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Seasonal variation in heavy metal distribution in the sediments of selected dams in Nasarawa State, Nigeria

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ABSTRACT

The study was carried out to ascertain seasonal variation in heavy metal distribution in sediments from Dams located in Nasarawa State, Nigeria. Sediment samples were collected twice each at two different seasons for two years from May to September, 2014 and November-December, 2014 to March, 2015 for wet and dry seasons, respectively. Similarly, sediment samples were collected from May to September, 2015 and November-December, 2015 to March, 2016 for wet and dry seasons, respectively. The samples were then assessed for heavy metal properties, using atomic absorption spectrophotography (AAS). Analysis of variance (ANOVA) was then applied. The mean results of the heavy metal levels showed high values in dry seasons and low values in wet seasons in the two years of the study. Herein, the results of ANOVA revealed significant difference in the heavy metal concentrations between the seasons, dams and years. Our study also indicated that for heavy metals, the levels determined in sediments were within the WHO acceptable standards, except for Pb and Mn. These exceeded the WHO acceptable standards for drinking water. Based on these results, the dam waters are, therefore, polluted and unsuitable for human consumption, except after treatment.

Keywords**:** Heavy metal, sediments, Dams, Seasonal variations

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1. INTRODUCTION

Monitoring the concentration of heavy metals in sediment is important since knowledge of trace metals level in surface waters gives vital information regarding their sources, distribution and degree of pollution. This is for the fact that sedimentation has been regarded as one of the most important fluxes in aquatic system (Asaolu *et al*., 1997). Sediments are significant in the assessment of the quality of aquatic system, because natural fresh water from lakes and dams have been the centre of important cultural development since the earliest days of civilization. Consequently increased population, industrialization densities and agricultural activities, have posed a pollution threat in acute form on areas that depend mainly on natural and man-made lakes and dams as major source of potable water (Kakulu & Osibanjo, 2007). The enrichment of metals in sediment is influenced by allocthonous influence which is made up of natural and civilization effects and autochthonous influence comprising of precipitation, sorption, enrichment of organism and organometallic completing during sedimentation as well as the post depositional effects of digenesis (Adefemi *et al*., 2007). While some of these minerals (Fe, Ca, Cu, Na etc.) are enzymatic biochemical activities in the body, some other like Cu, Pb, As and Hg are extremely toxic even at low concentration (Kakulu & Osibanjo, 2007; Faghbemi & Oshodi, 1991). It is relatively important to monitor the distribution of most important heavy metals in our dams. Since monitoring practice are more useful to prevent diseases, hazards as well as it checks the resources from going further polluted.

2. MATERIALS AND METHODS

Study Area

Nasarawa State is one of the 36 States in the Federal Republic of Nigeria. It is located in the North Central Geopolitical zone of Nigeria otherwise known as the middle belt region. The State is made up of 13 local government areas. Doma dam is found in Doma local government area. The local government is located at latitude 08°66' – 08°72' and longitude 07°64' – 07°69'. Both Ibuwan and Imon are found in Obi local government area. Ibuwan is located at latitude 08°34' – 08°38' and longitude 07°41' – 07°44' while Imon Dam is located at latitude 08°39' – 08°43' and longitude 07°45' – 07^0 48'. Awe Dam is found in Awe local government area at latitude 08°45' – 08°49' and longitude 07°50' – 07°54'. These local government areas share boundaries with Benue State of Nigeria. The physical features of these areas are mountainous most of which are rocky and of the tropical zone because of their locations. Its climate is quite pleasant with a maximum of 50F. Rainfall varies from 131.73 cm^3 in some places to 145 cm^3 in others (Obaje *et al.*, 2005).

The climate is characterized by two distinct seasons, dry and wet. The dry season spans from October to March while the rainy season is from April to September. The months of December, January and February are cold due to harmattan wind blowing across the local government areas from the North-East of Nigeria. Mineral resources such as granite rock and mica are found in some areas. The sediments are generally comprised of sand stones and forest soils which are rich in humus and very good for crop production. More than 80 % of the rural dwellers in these areas depend on these dams as source of potable water.

