Application of Pollution Indices in the Assessment of Heavy Metal Contamination of Surface Sediments of River Bonsa, Ghana

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Abstract

Heavy metal contamination of sediments is a major risk to ecological systems and human health. Not only do sediments influence the quality of the water column, but can be transferred to micro biota and fishes, ultimately ending up at higher trophic levels in the food chain though biomagnification. This study was carried out to assess the contamination levels of heavy metals in the sediments of river Bonsa. Ten sediment samples were taken along the river and analyzed for Copper (Cu), Lead (Pb), Manganese (Mn), Iron (Fe), Zinc (Zn), Cadmium (Cd), Chromium (Cr), Cobalt (Co), and Nickel (Ni) using Atomic Absorption Spectroscopy (AAS). Data analysis was accomplished by comparing the measured heavy metal concentrations to Australian and New Zealand Environment and Conservation Council (ANZECC) and National Oceanic and Atmospheric Administration (NOAA) fresh water sediment quality guidelines and by the computation of geo-accumulation indices and enrichment factors. The results show that apart from Ni which had two of its sample concentrations (at BS1 21.167 mg/kg and at BS2 29.374 mg/kg) exceeding the ANZECC lower limit (21 mg/kg) guideline for fresh water sediment, all other heavy metals recorded concentrations below the lower limits of their respective ANZECC standards. Out of the 10 samples analyzed, 7 recorded Mn concentrations above the NOAA ARC TEL. A one-sample t-test also showed that the mean concentrations of Cu, Pb, Cd, Zn, Ni, and Cr were significantly lower than their respective ANZECC threshold values and Fe concentration was also significantly lower than the NOAA threshold; however, there was no significant difference between Mn mean value and the corresponding NOAA guideline value. The assessment of heavy metal pollution was derived using the Enrichment Factor (EF) and geo-accumulation indices (I-geo). The computed enrichment factors indicated that all the heavy metals

except Ni are from natural sources (i.e., EF < 1.5) signifying a degree of heavy metal depletion rather than enrichment. The sources of Ni were attributed to domestic waste disposal into the river at sampling points BS1 and BS2 as well as run offs from a nearby auto mechanic workshop. All the metals had I-geo values between 0 and 1 (0 < I-geo < 1) denoting unpolluted to moderately polluted sediments. Thus, in terms of heavy metals, the river is unpolluted. These findings are very important as it shows that river Bonsa has not yet been impacted as far as heavy metals are concerned and the data gathered may serve as baseline for future studies.

Keywords

Heavy Metals, Sediment, Enrichment Factor, Geo-Accumulation Index, Pollution Indices, River Bonsa

1. Introduction

Heavy metal contamination of aquatic systems is currently one of the prominent environmental issues globally, and has drawn considerable attention due to their toxicity, persistence and bioaccumulation (Zahran et al., 2015; Kanchana et al., 2014; Varol & Sen, 2012; Zhan et al., 2010). Various authors (Kanchana et al., 2014; Yang et al., 2014; Gao & Chen, 2012; Gowd et al., 2010; Li et al., 2000; Chang et al., 1998) have reported elevated concentrations of heavy metals in different aquatic systems around the globe and their impact on ecological and human health.

All heavy metals are toxic if present in an organism in excess amount, however, some such as Cu, Zn, Fe, Cr, Mg are said to be micronutrients, essential in moderate quantities for metabolism of organisms. Other heavy metals including Al, Cd, Pb have no known biological importance and exhibit extreme toxicity even at trace levels (Manahan, 2005; Canli & Atli, 2003; Sures & Reimann, 2003).

The effects of heavy metal pollution on macro and microbiota have been documented by several researchers to include; species loss and extinction, genetic modification, retarded growth and the alteration of the electrokinetic properties of bacteria and yeasts (Uaboi-Egbennil et al., 2010; Davies et al., 2006; Mucha et al., 2003). Heavy metals may bioaccumulate in aquatic plants, fish and shellfish and may be transferred to humans through the food chain. This results in debilitating developmental, behavioral, psychological, and cognitive changes in an exposed person and sometimes death (Kanchana et al., 2014; Fagbote & Olanipekun, 2010).

