitable access to safe and affordable drinking water for all (UNICEF, 2024). The target focussed on "safely managed drinking water services" - in addition to healthy drinking water from improved water source, among which is borehole water. This is because water, irrespective of the source is essential for life.

UNICEF functions in collaboration with WHO in areas related to water and community safety in addition to water regulation, environmental sanitation and cleanliness of health care facilities. In 2022, both organizations developed WASH FIT (Water Quality, Hygiene and Sanitation for Health Facility Improvement Tool), a strategy to facilitate of the safe water for public health. WASH FIT is aimed at guiding primary health care facilities in low- and middle-income communities through a continued provision of robust assessments, prioritization of risk, and definition of specific, targeted actions (UNICEF, 2023). Similarly, organizations like SON, NAFDAC, APHA, and NSDWQ representing

Standards System of Nigeria; National Agency for Food and Drug Administration and Control; American Public Health Association and Nigeria Standard of Drinking Water Quality respectively, among others, have also been relating among themselves and with the WHO (SON, 2012).

Globally, in 2022, 90% of the populace could access to water from a suitable source that is ideal for drinking - called "improved water source" (Water Fact Sheet, 2023). Nearly 4.2 billion could access portable drinking water while another 2.4 billion could access public tap or wells. 1.7 billion people still consume from unhealthy water source which might have had contact with excreta. Water quality is important for maintenance of health and safety use for domestic and industrial purpose. Comprise on water quality can lead to severe diseases, such as typhoid, cholera, diarrhoea among others (Water Fact Sheet, 2023). A public health goal is great reduction in waterborne diseases and development of safe drinking water among developing nations.

Heavy metals are defined as metal elements that have a considerably high weight in comparison to water (Fergusson, 1990). With the relationship between their density and toxic effect, heavy metals also include metalloids, like arsenic, which have the capacity to cause toxic effect at low concentration during exposure. They could also be defined as any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentrations. Heavy metals are also regarded as trace elements owing to their availability in minute concentrations (ppb range to less than 10ppm) in several environmental matrices (Udongwo and Sambo, 2022). They are also metals with robust atomic mass and high heaviness, but can be less stronger than iron and some other metals. They are not readily available in nature like a few other metal types, but can be accumulated. They pose toxic effect to human health when ingested internally. Examples are lead, cadmium, arsenic (Ehi-Eromosele and Okiei, 2012). Metals are hardened materials that can be modified into different shapes but not common to all metals. The heavy metals earlier listed do not necessarily adopt this rule. Also, heavy metals are good conductors of electricity and heat and this property is not common to all metals: lead is a bad conductor while mercury is a bad conductor of heat/electricity. Metals find application in agriculture health sector and in industries. They constitute the biomolecules present in plants and animals (Aremu *et al*., 2017).

Heavy metal contamination of water bodies is a global problem affecting water resource because of their strong toxic effect even at very low level. Heavy metals are natural constituent of the earth's crust and they can find entry into food and water cycles through various geological and chemical methods. Exposure to contaminated concentration of heavy metals can lead to severe disease condition with many symptoms depending on the level of exposure to the contaminated heavy metal (Ishaleku *et al*., 2024). Heavy metals toxicity can lead to altered central nervous function, reduced energy level, damaged blood cells as well as reduced functioning capacity of the kidneys, liver, lungs and other vital organs of the body. Over exposure to heavy metals could lead to slow and progressive muscular, physical and neurological degenerative actions such as multiple sclerosis and muscular dystrophy (Alfred *et al*., 2023).

The toxicity of heavy metals is dependent on a few factors. Specific clinical observations vary according to the heavy metal in being considered, the total dose intake, and if the exposure was acute, sub-acute or severe/chronic. The age of the person involved can also influence the level of exposure to toxic metal. For example, young children are more prone to the effects of lead exposure because they absorb many times when liken to the percentage absorbed by an adults and because their brains are more plastic and even little exposure may influence children developmental processes. The route of exposure is also germane. Elemental mercury is considerably inert in the gastrointestinal tract and also poorly absorbed through intact skin, although it inhaled or injected elemental mercury could have very severe effects (Oko *et al*., 2017).

Previous investigations by Ogbeide and Henry (2024) gave insights into addressing heavy metal pollution in Nigerian communities. Umar et al (2023) assessed heavy metal presence of heavy metals in ten bore holes in Minna, Niger State, Nigeria. Opaluwa (2023) looked at the prevalence and effect of heavy metals on groundwater sources of two communities in Nasarawa State, Nigeria. Aremu *et al* (2024) studied the physicochemical and heavy metal status of water samples in Keana and Nasarawa-Eggon LGA of Nasarawa State. Hassan and Sada (2024) gave insight into pollution status of groundwater by some heavy metals in Kano State, Nigeria. Akoji (2019) analyzed the physicochemical and microbiological properties of bore holes and well water in Kuje, Abuja, Nigeria. Kana (2022). Analyzed the heavy metal in groundwater in part of Karu, Central, Nigeria.

Given these reports, only Opaluwa (2023) examined the availability and influence of heavy metal in some locations within Karu Local Government Area of Nasarawa State, Nigeria without information on the physicochemical and bacteriological profile of the studied locations. To the best of our knowledge therefore, there has not been any study in the open scientific literature that assessed the physicochemical and bacteriological profile of the said area in addition to heavy metal analysis. Consequently, this study seeks to determine the heavy metal, physicochemical and bacteriological profile of borehole water in selected locations within Karu LGA of Nasarawa State (Mararaba, New Karu, Masaka, Auta Balefi and Uke) in accordance with the requirements of the World Health Organization (WHO), to ascertain the suitability and/or quality of borehole water for domestic and industrial purposes.

2. Materials and Methods

2.1 Materials

2.1.1 Study Area

The research covered several locations within Karu. Karu is among the thirteen Local Government Areas of Nasarawa State, Nigeria (Figure 1) and situated between latitude 9.0167 of the equator and longitude 7.5833, 111 N 9’ 0’ E 7 3 4’ 60" of the Greenwich Median (Adeyemi *et al*., 2007).

