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Effect of artisanal mining on sediment quality in Southwest Nigeria.

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Abstract

The population of artisanal miners is rising globally. Currently, over 100 million is reported. Artisanal and small-scale production supply accounts for 80% of global sapphire, 20% of gold mining and 20% of diamond mining. Mining activities lead to contamination of sediments which is a major environmental problem. This study assessed the effect of mining on sediment quality of samples collected from the abandoned primary goldmine site and secondary goldmine site at Iperindo and Igun. A total of twenty sediments (at 0-15 and 15-30cm depth) samples were randomly collected. The sediment samples were subjected to physicochemical analysis using standard methods. The samples were analyzed for metals (Cd, Zn, Cu, Cr, As, Pb and Co) using Inductively Coupled Plasma/ Optical Emission Spectrometry (ICP/OES) technique. The physicochemical properties considered were pH, electrical conductivity (EC), cation exchange capacity (CEC), organic carbon (OC), organic matter content (OM), available phosphorus (AvP), and particle size analysis (PSA). Mean values for pH (7.0), CEC (53.32) and AvP (12.38) for sediments were higher in Igun compared to that in Iperindo, and the values were also compared with established standards for sediment quality. The trends for metal concentrations within the sediment samples in Iperindo were in the order, Cr >Zn >Cu >Co >Pb >As >Cd. In Igun, metal concentrations followed the trend; Zn> Cu >Cr >Pb >Co >As >Cd for the sediments. Both sites had high Cu and Cr content in sediments, but Cr was extremely high in Iperindo, connoting contamination from anthropogenic sources, such as mine wastes. The principal component analysis showed that Cd, Pb, Cr, Co, Cu, As, and Zn were strongly loaded to principal component 1, with these metals significantly contributing to variations 72.10% in Igun and 56.62% Iperindo. This study suggests a basis for remediation of sediments in the goldmines for specifically Cr and Cu.

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1.0 Introduction

Sediments play a useful role in assessing heavy metal contamination (Forstner & Wittmann, 1981). This is because in controlled environments, heavy metals are preferentially transferred from the dissolved to the particulate phase and as a result metal concentration in sediments are generally much higher than in the overlying water and therefore more easily detected (Bryan & Langston, 1992). The advantage of using sediments is that the analytical problems associated with detecting low but significant amounts of metals in water do not have to be addressed. Also, continuous monitoring of water is unnecessary as sediment concentrations indicate contamination loads over more extended periods (Forstner, 1989). Sediments containing much terrigenous material could have a greater capacity to bind metals than marine-derived sediments, because of the presence in the former of minerals such as iron and aluminum oxides and hydroxides which bind metals strongly (Bryan & Langston, 1992).

Copper, lead, and zinc concentrations in sediments at specific sites within estuaries have been reported to be higher than in other areas along harbours previously considered highly contaminated (Gangaiya *et al.,* 2003). The accumulation of heavy metals in sediments can be a secondary source of water pollution, once the environmental condition is changed (Chen *et al.,* 1996; Cheung *et al.,* 2003). Therefore, an assessment of heavy metal contamination in sediments is an indispensable tool to assess an aquatic environment's risk.

This study aims to assess the level of heavy metal concentrations in the sediments from Igun and Iperindo abandoned gold mining sites and to ascertain which of these mines had sediments, with more significant contamination problems.

1.1. Description of Study Area

Iperindo – odo Ijesha goldfield is located some 18 km south of Ilesa linked by asphalt road having compass direction of latitude 7°,27'N - 7°,35'N and longitude 4°,47'E - 4°,53'E, similarly Igun which falls within latitude 7°, 53'N and longitude 4°, 65'E.