Heavy metals may be introduced into the aquatic environment through natural sources such as atmospheric deposition and geological weathering or by anthropogenic sources including municipal and industrial discharges and agricultural run-off (Savadi et al., 2015; Kanchana et al., 2014). Upon their release into the aquatic environment, heavy metals eventually become deposited in se-

diments through physical, chemical or biological mechanisms.

Sediments are the major repository of heavy metals in aquatic systems and play a vital role in remobilization and enrichment of the overlying water column (Banerjee et al., 2017; Rodrigue et al., 2016). The concentration of heavy metals in sediments may be 3 - 5 times higher than that of the water column with the concentration being influenced by physicochemical adsorption, physical accumulation and biological uptake (Banerjee et al., 2017; El-Madani & Hacht, 2017; Akan et al., 2010).

Besides influencing water quality, sediments serve as sources of bioavailable contaminants for micro and macro aquatic biota and hence biomagnifications in the food chains. The transfer of heavy metals from sediments to aquatic biota is well reported (Rodrigue et al., 2016; Uaboi-Egbennil et al., 2010; Mucha et al., 2003). Sediment is therefore considered a sensitive indicator for monitoring aquatic pollution and therefore vital in preventing ecological and human health risks.

River Bonsa is the largest river draining the Tarkwa-Nsuaem municipality and serves as the source of water for domestic, agricultural and industrial activities for the riparian communities. It is also the source of water drawn, treated and distributed to all homes within the Municipality by the Ghana Water Company Limited. The quality of this water source is thus essential for the general health status of the populace.

This study aimed to assess the concentration of metal contaminants, their enrichment levels and the pollution status of sediments of river Bonsa in the Western Region of Ghana.

2. Materials and Methods

2.1. Study Area

River Bonsa is located in the Tarkwa Nsuaem municipality of the Western Region of Ghana on latitude 4˚5" and longitude 5˚5" (Figure 1). The Municipality is often labeled the Hub of mining activities in Ghana because it lies on the Birimian and Tarkwaian geological formations, which are the two most economically important formations as far as mineral deposits are concerned. As such the Municipality hosts three major mining companies and many other small-scale mining companies.

2.2. Survey and Sampling

Before the collection of sediments samples, a survey was conducted to identify suitable sampling sites taking into account factors such as accessibility, human activities and establishments near the river.

Ten sediment samples were collected at approximately 90 m along the river using a grab sampler and labelled BS1 to BS10. A handheld GPS receiver was used to record the coordinates of all the sampling points as shown in Table 1. Figure 2 shows sampling points along the river Bonsa. All samples collected

Table 1. Summary of sampling point coordinates.