Sample Collection

Sediment samples were collected twice each at two different seasons for two years from May to September 2014; and November – December, (2014) to March 2015 for wet and dry seasons, respectively. Similarly, sediment samples were collected from May to September, 2015 and November-December, 2015 to March, 2016. In each of season, samples were collected for the period of five months. Sediments and water samples were taken from the dams in the morning between the hours of 8 –11 am in the first week of every month. A diver was used to collect bed sediments from the dam at locations where water samples were taken in a polythene bag. All samples were taken to a laboratory and kept in deep freezer prior to analysis. The sampling sites for each dam are indicated in Figure 1.

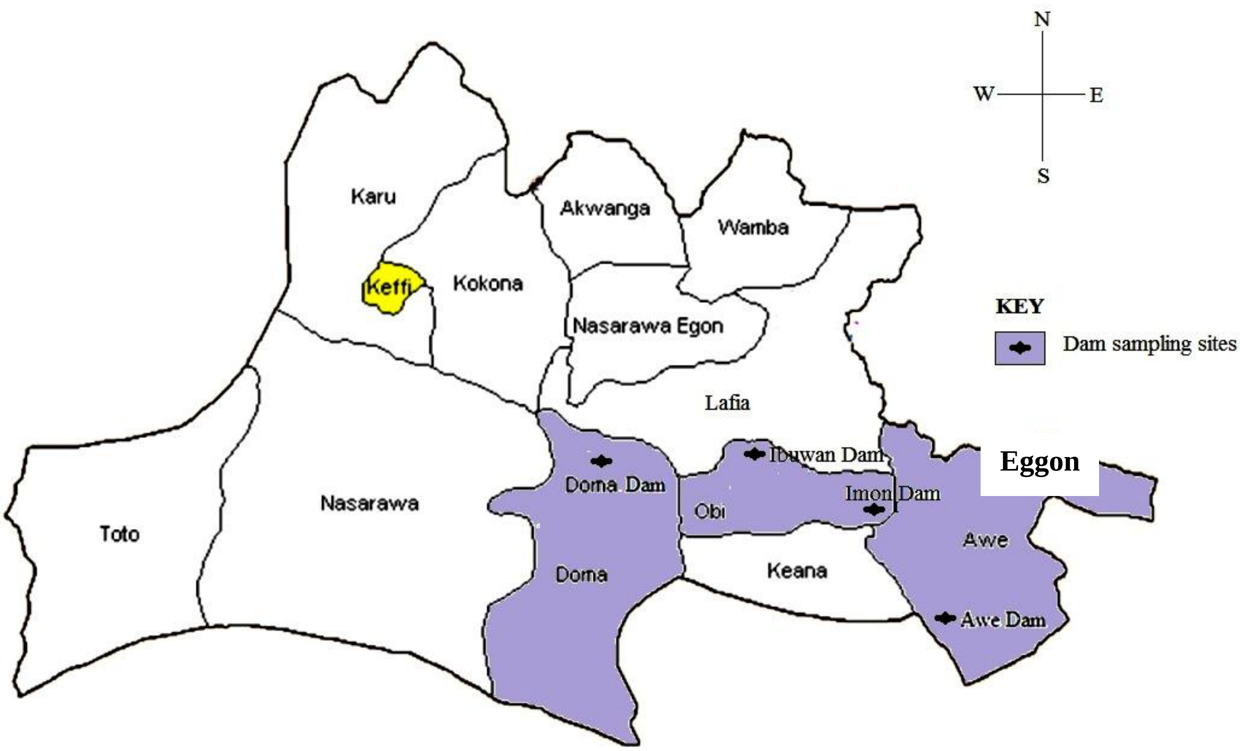

Figure 1. Map of Nasarawa State showing the sampling sites

Sample Preparation

The sediment samples were air-dried and then sieved using 200 mm mesh. 5 g of the sediment samples were weighed into 150 cm^3 conical flask, digested using 150 cm^3 nitric acid, 2 cm^3 perchloric acid and placed on a hot plate for 3 hours (Adeyeye, 1993). On cooling the digest was filtered into 100 cm^3 volumetric flask and make up to mark with distilled water. The digested samples were kept prior to AAS analysis.

