Exploring the Toxicity Potentials of Heavy Metals in Major Road Networks of Dass, Bauchi State, Nigeria

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Abstract*: The concentrations of some selected heavy metals in roadside soil samples collected from the major road networks of Dass, Bauchi State, Nigeria were determined using Atomic Absorption Spectrophotometry. The levels of chromium, cadmium, nickel, lead, copper, manganese, iron and zinc investigated ranged from 0.00 - 0.50, 0.33 – 0.67, 2.50 – 11.67, 0.33 – 3.67, 14.83 – 38.17, 5.00 – 53.33, 108.33 – 531.67 and 57.83 – 79.83 mg/kg respectively. Soil samples from Dass – Zwal road network contain the highest concentrations of chromium (0.50 mg/kg), nickel (11.67 mg/kg), copper (38.17 mg/kg) and iron (531.67 mg/kg) respectively. Soil samples from Dass - Bauchi road contain the highest levels of cadmium (0.67 mg/kg) and zinc (79.83 mg/kg) respectively. Soil samples from Dass – Mbak road network contain the highest concentration of lead (3.67 mg/kg), while samples from Dass - Bununu road network contain the highest concentration of manganese (53.33 mg/kg). The variations in the concentrations of nickel, copper, manganese and iron in all the road networks were found to be statistically different as revealed by Least Significant Difference test ($p < 0.05$), whereas the variations in the levels of chromium, cadmium, lead and zinc in all the road networks were found to be statistically the same ($p \geq 0.05$) as shown by One-Way Analysis of Variance. The toxicity potential values were all found to be less than 1.00. Based on the toxicity potential values, the concentrations of the selected heavy metals determined in all the road networks and comparison of the observed values of the heavy metals with permissible limits specified by World Health Organization, this shows that the soil samples from the different road networks have not reached maximum pollution mark and hence, does not currently pose any health threat to the inhabitants of Dass, Bauchi State, Nigeria.

***Keywords:* Atomic Absorption Spectrophoto-metry, heavy metals, analysis of variance, least significant difference, toxicity potentials and permissible limits.**

I. INTRODUCTION

The most common environmental pollutants in the world are heavy metals [1]. Heavy metals can accumulate in soils to toxic levels as a result of long term application of untreated waste waters and fertilizers. Soil irrigated with waste water accumulates heavy metals in surface soils and when the capacity to retain such heavy metals is reduced due to repeated application of waste water, heavy metals leach into ground water or soil solution available for plants uptake [1]. The presence of heavy metals at trace level and essential elements at elevated concentration can cause toxic effects if exposed to human population [2]. Children are generally considered to be the highest risk group since they have higher adsorption rate of heavy metals due to their active digestion and sensitivity of haemoglobin to heavy metals. This can therefore greatly increase ingestion of metal laden soil particles through hand-to-mouth activities. Adults can also be exposed to threat since inhalation is an easier pathway for toxic metals to enter their body. Heavy metals released from vehicular emission can accumulate in surface soils and their deposition over time can lead to abnormal enrichment, thereby causing metal contamination of the surface soils [2]. The knowledge of heavy metal accumulation in soils, the origin of these metals and their possible interactions with soil properties are a priority in many environmental monitoring [3]. The accumulation of heavy metals in agricultural soils is of increasing concern due to food safety issues and potential health risks as well as its detrimental effects on soil ecosystems [3].

Food chain contamination by heavy metals has become an issue of concern in recent years due to their potential accumulation in bio-systems through contaminated water, soil and air [4]. Metal poisoning arises from heavy metals that have toxic properties leading to adverse effects on human and ecosystem health [5]. Chronic exposure to heavy metals can accumulate in the food chain which leads to an increased stock in biota thereby magnifying the human dose. Heavy metals are non-biodegradable and once they enter into an environment, they will stay there for a long time [5]. The chronic problems associated with long term heavy metals exposure include serious haematological and brain damage, anaemia and kidney malfunctioning [6]. Heavy metals such as lead and cadmium are lethal even in very small doses. Lead has a negative influence on somatic development, decreases the visual acuity and auditory thresholds. Acute exposure to lead can cause brain damage, neurological symptoms and could lead to death [7]. Cadmium exposure can cause renal dysfunction, calcium metabolism disorders and also increased incidence of some forms of cancer possibly due to the inhibition by cadmium of DNA mismatch remediation [8].

