World Journal of Analytical Chemistry, 2016, Vol. 4, No. 1, 1-5
Available online at http://pubs.sciepub.com/wjac/4/1/1

DOI:10.12691/wjac-4-1-1

Health Risk Assessment for Exposure to Some Selected Heavy Metals via Drinking Water from Dadinkowa Dam and River Gombe Abba in Gombe State, Northeast Nigeria

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Abstract The concentrations of eight heavy metals (Fe, Mn, Cu, Pb, Cd, Ni, Co and Zn) were determined by atomic absorption spectroscopy in water from Dadinkowa dam and Kwadon boreholes which are the major sources of drinking water to Gombe town in Gombe State, North-East, Nigeria. The concentrations of metals in water from Dadinkowa dam were in the order: Fe (1.86mg/l), Mn(0.68mg/l), Cu(0.92mg/l), Pb(0.19mg/l), Cd(0.50mg/l), Ni(0.59mg/l), Co(0.42mg/l) and Zn(0.83mg/l).The concentrations of the metals in water from Gombe Abba River were in the order Fe(0.21 mg/l), Mn (0.24 mg/l), Cu (0.29 mg/l), Pb (0.02 mg/l), Cd (0.10 mg/l), Ni(0.04 mg/l), Co(0.12 mg/l) and Zn (0.41 mg/l). The human health risk assessment was performed by determining the chronic daily intake (CDI), hazard quotient (HQ) and total hazard index (THI) of the metals through human oral consumption for both adults and children. The HQ of iron, manganese, nickel and cobalt in water from Dadinkowa dam were all greater than unity and thus pose a potential health risk for both adults and children while cobalt was the only heavy metal of concern in water from Gombe Abba River as its HQ was greater than unity. The THI of water from all the sampled sites assessed were of high risk. Further monitoring of these sites is recommended as well as research by biomedical experts to reveal the exact adverse effects that heavy metal contamination of water might induce in humans, particularly among individuals in vulnerable populations such as children.

Keywords: *atomic absorption spectroscopy, chronic daily intake, drinking water, hazard quotient, health risk assessment, heavy metals, total hazard index*

Cite This Article: Maigari A. U., Ekanem E. O., Garba I. H., Harami A., and Akan J. C., “Health Risk Assessment for Exposure to Some Selected Heavy Metals via Drinking Water from Dadinkowa Dam and River Gombe Abba in Gombe State, Northeast Nigeria.” *World Journal of Analytical Chemistry*, vol. 4, no. 1 (2016): 1-5. doi: 10.12691/wjac-4-1-1.

1. Introduction

Heavy metals or toxic metals are trace metals which are detrimental to human health and having a density at least five times that of water. Once liberated into the environment through air, drinking water, food or countless varieties of man-made chemicals and products, heavy metals are taken into the body via inhalation, ingestion and dermal absorption [21]. If heavy metals enter and accumulate in body tissues faster than the body’s detoxification pathways can dispose of, then a gradual build-up of these toxins occurs. High concentration exposure is not a necessity to produce a state of toxicity in the body, as heavy metal accumulation occurs in body tissues gradually and, over time, can reach toxic concentration levels, much beyond the permissible limits. [22].

Heavy metal contamination is a major problem of the environment especially of growing medium sized cities in developing countries primarily due to uncontrolled pollution levels driven by causative factors like industrial growth and heavy increase in traffic using petroleum fuels. Heavy metal contamination may occur due to factors including irrigation with contaminated water, the addition of fertilizers and metal based pesticides, industrial emissions, transportation, harvesting process, storage and/or sale [8,18,23]. Heavy metals are generally not removable even after the treatment at treatment plants and thus, cause risk of heavy metal contamination of the soil and subsequently to the food chain [10].

Plants and animals take up metals from soil and water as well as from deposits on parts of plants exposed to the air from polluted environment [20]. The level of health risks posed by heavy metals in soils and water are determined using different indices, including transfer factor (TF), daily intake of metal (DIM) and health risk index (HRI) or hazard quotient (HQ) as reported by Liu et al., [16] and Khan et al., [15].

2. Objectives of the Study

The objectives of this present study were to determine the concentrations of eight heavy metals in water from Dadinkowa dam and Gombe Abba River using atomic absorption spectroscopy, determine the health risks by ingestion of water by the determination of their chronic daily intake (CDI), hazard quotient (HQ) and total hazard index (THI) for both adults and children.