Determination of heavy metals

The digested samples were aspirated into a Pye Unicam (Atomic Absorption Spectrophotometer AAS 969 Model, Japan) equipped with mono elemental hallow cathode lamps and digital display read the metal concentration in mg/L from the metal concentrated standard calibration curve. Spectroscopic analyses were done in triplicate for each element and values were recorded as described by Etonihu & Lawal (2013).

Statistical Analysis

The results obtained were subjected to statistical evaluation. Data obtained from the parameters were evaluated using mean, standard deviation and coefficient of variations percent. Analysis of variance (ANOVA) was carried out to examine the levels of heavy metal contamination from each dam and across the seasons. Statistical significance was accepted at a probability level of $P \leq 0.05$.

3. RESULTS AND DISCUSSION

Table 1. Mean Concentration (mg/kg) of Sediments from the four Dams in Nasarawa State during the Wet season (May – September, 2014)

Metal	Doma dam	Ibuwan Dam	Imon Dam	Awe Dam	Mean	SD	CV(%)	WHO 2014
Fe	1.24	1.27	1.24	1.26	1.25	0.01	1.04	3.00
Pb	0.05	0.21	0.04	0.08	0.10	0.07	71.59	0.01
Cd	0.0001	-	0.0001	0.00002	0.00	0.00	82.82	0.003
Cu	0.01	0.08	0.01	0.06	0.04	0.03	77.06	2.00
Zn	0.06	0.10	0.05	0.10	0.08	0.02	29.39	3.00
Ni	-	-	-	0.02	0.01	0.01	173.21	0.05
Mn	0.20	0.72	0.15	0.47	0.39	0.23	59.36	0.10
Cr	-	0.04	-	-	0.01	0.02	173.21	0.05

SD = Standard deviation, CV (%) = Coefficient of variation percent.

Table 2. Mean Concentration (mg/kg) of Sediments from the four Dams in Nasarawa State during the Dry Season (Nov., Dec., 2014– March, 2015)

Metal	Doma dam	Ibuwan dam	Imon dam	Awe dam	Mean	SD	CV (%)	WHO 2004
Fe	0.21	0.20	0.20	0.21	0.21	0.00	2.44	3.0
Pb	0.12	0.01	0.01	0.05	0.05	0.04	94.59	0.01
Cd	-	-	-	-	-	-	-	0.003

Cu	0.003	0.01	0.01	0.03	0.01	0.01	76.11	2.00
Zn	0.002	0.04	0.02	0.06	0.03	0.02	71.14	3.00
Ni	NA	0.0004	0.0003	0.04	0.01	0.02	169.24	0.05
Mn	0.14	0.07	0.17	0.18	0.14	0.04	30.72	0.10
Cr	0.02	0.05	0.02	0.02	0.03	0.01	47.24	0.05

SD = Standard deviation, CV (%) = Coefficient of variation percent.

Table 3. Mean Concentrations (mg/kg) of Sediments (mg/kg) from the four dams in Nasarawa State during the Wet season (May – September, 2015)

Metal	Doma dam	Ibuwan Dam	Imon Dam	Awe Dam	Mean	SD	CV(%)	WHO 2004
Fe	1.65	1.57	1.43	1.53	1.55	0.08	5.13	3.00
Pb	0.06	0.38	0.06	0.10	0.15	0.13	89.19	0.01
Cd	0.0004	0.001	0.001	0.001	0.00	0.00	30.57	0.003
Cu	0.03	0.08	0.002	0.07	0.05	0.03	68.83	2.00
Zn	0.09	0.17	0.005	0.18	0.11	0.07	63.43	3.00
Ni	-	-	-	0.04	0.01	0.02	173.21	0.05
Mn	0.26	1.26	0.26	0.59	0.59	0.41	68.90	0.10
Cr	-	0.07	-	-	0.02	0.03	173.21	0.05

SD = Standard deviation, CV (%) = Coefficient of variation percent.