Soil is the uppermost layer of the earth's crust. It is a mixture of sand and organic matter/material used to support plant growth and can be described in numerous ways by its appearance, position in the landscape, touch or by its physical, as well as chemical properties [9]. Environmental pollution is the unfavourable change of the environment due to wastes from anthropogenic activities, variations in the levels of radiation, physicochemical characteristics and abundance of organisms in a manner that is harmful [10]. High concentrations usually occur in soils below or near landfills and in agricultural lands that have been irrigated with contaminated water [11]. Long term and short term contamination of soils also have effects on microbial and enzyme activities of the soil [12]. The toxicity and mobility of heavy metals in soils depend not only on the total concentration, but also on their specific chemical form, bonding state, metal properties, environmental factors, soil properties and organic matter content [13]. This paper is aimed at exploring the toxicity potentials of heavy metals in major road networks of Dass, Bauchi State, Nigeria.

II. MATERIALS AND METHODS

Materials

Buck Scientific Atomic Absorption Spectrophotometer Model VGP 210 was used in this study. The solutions that were utilised in the research work were chemicals of analytical reagent grade purity. Distilled water was also used throughout the study. All the plastic and glass wares used were thoroughly washed with detergent solution, then with 20.00 % (v/v) trioxonitrate (V) acid, rinsed with tap water, distilled water and lastly with the solution that was used therein. The apparatus were then allowed to dry [14].

Methods

Sampling of Soil Samples and Treatment

Soil samples were collected on April 30, 2019 in polyethylene bags. The soil samples were collected from ten (10) different spots along five major road networks making a total of fifty (50) soil samples. The soil samples were sampled five meter (5.00 m) away from the road shoulders of the road networks and over a depth of 0 - 15 cm. The samples from each road network were homogenized separately in order to form a composite sample and air-dried. All clods and clumps were removed. A total of five (5) composite soil samples were collected from the following road networks: Dass-Bununu road network (DBRN), Dass-Mbak road network (DMRN), Dass-Zwal road network (DZRN), Dass-Bauchi road (DBR) and Dass-Lukshi road network (DLRN) respectively. The composite soil samples were ground using a wooden pestle and mortar. The crushed samples were sieved using a 2 mm sieve in order to eliminate coarse particles (pebbles) prior to analysis. The samples were stored in clean polyethylene containers and labelled appropriately.

Digestion of Soil Samples

The sieved soil samples from each road network were acid digested separately using modified method adopted by Odoemelam (2004) [15]. The method involves digesting 1.00 g of the sieved aliquot soil sample (in triplicate) with a di-acid mixture of 30.00 cm^3 of trioxonitrate (V) acid and tetraoxochlorate (VII) acid solution (HNO_3-$HClO_4$) in a volume ratio of 5:1. This was gently heated in a 250 cm^3 conical flask using a hot plate in a hood until a clear solution was obtained. After complete digestion and cooling, filtration was carried out using Whatman Filter Paper Number 1 into a 50 cm^3 volumetric flask. 5.00 cm^3 of 0.50 % (v/v) trioxonitrate (V) acid was added to the residue and filtered again into the same 50 cm^3 volumetric flask and water added to capacity. Digests were kept in pre-cleaned screw-capped polyethylene sample bottles. The same procedure was used for the other treated soil samples. The sample solutions (digests) were then labelled accurately for further determinations of the heavy metals of interest.

Determination of Heavy Metals

The sample solutions of the analytes prepared above were analyzed for cadmium, chromium, copper, iron, lead, manganese, nickel and zinc at their respective wavelengths using Buck Scientific Atomic Absorption Spectrophoto-meter Model VGP 210. Serial dilutions were carried-out for all the determinations of the levels of manganese and iron due to their high concentrations.

Evaluation of Toxicity Potentials

Toxicity potentials of heavy metals of interest were evaluated. Toxicity potential (T) is given by:

$T = \frac{c_x}{c_m}$, where

c_x = concentration of pollutant and

c_m = threshold limit or permissible limit based on standard [16]

Description of the Study Area

Dass is located on the basement complex rocks of North Central Highlands between latitude 9^0 45" and 10^0 15" North and longitude 9^0 15" and 9^0 45" East. The town is characterized by two distinct climatic seasons: dry and wet seasons. It is located within the Guinea Savannah type of climate with 6-7 months of rainfall, starting from April and 5-6 months of dry season from November to March every year respectively. The temperature in the area is relatively high with a mean annual temperature of 30 ^{0}C. There are different types of soil and soil profile in Dass because of the fact that the area is occupied by ridges and hills. Soils like laterites are typical example of soil found in the area. The geology of the area shows that the area is a basement complex with shallow water table at an average depth of 7.41 m. The following minerals are found in the area: tin, quartz, feldspar, zinc, iron, manganese and kaolin [17].