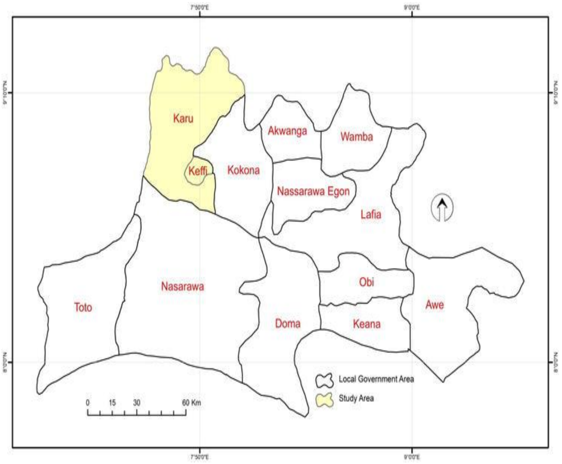

Figure 1: Map of Nasarawa State Showing Study Area (Karu) and other LGAs
Source: Aremu *et al* (2011)

2.1.2 Reagents, chemicals and apparatus

All the chemicals and reagent used in the study were procured from JHD China and are of analytical grade. The apparatus used in the study includes sample bottles, measuring cylinder, beaker, hot plate, cover glass, weighing balance, crucible and thermometer.

2.2 Methods

2.2.1 Collection of Water Sample

200 cm^3 of water sample were collected from fifteen randomly selected boreholes in Karu town within Karu Local Government Area of Nasarawa State. 5 cm^3 of Conc. HNO_3 were added for preservation (APHA, 2022). Samples were collected into clean sample container in three different locations within each study area. Table 1 shows the different locations where samples were collected in the study area.

Table 1: Location of collected borehole water samples in Karu LGA

Locations in Study Area	Sample Number
Mararaba by First Bank	Sample 1
Mararaba by Abacha Road	Sample 2
Mararaba by Royal Dream	Sample 3
New Karu by Carry-Carry Junction	Sample 4
New Karu by Church Road	Sample 5
New Karu by Esu Karu Palace	Sample 6
Masaka by God’s Own School	Sample 7
Masaka by Area 1	Sample 8
Masaka by Royal College	Sample 9
Auta Balefi by Area 1	Sample 10
Auta Balefi by Chief Palace	Sample 11
Auta Balefi by Goshen Junction	Sample 12
Uke by Total Filling Station	Sample 13
Down Uke	Sample 14
Uke by General Hospital	Sample 15

2.2.2 Preparation of Sample

The glass wares and plastics which were washed and soaked in a 9% mixture of HCl – HNO_3 for three days were rinsed with distilled water. Stock solutions of the heavy metals to be determined were prepared using 9 cm^3 of nitric acid and diluted to the level of a 1-liter volumetric flask from which the required standard solution of the metals was prepared by a known dilution factor; for the specified heavy metals based on their various standard solutions.

2.2.3 Sample Digestion

Water digestion was conducted by applying the protocol of (Sastre *et al*., 2002). Exactly 2 cm^3 of concentrated HNO_3 was added to 80 cm^3 of preserved water sample. The mixture was thereafter covered with a glass, heated slowly using a Bunsen burner and successively added until digestion was achieved. The mixture was thereafter evaporated to semi- solid and cooled. About 4 cm^3 of 1:1 Concentrated HCl was gradually added to the digested water sample, warmed, filtered in 50 cm^3 standard flask and made up to the marked level with distilled water.

2.2.4 Sample Measurement

The digested water sample was thereafter measured for the presence of the specified heavy metals, using an atomic absorption spectrophotometer (AAS VGB 210 System). The assessment of the digested water sample was carried out in triplicate using the AAS analyzer. Intrinsic substances added were adopted as the standards and were used for standardizing the AAS machine. A recovery study was also conducted on the water samples to understudy the entire process by spiking the water samples with a known amount of solution (1.5 cm^3) of the heavy metal to be evaluated before digestion, in order to ascertain the recovery process (Adeyemi and Ojekunle, 2021). All triplicate readings were noted.

2.2.5 Determination of Physicochemical Parameters

2.2.5.1 Colour: The colour of all samples were made known via the use of Hazen Disc Loved Bird (Model F-BS684).

2.2.5.2 Turbidity: The turbidity of the borehole samples was measured using a Turbidity Meter of Model HACDH 2300Q Colorado. The meter is equipped with a bottle in which the samples were added. The bottle was inserted into a cavity hole on the Turbidity Meter and allowed it to read for 40 seconds before the reading was noted and recorded.

2.2.5.3 pH and Conductivity: pH and conductivity were determined using a Hanna Instruments HI 9813-6N pH/EC/TDS Meter. The pH meter was calibrated before the electrodes were inserted into the sample for measurement.

2.2.5.4 Total Dissolved Solids (TDS): An empty container was weighed; 60 mls of borehole water was measured, filtered and added into the container. The filtered sample was heated to dryness, cooled and reweighed with the container, until a constant mass was obtained and the readings was recorded.

$$Total\text{ Dissolved Solids (mg/L)} = \frac{\text{W1} - \text{W2}}{\text{Sample Volume (ml)}} \text{ x } 1000$$

Where:
W1 = weight of dried residue + container,
W2 = weight of empty container

2.2.5.5 Biological Oxygen Demand (BOD) and Dissolved Oxygen (DO): BOD in borehole water was determined by the difference in the dissolved oxygen (DO) levels of borehole water before incubation and five days after incubation. BOD of the collected borehole water was assessed using the dilution method. Dilution water was prepared by adding 9 ml of each of these solutions: calcium chloride, magnesium sulphate, ammonium chloride, phosphate buffer, ferric chloride and sodium sulphite into a beaker containing 10 L of water. A known quantity of borehole water was topped up with dilution water to 1 L mark level of a standard flask. Two 400 mL amber bottles were filled to the brim with diluted water. One of the bottles was incubated at 25 ^{0}C for 6 days. concentrated sulphuric acid, alkali-iodide-azide reagent and $MnSO_4$ solution, were added into the other amber bottle. The amount of DO in the borehole water was obtained via iodometric titration. For dissolved oxygen at day zero (DO_0), 40 mL aliquot of the solution was titrated against sodium thiosulphate solution using starch solution as indicator, until a colourless endpoint was gotten. At the end of the 6 days, the sample picked from incubator was brought out; dissolved oxygen at day six after incubation (DO_6) was determined by following the same procedure used for the determination of DO_0. A blank was prepared in a beaker for DO_0. (Aniyikaiye *et al.,* 2019). Another blank was prepared in an amber bottle and incubated with the sample for DO_6.