The entire goldfield which covers Iperindo-Odo Iies communities lies within the tropical climatic region. Hot and humid weather conditions characterize it with the dry season from November to April and the rainy season from May to October (Oguntoyimbo et al., 1983). Annual rainfall is between 127cm and 152cm with maximum monthly values of 20cm and 18cm attained during June and September. In effect, sporadic light showers are common also during the dry season (Akanni, 1992). The humid and tropical climate has given rise to the thick rain forest in the entire goldfield area. However, this has been replaced mainly by cocoa, yam, plantain and cassava farms. In the abandoned mine, the original rainforest has been replaced by thick and dense forest many of which are 25-30m tall and about 45cm in diameter. Also prominent in the mine is a top layer with the abundance of tall and thick bamboo trees with evergreen canopy and very dense undergrowth made up of creeping and climbing vines and shrubs that grow on around the tailing dumps (Gbadegesin, 1992).

The central and western part of the goldfield area is of the dendritic pattern. The western hills described above form the headwaters of several tributaries in the region. These include rivers ora, Osun, Owena, Oukuro and Obudu. The first two rivers flow to the north-west on tributaries to Osun and Shasha rivers respectively. Trellis drainage pattern has developed in the sub-parallel ridges. The principal streams flow south, flanked by short tributaries that join them more or less at right angles. All the drainage from this area is discharged to rivers Egun in the west and Oni in the east of Iperindo. In Igun, the water body serving the whole community is river Oita which was dammed during the gold processing era and did not flow out to other tributaries.

The Iperindo old gold mine is in southwestern Nigeria's llesha schist belt (Wikipedia, 2007). The belt consists of gold mineralization which occurs with pyrite, pyrrhotite and minor chalcopyrite, galena, sphalerite, magnetite and ilmenite. (TML, 1996). The Iperindo gold mineralization is located in a series of auriferous quartz-carbonate veins localized by a subsidiary fault within biotite gneiss and mica schist, presently defined by sub-parallel old working extending overall for about 900 m in an NNE direction. However, Igun is underlain predominantly by foliated amphibolites, migmatites, gneisses and schists (Wikipedia, 2008). Proven reserves of 68,768 ounces of gold hosted by