Table 4. Mean Concentration (mg/kg) of Sediments from the four dams in Nasarawa State during the Dry season (Nov., Dec., 2015 – March, 2016)

Metal	Doma dam	Ibuwan dam	Imon dam	Awe dam	Mean	SD	CV(%)	WHO 2004
Fe	0.32	0.32	0.29	0.38	0.33	0.03	9.98	3.00
Pb	0.14	0.02	0.005	0.11	0.07	0.06	83.62	0.01
Cd	-	-	-	-	-	-	-	0.003
Cu	0.007	0.02	0.02	0.22	0.07	0.09	132.79	2.00

Zn	0.004	0.08	0.04	0.24	0.09	0.09	99.04	3.00
Ni	NA	0.001	0.005	0.03	0.01	0.01	136.31	0.05
Mn	0.29	0.14	0.29	0.37	0.27	0.08	30.52	0.10
Cr	0.05	0.10	0.04	0.06	0.06	0.02	36.44	0.05

SD = Standard deviation, CV (%) = Coefficient of variation percent.

3. 1. Discussion of findings

Concentrations of heavy metals in Sediments

Once heavy metals are released into water bodies, they become associated with particulates and are accumulated at the bottom of the sediments. The concentration of these metals in the sediments is important since knowledge of heavy metal levels in sediments gives vital information regarding their sources, distribution and degree of pollution. This is for the fact that sedimentation has been regarded as one of the most important refluxes in aquatic systems (Asaolu *et al.*, 1997). The heavy metals studied in this work were classified as principal pollutants and toxic for human beings.

Iron (Fe)

The monthly average concentrations of iron in sediment samples obtained from the dams in wet season within the two years of study ranged from 1.24 mg/kg to 1.27 mg/kg (Table 1) and 1.43 to 1.65 mg/kg (Table 3) while for the dry seasons the concentrations of iron ranged from 0.20 to 0.21 mg/kg (Table 2) and 0.29 to 0.38 mg/kg (Table 4). The mean concentration of Fe (1.25 mg/kg and 1.55 mg/kg) wet seasons and Fe (0.12 mg/kg and 0.33 mg/kg dry season are below the maximum acceptable concentration of 3.0 mg/kg as recommended by guidelines and standards for water quality and permissible limit for various uses (WHO, 2004).

High concentration of Fe in wet seasons could be attributed to contamination from weathering of soil through runoff into the various dams. Waziri *et al.* (2015) reported levels of Fe to vary from 4.37 mg/kg in sediments for Tiga dam, Kano State. Abdullahi *et al.*(2015) reported mean concentration of Fe in sediments ranged from 273.00 to 273.40 mg/kg (wet) and 387.37 to 397.52 mg/kg (dry) in Tungan Kawo Dam, Kontagora. Ahmed & Khalid (2015) reported a high mean concentration of Fe in sediments ranging from 4137.00±430.37 to 14222±691.02 mg/kg at the Northern Red Sea Coast.

Adefemi *et al.* (2007) reported high Fe concentration in sediments of major dam in Ekiti State with an average of 6.48 mg/100g and 4.90 mg/100g (2001) and 6.51 mg/100g and 3.62 mg/100g 2002 respectively. Statistical analysis of variance (ANOVA) revealed significant difference ($p \leq 0.05$) in the concentration of Fe examined across the sampling seasons. While analysis of variance between the dams showed that there was no significant difference ($p \leq 0.05$). However, the mean concentration value of Fe in the first year was completely at variance with the second year.

Lead (Pb)

