Assessment of Heavy Metal Contamination of Groundwater within Misau Town in North-Eastern Nigeria

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Abstract

The magnitude of heavy metal contamination of groundwater in Misau, North-Eastern Nigeria, was assessed using flame Atomic Absorption Spectrometry (AAS). Findings revealed that the concentrations of heavy metals in the groundwater within the study area ranged from 0.028 to 0.078 mg/L for Pb, 0.018 to 0.044 mg/L for Cd, 0.241 to 0.979 mg/L for Cu, 0.452 to 1.021 mg/L for Mn, 0.005 to 0.052 mg/L for Ni, and 0.430 to 1.036 mg/L for Zn. Findings also showed that Pb, Cd and Mn concentrations exceeded the World Health Organization's guidelines for drinking-water quality in 25%, 40% and 5% of the groundwater samples examined respectively. In view of the degree of groundwater contamination in Misau by Pb and Cd, the study suggests an urgent need for remediation and regular monitoring of the groundwater in Misau.

Keywords: Boreholes, Contamination, Groundwater, Hand-dug Wells, Heavy Metals

1.0 Introduction

Groundwater is the water located beneath the earth's surface. It constitutes about 97% of global freshwater and it is an important source of drinking water in many regions of the world [1]. The popular belief among the general public that groundwater, unlike surface water, is immune to chemical contamination has been disproved by the findings of several investigations which indicated that groundwater is also susceptible to contamination by both organic and inorganic contaminants [2-8]. Although contamination of groundwater could occur by natural processes, such as geological weathering and dissolution of numerous minerals beneath the earth's surface, the natural concentrations of these contaminants in groundwater are generally low [9]. Nevertheless, contamination of groundwater by anthropogenic sources, such as seepages from agricultural wastewaters, domestic sewages, mining activities and industrial effluents, has been shown to adversely affect the quality of groundwater in many parts of the world [10-13].

Assessing the dangers from metal contaminants to human health and the environment involves concerns that are different from those associated with organic chemicals. Unlike organic pollutants such as petroleum hydrocarbon and detergent which may visibly build up in the environment, metals may accumulate to toxic levels without being noticed in the environment. Furthermore, organic chemicals are generally broken down over time in the environment but metals are not, and can easily be accumulated and concentrated in living systems. In recent times, exposure of human population to drinking water contaminated with toxic metals has evoked an outburst of concern among scientists as well as the general public. This is mainly due to an ever increasing awareness of the negative roles that these toxic metals play in human health. The negative health effects of heavy metals to human beings are well documented in literature [14-19].

Misau is an ancient town in north-eastern Nigeria and it is currently the headquarters of Misau local government area in Bauchi State (Fig. 1). The town is about 170 km north of Bauchi, the state capital, on latitude 11.31584 ^{0}N and longitude 10.46610 ^{0}E. The vegetation is mainly Sudan Savannah and its inhabitants are mainly farmers [20]. According to the 2006 population census in Nigeria, Misau local government area has a population of 263,487 on an area of 1,226 km^2 [20]. The people of Misau depend mainly on groundwater for drinking and other domestic purposes. In view of the vulnerability of groundwater to toxic metal contamination and the health risk associated with these toxic metals, it is pertinent to assess the extent at which the groundwater in Misau has been contaminated with major heavy metals including lead, cadmium, copper, manganese, nickel and zinc.

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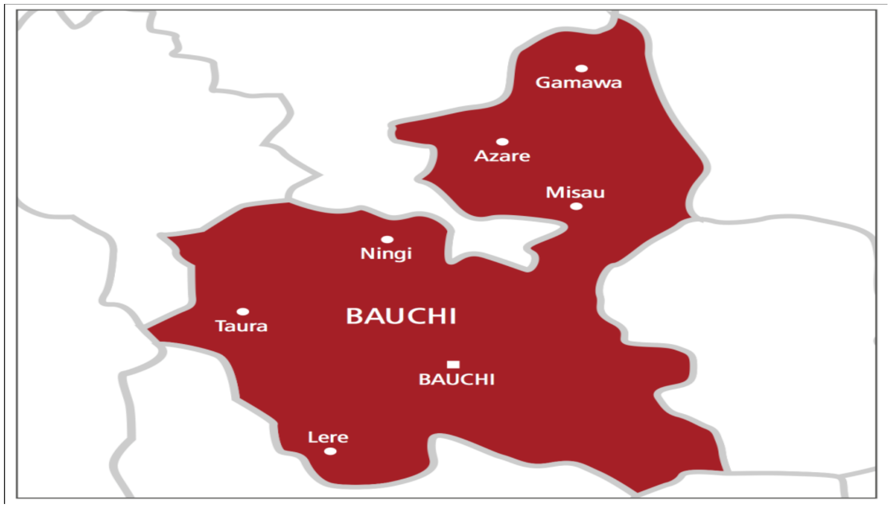

Fig. 1: Map of Bauchi State showing the location of Misau

2.0 Materials and Methods

2.1 Sample Collection and Preparation

Groundwater samples from boreholes and hand-dug wells were randomly collected from twenty sampling locations within the three districts (Gundari Ward, Kukadi South, and Kukadi North) in Misau town. The samples were preserved by adding 0.2% HNO_3 to bring the pH below 2.00 before transporting them to the laboratory [21]. The samples were then digested using acid digestion procedure for total recoverable metals as previously described [22].