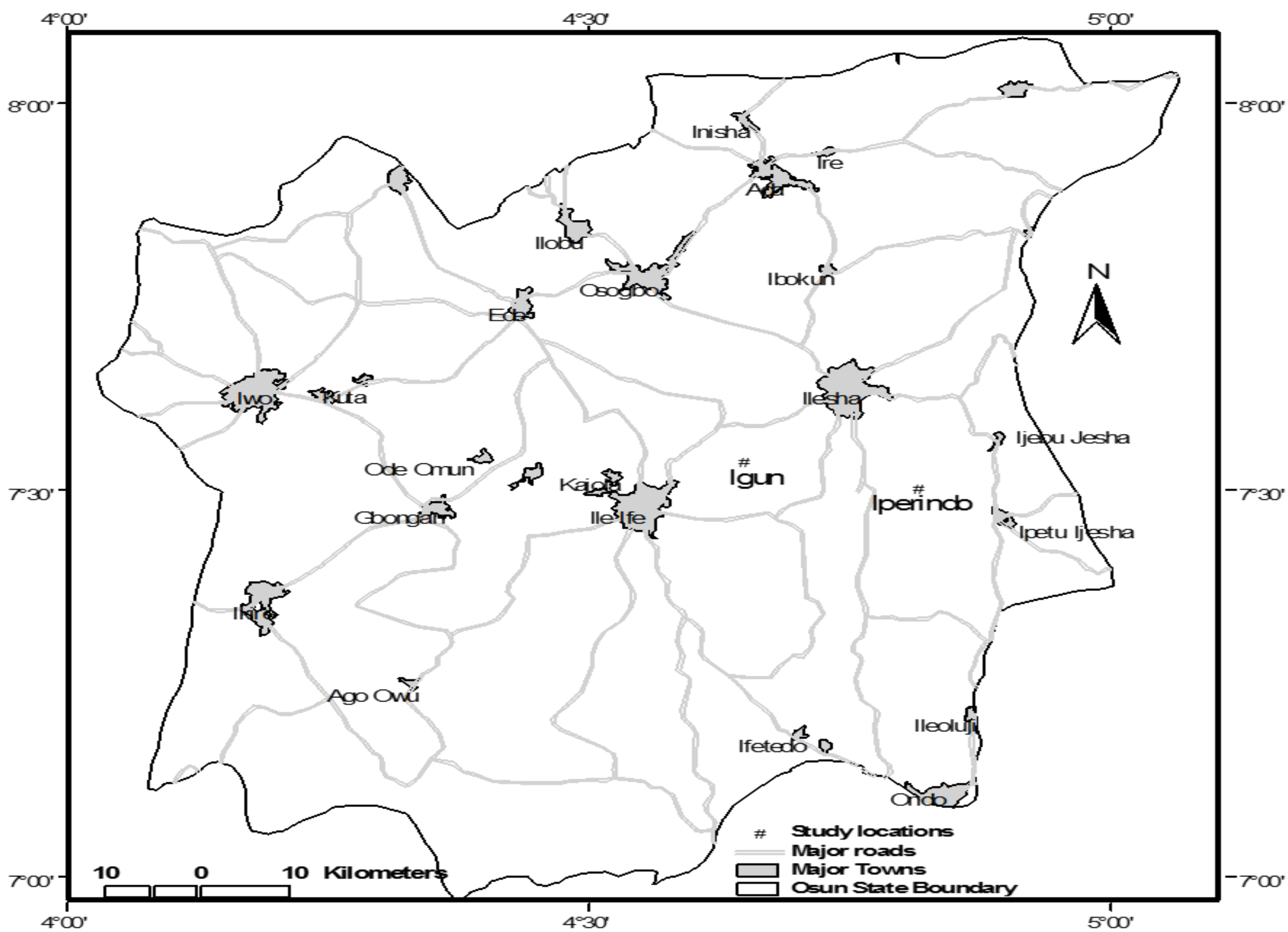

Figure 1: Map showing Iperindo and Igun location

14,104,702 m^3 of ore at an average of 0.00488oz/ m^3 have been reported for Igun deposits (NMC, 1987). Four broad groups of well-drained soil types, namely Okemesi, Ondo, Egbeda and Igun soil types, characterized the study area (TML, 1996).

2.0. Methods

Twenty (20) samples were randomly collected from both Iperindo and Igun mining sites. The samples collected were pulverized, sieved through a 2mm mesh and then stored in labelled plastic bags, before laboratory analysis.

2.1. Laboratory Analysis

The pH analysis of the sediment samples followed the method of Carter and Gregorich (1994), Particle Size Analysis was achieved using the hydrometer method (Table 1). The available Phosphorus content of the tailing samples was determined by Bray 1 method (Table 1). At the same time, cation exchange capacity (CEC) and organic matter content were by ammonium acetate method (Thomas, 1982) and Walkey-Black method (Nelson and Sommers, 1982), respectively. The physicochemical parameters analysis was carried out at the Department of Environmental Management and Toxicology laboratory at the University of Agriculture Abeokuta.

Analysis of the sediments' contents was carried out at the Activation laboratory Canada, using ICP/OES technique. Before this, 0.5g of each sample was digested with 0.5 ml H_2SO_4, 0.6 ml concentrated HNO_3, and 1.8 ml concentrated HCl for 2 hours at 95^{0c}. The sample was then diluted to 10ml with deionized water; these were then analyzed on a Varian Vista 735 ICP for the 35 element suite. A matrix standard and blank was run every 13 samples. A series of USGS and OREAS geochemical standards were used as controls (ACTLABS, 2008).

Data generated from both field and laboratory were subjected to both basic descriptive and detailed statistics of standard deviation, correlation and LSD; which were achieved using: Microsoft Excel for data entry, SAS for mean, range, ANOVAs and mean separation (LSD), values obtained were compared against already established global standards for sediment quality. Principal component analysis and correlation analysis using SYSTAT version 8.0 software. Principal Component Analysis (PCA) was performed using the metal dry weight concentration data. As PCA requires a complete matrix with no missing data, a random number generation process was used to replace non-detects with levels between 0.01 and 0.5, each element's detection limit.