The monthly average concentration of Pb in sediment samples obtained from these dams in wet seasons within the study period ranged from 0.04 to 0.21 mg/kg and 0.06 to 0.38 mg/kg (Tables 1 and 3). While for the dry seasons the average concentration ranged from 0.01 to 0.12 mg/kg and 0.005 to 0.14 mg/kg (Tables 2 and 4). The mean concentrations of Pb (0.10 mg/kg and 0.15 mg/kg) wet seasons and Pb (0.05 mg/kg and 0.07 mg/kg) dry seasons is above the maximum acceptable concentration of 0.01 mg/kg as recommended by WHO (2004) for domestic purposes. High concentration of Pb recorded in wet seasons of the study period could be related to discharge of solid waste into the dams during rains through water runoffs. Ahmed *et al.* (2015) recorded high mean concentration of Pb in sediments at Norther Red Sea Coast varying between16.00±82.82 to 80.33±4.19 μg/g. waziri *et al.* (2015) reported Pb concentration of 0.51±0.02 mg/kg in sediments of Tiga dam, Kano State. Abdullahi *et al.*(2015) reported mean concentration of Pb in sediments ranged from 3.70 to 7.30 mg/kg (wet) and 2.54 to .74 mg/kg (dry) in Tungan Kawo Dam, Kontagora. Adefemi *et al.* (2015) recorded higher mean concentration of Pb in dry seasons of major dams in Ekiti State than wet season ranging from 0.14 mg/100g (2001) to 0.61 mg/100g (2002) and 0.29 mg/100g (2001) to 0.41 mg/100g (2002), respectively. This result is not in agreement with the present study. Statistical analysis of variance (ANOVA) revealed significant difference ($p \leq 0.05$) in the concentration of Pb examined among the sampling seasons and the dams. However the mean concentration value of Pb in the first year was completely at variance with the second year.

Cadmium (Cd)

The average concentrations of Cd in sediment samples obtained from the dams in wet seasons within the study period ranged from 0.000 to 0.0001 mg/kg (2014) and 0.0004 to 0.001 mg/kg (2015) while for the dry seasons the concentrations was not detected at the various dams. The mean concentrations of Cd (0.000) wet seasons and Cd (not detected in dry seasons) is within the maximum acceptable limit of 0.003 mg/kg as recommended by WHO (2004) for drinking water. The level of Cd in wet seasons of these dams could be attributed to rural effluent runoffs into the dams during the raining season.

Ahmed & Khalid (2015) reported the annual mean concentration of Cd in sediments ranged from 1.73±0.36 to 4.40±1.99 mg/g. Adefemi *et al.* (2007) reported that Cd was not at detectable in both seasons for the period of two years in the sediments of major dams in Ekiti State. Abdullahi *et al.*(2015) reported mean concentration of Cd in sediments ranged from 1.38 to 1.43 mg/kg (wet) and 0.99 to 1.15 mg/kg (dry) in Tungan Kawo Dam, Kontagora.

Statistical analysis of variance (ANOVA) revealed significance difference ($p \leq 0.05$) in the concentration of Cd measured among the years and seasons of the dams. Also the analysis of variance measured across the dams revealed no significance difference ($p \leq 0.05$).

Copper (Cu)

The monthly average concentrations of Cu in sediment samples obtained from the dams in wet seasons within the period of study ranged from 0.01 to 0.08 mg/kg (2014) and 0.002 to 0.08 mg/kg (2015) while in the dry seasons, the concentrations of Cu ranged from 0.003 to 0.03 mg/kg and 0.007 to 0.22 mg/kg (Tables 4.61 and 4.63). The mean concentrations of Cu (0.04 mg/kg) 2014 and 0.05 mg/kg (2015) wet seasons and Cu (0.01 mg/kg 2014/2015) and

0.07 mg/kg (2015/2016) dry seasons are below maximum acceptable concentration of 2.0 mg/kg as recommended by guidelines and standard for water quality permissible limit for various uses (WHO, 2004).

Abdullahi *et al*. (2015) reported mean concentration of Cu in sediments ranged from 1.11 to 1.12 mg/kg (wet) and 1.13 to 1.17 mg/kg (dry) in Tungan Kawo Dam, Kontagora. Ahmed & Khalid (2015) reported the concentration of Cu in sediments varied between 8.5±0.37 to 111.3±23.89 µg/g. Adefemi *et al.* (2007) reported that the concentrations of Cu (2001) in both seasons were not detected while concentrations of Cu (2002) in both season was 0.008 mg/100g (wet season) and 0.004 mg/100g (dry season) in sediments of major dams in Ekiti State. Statistical analysis of variance (ANOVA) revealed significant difference ($p \leq 0.05$) in the concentration of Cu measured among the dams and seasons. However, the mean concentration value of Cu in the first year was completely at variance with the second year ($p \leq 0.05$).