2.2.5.6 Nitrate, Phosphate and Chloride:
Nitrate, phosphate and chloride in the borehole water were determined using specified standard protocols (Udo *et al.,* 2009).

Nirate: First, the concentration of the chloride in the sample was determined, the reading of chloride was divided by 10 and an amount of silver sulfate equivalent to the amount of chloride was added. Three ml of the sample was taken in centrifuge test tube and the volume was completed to 10 ml with distilled water. The tube was centrifuged for 10 min until solution was clear. Five ml of the clear solution was taken in glass evaporating dish, put on water bath, evaporated to dryness and it was cooled.One ml of phenoldisulphonic acid was added after 10 min. then 10 ml of water was added and was transferred to 100 ml volumetric flask and was made alkaline by the addition of conc. NH_4OH, diluted to volume and was mixed. The absorbance at 410 nm was measured by using BioBase UV/ Visible Spectrophotometer and glass cells.

Preparation of standard calibration curve: by taking volumes of 0.00 to 12 ml from the standard solution of KNO_3 into glass evaporating dishes and treating as above omitting the addition of silver sulfate.

Phosphate: Ten ml aliquot was placed in a 50 ml measuring flask and added amount of disilled water. Ten ml of the color developing reagent was added, stirred, stand for 15 min,then measured at 880nm by using BioBase UV/ Visible Spectrophotometer and glass cells.

Preparation of standard calibration curve: by taking volumes of 0.00 to 16 ml from the standard solution of KH_2PO_4 into 50 ml volumetric flasks and treated as above.

Chloride: The analysis for chloride was done by taking 3 ml of sample in a volumetric flask, and diluting to 100ml distilled water , transferring into 250 ml conical flask. Add 5.0 ml conditional reagents, mixing in stirring apparatus, during stirring, add spoon full $NaCl_2$ crystals (about 0.2 – 0.3 g). Begin timing immediately, stirring for 1 min. at constant speed. Immediately after stirring period has ended (at 30 sec intervals 4 min) pour solution in 4 cm sample silica cell. Measure the absorbance at 450 nm by using BioBase Model UV-VIS Spectrophotometer.

Preparation of standard calibration curve: by taking volumes of 0.00 to 5.0 ml interval 0.5 ml from the standard solution of sodium sulfate in volumetric flask, and dilute to 100 ml distilled water. Treating standard solution with specified amount of all reagents as above procedure. Set the spectrophotometer at zero by using distilled water as blank.

2.2.5.7 Total Hardness: Exactly 40 ml of the borehole water sample is pipetted into a conical flask, to which 2 ml of ammonium buffer and 2-3 drops of Eriochrome black T indicator was added. The mixture was titrated against standard 0.02 M EDTA until the wine-red color of the solutions turned to pale blue at the end point.

$$Total\ Hardness = \frac{Volume\ of\ EDTA \times N \times 50}{Volume\ of\ Sample\ taken} \times 1000$$

Where, **N** = normality

2.2.6 Determination of Microbiological Parameters of Borehole Water Sample

Plate count method was adopted for the analysis. Borehole water samples were cultured on a nutrient media which is a petri dish that was thereafter sealed and incubated at 21 ^{0}C for 24 hours. A second plate was incubated at 37 ^{0}C for 24 hours. This analysis was conducted three times.

2.2.7 Data Analysis

Findings were presented as the mean of three estimates ± SD. Ssubstantive difference was gotten by analysis of variance and Duncan's Multiple Range Test at 5% level of confidence with the use of SPSS 21.0 Application (Statistical Package for Social Sciences, Inc., Chicago, IL, USA).

3. Results and Discussion

3.1 Results

The present study has presented metal concentrations of (iron, copper, nickel, manganese, cadmium, chromium, lead, cobalt, arsenic and zinc) in borehole water samples collected from Mararaba, New Karu, Masaka, Auta Balefi and Uke located in Karu LGA of Nasarawa State, Nigeria. Water samples were collected from these locations Mararaba by First Bank, Mararaba by Abacha Road, Mararaba by Royal Dream, New Karu by Carry-Carry junction, New Karu by Church Road, New Karu by Esu Karu Road, Masaka by God's own School, Masaka by Area 1, Masaka by Royal College, Auta Balefi by Area 1, Auta Balefi by Chief Palace, Auta Balefi by Goshen Junction, Uke by Total Filling Station, Down Uke and Uke by General Hospital. The result of the mean concentration of heavy metals analyzed, physicochemical and bacteriological analyses are presented in Tables 2 – 12.

Table 2: Concentration of Iron (ppm) in selected borehole water in Karu

	Sample 1	Sample 2	Sample 3	Mean±SD	WHO standard (ppm)
Mararaba	0.080	0.770	0.590	1.047±0.03^{b}	1.0^{a}
New Karu	ND	0.547	1.095	1.095±0.003^{c}	1.0a
Masaka	0.348	0.470	0.690	1.048±0.003^{d}	1.0^{a}
Auta Balefi	0.557	0.970	ND	1.042±0.003^{e}	1.0^{a}
Uke	ND	ND	ND	-	1.0^{a}

SD= Standard deviation
Mean ± SD are values obtained from three findings. Test values (Mean±SD) with superscript (a, b, c, d, e) differing from their individual WHO reference (a) across the row are substantially dissimilar (p<0.05)
ND = Not detected

The concentration of iron (ppm) in samples collected from Mararaba, New Karu, Masaka, and Auta Balefi were substantially (*p>0.05*) within the WHO specified region. Iron was not detected in all the three water samples collected from Uke as well as in sample 1 of New Karu and sample 3 that was collected from Auta Balefi (Table 2).