3.0 Results

Sediments ranged between loam sand in Igun to clay in Iperindo (Table 1). The pH values for sediments ranged from 5.8-8.3, with an average of pH of 7 in Igun and 3.3-8.3, with a mean value of 5.54 in Iperindo (Table 1). Electrical conductivity ranged from 33-93 µS/Cm, with a mean value of 74.4 µS/Cm in Igun and 48-199 µS/Cm, with a mean value 129.4 µS/Cm in Iperindo. Available phosphorus ranged from 0.035-31.99 mg/L, with a mean value of 11.6 mg/l in Igun, in Iperindo it ranged from 0.035-0.01 mg/L with a mean value of 0.06 mg/l with a. In Igun % organic carbon (OC) ranged from 2.39-5.45, with a mean of 3.40, while in Iperindo values ranged from 2.99-10.57 with a mean value of 6.57. % Organic matter content (OM) in Igun was from 4.13-94 with a mean value of 5.87, while in Iperindo values ranged from 4.13-18.23 with a mean of 11.52, in the sediment samples (Table 1).

Table 1: Physicochemical Characteristics of Sediment Samples from Iperindo and Igun

Sediment samples	pH in water	EC (µS/cm)	CEC (Meq/100gsoil)	Available Phosphorus (Mg/L)	Organic carbon (%)	Organic Matter (%)
IGUN 1	8.3	86	110.55	11.65	2.99	5.16
2	8.3	84	40.06	10.98	2.59	4.47
3	5.8	76	39.25	31.99	5.45	9.4
4	5.8	33	42.43	0.035	2.39	4.13
5	6.8	93	34.31	3.65	3.59	6.19
Mean	7	74.4	53.32	11.661	3.402	5.87
SD	1.25	23.92	32.13	12.38	1.23	2.13
Range	5.8-8.3	33-93	34.31-110.6	0.04-31.99	2.59-5.45	4.13-6.19
Iperindo 1	3.3	166	57.71	0.069	8.98	15.51
2	8.3	142	26.33	0.059	2.39	4.13
3	4.7	92	50.98	0.048	10.57	18.23
4	4.7	48	21.74	0.101	7.34	13.52
5	3.6	199	47.34	0.035	3.59	6.19
Mean	4.92	129.4	40.82	0.0624	6.574	11.516
SD	1.99	59.93	15.85	0.025	3.49	6.082
Range	3.3-8.3	48-199	26.33-57.71	0.035-0.1	2.39-10.57	4.13-18.23

The results for sediment sample metal analysis (Table 2) showed that the range was < 0.5-0.8 mg/kg for Cd with mean of 0.68 mg/kg, 13-61 mg/kg Cu with mean of 45.2mg/kg, 5-34 mg/kg Pb with mean of 15.2 mg/kg, 30-128 mg/kg Zn with mean of 73.2 mg/kg, < 2-21 mg/kg As with mean of 5.74 mg/kg, 72-193 mg/kg Cr with mean of 144.4 mg/kg, and 15-48 mg/kg Co with mean of 27.6 mg/kg, in Igun (Table 2).

In Iperindo values ranged from 0.5-0.8mg/kg Cd, 66-114 mg/kg Cu, 30-39 mg/kg Pb, 61-131 mg/kg Zn, < 2-14 mg/kg As, 21-75 mg/kg Cr and 5-15mg/kg Co. Mean values were 0.62 mg/kg for Cd, 83.8 mg/kg for Cu, 34.6 mg/kg for Pb, 93.4 mg/kg for Zn, 4.26 mg/kg for As, 54.6 mg/kg for Cr and 10.6 mg/kg for Co (Table 2).

There was a significant difference between the means in Igun and Iperindo for Pb ($LSD_{0.05}$ = 11.96) Cr ($LSD_{0.05}$ 54.95) Co ($LSD_{0.05}$ = 14.41) and Cu ($LSD_{0.05}$ = 28.27) in the sediment samples at $p \leq 0.05$ level of significance (Table 4).