Zinc (Zn)

The mean concentrations of Zn in sediment samples obtained from the dams in wet seasons within the study period ranged from 0.05 to 0.10 mg/kg (2014) and 0.005 to 0.18 mg/kg (2015) while for the dry seasons the concentrations of Zn ranged from 0.002 to 0.06 mg/kg (Table 2) and 0.004 to 0.24 mg/kg (Table 4). The concentration of Zn in wet seasons of 2014 and 2015 were 0.08 mg/kg and 0.11 mg/kg respectively while in dry season of 2014 to 2015 and 2015 to 2016 were 0.03 mg/kg, 0.09 mg/kg respectively were below the maximum acceptable concentration by guidelines and standards for water quality and permissible for various uses (WHO, 2004). High concentration of Cu in wet seasons could be attributed to contamination from weathering of soil. Ahmed & Khalid *(*2015) recorded mean Zn concentrations in sediments ranged from 19.23±3.01 to 190.33±13.02 µg/g in Northern Red Sea Coast. Adefemi *et al.* (2015) reported Zn concentration ranging from 2.08 mg/100g (wet season) and 2.49 mg/100g (dry season) in the year 2001 while in 2002, the mean concentration ranged from 2.33 to 1.89 mg/100g in wet and dry season respectively. Abdullahi *et al*.(2015) reported mean concentration of Zn in sediments ranged from 98.59 to 98.90 mg/kg (wet) and 88.40 to 89.24 mg/kg (dry) in Tungan Kawo Dam, Kontagora. Statistical analysis of variance (ANOVA) revealed significant difference ($p \leq 0.05$) in the concentration of Zn examined among the dam, across the dams and the years during the period of study.

Nickel (Ni)

The monthly average concentration of Ni in sediment samples obtained from these dams in wet seasons within the study period was 0.02 mg/kg and 0.04 mg/kg in Awe dam. While in Doma, Ibuwan and Imon dams, Ni was not at detectable range (Table 4.60 and 4.62). In the dry seasons, the average concentrations of Ni were 0.00 to 0.04 mg/kg in 2014/2015 and 0.001 to 0.03 mg/kg in 2015/2016, while it was not detected in Doma dam of the seasons (Table 2 and 4). The mean concentration of Ni (0.01 mg/kg) dry season were below the maximum acceptable concentration of 0.05 mg/kg as recommended by WHO (2004) for domestic purposes. Abdullahi *et al*.(2015) reported mean concentration of Ni in sediments ranged from 2.39 to 2.45 mg/kg (wet) and 2.70 to 2.85 mg/kg (dry) in Tungan Kawo Dam, Kontagora. Analysis of variance (ANOVA) revealed significant difference ($p \leq 0.05$) in the concentration of Ni examined across and among the dams. Also the analysis of variance revealed no significant difference ($p \leq 0.05$) in the concentration of Ni measured across the sampling seasons. However, the mean concentration value of Ni in the first year was completely at variance with the second year.

Manganese (Mn)

The monthly average concentrations of Mn in sediment samples obtained from the dams within wet seasons ranged from 0.15 to 0.72 mg/kg (2014) and 0.26 to 1.26 mg/kg (2015) while for the dry seasons, the average concentration of Mn ranged from 0.07 to 0.18mg/kg (2014/2015) and 0.14 to 0.39 mg/kg (2015/2016). The mean concentrations of Mn ranged from 0.39 mg/kg to 0.59 mg/kg wet seasons and Mn ranged from 0.14 mg/kg to 0.27 mg/kg dry seasons are above the maximum acceptable concentration limit of 0.1 mg/kg in drinking water as recommended by WHO (2004). Adefemi, *et al.* (2007) reported the concentration of Mn to vary form 1.11 to 1.54 mg/100g in 2001 (dry and wet season) while in 2002 the mean concentration varied from 2.06 to 2.24 mg/100g wet and dry season) in sediments of major dams in Ekiti State. Ahmed & Khalid (2015) reported the Mn concentration in sediments ranged from 136.00±10.20 to 323.33±46.35 mg/kg. Abdullahi *et al.*(2015) reported mean concentration of Mn in sediments ranged from 4.25 to 4.40 mg/kg (wet) and 4.01 to 4.70 mg/kg (dry) in Tungan Kawo Dam, Kontagora. Statistical analysis of variance (ANOVA) revealed significant difference ($p \leq 0.05$) in the concentration of Mn measured between and across the dams and sampling seasons. However, the mean concentration value of Mn in the first year is completely at variance with the second year ($p \leq 0.05$).