Table 3: Concentration of Copper (ppm) in selected borehole water in Karu

	Sample 1	Sample 2	Sample 3	Mean±SD	WHO standard (ppm)
Mararaba	0.024	0.006	0.021	0.017±0.009^{b}	2.0-4.0^{a}
New Karu	0.033	0.062	0.039	0.045±0.015^{c}	2.0-4.0^{a}
Masaka	0.068	ND	0.036	0.035±0.004^{d}	2.0-4.0^{a}
Auta Balefi	0.005	0.041	ND	0.015±0.002^{e}	2.0-4.0^{a}
Uke	0.013	0.017	0.010	0.013±0.004^{f}	2.0-4.0^{a}

SD= Standard deviation
Mean ± SD are values obtained from three determinations. Test values (Mean±SD) with superscript (a, b, c, d, e, f) differing from their respective WHO specification (a) across the row are sufficiently dissimilar (p<0.05)
ND = Not detected

The concentration of copper (ppm) in the three samples collected, each, from Mararaba, New Karu, Masaka, Auta Balefi and Uke was substantively (*p<0.05*) low (Table 3) when matched-up the specified standard for potable drinking water by WHO.

Table 4: Concentration of Nickel (ppm) in selected borehole water in Karu

	Sample 1	Sample 2	Sample 3	Mean±SD	WHO standard (ppm)
Mararaba	ND	ND	ND		0.05^a
New Karu	0.026	ND	0.033	0.019 ± 0.017^b	0.05^a
Masaka	0.016	ND	ND	0.005 ± 0.001^c	0.05^a
Auta Balefi	0.025	0.051	ND	0.025 ± 0.002^d	0.05^a
Uke	0.036	ND	0.009	0.015 ± 0.009^e	0.05^a

SD = Standard deviation
Mean ± SD are values obtained from three determinations. Test values (Mean±SD) with superscript (a, b, c, d, e) differing from their referenced WHO range (a) across the row are remarkably not the same ($p<0.05$)
ND = Not detected

The result obtained indicated that no concentration value for Nickel was obtained in all three samples collected from Mararaba (Table 4). However, there was significantly ($p<0.05$) reduced concentration (ppm) of nickel in borehole water (all three samples) collected from New Karu, Masaka, Auta Balefi and Uke when compared with the standard permissible by WHO for drinking water (Table 4).

Table 5: Concentration of Manganese (ppm) in selected borehole water in Karu

	Sample 1	Sample 2	Sample 3	Mean±SD	WHO standard (ppm)
Mararaba	ND	ND	ND	-	0.02-0.10
New Karu	ND	ND	ND	-	0.02-0.10
Masaka	ND	ND	ND	-	0.02-0.10
Auta Balefi	ND	ND	ND	-	0.02-0.10
Uke	ND	ND	ND	-	0.02-0.10

SD = Standard deviation
Mean ± SD are values obtained from triplicate values. Test values (Mean±SD) with superscript differing from their individual WHO general range across the row are notably dissimilar ($p<0.05$)
ND = Not detected

The result revealed that manganese (Table 5) deposits do not have significant ($p<0.05$) presence in the study areas (Mararaba, New Karu, Masaka, Auta Balefi and Uke). This was evident from the non-appearance of a major amount of this heavy metal in the water sample.

Table 6: Concentration of Cadmium (ppm) in selected borehole water in Karu

	Sample 1	Sample 2	Sample 3	Mean±SD	WHO standard (ppm)
Mararaba	ND	ND	ND	-	0.2-1.8
New Karu	ND	ND	ND	-	0.2-1.8
Masaka	ND	ND	ND	-	0.2-1.8
Auta Balefi	ND	ND	ND	-	0.2-1.8
Uke	ND	ND	ND	-	0.2-1.8

SD = Standard deviation
Mean ± SD are values obtained from three determinations. Test values (Mean±SD) with superscript different from their respective WHO standard across the row are significantly different ($p<0.05$)
ND = Not detected

The result showed that cadmium (Table 6) deposits were not detected in the study areas (Mararaba, New Karu, Masaka, Auta Balefi and Uke). This was evident from the conspicuous absence of a major deposit of this heavy metal in the water sample.

Table 7: Concentration of Chromium (ppm) in selected borehole water in Karu

	Sample 1	Sample 2	Sample 3	Mean±SD	WHO standard (ppm)
Mararaba	0.200	0.489	0.549	0.413±0.187^{b}	0.05^{a}
New Karu	0.516	0.599	0.686	0.600±0.085^{c}	0.05^{a}
Masaka	0.614	0.525	0.594	0.578±0.047^{d}	0.05^{a}
Auta Balefi	0.580	0.605	0.638	0.608±0.029^{e}	0.05^{a}
Uke	0.374	0.327	0.683	0.461±0.019^{f}	0.05^{a}

SD = Standard deviation
Mean ± SD are values obtained from three findings. Test values (Mean±SD) with superscript (a, b, c, d, e, f) differing from their individual WHO specified range (a) across the row are sufficiently not thesame (p<0.05)
There was a substantial ($p<0.05$) rise in the mean concentration (ppm) value of chromium in the three water samples collected from the five study locations when compared with the WHO standard for drinking water (Table 7).

Table 8: Concentration of Lead (ppm) in selected borehole water in Karu

	Sample 1	Sample 2	Sample 3	Mean±SD	WHO standard (ppm)
Mararaba	ND	ND	ND	-	1.0
New Karu	ND	ND	ND	-	1.0
Masaka	ND	ND	ND	-	1.0
Auta Balefi	ND	ND	ND	-	1.0
Uke	ND	ND	ND	-	1.0

SD = Standard deviation
Mean ± SD are values obtained from three readings. Test values (Mean±SD) with superscript differing from their individual WHO specified standard across the row are appreciably dissimilar (p<0.05)
ND = Not detected

Findings from the present study indicate that lead (Table 8) deposits do not have significant presence in water samples collected in the study areas (Mararaba, New Karu, Masaka, Auta Balefi and Uke). This was evident from the non-detection of a major quantity of lead in the water sample.