In the sediment samples collected from Igun, the correlation matrix showed a positive relationship among metals except As and Pb, indicating a negative relationship (Table 5). A relatively strong significant relationship existed between Co and As ($r^2 = 0.881$) at 0.05 level of significance. In Iperindo the interaction among most metals was negative, though significant strong positive interaction existed between Co and Cr ($r^2 = 0.952$), Zn and Co ($r^2 = 0.929$), while a significantly strong negative relationship existed between Cu and As ($r^2 = -0.904$), all at 0.05 level of significance (Table 6).

PCA results for Igun location revealed that three of the principal components had Eigenvalues greater than 1.0. These first three principal components, recorded Eigenvalues of 5.768, 1.315 and 0.917, respectively, jointly accounting for 100.00% of the variation among environmental samples (Table 7). The PC1 accounted for 72.103% of the variability Cd (0.726), Cr (0.934), As (0.863), Co (0.998) Zn (0.869), Cu (0.963), Fe (0.940). PC2 accounted for 16.432% of the total variation and was related to Pb

Table 2: Mean Concentrations and standard deviations of metals in sediment samples from Igun and Iperindo Locations

Parameters (mg/kg)	**Igun**		**Iperindo**		**CRM (mg/kg)**	**TEL (mg/kg)**	**PEL (mg/kg)**
	Mean ± SD	**Range**	**Mean±SD**	**Range**			
Parameters (mg/kg)	Mean ± SD	Range	Mean±SD	Range	CRM (mg/kg)	TEL (mg/kg)	PEL (mg/kg)
Cd	0.67 ± 0.14	0.47-0.8	0.62 ± 0.13	0.5-0.8	3.3	0.6	3.5
Pb	15.2 ± 11.03	5-34	34.6 ± 3.57	32-39	730	35	91.3
Cr	144.4 ± 46.36	72-193	54.60 ± 26.27	21-75	12	37.3	90
As	5.74 ± 8.53	1.87-21	4.26 ± 5.44	1.67-14	427	5.9	17
Co	27.6 ± 12.97	15-48	10.60 ± 5.18	5-15	8.2	—	—
Zn	73.20 ± 36.62	30-128	93.40 ± 31.05	61-131	760	123	315
Cu	45.20 ± 20.62	13-61	83.80 ± 18.06	66-114	1110	35.7	197

TEL ; Threshold Effect Level mg/L (CCME, 1999), PEL ; Probable Effect Level mg/L (CCME, 1999),CRM ; Certified Reference Material (Actlabsint, 2009)

Table 3: EPA guidelines for sediments

	Not Polluted	**Moderately Polluted**	**Heavily Polluted**
Cd	-	-	>6
Cr	<25	25-75	>75
Cu	<25	25-50	>50
Pb	<40	40-60	>60

Values are in mg/kg.

Table 4: LSD among Metals in Sediments Samples from Igun and Iperindo Locations.

Parameters	**Igun**	**Iperindo**	**LSD($_{0.05}$)**
Cd	0.674	0.620	NS
Pb	15.200	34.600	11.96
Cr	144.40	54.60	54.95
As	5.746	4.262	NS
Co	27.600	10.600	14.405
Zn	73.20	93.40	NS
Cu	45.20	83.80	28.269
Fe	7.248	3.038	2.153

NB: NS = not significant at $p \leq 0.05$

Table 5: Pearson's Correlation Matrix showing Interactions among Metals in Sediment Samples from Igun location.

	Cd	Pb	Cr	As	Co	Zn	Cu	Fe
Cd	1	.004	.670	.501	.634	.279	.490	.918*
Pb		1	.541	-.157	.261	.311	.081	.116
Cr			1	.590	.796	.794	.781	.869
As				1	.881*	.818	.593	.710
Co					1	.815	.509	.800
Zn						1	.756	.625
Cu							1	.753
Fe								1

* Correlation is significant at the 0.05 level (2-tailed).