The major anthropogenic sources of heavy metals in rural aquatic environments are known to be agricultural activities, homes, local markets, abattoirs, traditional industries such as blacksmithing, foundries and smelting of metals and crude oil [11]. All these activities severe water sources quality by introducing harmful toxic metals into soil and water.

Other sources of heavy metals can include leaded gasoline and paints, application of fertilizer, discarding high metal wastes in inappropriately protected landfills, animal manure, biosolids, compost, petrochemicals, pesticides and deposition in atmosphere [5,15,26].

2.1. Effects of Heavy Metals on Humans

Heavy metals are reported to encourage tumor and mutations at greater amounts in animals. They have the capacity of producing genetic harm to germ cells of both male and female animals. They are observed as growing toxins which through biomagnifications in plants affect the health of humans [21].

In animals (including human being), heavy metals are extremely poisonous at comparatively smaller amount. Ingesting food or drinking water with very greater degree of heavy metals relentlessly infuriates the stomach results in diarrhoea and vomiting. Correspondingly greater degree of lead (Pb) might be minimizing response period, and result in anaemia, a disease of blood in humans [4].

Dudka and Miller [9] and Bhagure and Mirgane reported several ways for the connection of heavy metals to the human body comprises direct breathing of polluted air, drinking of polluted water and direct contact with soil and ingestion of food comprising of plants developed in metal polluted soil.

Metals are non-decomposable and are recognised as main environmental contaminants causing cytotoxic, mutagenic and carcinogenic effects in animals [2]. Long contact to heavy metals like cadmium, copper, nickel and zinc can result in lethal health problems in humans. The biotic half-lives of these heavy metals are lengthy and furthermore these have capacity to store in various organs of the body and therefore results in annoying side effects [3].

Existence of poisonous heavy metals in lakes, reservoirs and river water disturbs the lives of native people that rely on these water bodies for their regular supply of water according to a study by Rai et al. [19]. Al- Busaidi et al [1] reported that fish is one of the chief protein sources for humans that plays role in lowering the blood cholesterol level and offers omega-3 fatty acids that minimise the danger of stroke and heart related disorders. There are metals that can be stored by fish through the food chain as well as water.

2.2. Health Risk Assessment

Health risk assessment models were developed basically in Europe and in the United States. The risk assessment is a multi-step procedure that comprises of data collection (gathering and analyzing the site data relevant to human health), exposure assessment (estimation of the magnitude of actual and/or potential human exposures), toxicity assessment (determination of adverse effects associated with exposure to different metals) and risk characterization (summarizes and combines outputs of the calculations of exposure and toxicity assessments) [12].

2.3. Sampling Design and Questionnaire

Water and soil samples were taken directly from the source at the sampling sites and stored in plastic bottles washed with detergents and copiously rinsed severally with deionised water. The water upon collection was acidified with few drops of concentrated nitric acid to keep the metals in solution. The samples were transported to the laboratory in an ice-water mixture boxes and kept in a refrigerator before analysis was done.

A questionnaire, which inquired about demographics of participants, was administered by the researcher during the visit. The participants were asked to declare their age, gender, educational level and amount of water taken daily. Dietary exposure due to use of drinking water in hot or cold beverages and food items such as soups was not determined.

2.4. Exposure and Risk Assessment

In order to estimate the daily exposure of an individual, USEPA [25] suggests the lifetime average daily dose (LADD) as the exposure metric. The following equation is a similar representation of daily exposure route modified from USEPA [24] and Chrostowski [7] and adopted by Kavcar et al., [14]:

$$CDI = C \times DI / BW \tag{1}$$

Where CDI is the chronic daily intake (mg/kg/d), C is the drinking water contaminant concentration (mg/l), DI is the average daily intake rate of drinking water (l/d), and BW is the body weight in (kg).

The hazard quotient, (HQ) is calculated using the following equation [14,24]:

$$HQ = CDI / RfD \tag{2}$$

Where R*f* D is the reference dose (mg/kg/d). R*f* D values employed in this study were obtained from the USEPA (IRIS, 2010).

Health Risk assessment of the toxicants was interpreted based on the values of HQ and THI. Values less than (HQ or THI < 1) means no risk and the greater the values above one, the greater is the risk level of the toxicants manifesting long term health hazard effects increasing.