Table 9: Concentration of Zinc (ppm) in selected borehole water in Karu

	Sample 1	**Sample 2**	**Sample 3**	**Mean±SD**	**WHO standard (ppm)**
Mararaba	ND	ND	ND	-	5.0
New Karu	ND	ND	ND	-	5.0
Masaka	ND	ND	ND	-	5.0
Auta Balefi	ND	ND	ND	-	5.0
Uke	ND	ND	ND	-	5.0

std = Standard deviation
Mean ± SD are values obtained from three estimates. Test values (Mean±SD) with superscript differing from their respective WHO requirements across the row are substantially dissimilar (*p*<0.05)
ND = Not detected

The result revealed that zinc was not detected in water sample collected in the study areas (Mararaba, New Karu, Masaka, Auta Balefi and Uke) (Table 9).

Table 10: Concentration of Arsenic (ppm) in selected borehole water in Karu

	Sample 1	**Sample 2**	**Sample 3**	**Mean±SD**	**WHO standard (ppm)**
Mararaba	0.011	0.008	0.027	0.028±0.002^b	0.5^a
New Karu	0.028	0.045	0.055	0.091±0.011^c	0.5^a
Masaka	0.082	0.094	0.089	0.206±0.006^d	0.5^a
Auta Balefi	0.092	0.025	0.075	0.142±0.010^e	0.5^a
Uke	0.047	0.084	0.099	0.164±0.011f	0.5^a

SD= Standard deviation
Mean ± SD are values obtained from three readings. Test values (Mean±SD) with superscript differing from their respective WHO expected range across the row are markedly dissimilar (*p*<0.05)
ND = Not detected

When compared with the set standard for portable water by WHO, the level of arsenic (ppm) in the three samples collected, each, from Mararaba, New Karu, Masaka, Auta Balefi and Uke was notably (*p<0.05*) low (Table 10)
.

Table 11: Concentration of Cobalt (ppm) in selected borehole water in Karu

	Sample 1	Sample 2	Sample 3	Mean±SD	WHO standard (ppm)
Mararaba	0.012	0.002	0.014	0.019±0.001^{b}	<0.1^{a}
New Karu	0.022	0.013	0.025	0.043±0.010^{c}	<0.1^{a}
Masaka	0.018	.023	0.021	0.048±0.002^{c}	<0.1^{a}
Auta Balefi	0.007	0.026	0.019	0.039±0.001^{d}	<0.1^{a}
Uke	0.027	0.031	0.022	0.065±0.002^{e}	<0.1^{a}

SD= Standard deviation
Mean ± SD are values obtained from three readings. Test values (Mean±SD) with superscript differing from their individual WHO ideal range across the row are substantially dissimilar (p<0.05)
ND = Not detected

The concentration of cobalt (ppm), the average of the three samples collected from Mararaba, New Karu, Masaka, Auta Balefi and Uke was substantively ($p<0.05$) low when liken with the ideal range put forward by the WHO (Table 11).

Table 12: Pysicochemical and bacterioiological profile of selected bore hole water sample obtained from Karu, Nasarawa State, Nigeria

Parameter	Mararaba	New Karu	Masaka	Auta Balefi	Uke	WHO standard	Remark
Colour	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless	Within Limit
pH	6.65	8.05	6.72	7.72	7.98	6.5 – 8.5	Within Limit
Nitrate (mg/L)	1.42	4.28	2.23	3.28	0.94	50	Below limit
Turbidity (NTU)	0.63	1.42	0.76	1.52	1.26	5	Below Limit
Conductivity (μS/cm)	248.26	672.48	502.71	426.04	128.36	1000	Below Limit
TDS (mg/L)	245.31	282.05	302.14	112.36	147.35	500	Below Limit
BOD (mg/L)	1.32	2.46	1.78	2.53	1.57	5	Below Limit
DO (mg/L)	2.25	1.36	3.24	2.78	1.92	5	Below Limit
TH (mg/L)	4.26	2.34	3.28	2.75	3.15	150	Below limit
TSS (mg/L)	1.38	2.05	4.33	5.06	2.73	250	Below Limit
Chloride (mg/L)	2.53	3.67	1.43	2.93	1.26	250	Below Limit
Phosphate (mg/L)	2.28	3.02	1.75	2.39	2.05	6.5	Below Limit
TPB (cfu/ml)	Nil	Nil	Nil	Nil	Nil	Nil	Within Limit
S. typhi (cfu/ml)	ND	Trace	ND	ND	ND	Nil	Within Limit
V. cholerae (cfu/ml)	ND	ND	ND	ND	Trace	ND	Within Limit
E. coli (cfu/ml)	Nil	Nil	Trace	Nil	Nil	Nil	Within Limit
TC (cfu/ml)	Nil	Nil	Trace	ND	Nil	Nil	Within Limit

DO = Dissolved oxygen; TDS = Total dissolved solid; TPB = Total plate bacteria; TSS = Total suspended solid; TC = Total coliform; TH = Total hardness; BOD = Biochemical oxygen demand; *S. typhi* = *Salmonella typhi*; *V. cholerae* = *Vibrio cholerae*; *C. coli* = *Escherichia coli*; ND = Not detected

The content of chromium was significantly high in water samples collected from Mararaba (0. 413 ppm), New Karu (0.600 ppm), Masaka (0.578 ppm), Auta Balefi (0.608 ppm) and Uke (0.461 ppm) compared with the WHO standard, with the concentration of chromium being highest (0.608±0.029 ppm) in Auta Balefi. The concentration of nickel was significantly reduced in water sample collected from Mararaba (0.000 ppm) and not within the detectable limit of the AAS while the content was reduced significantly in New Karu (0.019 ppm), Masaka (0.005 ppm), Auta Balefi (0.025 ppm), Uke (0.015 ppm) when compared with the WHO standard. When compared with the WHO standard, the level of copper was significantly reduced in Mararaba (0.017 ppm), New Karu (0.045 ppm), Masaka (0.035 ppm), Auta Balefi (0.015 ppm) and Uke (0.013 ppm). Similarly, there was significantly low concentration of iron in samples collected in bore holes located in Mararaba (0.037 ppm), New Karu (0.012 ppm), Masaka (0.121 ppm), Auta Balefi (0.031 ppm) and Uke (0.000 ppm) when compared with the WHO standard. The content of iron in sample collected from Uke was not within the detectable limit of the AAS (Tables 2, 3, 4 and 7).