Table 6: Pearson's Correlation Matrix showing Interactions among Metals in Sediments from Iperindo Location.

	Cd	Pb	Cr	As	Co	Zn	Cu	Fe
Cd	1	-.665	.479	-.343	.652	.853	.180	-.179
Pb		1	-.746	.204	-.821	-.865	-.007	-.394
Cr			1	.294	.952*	.859	-.600	.733
As				1	.268	-.081	-.904*	.306
Co					1	.929*	-.499	.509
Zn						1	-.196	.344
Cu							1	-.603
Fe								1

* Correlation is significant at the 0.05 level (2-tailed).

Table 7: PCA of Sediment Samples in Igun and Iperindo Locations

	Igun			Iperindo		
	PC1	PC2	PC3	PC1	PC2	PC3
Eigen value	5.768	1.315	0.917	4.530	2.492	0.786
Total Variance (%)	72.103	16.432	11.465	56.622	31.144	9.822
Cummulative Variance (%)	72.103	88.535	100.00	56.622	87.766	97.587
Cd	0.726	-0.243	0.643	0.625	-0.672	0.371
Pb	0.249	0.961	0.124	-0.838	0.392	0.207
Cr	0.934	0.340	0.112	0.978	0.168	-0.088
As	0.863	-0.418	-0.283	0.200	0.879	0.397
Co	0.998	-0.058	0.013	0.989	0.007	0.130
Zn	0.869	0.146	-0.472	0.935	-0.329	0.093
Cu	0.963	0.033	-0.268	-0.478	-0.848	-0.205
Fe	0.940	0.128	0.317	0.998	0.509	-0.610

