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Impact of Rutile mining on water quality in Mogbwemo, Southwestern Sierra Leone

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ABSTRACT

A study to assess the impact of Rutile mining on the quality of surface and well waters in Mogbwemo was conducted. Results showed significant levels ($p<0.05$) of heavy metals (Cd, Cu, Fe, Pb, Ti and Zn) in the water bodies. A four stage sequential extraction procedure according to Tessier protocol applied to sediment of the water bodies for the metals Cu, Fe and Zn revealed about 1% and 15% for the exchangeable and bioavailable fraction respectively of the total metal within the sediment. The bioavailable metal fraction in the sediment correlated strongly to the level of metals present in the water bodies for Fe ($R^2 = 0.66$), but a much weaker correlation for zinc ($R^2 = 0.34$) and no correlation for Cu. It was concluded that pollution in the water bodies of Mogbwemo could possibly have originated from the mining activities of Rutile.

KEYWORDS: Chemical speciation, heavy metals, pollution, sediment

INTRODUCTION

Sierra Leone has a number of useful mineral deposits including iron ore, bauxite, rutile, gold, chromite ilmenite, columbite, kimberlite and cassiterite (Gwynne-Jones *et al*., 1978). Rutile (TiO_2) and ilmenite ($FeTiO_2$) are mined by the Sierra Rutile mining company operating in the Impere Chiefdom, Bonthe District in the Southern province of Sierra Leone. The mining activities have resulted in mine spoil heaps and sand tailings covering very large areas of land that was once organic-rich. Another consequence of the mining operations in the region is the change in the physical properties (e.g. colour, taste etc.) of the fresh water resources reported by inhabitants living in and around the site.

Mogbwemo is a fairly large settlement in the neighbourhood of Sierra Rutile Mines. Residents of Mogbwemo and surrounding communities around the Rutile mines depend on water from nearby streams and wells for various domestic purposes. The presence of significant quantities of toxic metals in these bodies of water may pose a real threat to the survival of the inhabitants of the region both in the short and long term. However, where heavy metal poisoning occurs, the effect cannot be easily detected or diagnosed in the short term. Consequently, local residents will be expected to face long-term metal pollution effects as a result of regular consumption of water in their environment. Although, the level of metal pollution is important, they do not provide adequate information about their impact on the environment (i.e. their interaction with sediments, bioavailability or toxicity) (Alonso *et al*., 2004). For instance, the bioavailability of a metal and metal toxicity for aquatic organisms is dependant on the physical and chemical form (e.g. the amount of free metal ions and very labile complexes under diverse range of environmental conditions) of the metal (Allen and Hansen, 1996; Mota and Simoes, 1996). In view of this, this study aim to assess the potential impact of the mining activities on the quality of surface and well waters in Mogbwemo.

MATERIALS AND METHODS

Study area and sample collection

Sierra Rutile is located in the south-western province of Sierra Leone. It holds mineral leases over an area of 224 square miles (Lee Peck communication, 1991). This area includes the Gambia, Jagbahun, Nyandehun, Sembehun and Taninahun Boka prospects. The area around the plant site no longer holds mineral deposits for the past five years. It is already mined out and consists of mine spoils, sand tailings and ponds. Water samples for this research were collected from some of the bodies of water in these mined out areas (S1, S2, S3) and from two wells (W1 and W2), all within approximately 1km radius of the plant site where secondary ore processing was carried out. The water bodies S2 and S3 are very large ponds, which are used by local residents for domestic purposes such as laundry as well as cooking and drinking after chlorination. These are provided with hand pumps. Site S1 is a much smaller pond than S2 and S3 and is not used in any way by local residents. S1 is also closest to the central processing plant (~100m) compared to the others. W1 and W2 are deep aquifer wells approximately 10m deep. Approximately 200ml of water samples were collected using a sampling bottle with a wide mouth made of polyethylene material. The bottle was tied to a string carrying a weight and then lowered into the water. Water samples were collected at various depths ranging from ½m to 1m below the surface of each of S1, S2, and S3, and at intervals of about 25m along the length of the pond. The small volumes of samples were then added to obtain representative samples from each water body. In the case of well water W1 and W2, small volumes of ~50ml collected in batches making up to 200ml were collected using a hand pump.