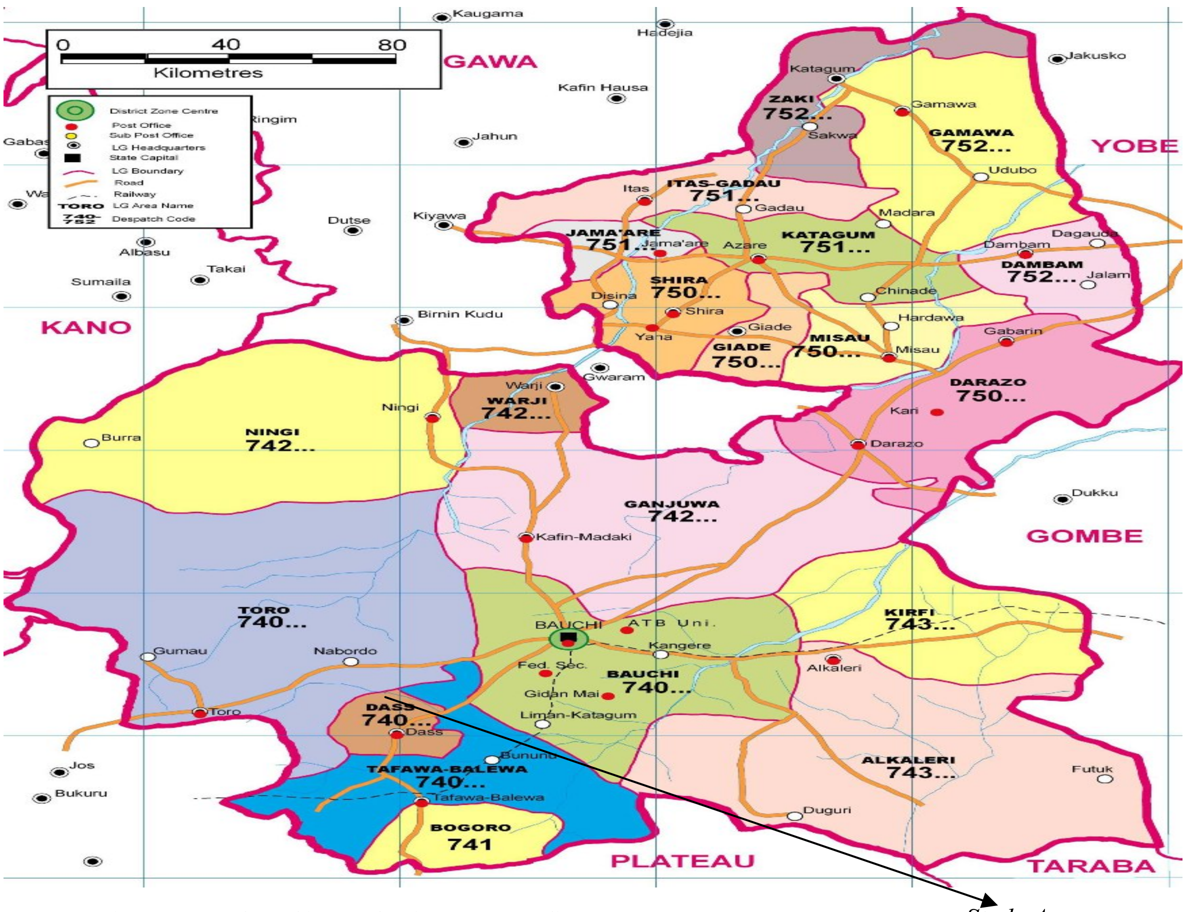

Figure 1: Map of Bauchi State Showing Dass (Sampling Town)

Study Area

III. RESULTS AND DISCUSSION

Results

The levels of cadmium, chromium, copper, iron, lead, manganese, nickel and zinc (mg/kg) in the roadside soil samples from five major road networks of Dass, Bauchi State, Nigeria as well as the variations between the concentrations of the metals in the road networks studied are depicted in Table 1.

