

## PRELIMINARY ENVIRONMENTAL ASSESSMENT OF METAL CONTAMINATION FROM MINING AREAS: CASE OF THE KAFUE RIVER, ZAMBIA

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### ABSTRACT

Environmental pollution due to metal contaminants is of major concern globally. Most chemical discharge is waterborne and consequently, the highest impact of contamination is on the aquatic environment. Therefore, aquatic habitats are crucial in investigating levels of toxicity imposed and designing regulatory policies thereof. The general objective of this study was to address the potential risk from metal pollution sources in Zambia on the local environment and eventual risk to the local communities through direct intake of contaminated water and/or food items. This study investigated impacts of mining activities along the Kafue River. Metal concentrations were analyzed in the non-living environment (sediments and water) and additionally, edible fish species (*Brycinus imberj*; *Clarias ngamensis*; *Hepestus odoe*; *Marcusenius Macrolepidotus*; *Oreochromis andersonii*, *Oreochromis macrochir*; *Sargochromis codringtonii*; *Schilbe intermedius*; *Serranochromis angusticeps*; *Synodontis macrostoma* and *Tilapia rendalii*) were sampled in Kafue River. Sediments Cu and As surpassed United States Environmental Protection Agency (USEPA) limits while Zn was above FAO permissible limits in all fishes. Indeed, the impact of metal pollution cannot be overemphasized and intervention strategies are needed.

**Keywords:** metals, mining, concentration, pollution, Kafue.

### 1. Introduction

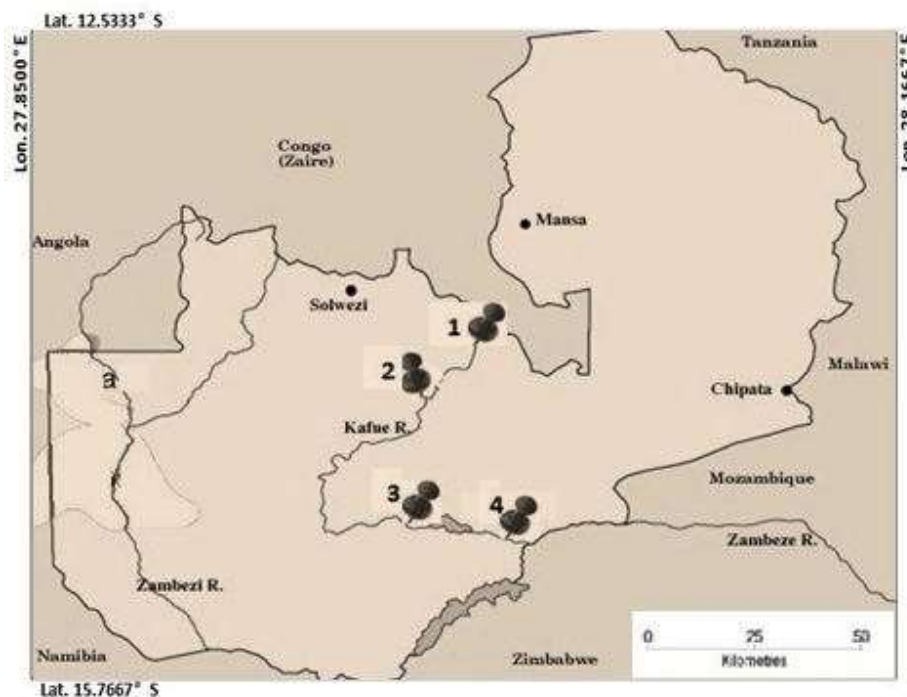
Environmental pollution due to metals is of major concern the world over such that they have been ranked the major polluting substances in both developing and developed countries (Lloyd, 1992) as cited in (Ibrahim and Said, 2010). Metals are natural components of the earth's crust (Martí-Cid *et al.*, 2008) and are mostly present in trace amounts in the environment yet due to intensified anthropogenic activities, concentrations of these metals may rise to alarming levels (Ibrahim and Said, 2010; Çoğun *et al.*, 2003). According to several studies (Begum *et al.*, 2009; Javed and Usmani, 2011; Olade, 1987; Çoğun *et al.*, 2003), sources of metal contaminants include those associated with mining and industrial activities. Mining is an important industry in many countries (Zambia inclusive) as it provides employment and national revenue (Nriagu, 1992); thereby contributing to economic growth.