About 500g sediment samples were collected from the banks of each of the sample sites to determine speciation of the metals, pH and conductivity. The soil samples/sediments were dug out from three different levels within 6-12 inches (i.e. surface, ~6inches and ~12inches from six different locations at each site. The three categories of soil/sediments from the banks of each water body were added to form a uniform mixture from which a representative 1g sample was withdrawn for the study of speciation of the metals in the sediments.

Analytical determination

All physico-chemical analysis was carried out according to standard methods (APHA, 1998). For each determination, number of replicate samples was three. Conductivity and pH of the water samples and solutions of the soil were measured by means of a conductivity meter (JENWAY 4320) model and HACH Sension 1 pH meter respectively after calibration of the instrument.

The following elements: titanium (Ti), cadmium (Cd), copper (Cu), Iron (Fe), zinc (Zn) and lead (Pb) were determined quantitatively using a portable data logging spectrophotometer (HACH DR 2010 model) following qualitative confirmation of their presence in water and soil/sediments samples according to standard methods as outlined in Vogel (1995).

Sequential extraction techniques to assess the types of associations between metals and sediment was carried out using the established Tessier sequential extraction scheme as described in Gumgum and Ozturk (2001). The scheme divides metals into five fractions: exchangeable, carbonate-bounded, Fe /Mn oxides-bounded, organic matter-bounded and residual. The residual fraction was calculated by difference (i.e. total metal concentration – sum of exchangeable, carbonate-bounded, Fe /Mn oxides-bounded and organic matter-bounded fractions).

Statistical analysis

A one-way analysis of variance (ANOVA, $p<0.05$) was performed using Microsoft excel to determine differences between levels of metals in the water samples collected from the various locations . The Spearman rank correlation was used to test the relationships between level of metals in the water samples and sediments.

RESULTS

Level of pollutants

Table 1.0 presents results of physico-chemical parameters of water samples from sites S1, S2, S3, W1 and W2. pH of all water samples investigated were acidic and well below WHO standard of 6.8-6.9 for drinking water as well as the European Union (EU) standard of 6.5-8.5 for surface water (Sowa, 1994). Values of pH for water samples from the various locations were significantly different from each other ($p<0.05$) with S1 been the most acidic. Conductivity values for water samples from the different locations are significantly different from each other ($p<0.05$) with conductivity of S1 a factor of 3 – 12 times more than the conductivity of the others. Conductivity values for water samples from the different locations exceeded the EU limit of 1000 mS^{-1} for surface water used for potable abstraction (Sowa, 1994).

For all metals investigated, there was no significant difference ($p>0.05$) in level between locations. However, there was significant difference ($p<0.05$) in levels between the different metals within a given location. Average levels of Ti, Cd and Fe are 3-4 times higher than Pb, Cu and Zn (Table 1). Highest level of metals was found in S1 as in the case for pH and conductivity.

Table 1.0: Summary of physical and chemical characteristics of waters from the various locations. Values represent Mean± standard error for three replicates.

Parameters	S1	S2	S3	W1	W2
pH	3.52±0.3	5.05±0.2	5.58±0.3	4.55±0.5	4.77±0.4
Conductivity (µS cm^{-1})	154.6±6.4	19.7±4.8	12.1±0.4	48.5±5.4	27.4±9.7
Ti (mg L^{-1})	0.17±0.1	0.18±0.1	0.19±0.1	0.21±0.1	0.14±0.1
Pb(mg L^{-1})	0.03±0	0.05±0	0.03±0	0.08±0	0.03±0
Zn(mg L^{-1})	0.035±0	0.036±0	0.035±0	0.038±0	0.036±0
Cd(mg L^{-1})	2.33±2.0	0.38±0.2	0.32±0.2	0.36±0.3	0.39±0.2
Fe(mg L^{-1})	0.43±0.2	0.18±0.1	0.15±0.1	0.01±0	0.01±0
Cu(mg L^{-1})	0.07±0	0.04±0	0.05±0	0.05±0	0.06±0