Sampling Points	BS1	BS2	BS3	BS4	BS5	BS6	BS7	BS8	BS9	BS10
Long. E	606,882	606,554	606,371	606,223	605,988	606,038	606,120	605,916	605,712	605,460
Lat. N	572,713	572,795	572,403	572,380	572,404	572,543	572,656	572,686	572,723	572,871
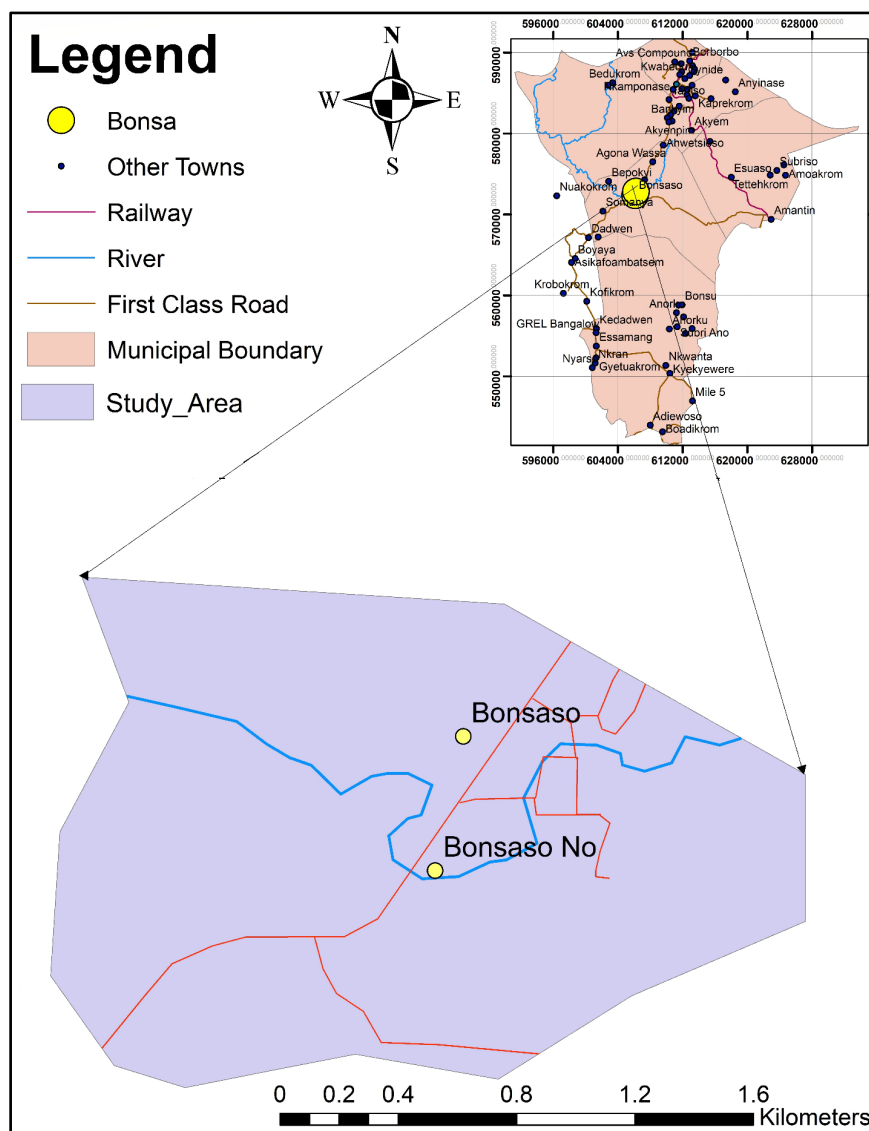
Figure 1. A map of Tarkwa showing Bonsaso (riparian community).

were stored in well labeled Ziploc bags, sealed and transported to the laboratory for pre-treatment and analyses.

2.3. Sample Preparation

In the laboratory, the sediment samples were oven dried at a temperature of 110˚C for one hour to remove the moisture content. The dried samples were allowed to cool and subsequently acid digested.
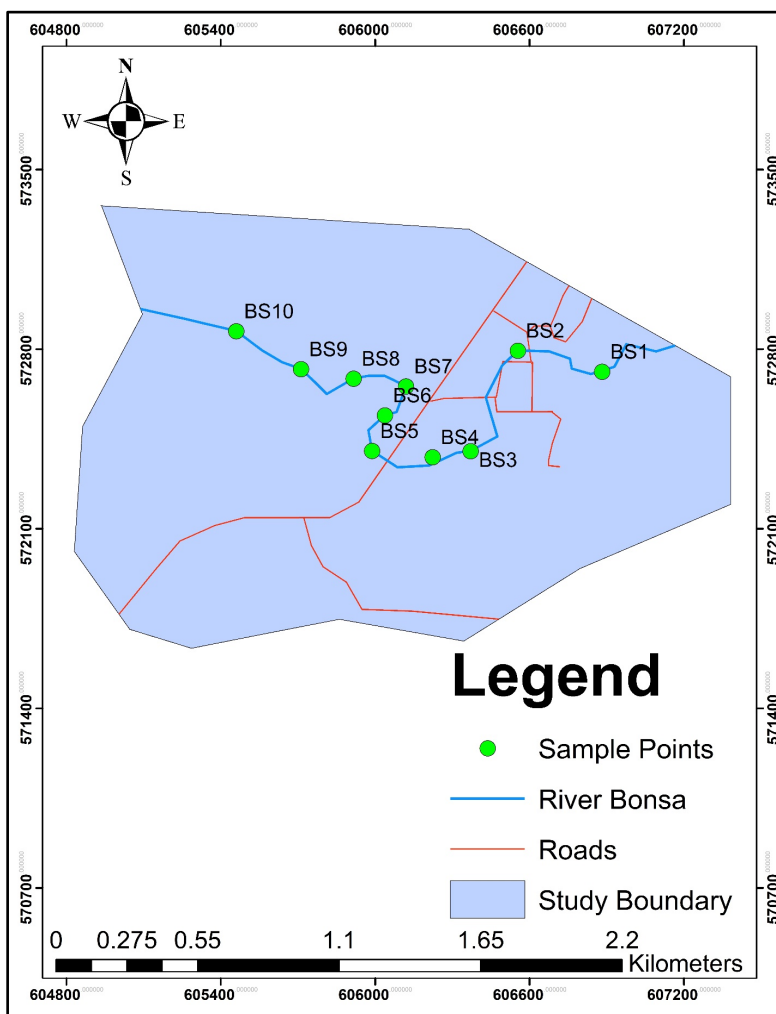
Figure 2. Map of river Bonsa showing sampling points.