2.5. Hazardous Index (HI)

To estimate the risk to human health through more than one HM, the hazard index (HI) has been developed (US EPA, 1989). The hazard index is the sum of the hazard quotients for all HMs, which was calculated by the Eqn. [13].

$$THI = \Sigma HQ = HQ_{Fe} + HQ_{Mn} + HQ_{Cu} + HQ_{Pb} + HQ_{Co} + HQ_{Ni} + HQ_{Cd} + HQ_{Zn}$$

It assumes that the magnitude of the adverse effect will be proportional to the sum of multiple metal exposures. It also assumes similar working mechanisms that linearly affect the target organ.

3. Study Site

The study sites are Dadinkowa dam and the boreholes in Kwadon town which are in Yamaltu Deba Local Government Area in Gombe Central Senatorial District. River Dadinkowa is found in the eastern part of the state in Yamaltu/ Deba Local Government area of Gombe State. It is a tributary of river of River Gongola, the major river that traverses Gombe state in the north and east through Dukku at Gombe Abba, Nafada and all the eastern LGAs to join River Benue at Numan. It is the sixth longest river in Nigeria, being about 530km, much of which is in Gombe state. Soils in this area are shallow to deep loamy, sandy clay, loam and vertisols with cracking clays that have weathered from shales.

Dadinkowa dam has an irrigation capacity of 44000ha of fertile land for the production of maize, rice and groundnuts twice a year; and vegetables almost year round. Its hydroelectric power generation is expected to be 130GWH. It has the capacity to produce an estimated 20000 tonnes of fresh fish from its artificial lake when fully harnessed. It is the major source of water supply to Gombe town and villages downstream.

3.1. Elemental Analysis of Samples

Determination of Fe, Mn, Cu, Pb, Co, Ni and Zn were made directly on each final solution using Buck Scientific Atomic Absorption spectroscopy (AAS).

3.2. Calibration Solution

Standard solutions of each sample Fe, Mn, Cu, Pb, Co, Cd, Ni and Zn were prepared according to the manufacturer procedure for atomic absorption spectroscopy to be used.

Table 1. Summary of Health Risk Assessment for some metals in water from Dadinkowa Dam through ingestion Pathway

Metal	RfD	CDI_{Adult}	CDI_{child}	HQ_{Adult}	HQ_{Child}
Fe	0.007	0.16	0.14	1.27	1.11
Mn	0.046	0.05	0.07	1.07	1.52
Cu	0.01	0.08	0.07	0.01	0.01
Pb	0.02	0.02	0.02	0.36	0.36
Cd	0.10	0.04	0.04	0.4	0.4
Ni	0.02	0.05	0.04	2.5	2.00
Co	0.0003	0.04	0.03	133.33	100
Zn	0.3	0.07	0.07	0.20	0.23
			THI	139.14	105.63

4. Discussion

The CDI of iron in Dadinkowa dam water for adults and children determined by AAS is 0.16 and 0.14mg/kg/day. The RfD for iron in water is 0.126mg/kg/day, the results for AAS thus are greater than the RfD.

The calculated CDI for iron in water from Gombe Abba River as determined by AAS for adults and children is 0.06mg/kg/day and 0.09mg/kg/day respectively. The recommended daily intake of iron in water is 0.126mg/kg/day. Thus, iron poses no risk of contamination for those exposed to the water of Gombe Abba.

Nwachukwu et al., [17] reported iron concentration was found to be above the recommended level in domestic water use in all the water samples analysed in water sources in rural regions of South East, Nigeria. They reported CDI values greater than the recommended daily dose of iron in all the sampled sites with values ranging from 0.0286 to 0.0368mg/kg/day in rivers to 0.07-0.092 mg/kg/day in lakes and ponds to 0.013-16.30 mg/kg/day in shallow hand dug wells.

For manganese, the calculated CDI in water from Dadinkowa dam for adults and children determined by AAS is 0.05 and 0.07mg/kg/day. The recommended daily concentration of manganese in water is 0.04mg/kg/day. The results of this study show that the CDI of manganese in water from Dadinkowa dam is greater than the R*f* D.

Manganese has an RfD of 0.046mg/kg/day, the CDI calculated in this study shows 0.012 for adults and 0.018 for children as determined by AAS. The results from this study show that the CDI is below the RfD of manganese, thereby making manganese not hazardous for those exposed to the water of Gombe Abba.