Fish is generally appreciated as a healthier and cheaper source of protein. They acquire metals from the diet and from the water; and will accumulate extra contaminants through intimate contact with the medium carrying the chemicals in solution/suspension (Javed and Usmani, 2011) and also because it has to extract oxygen by filtering enormous volumes of water over the gills (Begum *et al.*, 2009; Javed and Usmani, 2011). Once in the fish, toxins may be transferred to humans through biomagnification (Begum *et al.*, 2009). Metal exposure can cause irreversible health disorders in humans and animals due to their reactions with proteins in the body (Tembo *et al.*, 2006). Bury *et al.* (2003) explains that the ambiguity of metals is governed by their ability to form a wide range of coordination geometries and redox states, allowing them to interact with many cellular entities/components.

Mining is Zambia's most important economic industry; with 3% of the world's annual copper production while that of cobalt stood at 20% as at 1997 (Stockwell *et al.*, 2001) as cited by (Almli *et al.*, 2005), with most of the mines concentrated on the Copperbelt Province of the country (Pettersson and Ingri, 2001). Due to the influence of mining activities, the Kafue River is threatened with degradation and probable loss of biodiversity (Kambole, 2003) owing to the fact that it originates and transects through this mining region (Ntengwe, 2005; Von der Heyden and New, 2005). Therefore, the main objective of this study was to address the potential risk from metal pollution sources in Zambia i.e. silver (Ag); cadmium (Cd); lead (Pb), uranium (U); aluminium (Al); vanadium (V); chromium (Cr); manganese (Mn); iron (Fe); cobalt (Co); nickel (Ni); copper (Cu); zinc (Zn) and arsenic (As) on the local environment and eventual risk to the local communities.

### 1.1. Study Area

Sampling was conducted in the dry season, from July to August, 2012 from four (4) locations along the Kafue River. These were the Copperbelt (12.5333° S and 27.8500° E); Mumbwa (14.9833° S and 27.0667° E) in Central; Mazabuka (15.8667° S and 27.7667° E) in Southern and Kafue (15.7667° S and 28.1667° E) in Lusaka Province. Water, sediment and fish samples were collected from each of the locations. The Copperbelt location is situated right within the mining region while Mumbwa is further downstream, located within the Kafue National Park and Mazabuka is sited in a highly active agricultural area; such as the Nakambala Sugar Estate. Kafue was the furthest location from the Copperbelt with historic industrial activities of the Kafue Town such as the Nitrogen Chemicals of Zambia. Distance separating the sites was as follows: with Copperbelt location designated as approximately 20km; Mumbwa = 300km; Mazabuka = 600km and Kafue = 650km away from mining region.



**Figure 1.1.:** Map of the Kafue River showing the four (4) sampling locations: <sup>1</sup>Copperbelt; <sup>2</sup>Mumbwa; <sup>3</sup>Mazabuka; <sup>4</sup>Kafue.

**Source:** adapted from <http://www.google.be/search?q=kafue+river+basin>

## 2. Study approach and methods

### 2.1. Sampling

**Fish** samples were bought from fish markets around each sampling locations. Eleven (11) (*Brycinus imberi*; *Clarias ngamensis*; *Hepestus odoe*; *Marcusenius Macrolepidotus*;

*Oreochromis andersonii*, *Oreochromis macrochir*; *Sargochromis codringtonii*; *Schilbe intermedius*; *Serranochromis angusticeps*; *Synodontis macrostoma* and *Tilapia rendalii*) were sampled (at least 3 replicates each). They were immediately kept in sterile polythene bags. In the laboratory, the fish were identified to species level using standard identification keys for freshwater fishes (Skelton, 2001). After identification, standard length was taken using ordinary 30cm ruler and finally the caudal fin was chopped using a clipper and stored in sterile polypropylene vials and labelled.