2.4. Sample Digestion

Aqua Regia (68% w/w Nitric acid (HNO_3) and 35% w/w Hydrochloric acid (HCl)) in the ratio 1:3 (i.e. 10 mL of HNO_3 and 30 mL of HCl) was added to 5 g each of the dried sediment samples and heated on a hot plate at 105°C for 15 minutes. 10 mL each of the digests were transferred into 50 mL standard flask and topped up to the mark with distilled water. These were then filtered through 0.45 μm Whatman filter paper and used for heavy metal analysis.

2.5. Heavy Metal Analysis

Cu, Cd, Pb, Fe, Mn, Ni, Cr, Zn and Co were analyzed using the Varian AA240FS Fast Sequential Atomic Absorption Spectrometer (AAS) at absorbance wavelength of 324.8, 228.8, 217.0, 243.8, 279.5, 232.0, 357.9, 213.9, and 240.7 nm respectively. The results were then compared with the Australian and New Zealand Environment and Conservation Council (ANZECC) and National Oceanic and Atmospheric Administration (NOAA) Guidelines for fresh water sediment quality.

The ANZECC and NOAA guidelines both have two limits, the ISQG-low concentration also known as the trigger concentration and the ISQG high concentration. The trigger concentration is the threshold below which the probability of adverse effect is very low or negligible whilst the ISQG high concentration is the limit beyond which the heavy metals become bioavailable. Exceeding this value however does not mean adverse effects will occur in the sediments, but will require further investigation into other factors that influence bioavailability to confirm whether or not an adverse effect will be produced.

2.6. Contamination Assessment

The study employed the geo-accumulation index (I-geo) and Enrichment Factor (EF) to determine the status and sources of heavy metal contamination of the sediments respectively.

2.6.1. Enrichment Factor

Enrichment is a method used to estimate the anthropogenic impact on sediments by calculating the difference between the metals originating from human activities and those from natural provenance. Enrichment factor is a means of determining anthropogenic influence on heavy metal concentration in sediments (Rodrigue et al., 2016). The EF is calculated by using Equation (1);

$$EF = \frac{(Cx/Cref)\,sample}{\left(\dfrac{Bx}{Bref}\right)reference\ sample} \tag{1}$$

where,

Cx = Content of the examined element in the examined environment

Cref = Content of the examined element in the reference environment

Bx = Content of the reference element in the examined environment

Bref = Content of the reference element in the reference environment

The contamination categories are recognized on the basis of the enrichment factor as follows:

EF < 2, Deficiency to minimal enrichment,

EF = 2 - 5, Moderate enrichment,

EF = 5 - 20, Severe enrichment,

EF = 20 - 40, Very high enrichment and

EF > 40, extremely high enrichment (Sutherland, 2000).

2.6.2. Geo-Accumulation Index (I-geo)

Index of geo-accumulation (I-geo) was originally defined by Muller in 1969, in order to define and determine metal contamination in sediments by comparing the levels of heavy metal obtained to a background level originally used with bottom sediments (Atiemo et al., 2011). It is calculated by using Equation (2);

$$Igeo = \log 2\,\frac{(Cx)}{1.5Bref} \tag{2}$$

where,

Cx = Content of the examined element in the examined environment

Bref = Content of the reference element in reference environment

Loska & Wiechuya (2010), gave the following interpretation for the geo-accumulation index:

I-geo < 0 = practically unpolluted,

0 < I-geo < 1 = unpolluted to moderated polluted,

1 < I-geo < 2 = moderately polluted,

2 < I-geo < 3 = moderately to strongly polluted,

3 < I-geo < 4 = strongly polluted,

4 < I-geo < 5 = strongly to extremely polluted,

I-geo > 5 = extremely polluted.