Table 2a: Result of chemical speciation for site S1

Fractions	Concentration (mg Kg^{-1})		
	Fe	Cu	Zn
Exchangeable	2.0±0	48.4±2.4	0
Carbonate-bound	0	56.1±2.8	0
Fe-Mn bound	194.1±9.7	274.0±13.7	88.1±4.6
Organic	210.0±	258.2±12.9	92.0±4.6
Residual	3626.0	2964.0	972.0
Total	4032.3±201.6	3600.1±180	1152,3±57.6

Table 2b: Result of chemical speciation for site S2

Fractions	Concentration (mg Kg^{-1})		
	Fe	Cu	Zn
Exchangeable	2.0±0.1	22.0±1.0	62±3.0
Carbonate-bound	4.1±0.1	10.0±0.4	6.0±0.3
Fe-Mn bound	210.1±10.4	366.1±17.3	20.1±0.9
Organic	422.0±21.0	280.2±13.8	28.0±1.4
Residual	9442.0	4218.0	3484.0
Total	10080.1±501.4	4896.0±244.8	3600.0±179.0

Table 2c: Result of chemical speciation for site S3

Fractions	Concentration (mg Kg^{-1})

	Fe	Cu	Zn
Exchangeable	10.1±0.5	38.1±1.9	24.0±1.1
Carbonate-bound	4.0±0.2	2.0±0	0
Fe-Mn bound	390.2±18.7	338.1±16.7	0
Organic	366.2±18.1	210.0±10.4	28.3±1.4
Residual	6862.0	4572.0	5468.0
Total	7632.1±387.2	5160.0±257.9	5520.3±267.3

Table 2d: Result of chemical speciation for site W1

Fractions	Concentration (mg Kg^{-1})		
	Fe	Cu	Zn
Exchangeable	126.1±6.5	46.0±2.3	0
Carbonate-bound	10.0±0.4	2.0±0	4.0±0.1
Fe-Mn bound	522.0±26.1	612.2±30.5	416.2±21.0
Organic	262.1±13.2	234.1±11.7	128.0±6.4
Residual	7000.0	3906.0	4012.0
Total	7920±397.0	4800.0±192.0	4560.0±228.0

Table 2e: Result of chemical speciation for site W2

Fractions	Concentration (mg Kg^{-1})		
	Fe	Cu	Zn
Exchangeable	20.0±1.0	252.0±12.6	28.0±1.4
Carbonate-bound	26.0±1.3	12.0±0.7	6.0±0.3
Fe-Mn bound	410.0±20.5	726±36.3	8.0±0.4
Organic	228.0±11.4	160.0±8.0	400.0±20.0
Residual	4356.0	4130.0	4358.0
Total	5040.0±252.0	5280.0±264.0	4800.0±240.0

Values in tables 2a-2e represent Mean± standard error for three replicates with the exception of the residual fraction which was obtained by difference.

Chemical speciation study

Results of chemical speciation of metals in sediments at the banks of the water bodies are presented (Tables 2a-e). In almost all the sites, the availability of the three metals decreases in the order: Fe>Cu>Zn, except for S3 where the order is Fe>Zn>Cu.

The bioavailable fraction of Fe, Cu and Zn in all locations was low, averaging 15% of the total metal adsorbed to the sediment (Figure 1.0). Of the bioavailable fraction, the exchangeable and carbonate fractions constitute the lowest percentage (Figure 2) averaging 5 and 1% for Fe, 6 and 2% for Cu and 9 and 1% for Zn for exchangeable and carbonate fractions respectively. For virtually all the sites, the Fe-Mn fraction contains the highest level of the bioavailable fraction.