2.2 External Standard Calibration

Stock solutions containing 1000 mg/L of Pb^{2+}, Cd^{2+}, Cu^{2+}, Mn^{2+}, Ni^{2+} and Zn^{2+} were prepared using analytical grade of $Pb(NO_3)_2$, $Cd(NO_3)_2.4H_2O$, $Cu(NO_3)_2.3H_2O$, $Mn(NO_3)_2.4H_2O$, $Ni(NO_3)_2.6H_2O$ and $Zn(NO_3)_2.6H_2O$. Working standard solutions with concentrations ranging from 0.05 – 1.00 mg/L for Pb^{2+}, 0.10 – 1.00 mg/L for Cd^{2+}, 0.10 – 6.00 mg/L for Cu^{2+}, 0.10 – 2.00 mg/L for Mn^{2+}, 0.10 – 1.00 mg/L for Ni^{2+} and 0.10 – 6.00 mg/L for Zn^{2+} were prepared from the stock solutions as described elsewhere [23]. The standard solutions were later used for external standard calibration.

2.3 Recovery Study

The analytical procedure employed in this study was validated by carrying out a recovery study. This was accomplished by determining the concentrations of lead, cadmium, copper, manganese, nickel and zinc in some of the groundwater samples before and after spiking each of the samples with a predetermined amount of Pb^{2+}, Cd^{2+}, Cu^{2+}, Mn^{2+}, Ni^{2+} and Zn^{2+} [24]. The guideline offered by the International Atomic Energy Agency on the validation of analytical methods using recovery study was adopted [25].

2.4 Analytical Technique

The absorbance values of all standard and test solutions were determined in triplicate using MODEL 210 VGP flame Atomic Absorption Spectrophotometer (AAS).

2.5 Statistical Analysis

The concentrations of heavy metals are reported as mean (± standard deviation) of triplicate determinations. Regression analyses were carried out on the results of external standard calibration using least-squares method and the concentrations of heavy metals in each sample were obtained from the resulting equations. The mean concentrations of heavy metals in all the samples were statistically compared with the World Health Organization's guidelines for drinking-water quality using t-test at $\alpha = 0.01$ [26]. All statistical analyses were performed with the aid of Microsoft Excel® 2007.

3.0 Results and Discussion

The results of regression analyses and recovery studies are presented in Table 1. The high values of coefficients of determination (R^2 = 0.999 for all metals or R^2 = 0.998 for Mn) obtained in the regression analyses indicate that there were strong relationships between the concentrations of standard solutions and the absorbance values. The R^2 value of 0.998 for Mn indicates that 99.8% of the variation in AAS signals can be explained by the linear model for Mn while the R^2 values of 0.999 for the remaining heavy metals indicate that 99.9% of the variations in AAS signals can be explained by the linear models for Pb, Cd, Cu, Ni and Zn [27, 28]. The average percent recoveries indicate values ranging from 81.13% for Cd to 97.00% for Zn which are comparable with the levels of accuracy reported in literature [29-31].

Table 1: Coefficients of determinations and average percent recoveries of spiked groundwater samples

Heavy Metal	R^2	% Mean Recovery
Pb	0.999	94.97
Cd	0.999	81.13
Cu	0.999	93.21
Mn	0.998	90.14
Ni	0.999	87.41
Zn	0.999	97.00

Concentrations of heavy metals in all the 20 groundwater samples collected within Misau town ranged from 0.028 to 0.078 mg/L for Pb, 0.018 to 0.044 mg/L for Cd, and 0.241 to 0.979 mg/L for Cu (Table 2). Similarly, concentrations of Mn, Ni and Zn ranged from 0.452 to 1.021 mg/L, 0.005 to 0.052 mg/L, and 0.430 to 1.036 mg/L respectively (Table 2).