3. Results and Discussion

For effective interpretation and discussions, the result of the concentrations of the various heavy metals studied have been compared with the Australian and New Zealand Environment and Conservation Council (ANZECC) Guidelines for fresh water sediment quality. Where appropriate, the results have also been compared with the National Oceanic and Atmospheric Administration (NOAA) fresh water sediment quality guidelines. The data have been presented graphically in Figures 3-11.

3.1. Sediment Quality Guideline

The concentrations of zinc, lead, cadmium, chromium and copper in all the 10 samples analyzed were below their respective ANZECC trigger concentrations or threshold limits (Figures 3-8). The concentrations of iron in all the samples analyzed were found to be below its corresponding NOAA ARC TEL. This implies a very low probability of bioavailability of these metals and hence no ecological or human health impact.

With the exception of BS1 and BS2, all samples analyzed had Ni concentrations below the ANZECC trigger value (Figure 9). The Ni concentrations at BS1 and BS2 although greater than the trigger limit were all found to be well below the ISQG high concentration. The high Ni concentration at BS1 and BS2 could
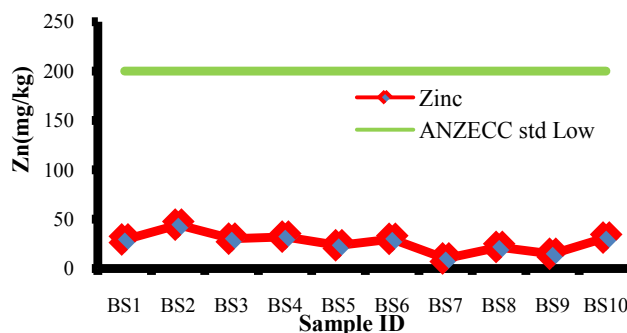

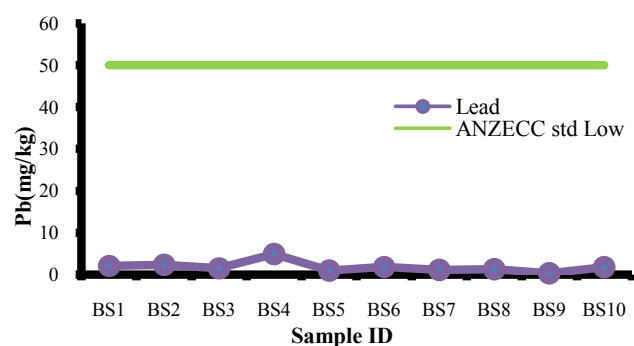**Figure 3.** Zn concentrations in sediment samples.

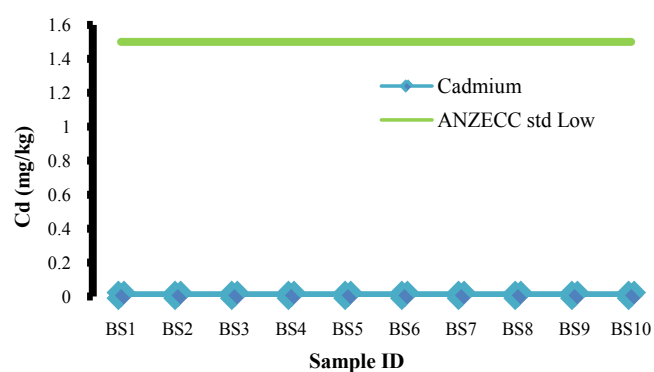**Figure 4.** Pb concentrations in sediment samples.

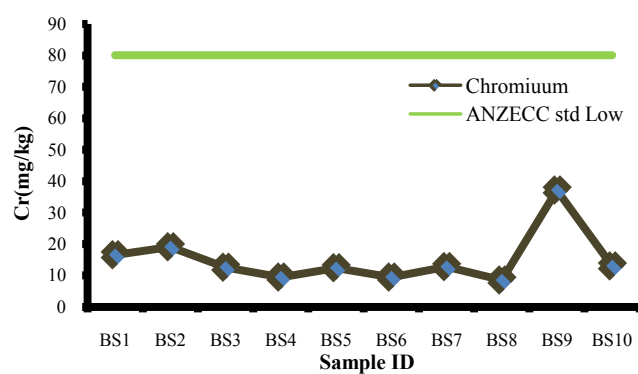**Figure 5.** Cd concentrations in sediment samples.