Table 1: Concentrations of Heavy Metals (mg/kg) in the Major Road Networks of Dass, Bauchi State, Nigeria

SAMPLE SITES					
Metals	DBRN	DZRN	DMRN	DLRN	DBR
Cd	0.33b ± 0.17	0.33b ± 0.17	0.50b ± 0.29	0.33b ± 0.17	0.67b ± 0.44
Cr	ND	0.50a ± 0.00	ND	ND	ND
Cu	33.00e ± 5.21	38.17a ± 5.85	36.83d ± 3.23	18.83b ± 3.09	14.83c ± 6.57
Fe	455.00d ± 34.08	531.67a ± 27.47	405.00e ± 53.06	108.33c ± 71.64	331.67b ± 33.25
Pb	0.34c ± 0.33	2.17c ± 0.44	3.67c ± 0.44	2.17c ± 1.43	1.83c ± 0.34
Mn	53.33a ± 13.66	50.00e ± 2.89	15.00c ± 2.89	5.00d ± 2.89	20.00b ± 7.65
Ni	8.00b ± 0.29	11.67a ± 0.29	4.50d ± 0.29	2.50e ± 0.87	4.67c ± 0.44
Zn	57.83d ± 6.83	78.50d ± 6.36	67.00d ± 9.79	74.17d ± 6.98	79.83d ± 3.59

Values are mean ± standard error of the mean (n = 3). Values on the same row with the same superscript letters are statistically the same ($p \geq 0.05$), while those with different superscript letters on the same row are statistically different as revealed by one-way ANOVA and Least Significant Difference test($p < 0.05$). DBRN = Dass – Bununu road network, DZRN = Dass – Zwal road network, DMRN = Dass – Mbak road network, DLRN = Dass – Lukshi road network, DBR = Dass – Bauchi road, ND = Not detected.

Discussion

The levels of cadmium determined in the road networks of Dass ranged from 0.33 mg/kg (Dass – Bununu road network, Dass – Lukshi road network and Dass – Zwal road network) to 0.67 mg/kg (Dass – Bauchi road) with 0.50 mg/kg (Dass – Mbak road network) falling in between the concentration ranges of cadmium. The experimental values (0.33 to 0.67 mg/kg) are comparatively lower than 3.67 to 4.00 mg/kg determined in roadside soil samples of Bauchi [18]. The experimental values are also lower than the tolerable limit of 3.00 mg/kg [19]. The toxicity potentials of cadmium in the major road networks ranged from 0.1100 (Dass – Bununu road network, Dass – Lukshi road network and Dass – Zwal road network) to 0.2233 (Dass – Bauchi road) with 0.1667 (Dass – Mbak road network) falling in between the extreme toxicity potential values. Based on the tolerable limit and the toxicity potential values in all the road networks, the inhabitants of Dass are therefore free from toxic/harmful effects of cadmium. This is because only toxicity potentials that are greater than one (1.00) can manifest their toxic effects. There was no statistical significant difference in the levels of cadmium in all the road networks ($p \geq 0.05$) as depicted in Table 1. Cadmium is responsible for the outbreak of osteomalacia, a disease that is due to food poisoning. It can also cause temporary gastrointestinal haemorrhage [20]. Cadmium is a toxic metal and it is said to be carcinogenic [21].

Chromium was not detected in all the road networks of Dass except in Dass - Zwal road network where the observed value was 0.50 mg/kg (Table 1). The observed chromium levels are lower that reported literature value of 16.73 mg/kg found in vegetable soil of Yargalma [22]. The observed values are similarly lower than reported literature range of values (0.234 to 1.577 mg/kg) found in agricultural soils of Tehraan [23]. The levels of chromium determined in the roadside soil samples of Dass are generally low when compared with the permissible limit of 50.00 mg of chromium per kg of soil set by WHO (2001) as reported by Lente *et al.,* 2014 [24]. An observed toxicity potential value of 0.0100 was found in Dass – Zwal road network as against all other roadnetworks where chromium was not detected. This therefore implies that the inhabitants of Dass are safe from the toxic effect of the element. The observed values of chromium are statistically the same ($p \geq 0.05$) as shown in Table 1. Chromium is an essential trace, mineral element that improves the sensitivity of insulin and enhances the metabolism of lipids, carbohydrates and proteins [25].