Table 2: Concentrations of heavy metals in groundwater samples from Misau, North-Eastern Nigeria

Sample	Pb (mg/L)	Cd (mg/L)	Cu (mg/L)	Mn (mg/L)	Ni (mg/L)	Zn (mg/L)
S1	0.057 ± 0.033	0.038 ± 0.007*	0.651 ± 0.158	0.852 ± 0.133	0.005 ± 0.003	0.430 ± 0.139
S2	0.057 ± 0.016	0.040 ± 0.010	0.635 ± 0.130	0.791 ± 0.254	0.022 ± 0.004	0.506 ± 0.105
S3	0.053 ± 0.028	0.032 ± 0.009	0.504 ± 0.124	0.452 ± 0.244	0.025 ± 0.014	0.551 ± 0.160
S4	0.060 ± 0.012*	0.027 ± 0.005*	0.733 ± 0.098	0.575 ± 0.162	0.030 ± 0.008	0.809 ± 0.120
S5	0.042 ± 0.018	0.036 ± 0.005*	0.651 ± 0.320	0.514 ± 0.270	0.014 ± 0.003	0.824 ± 0.146
S6	0.053 ± 0.018	0.041 ± 0.009*	0.438 ± 0.049	0.683 ± 0.184	0.022 ± 0.007	0.566 ± 0.114
S7	0.042 ± 0.021	0.030 ± 0.015	0.356 ± 0.173	0.652 ± 0.096	0.028 ± 0.016	0.581 ± 0.208
S8	0.046 ± 0.033	0.038 ± 0.011	0.422 ± 0.075	0.560 ± 0.070	0.033 ± 0.016	0.733 ± 0.139
S9	0.042 ± 0.011	0.036 ± 0.008*	0.487 ± 0.098	0.560 ± 0.096	0.025 ± 0.006	0.703 ± 0.205
S10	0.046 ± 0.034	0.018 ± 0.008	0.339 ± 0.197	0.683 ± 0.231	0.032 ± 0.009	0.536 ± 0.091
S11	0.071 ± 0.006*	0.029 ± 0.014	0.307 ± 0.173	1.006 ± 0.710	0.018 ± 0.012	0.733 ± 0.250
S12	0.042 ± 0.039	0.040 ± 0.003*	0.339 ± 0.130	0.822 ± 0.092*	0.022 ± 0.004	0.884 ± 0.184
S13	0.049 ± 0.006*	0.038 ± 0.015	0.241 ± 0.130	1.021 ± 0.672	0.052 ± 0.028	0.794 ± 0.160
S14	0.053 ± 0.028	0.036 ± 0.014	0.438 ± 0.130	0.914 ± 0.394	0.051 ± 0.011	0.900 ± 0.091
S15	0.067 ± 0.012*	0.044 ± 0.007*	0.372 ± 0.124	0.575 ± 0.175	0.024 ± 0.008	0.824 ± 0.069
S16	0.078 ± 0.027	0.043 ± 0.011	0.569 ± 0.124	0.683 ± 0.211	0.037 ± 0.020	1.036 ± 0.536
S17	0.039 ± 0.006*	0.041 ± 0.012	0.405 ± 0.205	0.914 ± 0.348	0.035 ± 0.006	0.794 ± 0.335
S18	0.042 ± 0.019	0.030 ± 0.012	0.569 ± 0.102	0.975 ± 0.208	0.033 ± 0.009	0.854 ± 0.253
S19	0.056 ± 0.033	0.036 ± 0.008*	0.454 ± 0.075	0.545 ± 0.231	0.030 ± 0.006	0.839 ± 0.052
S20	0.028 ± 0.012	0.041 ± 0.012	0.979 ± 0.177	0.498 ± 0.166	0.028 ± 0.006	0.854 ± 0.157
WHO guideline	0.010	0.003	2.000	0.400	0.070	5.000

***Values marked with asterisks are concentrations that were significantly greater than WHO guidelines for drinking-water quality at $p < 0.01$**

None of the samples contains Cu, Ni and Zn in concentrations above the WHO maximum permissible levels of 2 mg/L, 0.07 mg/L and 5 mg/L respectively. However, concentrations of Pb in samples S4, S11, S13, S15 and S17 exceeded the WHO maximum permissible level of 0.01 mg/L. The data also indicate that samples S1, S4, S5, S6, S9, S12, S15 and S19 contain Cd concentrations in excess of the 0.003 mg/L maximum permissible level recommended by World Health Organization (WHO). Only sample S12 contains Mn concentration in excess of the WHO guideline of 0.4 mg/L. Percentages of groundwater samples within Misau town that contain heavy metal contaminants in excess of WHO guidelines for drinking-water quality correspond to 25% for Pb, 40% for Cd and 5% for Mn. The findings presented in this study agree with the reports of similar studies conducted in Nigeria and elsewhere which indicate that groundwater resources are being increasingly contaminated by heavy metals beyond WHO guidelines for drinking-water quality [5, 32-35]. Since no mining and industrial activities take place in the study area, the source of heavy metal contamination of the groundwater in Misau may be attributed to weathering and dissolution of minerals in the underground formation [36].

4.0 Conclusion

The results generated in this study indicate that some of the groundwater samples contained lead and cadmium concentrations above the World Health Organization's guidelines for drinking-water quality. In view of the magnitude of contamination of groundwater in Misau by Pb and Cd; and the health risks associated with drinking water contaminated with these toxic metals, it is recommended that remediation and regular monitoring programmes be set up for groundwater system in the town.

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