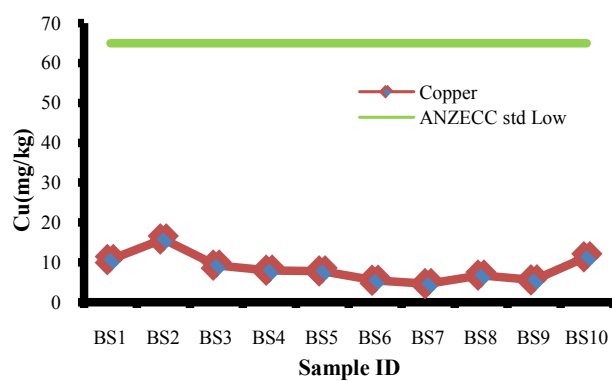**Figure 6.** Cr concentrations in sediment samples.

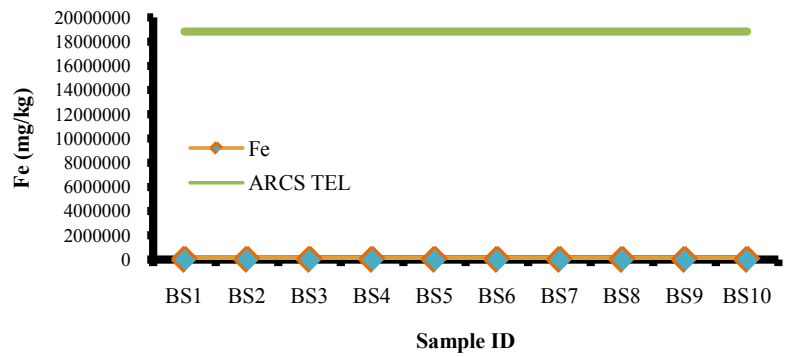**Figure 7.** Cu concentrations in sediment samples.

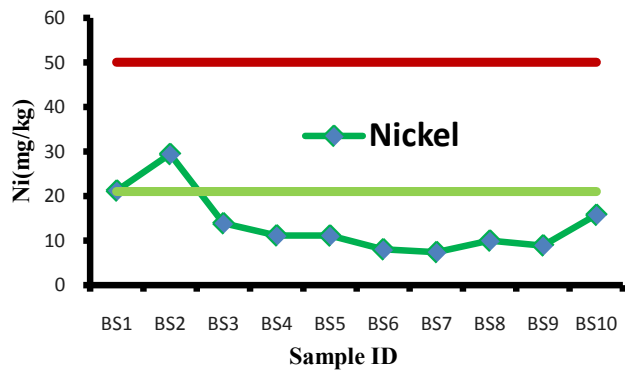**Figure 8.** Fe concentrations in sediment samples.

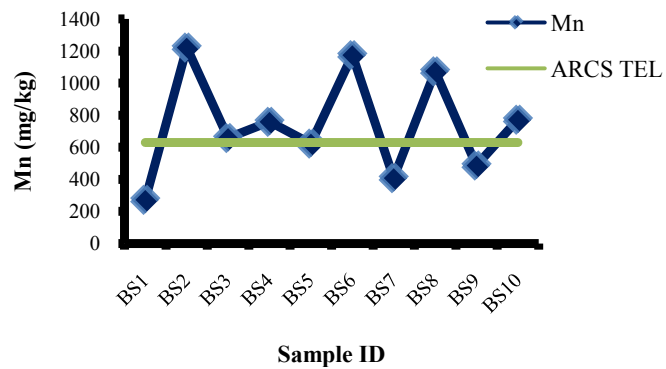**Figure 9.** Ni concentrations in sediment samples.

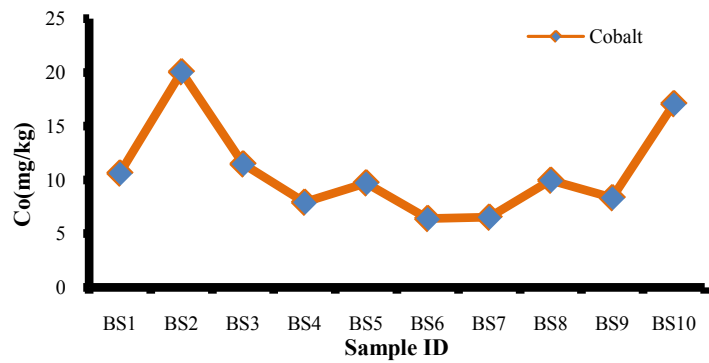**Figure 10.** Mn concentrations in sediment samples.