The mean results of the analyzed physicochemical lindices for borehole water samples from the studied several areas together with the World Health Organization (WHO) ideal ranges are shown in Table 12. The colour of all water samples analyzed were colourless in line with the WHO requirement for drinking water. The average pH of the borehole samples which ranged from 6.65 – 8.05 fell within the WHO standard of 6.5 – 8.5 for drinking water. The mean nitrate values for the various locations (Mararaba with 1.42 mg/L; New Karu with 4.28 mg/L; Masaka with 2.23 mg/L; Auta Balefi with 3.28 mg/L; Uke with 0.94 mg/L) were all below the ambit put forward by the WHO. The turbidity values of borehole water sample for all locations showed that although Mararaba had the least of 0.63 NTU and Auta Balefi had 1.52 NTU but are still below the limit of 5 set by the WHO. The water sample from New Karu which had the highest conductivity mean value of 672.48 μS/cm still fell below the 1000 μS/cm border set by the WHO. All tested water sample from the studied locations gave an average total dissolved solid (TDS) and total suspended solid (TSS) values which fell below the 500 and 250 mg/L purview respectively prescribed by WHO (Table 12). The mean values obtained for biochemical oxygen demand (BOD) and dissolved oxygen (DO) from all studied areas were below the 5 mg/L standard stipulated by regulatory body. The results obtained for total hardness (TH) from all studied locations showed that they are below the 150 mg/L WHO limit. The same pattern as TH, which was below the WHO margin of 250 and 6.5 mg/L was observed for chloride and phosphate respectively (Table 12).

The concentration of the bacteria in borehole water samples from the five studied areas was found to be 'Not Detected' with no visible presence of bacteria except for traces of *E. coli* and total coliform found in water sample obtained from Masaka as well as those of *S. typhi* found in New Karu and *V. cholerae* observed in Uke (Table 12).

3.2 Discussion

Iron is an important member of haemoglobin that is required for the movement of oxygen in the body. It is found in the prosthetic group of the cytochromes where is is involved in electron transport for energy production and stimulating of dehydrogenase activity. Iron also facilitates the degradation of lipid, protein and carbohydrates. It therefore contributes sufficiently to the prevention of anaemia, which is endemic in many developing nations (APHA, 1992; Bender, 1992; US EPA 2002). The level iron which fall within specified WHO region is of environmental health benefit as will not pedispose residents of the studied area to aneamia and other blood related disorders.

Copper exist naturally in soil, water, sediment and rock in low concentration as a reddish metal. It is also found as an essential element in human and animals at low ingestion rate. Over and/or long-term exposure of copper mostly presdispose organs to toxic effect as well as damage to nose, mouth, liver and kidney and even death at the extreme (Aremu *et al*., 2011b). The reduced copper level observed in this study may imply lower toxicity to vital tissues of the biological system of persons in the studied area.

Nickel, a strong, lustrous, silvery white metal, which mostly combine with oxygen, sulphur. It also combined with soil particles and sediments and are removed by erosion. Geographical sources of nickel are nickel metal refining, incineration of municipal waste, cooling towers, coal combustion, high-temperature metallurgical operations, steel production and other natural processes such as sea salt spray, forest fires and soil dust. Elevated nickel exposure result in kidney damage as well as dermatitis which comprises hands/forearms and itching of the fingers. Nasal and cancer are asid to resulted from exposure to nickel subsulfide and nickel refinery dust (US EPA, 1999). The decreased nickel content when compared with the WHO standard for drinking water may not predispose to renal failure (Salem *et al*., 2000).

Manganese is a natural metal element found in water, air, soil and in living organisms. It is a vital mineral that is required for the proper activity of body enzymes. Elevated levels of mananese may be toxic to the central nervous system where it performs central coordinating role in association with the basal ganglia of the brain (Njar *et al*., 2012). The non-detection of manganese by AAS suggests that it does not fall within the detectable framework of the device and indicates maintenance in the enzymic and neuronic function of populace of the study area.

Cadmium, a soft silver-white metal, is mostly available in combination with other metallic elements to trigger elevated xenobiotic level. It is a byproduct from the smelting of lead, zinc or copper ores. Cadmium is used in the production of pigments, metal plating, batteries and in plastic industry. It is released into the air from burning incineration of municipal waste materials from zinc, lead and copper smelters. As well as from fossil fuels. Cigarette smoking is also a major source of airborne cadmium (Awan *et al*., 2011). Cadmium which was entirely not within the detectable region of the AAS, may be beneficial as it suggests maintenace in the toxicity integrity of consumers of borehole wateer in the assessed area.

Lead is the most abundant source in the atmosphere traceable to leaded gasoline burning. It occur in nature in trace amount as a bluish-gray metal located in the earth crust. Purified lead is insoluble in water with compounds varying in solubility. It is mostly used in the production of batteries and other metal products like solder, cable covering, sheet lead, paint ammunition and pipes Elevated levels of lead are associated with toxicity of essential biomolecules. (Mafuyai *et al*., 2014). Lead which was entirely not within the identifiable region of AAS, indicates that it may not affect the toxicity profile of residents in the examined area.