The levels of copper assayed in the road networks of Dass spread from 14.83 mg/kg (Dass – Bauchi road) to 38.17 mg/kg (Dass – Zwal raod network). The levels (mg/kg) of 18.83 (Dass – Lukshi road network), 33.00 (Dass – Bununu road network) and 36.83 (Dass – Mbak road network) fell in between the extreme observed values. The highest observed value (38.17 mg/kg) was found at Dass – Zwal road network. This may be due to burnt vehicles along the road since copper is commonly used in electrical wiring as well as because of deliberate disposal of different domestic wastes and organic substances containing copper. Another reason is based on the soil type and source of pollution [26]. The observed concentration ranges of copper (14.83 to 38.17 mg/kg) are relatively higher than 12.33 to 29.67 mg/kg found in Bauchi roadside soil samples [18]. The observed values are lower than 100.00 mg/kg permissible limit of copper in soil [19]. The toxicity potentials of copper were found to be 0.1483 (Dass – Bauchi road), 0.1883 (Dass – Lukshi road network), 0.3300 (Dass – Bununu road network), 0.3683 (Dass – Mbak road network), and 0.3817 (Dass - Zwal road network) respectively. The observed toxicity potentials of copper are not even up to 1.00, it therefore shows that the residents of Dass are free from the toxic effect of copper. Table 1 show that statistical significant difference exists in the levels of copper in all the road networks ($p < 0.05$). Copper aids in the synthesis of haemoglobin as well as in the normal functioning of the central nervous system and the development of bone and elastics tissues [27].

The concentrations of iron determined in the roadside soil samples of Dass ranged from 108.33 (Dass – Lukshi road network) to 531.67 mg/kg (Dass – Zwal road network). The levels of 331.67 mg/kg (Dass Bauchi road), 405.00 mg/kg (Dass – Mbak road network) and 455.00 mg/kg (Dass – Bununu road network) fell in between the lowest and highest values of iron determined. The observed values are much lower than 7,740.00 to 14, 106.67 mg/kg found in Bauchi road networks [14]. The concentration ranges of iron determined are much lower than 50,000.00 mg/kg permissible limit [19]. The toxicity potentials of iron ranged from 0.0022 (Dass – Lukshi road network) to 0.0106 (Dass – Zwal road network) with 0.0066 (Dass – Bauchi road), 0.0081 (Dass – Mbak road network) and 0.0091 (Dass – Bununu road network) falling in between the extreme toxicity potential values. Based on the observed values, permissible limit and the toxicity potentials, the inhabitants of Dass are therefore safe from the health threat of the element. Statistical significant differences ($p < 0.05$) were found to exist in the levels of iron in all the road networks of Dass (Table 1). Chronic toxicity of iron may lead to hostility, gut damage, headache, metabolic acidosis, liver damage, anorexia, arthritis, increased oxidative stress, heart disease and cancer [28].

Table 1 indicates that the concentration of lead spread from 0.34 mg/kg (Dass – Bununu road network) to 3.67 mg/kg (Dass - Mbak road network) with 1.83 mg/kg (Dass – Bauchi road) and 2.17 mg/kg (Dass – Zwal road network and Dass – Lukshi road network) falling in between the extreme levels. The experimental values of lead are comparatively much lower than 36.60 to 525.00 μg/g (36.60 to 525.00 mg/kg) found in Garki Area Council of Abuja soil [29]. The observed values of lead in Dass road networks are far less than the threshold limit of 100.00 mg/kg [19]. The toxicity potentials of lead in the present study are 0.0034 (Dass – Bununu road network), 0.0183 (Dass – Bauchi road), 0.0217 (Dass –

Lukshi road network and Dass – Zwal road network) and 0.0367 (Dass – Mbak road network) respectively. It is therefore evident that the levels of lead in all the road networks of Dass are within the permissible limits and hence does not pose any health threat to the inhabitants. The levels of lead determined in all the road networks were founds to be statistically the same ($p \geq 0.05$) as illustrated in Table 1. Too much lead can cause coma, seizure, encephalopathy (irreversible brain damage) and death if not taken care of instantly [30].