Figure 11. Cobalt concentrations in sediment samples.

be attributed to the disposal of domestic waste into the river at sampling points BS1 and BS2. These wastes usually include batteries and other Ni containing substances (Harasim & Filipek, 2015). The Ni concentration at BS2 could have been further enhanced by run offs from an auto mechanic workshop closely associated with BS2. Concentrations in between the low and high ISQG value do not necessarily mean adverse impact will occur. Other factors in addition, will help determine the bioavailability of the metal. More so, the average Ni concentration was found to be 13.645 mg/kg, which is below the trigger value of 20 mg/kg, hence the frequency of occurrence of the adverse impact will be very low.

Mn recorded a maximum concentration of 1221.602 mg/kg at sample point BS2 and a minimum concentration of 273.216 mg/kg at BS1 (Figure 10) with an average concentration of 745.097 mg/kg. Apart from BS1, BS7 and BS9, all other samples recorded Mn concentration above NOAA ARC TEL ($p < 0.05$). According to (El-Madani & Hacht, 2017, Barceloux, 1999), about 0.1% of the earth's crust is composed of Mn. Moreover, the high Mn concentrations are as expected, as the study area is high in Mn deposits and the metal is being mined in commercial quantities, about 15.4kilometers from the river (Google Map, 2018). The high Mn concentrations are attributable to geogenic sources as was later indicated by the calculated EF (Table 3). The use of Mn gangue for construction activities in the catchment areas may have contributed to the differences in the concentration levels recorded at the different sampling points. Mn concentrations are within natural limits and will not impact human and ecological health negatively.

Cobalt had maximum and minimum concentrations of 20.039 mg/kg and 6.401 mg/kg respectively (Figure 11) with an average of 10.805 mg/kg. Both ANZECC and NOAA guidelines for fresh water sediment quality do not state any value(s) for cobalt concentrations in sediments. As Co is naturally occurring, all aquatic environment contains trace concentration of this element, sometimes referred to as background concentration. Additionally, the mean concentration of 10.805 mg/kg recorded is much lower than 15.42 mg/kg mean Co concentrations recorded by (Li et al., 2018) although background concentrations differ from region to region.

3.2. Statistical Analysis

The mean concentrations of the various heavy metals were compared with their corresponding ANZECC or NOAA ARCS TELL threshold guideline values using a one-sample t-test as shown in Table 2. It was observed that the mean concentrations of Cu, Pb, Cd, Zn, Ni, and Cr were significantly lower than their respective ANZECC threshold values ($p < 0.05$). The mean Fe concentration was also significantly lower than the NOAA threshold, however there was no significant difference between Mn mean value and the corresponding NOAA guideline value. However, it was close to the NOAA threshold value. These higher Mn levels corroborate the economic deposit of Mn in the study area.

Table 2. One sample t-test comparison of mean heavy metal concentrations and ANZECC/ NOAA standards.

Sampling locations	Cu Mg/kg	Pb Mg/kg	Cd Mg/kg	Co Mg/kg	Mn Mg/kg	Zn Mg/kg	Ni Mg/kg	Cr Mg/kg	Fe Mg/kg
BS1	10.689	2.05	0.008	10.62	273.21	29.493	21.167	16.56	7916.3
BS2	15.85	2.34	0.008	20.04	1221.6	44.52	29.37	19.09	10,116.3
BS3	9.291	1.49	0.008	11.47	658.23	30.29	13.83	12.59	3313.67
BS4	8.035	4.93	0.008	7.912	759.07	32.36	11.11	9.47	5320.84
BS5	7.85	0.94	0.008	9.72	623.56	23.59	11.07	12.43	3591.07
BS6	5.51	1.81	0.008	6.4	1174.2	30.13	7.99	9.47	3362.29
BS7	4.667	1.13	0.008	6.52	408.33	10.24	7.37	12.78	3460.34
BS8	6.796	1.279	0.008	9.96	1073.5	21.92	9.93	8.52	2106.01
BS9	5.59	0.29	0.008	8.33	487.04	14.946	8.87	37.14	1613.55
BS10	11.38	1.749	0.008	17.07	772.22	31.41	15.73	13.01	2294.46
ANZECC Low std.	65	50	1.5	-	-	200	21	80	-
ARCS TEL	-	-	-	-	630	-	-	-	18,840,000
Mean	8.57	1.80	0.008	10.80	745.10	26.99	13.64	15.11	4309.48
Std. Error of mean	1.07	0.39	-	1.41	102.47	3.06	2.18	2.65	863.20
t-statistic	−52.67	−122.25	-	-	1.12	−56.48	−3.368	−24.456	−21,820.70
df	9	9	-	-	9	9	9	9	9
p-value	0.000	0.000	-	-	0.290	0.000	0.008	0.000	0.000