Copper CDI determined by AAS had a value of 0.08mg/kg/day for adults and 0.07mg/kg/day for children while the CDI determined from the concentration of copper determined by complexometric analysis was 0.05mg/kg/day for both adult and child. All the calculated CDI for both adults and children determined by both methods were all greater than the RfD value of copper which is 0.001mg/kg/day. Thus, copper poses a health hazard for both adults and children exposed to the water through ingestion from Dadinkowa Dam.

Copper had a calculated CDI of 0.014mg/kg/day for adults and 0.022mg/kg/day for children as determined by AAS and for complexometric analysis, the CDI for adults is 0.024 mg/kg/day and 0.038mg/kg/day for children as determined by complexometric analysis. The RfD of copper in water is 0.001mg/kg/day. This shows that the results from this study are all above the recommended daily intake, thus making the concentration of copper in water from Gombe Abba of concern. Copper poses a health risk to those exposed to the water from Gombe Abba.

Nwachukwu et al. [17] reported that the concentration of copper is within the set limit and the health risk assessment showed that copper poses no health risk as the CDI values were between 0.00408 mg/kg/day for rivers, 0.01327 mg/kg/day for lakes and ponds and 0.147 mg/kg/day for shallow hand dug wells.

Lead in water from Dadinkowa dam had a calculated CDI of 0.02mg/kg/day for both adults and children and as determined by both AAS. The RfD of lead in water is 0.35mg/kg/day, thus the results from this study show that the calculated CDI for both adults and children pose no hazard or risk to the people that are exposed to the water from Dadinkowa dam through oral ingestion.

Lead had a calculated CDI of 0.00098 and 0.00049 mg/kg/day for adults and children respectively as determined by AAS. The RfD of lead in water is 0.35 mg/kg/day. The results from this study are below the recommended daily intake, thus making lead safe for those exposed to the water from Gombe Abba.

This study corroborates that of Nwachukwu et al. [17] who reported that lead was below any alerting values in waters in rural areas of South East Nigeria. Thus, lead poses no health hazard to those exposed to the wasters through ingestion.

The CDI for cadmium in water from Dadinkowa dam for adults and children is 0.04mg/kg/day as determined by AAS . All the values in this study are below the RfD of cadmium in water which is 0.1mg/kg/day. Thus, cadmium poses no health risk or hazard for those drinking water from Dadinkowa dam.

Cadmium has a CDI of 0.0049 and 0.0077mg/kg/day for adults and children respectively. The RfD of cadmium in water is 0.1 mg/kg/day. This shows that cadmium poses no risk for those exposed to the water from Gombe Abba.

Nwachukwu et al. [17] reported cadmium CDI values of between 0.00002 – 0.0084 mg/kg/day for rivers, 0.00102 – 0.00225 mg/kg/day for lakes/ponds and 0.0194 – 0.02042 mg/kg/day for shallow hand dug wells in different water sources in rural areas in South East Nigeria. All these values fall below the recommended daily dose of cadmium as the present study.

The RfD for nickel in drinking water is 0.02mg/kg/day while the calculated CDI for adults and children is 0.05 and 0.04mg/kg/day in water from Dadinkowa dam. This is greater than the RfD, thus making nickel a source of concern for those drinking the water in Dadinkowa. CDI for nickel in water from Gombe Abba river for adults is 0.0196 mg/kg/day and 0.00308 mg/kg/day for children. The results from this study, therefore, is far below the RfD of nickel, thus nickel poses no health hazard for those exposed to the water from Gombe Abba.

The CDI for cobalt in water from Dadinkowa dam for adults and children was 0.04 and 0.05mg/kg/day. The RfD of cobalt in water is 0.0003mg/kg/day. This makes cobalt hazardous for those exposed to the water from Dadinkowa dam as the CDI far exceeds the recommended daily intake. Cobalt has a CDI of 0.0059 mg/kg/day for adults and 0.0092 mg/kg/day for children. Therefore, the calculated CDI for both adults and children are higher than the RfD, thus making cobalt a risk for those exposed to the water from Gombe Abba river.

Zinc had a CDI of 0.07mg/kg/day for both adults and children in water from Dadinkowa. The results from this study all fall below the zinc RfD of 0.3mg/kg/day, thus making zinc a non-hazardous metal for those exposed to the water of Dadinkowa dam through ingestion. The calculated CDI for adults is 0.0205 mg/kg/day and 0.0315 mg/kg/day for children in water from Gombe Abba River. The results from this study show that zinc poses no risk for those exposed to the water from Gombe Abba river.