The levels of manganese (mg/kg) determined ranged from 5.00 (Dass – Lukshi road network) to 53.33 (Dass – Bununu road network). The concentrations (mg/kg) of 15.00 (Dass – Mbak road network), 20.00 (Dass – Bauchi road) and 50.00 (Dass – Zwal road network) fell in between the lowest and highest manganese values obtained. The observed values in the present study are generally much lower than reported literature values of 270.00 to 558.00 µg/g (270.00 to 558.00 mg/kg) determined in Garki Area Council of Abuja soil [29]. The levels of observed manganese revealed that it is below the acceptable limit of 2,000.00 mg/kg [19]. The corresponding toxicity potentials of manganese were found to be 0.0025 (Dass – Lukshi road network), 0.0075 (Dass – Mbak road network), 0.0100 (Dass - Bauchi road), 0.0250 (Dass – Zwal road network) and 0.0267 (Dass – Bununu road network) respectively. This therefore shows that the observed manganese values will not pose any threat health-wise to the residents of Dass. Table 1 revealed that significant differences exist in the levels of manganese ($p < 0.05$) in the road networks investigated. Manganese is an essential trace element needed for both plants and animals growth [31]. Its deficiency produces severe skeletal and reproductive abnormalities in mammals. High levels of the element can cause hazardous effects on brains and lungs of humans.

The concentrations of nickel determined in the road networks of Dass spread from 2.50 mg/kg (Dass – Lukshi road network) to 11.67 mg/kg (Dass – Zwal road network). The levels of 4.50 mg/kg (Dass – Mbak road network), 4.67 mg/kg (Dass – Bauchi road) and 8.00 mg/kg (Dass – Bununu road network) fell in between the extreme experimental nickel values. The experimental values are much lower than 16.16 to 24.60 µg/g (16.16 to 24.60 mg/kg) found in Garki Area Council of Abuja soil [29]. The levels of nickel obtained in the roadside soil samples of Dass are comparatively lower than the permissible limit of 50.00 mg of nickel per kg of soil sample [19]. The toxicity potentials of nickel spread from 0.0500 (Dass – Lukshi road network) to 0.2334 (Dass – Zwal road network). The toxicity potentials of 0.0900 (Dass – Mbak road network), 0.0934 (Dass – Bauchi road) and 0.1600 (Dass – Bununu road network) fell in between the spread values. This therefore shows that the observed values of nickel in the road networks of Dass will not pose health threat to the inhabitants. Statistical significant differences exist ($p < 0.05$) in the observed levels of nickel as shown in Table 1. Nickel is important to many living organisms; though high levels can be harmful [32]. Carbonyl nickel is acutely toxic and is responsible for cancer of the respiratory tract. Elemental nickel is a potent toxicant [33].

The levels of zinc determined in the study area ranged from 57.83 mg/kg (Dass – Bununu road network) to 79.83 mg/kg (Dass – Bauchi road) with 67.00 mg/kg (Dass – Mbak road network), 74.17 mg/kg (Dass – Lukshi road network) and 78.50 mg/kg (Dass – Zwal road network) falling in between the spread observed values. The observed values are comparatively lower than 96.67 to 191.33 mg/kg found in Bauchi road networks [18]. The levels of zinc determined are lower than 300.00 mg/kg threshold limit of zinc in soil [19]. The toxicity potential values of zinc in the analytes are 0.1928 (Dass – Bununu road network), 0.2233 (Dass – Mbak road network), 0.2472 (Dass – Lukshi road network), 0.2617 (Dass – Zwal road network) and 0.2661 (Dass – Bauchi road) respectively. Based on these values, the inhabitants of Dass are therefore free from the harmful effects of zinc. Table 1 shows that the determined values are statistically the same ($p \geq 0.05$). Zinc is regarded as relatively non-toxic since the oral lethal dose is approximately 3.00 g/kg body mass [34]. Zinc is an essential micronutrient that is relevant in biological processes, particularly in the proper functioning of proteins in all living organisms [35].

IV. DATA ANALYSES

All the experimental values were subjected to standard error of the mean (a measure of precision) and One-Way Analysis of Variance. Experimental values that were statistically different ($p < 0.05$) were further subjected to the Least Significant Difference test (LSD) with a view to determine where the significant difference lies.

V. CONCLUSION

In this study, the levels of some selected heavy metals in the major road networks of Dass, Bauchi State, Nigeria were determined. The observed levels of the heavy metals were below their corresponding threshold limits and the toxicity potentials were also found to be less than one (1.00). Based on the observed values of the heavy metals and their corresponding toxicity potentials, it can therefore be concluded that the inhabitants of Dass are presently safe from the toxic effects of the metals studied.

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