NB: Bolded: Significant Contribution

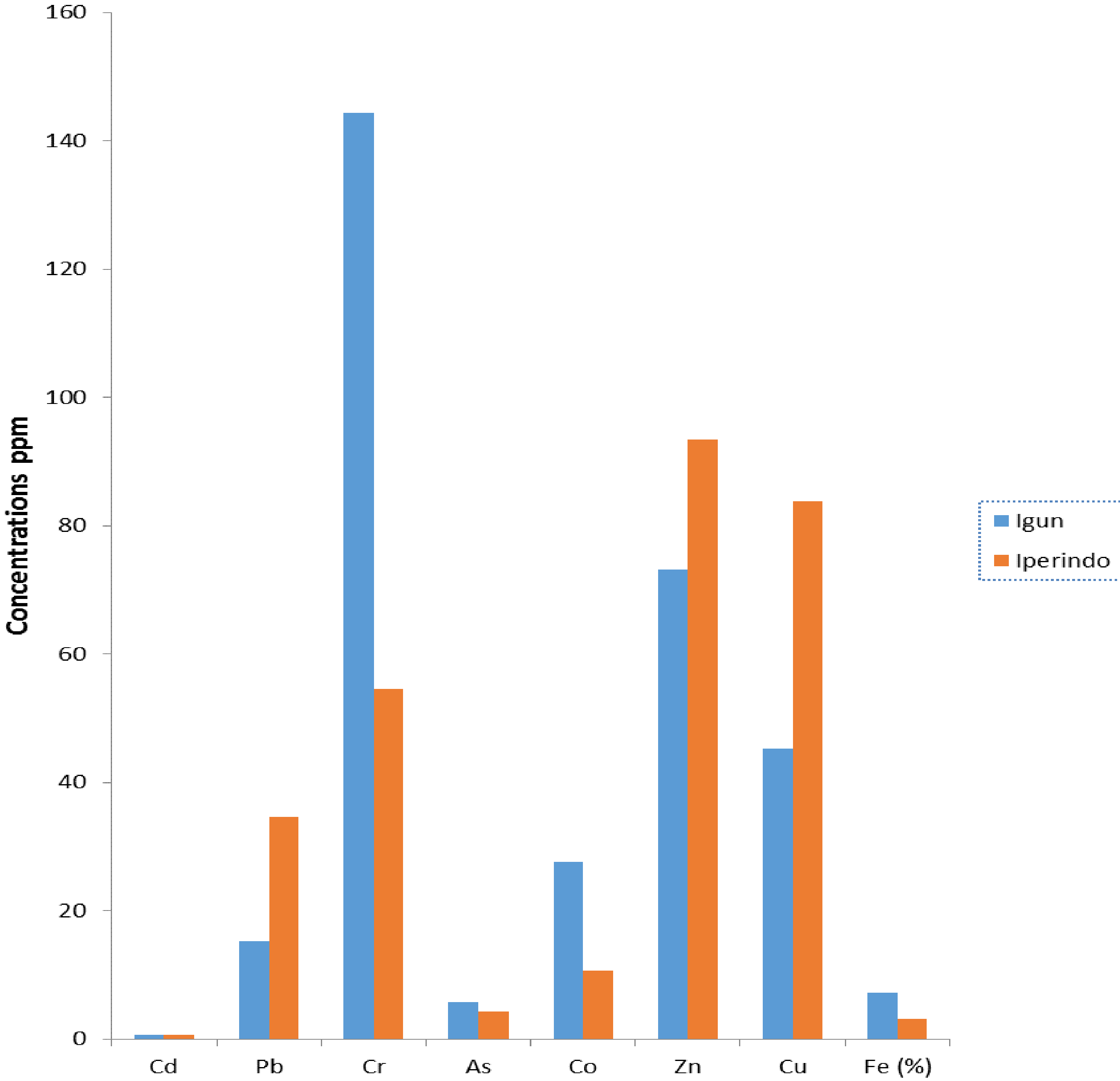

Figure 1: Average metal concentrations in sediments from Igun and Iperindo

(0.961), Cr (0.340), As (0.418). The PC3 accounted for 11.465% of the total variation and was dominated by three metals Cd (0.643), Zn (0.472) and Fe (0.317). PCA for Iperindo location revealed three components (PC 1 - 3), all accounting for 56.622, 31.144 and 9.822% of the model's total variance. According to the PCA model, Cd, Pb, Cr, Co Zn Cu and Fe were strongly loaded (component coefficient ≥0.30) onto PC1, while PC2 had Cd, Pb, As, Zn, Cu and Fe dominating, Cd (0.371), As (0.397) and Fe (0.610) were strongly loaded on PC3 as compared with other metals in the sediment samples (Table 7).

4.0. Discussion

The average concentrations recorded for Cd, Cu, Pb, Zn, As, Cr and Co; in the sediment samples are often lowered the probable effect level (PEL) standards. However, Cu in the sediment was observed to be higher than the threshold effect level (TEL) standards (35.7 mg/kg) established for Canadian sediment quality guidelines but lower than PEL values (197 mg/kg). If the metals in sediments are below the TEL, harmful effects are unlikely to be observed. If the metals are above the PEL, harmful effects are likely to be observed MacDonald *et al. (2000)*, noted in his studies that most of the TEL provide an accurate basis for predicting the absence of sediment toxicity, and most of the PEL provide an accurate basis for predicting sediment toxicity (MacDonald *et al.,* 2000). The concentration of Pb, Zn and As from the two locations were observed to be below TEL stated in Canada sediment quality guidelines (CCME, 1999). This study also recorded a considerable variation in the mean concentration of Cr between the two locations. In Igun the mean Cr value (144.4 mg/kg) was above the standards (CCME, 1999), 90.0 mg/L (PEL) and 37.3 mg/L

(TEL) and when values recorded for metals for this study was compared with USEPA guidelines, there was an indication of heavy pollution from Cr and moderate pollution from Cu. While in Iperindo, it can be observed that Cr 50.6 mg/kg was above the TEL standards (CCME, 1999). It could be concluded that sediments in Igun were contaminated with Cu, as sediments from both locations studied indicate Cr pollution, as well USEPA guidelines suggest that this site is heavily polluted with Cu and moderately polluted with Cr. This could be due to weathered rock materials (Ajakaiye, 1985) and the influence of these sediments' physicochemical properties.

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