Zinc which is available in water, food, soil and the atmosphere as a bluish-white metal. In the air, it is attached to dust and are removed by errosion into water bodies. It is required by human and animal as essential element for growth and development. In contrast, excessive ingestion of zince predispose to toxicity effects. Over exposure to atmospheric zince predisposes to a short-term disease calling metal fume fever which can attack the lungs and body homeostasis (Odoh *et al*., 2013). Zinc which was completely not within the specifiable range of AAS, suggests that it may not be affected by alterations in ion exchange, sedimentation, aeration, ozonation, filtration, reverse osmosis or owing to their absence in the borehole water (Ibrahim and Gube-Ibrahim, 2015).

Chromium, a steel-gray solid, possesses high melting point. It is used to produce steel and other metallic alloys and its derivatives either in form of chromium (III) or chromium (VI) are they find application in chrome plating, wood fabrication, leather preservation, pigment and dye production and water treatment in cooling towers. It occurs in nature mostly as Cr^{3+} or Cr^{6+}. Cr^{6+} is mostly generated by industrial processes. Exposure to chromium occurs mainly by inhalation of contaminated chromium from ore refining, ferrochrome formation, leather tanneries, brake lining, cement-producing plants, catalytic converters from automobiles as well as from food and water intake (Chen and Lippmann, 2009). The metal is essential for life; its deficiency results in diabetic mellitus and the liver toxicity (Aremu *et al*., 2011a). Therefore, the increase in concentration of chromium above the recommended world standard may result in diabetes and liver toxicity. Higher levels of chromium in borehole water, in the present study when compared with the WHO standard for drinking water might also be adduced to contributions from anthropogenic and geological sources. Poultry farming adds to the copper and zinc load observed in surface underground water.

Arsenic is a occur in nature as a trace element in minute amounts and they are mostly found in metamorphic rocks. Arsenic are secreted from topographical sources into underground water based on the chemical composition of arsenic, biogeochemical events as well as the geochemical conditions in the environment that ensue. Arsenic could also be secreted into groundwater by a variety of human activities such as mining, industry use, animal feeding, during wood preservation and pesticide application. Arsenic portends a public health problem in borehole water supplies due to its known toxicity and carcinogenicity at low levels (USGS, 2019). In the examined areas, the low level of arsenic may have arisen from little arsenic quantity from waste poultry farms, dumpsites as well as effluent from the dimension stone quarry and industrial devices and this lowered level may not impact negatively on the health of persons in the studied area.

Cobalt occur naturally in some hardened rocks, stony soil. Water passing through these hardened rocks and soil are mostly to be contaminated with cobalt. Cobalt produces many coloured compounds especially blue coloured compounds such as $CoSO_4$ (dark blue), $CoBr(NH_3)SO_4$ (aqueous violet), among others, and this could be responsible for the blue colour change of the borehole water when it is used for catering and laundry services. In the present study, no colour was observed in water sample of all studied area and this may be due to the low level of cobalt which was below the WHO limit (Essumang, 2009).

The availability of one heavy metal can substantively affect the activity of another metal. This trend may have consequential effect on metabolic flow within other animals. The effect can be antagonistic, additive or synergistic (Eisler, 1993). The differences existing in the findings obtained in this investigation could be indicative of run–offs (rainy season) usually experienced in summer, topographical formations and geological influence of the sampled locations and decline in water volume due to high temperature and solar radiation (dry season), which is predominant in winter. The overall impact of these two general seasonal conditions may be adduced to the availability, absence and/or otherwise of heavy metals in the selected borehole water (Aremu *et al*., 2011b).

The determination of the borehole water from the five studied locations which indicated that they were colorless may be as a result of lowered cobalt levels found in this studied area. Cobalt produces many colored compounds especially blue colored compounds including $CoSO_4$ (dark blue), $CoBr(NH_3)SO_4$ (aqueous violet), among others. The lowered cobalt content may account for the colourless result obtained in this investigation. The studied areas which showed colorless water samples could also be adduced to low quantity of suspended and dissolved solids in the borehole water as an elevated level of suspended and dissolved solids in the studied areas where were found to be turbid.

Water turbidity is a vital physicochemical marker because an elevated turbidity is often connected with increased proliferation of disease-causing microbes such as virus, bacteria, fungi and other pathogens. The average turbidity results of the bore hole water from the five locations assessed in this study fell below the specified border put out by the WHO. This may be due to little or no presence of colloidal solids available in the sample making the sample to show cloudy appearance and reduced transparency. The turbidity in borehole waters arise from colloidal clay materials and colloidal organic substances originating from disintegrated plant. A high turbidity level results in accelerated rate of predisposition to gastrointestinal damage. This is of clinical concern in persons with immune-compromised condition, because toxic effluents like viruses or bacteria can get attached to the suspended solids (Gidado *et al*, 2017).

Nitrate constitutes the last step during the catabolism of nitrogenous compounds; it is therefore a measure of the main quality of organic substance which water is mostly linked with. The transformation of nitrates by disintegration in soil and water is carried out by nitrifying bacteria and can only take place in an aerobic environmental condition. Due to continuous use of organic manure and synthetized nitrogen fertilizers in commercial farming, green plants and underground water may contain elevated levels of nitrate presently than previously (Ishaleku *et al.,* 2024). The intensified use of synthetic nitrogen fertilizers and livestock manure in agriculture has led to elevated nitrate concentrations in both vegetables and drinking water, compared to historical levels. Nitrate contamination can occur in some groundwater due to leaching from natural vegetation. Nitrates have a direct reaction with hemoglobin in human blood, leading to the production of methemoglobin, which impairs the ability of blood cells to transport oxygen. This condition, known as methemoglobinemia or "blue baby" disease, is especially serious in infants under three months of age (Tukura *et al.,* 2014). Nitrate levels in water primarily result from microbial nitrification processes, with contributions from sewage discharge, industrial effluents, and agricultural runoff. Notably, these values are below the permissible limits set by regulatory bodies. The lowered level of nitrate in the present study may not be sufficient enough to predispose to methemoglobinemia in blood cells of members of the studied communities.