**Water** Samples were collected from the surface using a bucket. It was filtered into sterile polypropylene vials through Whatman No.1 filter paper and labelled.

**Sediments** were collected along the shoreline (approximately 50cm inshore and 10cm depth) using a shovel; small portion was transferred into sterile vials and labelled.

### **Storage and transportation**

From each sampling exercise, samples were first stored on ice in cooler boxes and then refrigerated to await transportation to the Ecophysiology Laboratory of the University of Antwerp, Belgium for analysis. In the laboratory, they were stored at -20 °C until the digestion process.

## **2.2. Laboratory Analysis**

### **2.2.1.Fish samples**

Samples were first defrosted then the wet weight noted before drying them in the oven to constant weight. As a quality control measure, certified reference materials were processed in the same manner as the samples. To each sample, 5mL high purity HNO<sub>3</sub> was added and left to digest for 48 hours. At the same time, five process blanks were prepared by adding 5mL HNO<sub>3</sub> to empty tubes. Samples were then transferred to the hot block (Environmental Express SC154) and cooked at 110°C for 30 minutes and then removed to cool for not less than 5 minutes. Thereafter, 0.25mL H<sub>2</sub>O<sub>2</sub> was added and returned to continue digesting on the hot block for another 30 minutes at 110°C. They were removed and left to cool to room temperature and then diluted with 40mL Milli-Q water. A further dilution (x4) was carried out by adding 6mL water to 2mL sample. At this point, samples were stored at room temperature; ready for metal analysis.

### **2.2.2.Sediment samples**

Samples were first defrosted and then transferred into clean (acid rinsed) porcelain dishes which were well labelled. They were then dried to constant weight in the oven at 110°C then ground using a porcelain motor to achieve homogenised samples. Certified reference material (sewage sludge amended soil, BCR-143R) was weighed in five replicates and prepared just like the samples. Approximately 0.2g of each sample was transferred to well labelled sterile vials to which 1.5mL HNO<sub>3</sub> and 4.5mL HCL were added and left overnight at room temperature. Five blanks were prepared in a like manner. Samples were then digested in a laboratory automated microwave - auto sampler (Discover SP, CEM Corporation, USA). They were left to cool to room temperature before diluting with 40mL Milli-Q water. A further dilution of 3x followed by adding 2mL of sample to 4mL Milli-Q water then kept at room temperature.

### **2.2.3 Water samples**

Samples were first defrosted by keeping them at room temperature overnight before acidifying to 3% with high grade HNO<sub>3</sub> and directly analyzed alongside a NIST standard (National Institute for standards and Tests) of the USA.

### **2.2.4.Metal Analysis**

All analyses were performed using a High performance resolution ICP-MS (ELEMENT XR, Thermo Fischer Scientific, Bremen, Germany). For calibration, both internal standard (Yttrium) and standard addition methods were used.

### 3. Results

#### 3.1. Correlation of Concentration in the Environment with Distance

**Table 3.1.** Correlation of metal concentrations in sediment/water with distance from mining region

Sediments vs distance			Water vs distance		
	r	p value		r	p value
Ag	-0.673	0.030	Ag	-0.748	0.013
Cd	-0.814	0.004	Cd	-0.688	0.028
Pb	-0.902	0.005	Pb	-0.296	0.407
U	-0.724	0.018	U	-0.686	0.029
Al	-0.585	0.076	Al	-0.828	0.015
V	-0.898	0.012	V	-0.686	0.029
Cr	-0.321	0.410	Cr	-0.384	0.273
Mn	-0.170	0.639	Mn	-0.485	0.156
Fe	-0.422	0.005	Fe	-0.183	0.614
Co	-0.529	0.148	Co	-0.913	< 0.001
Ni	-0.551	0.171	Ni	-0.823	0.054
Cu	-0.774	0.009	Cu	-0.925	< 0.001
Zn	-0.355	0.336	Zn	-0.863	0.001
As	-0.052	0.912	As	-0.598	0.068

#### 3.2. Metal Concentration in Fish

For analysis, fish species which occurred at more than two locations (*B. imberi*, *C. ngamensis*, *M. Macrolepidotus* and *S. angusticeps*) were employed.