4.1. Hazard Quotient

The hazard quotient of iron in water from Dadinkowa dam was 1.27 for adults and 1.11 for children, this is greater than 1. The same applies to manganese, with the giving a HQ of 1.07 for adults and 1.52 for children. Thus, the HQ is greater than unity which poses a risk.

For copper, the calculated HQ for both adults and children is 0.01, which is far less than 1, which makes copper a no-risk metal in water from Dadinkowa dam.

Lead also indicated no risk for both adults and children in water from Dadinkowa dam as the HQ calculated was 0.36 which is lower than 1.

Cadmium also poses no health risk in water from Dadinkowa dam as the HQ was far below unity, as the HQ for both adults and children determined was 0.4.

Nickel in water from Dadinkowa dam had a HQ of 2.5 for adults and 2.00 for children. This poses a great risk or hazard since it is greater than unity which shows that the chronic daily intake is far greater than the RfD of nickel in water which is 0.02.The HQ for adults is equal to the RfD of nickel while that of children is a bit lower. Even though it is not close to unity, but it calls for more monitoring of the water for future nickel contamination.

Cobalt had a HQ for adults and children of 133.33 and 100 respectively. Thus, from the results of this study, cobalt poses a high risk of contamination for both adults and children exposed to the water of Dadinkowa dam.

Zinc had a HQ of 0.20 and 0.23 for adults and children in water from Dadinkowa dam. The results from this study indicate that zinc, which has a R_fD of 0.3mg/kg/day poses no risk or hazard for those exposed to the water of Dadinkowa dam as the results from this study are below the daily reference dose.

The hazard quotient calculated for iron in water from Gombe Abba river showed that the values in this study are all below one, thus iron poses no long term health risk for those exposed to the water. The values for adults and children as determined by AAS were 0.476 and 0.739 respectively.

Manganese also poses no long term health risk as the HQ values were 0.261 and 0.402 for adults and children.

Copper had a HQ value of 0.0025 for adults and 0.00411 for children. Both HQ values in this study fall below one, thus making copper concentration in water from Gombe Abba not at an alerting point.

The HQ values of lead in water from Gombe Abba fall below the unity level in this study, thus lead poses no long term delirious health effect on those exposed to the water as the values obtained by AAS for adults and children were 0.0176 and 0.00879 respectively.

Cadmium also poses no long term health risk as all the values of HQ in this study fall below one as the HQ values obtained were 0.049 for adults and 0.077 for children.

Nickel also poses no long term health effect as all the HQ values in this study are below unity as shown in Table 2.

Table 2. Summary of Health Risk Assessment for some metals in water samples from Gombe Abba River through ingestion pathway

Metal	RfD	CDI_{Adult}	CDI_{child}	HQ_{Adult}	HQ_{Child}
Fe	0.007	0.060	0.0931	0.476	0.739
Mn	0.046	0.012	0.0185	0.261	0.402
Cu	0.01	0.014	0.0223	0.0025	0.004
Pb	0.01	0.000984	0.000492	0.018	0.009
Cd	0.10	0.00492	0.00769	0.492	0.077
Ni	0.02	0.00196	0.00308	0.098	0.154
Co	0.0003	0.00590	0.00923	19.67	30.77
Zn	0.3	0.0205	0.0315	0.068	0.105
			THI	21.09	32.26

The HQ values in this study shows a high HQ value for cobalt, all greater than one as the values for adults are 19.67 and for children, the HQ value is 30.77. These values show that children are more at risk of a long term health threat than an adult as the child HQ are almost twice that of an adult.

Zinc poses no long term health threat to those exposed to the water from Gombe Abba river as all the HQ values are below one for both adults and children.

5. Conclusion

Health risk assessment for all the sites indicated that there is no particularly dangerous single heavy metal, but their cumulative effect, indicated by the total hazard index (THI), calls for concern. Water samples from Dadinkowa dam have the concentration of iron, manganese, nickel and cobalt all above unity. This calls for concern for both adults and children exposed to the water through ingestion. Water samples from Gombe Abba River are contaminated by only cobalt but it also calls for more monitoring of this site.

6. Recommendation

From the results of this research, the following recommendations are made:

- Research by biomedical experts should be conducted to reveal the exact adverse effects that heavy metal contamination of soil and water might induce in humans, particularly among individuals in vulnerable populations such as children
- The effects of heavy metals in plants and crops grown in those areas can be conducted to determine the impact on irrigated farmlands.

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