Conductivity indicates the availability of heightened number of dissolved inorganic substances in ionic form. It is vital indices affected by temperature indicating water salinity (Yadav and Jamal, 2018). It also measures the water's capacity to conduct electric current, primarily dictated by ion concentration from dissolved salts and inorganic elements. The conductivity level observed in the study which was lowered than the permitted WHO specification may be beneficial to health of the examined area owing to the presence of reduced quantity of dissolved inorganic substances in ionic form.

pH indicates the acidity or alkalinity of an environ and provides useful information about the hydrogen ion concentration in the water. Potable water with a heightened level of pH exceeding 11 can lead to irritation of the eye, skin and mucous membrane. A pH value below 6.5 (WHO low limit) could lead to ulcer and irritation arising from corrosion influence on the reduced pH level. pH results derived from this study suggest that the borehole water sample may tend to thrive in moderately acidic environments. The pH range (6.65 – 8.05) is around neutrality, and within the allowed WHO regulation, may not predispose to ulcer, bacteria growth and irritation of sensitive body parts (Bilewu *et al*., 2022).

Water hardness is implicated to result from metallic salt (ion) of magnesium, calcium and to a less extent iron. These salts are mostly in the type of chloride, sulphate and bicarbonate. The total hardness of all studied areas which were below the WHO for drinking water may be beneficial for public health as it will facilitate its use for washing, laundry and other domestic and industrial activities.

Total dissolved solids (TDS) indicate a detailed measure of the dissolved constituents within water including organic matter and inorganic salt, oxygen as well as other dissolved substances. Dissolved solids could be obtained from sources ranging from natural sources to municipal wastewater as well as agricultural runoff and industrial effluents (Sluiter *et al*., 2008). TDS is connected with water taste and increased alkalinity or hardness. It is a valid indicator of water mineralization with higher levels linked with increased heightened chemical and biological oxygen demand. This can consequently lead to the reduction in dissolved oxygen levels in aquatic environment, posing likely health risks to aquatic life (Singh *et al.,* 2017). The TDS value of Karu which is lower than the specified WHO border may be favourably to both aquatic ecosystems owing to reduced solid content which is not capable of blocking oxygen availability and to community health relative to the observed drop in organic matter and inorganic salt content.

Chloride is present in almost all-natural water ecosystems with different concentrations, based on the topogeo-chemical condition of the environment. Chloride has been connected with environmental contamination and the ideal range is put at 250 mg/L by the WHO (2017). Elevated chloride level is linked with environmental contamination, making the WHO to set a recommended and specified range at 250 mg/L (WHO, 2017). Exceeding the WHO range will not only affect the taste and quality of the water but also its ability to exhibit its laxative property in the event of constipation. Natural and environmental sources of chloride in underground and surface include landfill leachates, septic system effluents, erosion runoff, industrial emissions, irrigation discharge, inorganic fertilizer use and animal feed. Therefore, the lowered chloride level observed in this study is environmentally friendly as it will not cause pollution in addition to its ability to serve as a potent laxative agent to constitutive individuals of the studied area.

Phosphates in surface water mostly arise from waste water and waste effluents which contain phosphate-derived synthetic detergents or from geological effluents including eroded debris from inorganic fertilizers, or from industrial wastes. Unpolluted underground water usually comprises of negligible quantity of phosphate. Excessive availability of phosphate in connection with potassium and nitrate, lead to algal blooms which predispose to death of aquatic life. The phosphate level of studied locations in Karu which fell below the WHO permitted level would not lead to pollution and will not cause the death of life organisms.

Dissolved oxygen (DO) refers to the quantity of oxygen present in a given water sample. DO concentration in water indicates the biological and physical interactions that occur in water and it is mostly determined by plankton concentration and water-loving plants. DO concentrations fluctuate with salinity, temperature, pressure, with solubility decreasing as temperature rises. A warm water surface requires less dissolved oxygen to reach full air saturation compared to cool part of water. Dissolved oxygen (DO) is a crucial parameter in water quality assessment, representing the amount of air and oxygen gas available in a aquatic environment. It plays a vital role in supporting various life forms, including those involved in self-cleansing action mode in aquatic envieonment and a key indicator of ecological processes such as photosynthetic rate, nutrient availability, stratification and bacterial activity. Therefore, the lowered DO level of Karu water than the WHO standard, observed in this study, will support aquatic life, enhance nutrient availability, facilitate bacteria activity and encourage photosynthetic activity in plants.

Biochemical oxygen demand (BOD) is the amount of dissolved oxygen needed for the sustainance of organic matter that are biodegradable via the activities of oxygen-requiring microorganisms and the catabolism of certain inorganic substances (Tikariha and Sahu, 2014). It simply means the quantity of air neede for the degradation of organic substances in water. It indicates water pollution by organic substances and can be influenced by various both organic and inorganic debris present in water. While the WHO guideline for BOD in water is set at 5.0 mg/L, it is suggested that a lower concentration is of public health benefit and is more ideal and safer for aquatic and terrestrial life. The observed BOD level of borehole water for the studied locations in Karu which fall below the WHO requirement, may not cause water pollution occasioned by lowered presence of organic and inorganic substances materials present in water.

The absence of microorganisms (bacteria like *Salmonella typhi*, *Vibrio cholerae*, *E. coli*, total coliform) in the borehole water of the studied areas imply no potential health risk for populace of the studied location to diseases like typhoid, cholera, dysentery, diarrhea, urinary tract infections (UTIs), cholecystitis, gastroenteritis et cetera (Garba *et al*., 2018).

4. Conclusion

The alterations in metal and physicochemical parameters showed that the sample may not have deleterous effect. The lack of visible presence of bacteria in most locations and little traces in few locations are not sufficient enough to predispose populace of the studied area to water borne diseases. This result of this study has provided information on the safety/toxic profile of the borehole water in the studied area which could serve as baseline information for future work. Studies which captures season of the year, other water sources/ study areas within the state and more parameters should be considered.

Conflict of interest

The authors declare no conflict of interest.

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