**Table 3.2.** Correlating metal concentration in the fish with environmental concentrations

Fish - water correlation															
Fish_spp	Ag	Cd	Pb	U	Al	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	
<sup>1</sup> Spp_1	r_coef.	0.867	0.751	0.322	0.599	0.926	0.328	-0.188	0.779	0.451	0.703	0.684	0.680	0.000	0.070
	p_value	< 0.001	0.003	0.283	0.031	< 0.001	0.274	0.540	0.002	0.122	0.007	0.014	0.011	1.000	0.819
<sup>2</sup> Spp_2	r_coef.	0.529	0.104	0.190	0.791	0.522	0.128	0.399	0.336	0.312	0.627	0.290	0.703	0.146	0.395
	p_value	0.014	0.681	0.409	< 0.001	0.015	0.581	0.074	0.148	0.168	0.002	0.657	< 0.001	0.540	0.076
<sup>4</sup> Spp_4	r_coef.	0.559	0.802	-0.187	-0.566	0.882	0.263	0.584	0.636	0.751	0.712	0.700	0.597	0.636	0.649
	p_value	0.093	0.014	0.003	0.089	0.003	0.462	0.076	0.048	0.012	0.021	0.024	0.068	0.048	0.043
<sup>9</sup> Spp_9	r_coef.	0.332	0.945	0.945	0.842	0.902	0.386	0.352	0.902	0.936	0.713	0.902	0.498	0.241	0.177
	p_value	0.385	0.003	0.003	0.006	0.002	0.313	0.359	0.002	0.001	0.037	0.002	0.178	0.521	0.644
Fish - sediment correlation															
Fish_spp	Ag	Cd	Pb	U	Al	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	
<sup>1</sup> Spp_1	r_coef.	0.867	0.751	-0.740	0.599	-0.856	0.328	0.727	0.780	-0.643	0.516	0.042	0.680	-0.076	0.234
	p_value	< 0.001	0.003	0.009	0.031	< 0.001	0.274	0.005	0.002	0.018	0.071	0.898	0.011	0.805	0.441
<sup>2</sup> Spp_2	r_coef.	0.213	0.104	0.300	0.791	-0.052	0.128	0.240	0.336	0.146	0.628	0.086	0.703	-0.364	0.439
	p_value	0.353	0.681	0.195	< 0.001	0.822	0.581	0.296	0.148	0.527	0.002	0.712	< 0.001	0.105	0.046
<sup>4</sup> Spp_4	r_coef.	0.695	0.802	-0.187	-0.791	-0.320	0.764	0.264	0.636	-0.136	0.802	0.135	0.572	-0.905	0.379
	p_value	0.043	0.014	0.644	0.006	0.401	0.010	0.462	0.048	0.708	0.014	0.710	0.084	< 0.001	0.280
<sup>9</sup> Spp_9	r_coef.	0.769	0.945	0.945	0.842	0.945	0.816	0.283	0.902	0.576	0.970	0.644	0.498	-0.601	0.910
	p_value	0.021	0.003	0.003	0.006	0.003	0.011	0.463	0.002	0.108	< 0.001	0.067	0.178	0.097	0.001

<sup>1</sup> *B. Imberi*; <sup>2</sup> *C. Ngamensis*; <sup>4</sup> *M. Macrolepidotus*; <sup>9</sup> *S. angusticeps*

#### 4. Conclusion

For the studied metals, it is concluded that the mining activities on the Copperbelt are the main source of environmental pollution along the Kafue River. While the mines may be the primary source, there may also be other anthropogenic activities (such as agriculture, manufacturing industries as well as other less intensive mining activities and historical pollution) along the river catchment which may aggravate metal concentrations at specific sites. The study has confirmed that sediments are an important sink for metal pollutants in the Kafue River and constitutes a major source of bioavailable metals particularly for bottom dwelling species such as *C. ngamensis*. In view of non-consistence in trends with regards to environmental concentration

gradients, uptake/accumulation may be influenced by some site-specific differences in key physiochemical water parameters such as pH and organic matter content among others.

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