3.3. Contamination Assessment

Based on the individual elements' measured concentrations and their background values, geo-accumulation indices and enrichment factors were calculated to determine the levels and sources of contamination, respectively, and the results are shown in Table 3.

3.3.1. Enrichment Factor (EF)

The EF values for all the metals except Ni analyzed were less than 1.5 which denotes no enrichment. This means all the heavy metals measured had their sources from the natural environment or geogenic source except Ni. Ni had a calculated EF of 3.44 denoting moderate enrichment (Table 3).

3.3.2. Geo-Accumulation Index (I-Geo)

According to (Saleem et al., 2015), I-geo is the quantitative value of contamination index in sediments and as such any increase in the reference level may be envisaged as anthropogenic (Rodrigue et al., 2016). All the heavy metals analyzed had I-geo values between 0 and 1 which denotes unpolluted to moderately polluted. Hence the river may be said to be unpolluted with respect to heavy metals.

Table 3. Enrichment Factor and Geo accumulation Index of the various heavy metals.

| Metals | Mean Conc. (mg/kg) | ANZECC Low std (mg/kg) | NOAA | | ^{2}EF | ^{3}DE | ^{4}GI | ^{5}DI |
			ARCS TEL mg/kg	^{1}BG mg/kg				
Cu	8.568	65	-	-	0.698	Depletion	0.021	Unpolluted to Moderately
Pb	1.804	50		-	0.191	Depletion	0.0045	Unpolluted to Moderately
Cd	0.008	1.5	-		0.028	Depletion	0.00002	Unpolluted to Moderately
Zn	26.891	200	-	-	0.712	Depletion	0.067	Unpolluted to Moderately
Ni	13.646	21	-	-	3.44	Moderate	0.034	Unpolluted to Moderately
Cr	15.107	80	-	-	1	Depletion	0.038	Unpolluted to Moderately
Co	10.804	-	-	10	0.930	Depletion	0.2168	Unpolluted to Moderately
Mn	745.096	-	630	400	1.503	Depletion	0.3738	Unpolluted to Moderately
Fe	4309.48	-	18,840,000	1,800,000	0.002	Depletion	0.0004	Unpolluted to Moderately

1: Background Concentration; 2: Enrichment Factor; 3: Degree of Enrichment; 4: Geo-accumulation index; 5: Degree of I-geo.

4. Conclusion

This study was carried out on the sediments of River Bonsa to examine the levels and sources of heavy metal contamination. ANZECC and NOAA standards for fresh water sediment quality were used as the benchmark against measured concentrations of the heavy metals in the sediments of river Bonsa. Geo-accumulation indices and enrichment factors were also calculated.

The concentrations of Cu, Pb, Cr, Cd, Zn and Fe were all below their respective trigger values. Out of the ten samples of Ni analyzed, two had Ni values above the ISQG lower limit but below the upper limit. The mean Ni value was below the ISQG threshold limit. Out of the 10 samples analyzed, 7 recorded Mn concentrations above the NOAA ARC TEL. Co although had no ISQG standard guideline values when compared to similar ecosystems showed no alarming conditions.

The calculated enrichment factor showed that all the heavy metals except Ni are from natural/geogenic sources. The sources of Ni were attributed to domestic waste disposal into the river as well as run offs from a nearby auto mechanic workshop. The pollution status of River Bonsa inferred from the calculated I-geo is unpolluted to moderately polluted. The River could be said to be unpolluted with heavy metals and may not adversely impact the health of the ecosystem or humans. However, continuous monitoring of the river sediment is required to detect future changes in the concentrations of heavy metals and their impact on aquatic ecosystem health.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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