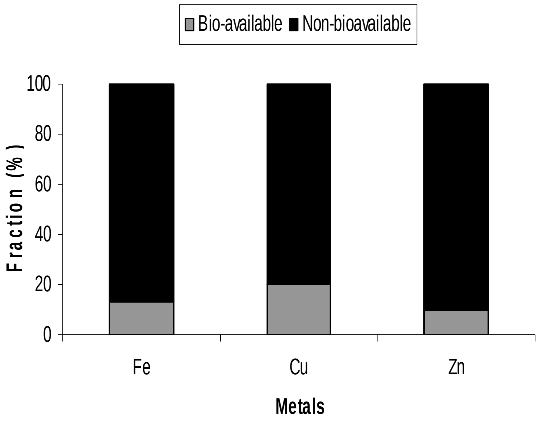

Figure 1.0: Comparison of total bioavailable and non-bioavailable fractions of metals in sediments of water bodies.

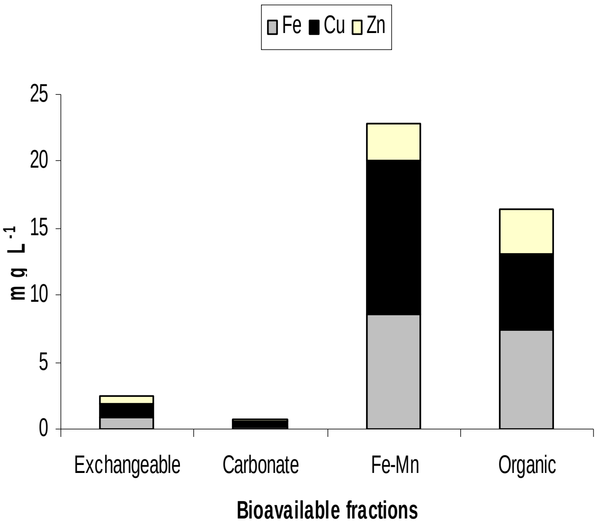

Figure 2: Levels of bioavailable fractions in sediments

DISCUSSION

All water samples investigated were acidic and well below WHO standard of 6.8-6.9 for drinking water as well as the European Union standard of 6.5-8.5 for surface water (Sowa, 1994). This indicates that waters from sites S2 and S3 which are used by the local community for domestic purposes including drinking may have severe health implications on local residents.

Conductivity show similar trend to pH, with S1 the most acidic and having highest conductivity value. The significantly high conductivity for S1 ($p<0.05$) may be attributed to the close proximity to the plant site which is about 100m compared to S2 and S3 which are several hundreds of metres away. At the plant site, stockpiles of gangues from processing operations can be found exposed to air, water and heat which may have easily leached into

S1. In comparison, conductivity values obtained in this study exceeded polluted waters of streams and estuarine water in the neighbourhood of the Kingtom dumpsite in Freetown, Sierra Leone (Barry, 2003) indicating that all water sources are polluted.

Generally, the concentrations of metals obtained in this study are either higher or comparable to reported means of surface waters or rivers in Sierra Leone and elsewhere. The results of Cu obtained in this study (0.04-0.07 mg L^{-1}) is higher than 0.0083 mg L^{-1} for Cu but lower (0.035-0.038 mg L^{-1}) than 0.06 mg L^{-1} for Zn reported by Barry (2003) for streams of the Kingtom dumpsite in Freetown, Western area of Sierra Leone. Okonkwo and Mothiba (2004) reported a much lower concentrations in the range of 1.6-9.3μg L^{-1} for Cd, 2.0-3.0 μg L^{-1} for Cu, 10.5-20.1 μg L^{-1} for Pb and 2.1-2.5μg L^{-1} for Zn in the rivers of Thohandou, South Africa. The relatively high concentrations of metals found in the surface waters of the study area possibly reflect the mining activity as is usually the case for water bodies within the vicinity of mining regions (Nordstrom *et al*., 2000).