Chromium (Cr)

The monthly average concentrations of Cr in sediments obtained from the dams in wet seasons within the period of study was not at detectable range with AAS in Doma, Imon and Awe dams respectively while the concentration of Cr in Ibuwan dam was 0.04 mg/kg (2014) and 0.07 mg/kg (2015). In the dry seasons, the average concentrations of Cr ranged from 0.02 to 0.05 mg/kg (2014 to 2015) and 0.04 to 0.10 mg/kg (2015 to 2016). The mean concentration of Cr (0.01 mg/kg and 0.02 mg/kg) wet seasons and Cr (0.03 mg/kg and 0.06 mg/kg) dry seasons were within the maximum acceptable concentration limit of 0.05 mg/kg as recommended by WHO (2004) for domestic uses except for the dry season of the second year where the mean concentration of Cr is slightly above the maximum acceptable limit of 0.05 mg/kg as recommended by WHO (2004). Adefemi *et al.* (2007) reported that the concentration of Cr was not detected in major dams of Ekiti State. Abdullahi *et al.*(2015) reported mean concentration of Cr in sediments ranged from 6.54 to 6.63 mg/kg (wet) and 4.83 to 5.00 mg/kg (dry) in Tungan Kawo Dam, Kontagora. Statistical analysis of variance (ANOVA) revealed significant difference ($p \leq 0.05$) in the concentration of Cr measured between the years and dams. However, the mean concentrations of Cr values of wet seasons showed no significant differences with that of dry seasons ($p \leq 0.05$).

In wet season (2014) the highest variability was found in nickel and chromium (173.21%) while the least was iron (1.04%). According to the calculated coefficient of variation the order of variation was found to be as; Ni = Cr > Cd > Cu > Pb > Mn > Zn > Fe. In dry season (2014/2015) the highest variability was found in Ni (169.24%) and the least was found in Fe (2.44%). The order of variation was found to be as; Ni > Pb Cu>Zn > Cr > Mn >

Fe. In the second year, the highest variability was found in Ni and Cr (173.21%) and least was found in Fe (5.13%) wet season 2015. The order of variation was found to be as: Ni = Cr > Pb > Mn > Cu > Zn > Cd > Fe. While in the dry season (2015/2016), the highest variability was found in Ni (136.31%) and the least was found in Fe (9.98%). The order of variation was Ni > Cu > Zn > Pb > Cr > Mn > Fe.

4. CONCLUSIONS

This study has presented data on the concentrations of heavy metals in sediments from four major dams (Doma, Ibuwan, Imon and Awe) located in Nasarawa State, Nigeria. Heavy metals such as Fe, Pb, Cd, Cu, Zn, Ni, Mn and Cr were investigated on the four dams using atomic absorption spectrophotometer. Sediment samples were collected for two years. In each year, samples were collected from May to September (wet season) and November to March (dry seasons) were analysed for water quality parameters and heavy metals. Analysis of variance statistical technique was used to analyse the results of metal concentrations in sediments of these dams for the period of four seasons. The results of analysis of variance showed significant difference ($p \leq 0.05$) in the metal concentrations recorded between and among the dams, seasons and years. The results for heavy metals revealed that most of the parameters determined in sediments were within the WHO acceptable standards except for Pb and Mn exceeded the WHO acceptable standards for drinking water. The implications of these heavy metals are that prolonged intake of water in these dams could cause lungs cancer, anaemia, damage to kidneys, gastro intestinal tract, joints and reproductive system, acute or chronic damage to the nervous system, decrease in body weight, heart and liver damage and skin irritation, hallucinations, ulceration, damage to circulatory and nerve tissues, renal dysfunction, cardiovascular disease and hypertension humans. Based on these results, the dams are assessed to be polluted and unfit/unsuitable for domestic purposes. Water from these dams must be treated before human consumption.

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