For all metals investigated, there was no significant difference ($p>0.05$) in level between locations. However, there was significant difference ($p<0.05$) in levels between the different metals within a given location.The average levels of Ti, Cd and Fe are 3-4 times higher than Pb, Cu and Zn (Table 1). Highest level of metals was found in S1 as in the case for pH and conductivity. In almost all the sites, the availability of the three metals decreases in the order: Fe>Cu>Zn, except for S3 where the order is Fe>Zn>Cu.

The result of bioavailable fraction of metals revealed that Fe, Cu and Zn in all locations was low, averaging 15% of the total metal adsorbed to the sediment (Figure 1.0). Low levels of bioavailable fraction compared to the non-bioavailable (non –labile) fraction of metals in sediments are consistent with literature (Hu, 2002; Abu-Kutaki, 2001), although elsewhere, a much higher level of bioavailable fractions (e.g. 48% Cu, 53% Co and 25% Ni) has been reported (Luo *et al*., 2008). Of the bioavailable fraction, the exchangeable and carbonate fractions constitute the lowest percentage averaging 5 and 1% for Fe, 6 and 2% for Cu and 9 and 1% for Zn for exchangeable and carbonate fractions respectively. Comparable low levels of exchangeable fractions from speciation studies have also been reported (Luo *et al*., 2008). In general, exchangeable and carbonate bound metals can easily be released to the surrounding waters as a result of a change in the ionic composition of the water or a decrease in pH (Sobczyński and Siepak, 2001). Hence, in this study, the low pH of the water bodies and sediments could have resulted in remobilization of the carbonate fraction of the metals. Furthermore, the exchangeable fraction is easily available for leeching into the aquatic environment because the metals are weakly adsorbed via weak electrostatic attraction (Abu-Kutaki, 2001). For virtually all the sites, the Fe-Mn fraction contains the highest level of the bioavailable fraction. This may be due to the fact that metals usually have strong affinities for iron-manganese oxyhydroxides (Elder, 1988). Despite the relatively low bioavailable fraction (15%) compared to the non-bioavailable fraction (85%) in the present study, the concentration of metals in the bioavailable fraction available to the aquatic systems exceeds the toxicity limit of these metals on algae (Florence *et al*., 1992) implying that the levels of metals present in the water bodies potentially pose a health risk to the local residents in the region.

There was a relatively strong correlation between the level of bioavailable metal found in the sediments to the level of metal present in the water bodies for Fe (R^2 = 0.66 for Fe) but a much weaker correlation for zinc (R^2 = 0.34). No correlation exists for Cu. Similarly, there was also a relatively strong correlation for Fe between the exchangeable fraction in sediment and that present in the water bodies (R^2 = 0.69). Correlation for Cu was however weak (R^2 = 0. 19) whilst no correlation exist for Zn.

CONCLUSIONS

The mining activities carried out in Mogbwemo and its environs by the Sierra Rutile Mining Company have resulted in many streams, dams and lakes to emerge. The quality of water bodies in the surrounding areas has been affected as evident by the low pH, high conductivity and significant levels (ANOVA, $p<0.05$) of heavy metals in the water bodies compared to unpolluted waters. The chemical speciation studies revealed about 1% and 15% for exchangeable and bioavailable fraction respectively of the total metal within the sediment of the water bodies. The Spearman rank correlation revealed a strong correlation between the level of bioavailable metals found in the sediments to the level of metals present in the water bodies for Fe (R^2 = 0.66), a much weaker correlation for zinc (R^2 = 0.34) and no correlation for Cu. The results show that pollutants from the mining activities may possibly have been the primary source of these metals in the water bodies. As this water source is used by local residence of the Mogbwemo community, the findings of this study is of environmental and health significance.

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