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Review

Analysis of heavy metals in soil and water systems of urban and semi-urban areas in Malawi: Insights from comparative research with other nations

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Growth of cities in developing countries comes with increasing transportation and industrial activities which may contribute to accumulation of heavy metals in the environment. This paper provides a review of studies on heavy metals in Malawi`s environment, their potential environmental impacts and possible removal methods with comparisons to other selected countries. The reviewed data from Malawi showed that in water samples, heavy metal concentrations were higher than World Health Organisation (WHO) and Malawi Bureau of Standards (MBS) safe limits especially in streams passing through industrial sites. Reports of heavy metals (especially Cu, Mn and Zn) showed that in industrial effluents, the individual levels of each of them were at least 6 times higher as compared to those in surface water bodies. In rivers there was accumulation of heavy metals (Cu, Cd, Cr, Fe, Mn, Pb, Ni and Zn) by algae whereby bioconcentration factors (BCF) ranged from 1.0 to 42 in some of the studies. Generally, metal levels in soils and selected organisms were much higher than those in water samples which further confirm possible accumulation. Since some aquatic organisms are consumed by humans, there is potential for the heavy metals to cause cancer and kidney damage. The studies done in Malawi compared well to those conducted elsewhere. The degradation of water resources by heavy metals compromises sustainability of water bodies and vital aquatic ecosystems hence negatively impacting on Integrated Water Resource Management (IWRM) efforts. This calls for periodic heavy metal monitoring and identifying ways of reducing their release into the environment.

Key words: Environment, heavy metals, pollution, public health, Malawi.

INTRODUCTION

Heavy metal pollution is a serious problem worldwide especially in areas with high anthropogenic pressures (Yeh et al., 2009; Nagajyoti et al., 2010). Heavy metals are toxic, resist degradation and tend to accumulate in organisms and also the environment (Ahmad et al., 2010; Abbas et al., 2014). In urban environment, the concentration of heavy metals tends to be higher than background levels especially in areas close to large industrial complexes (Sun et al., 2010; Wei and Yang, 2010) which could potentially pollute the environment especially soils and aquatic systems. In polluted aquatic ecosystems the transfer of metals through food chains can be high enough to bring about harmful concentrations in the tissues of aquatic organisms (Dallinger et al., 1987).The accumulation of metals in organisms in the environment is highly dependent on their availability for uptake by the organisms (Janssen et al., 1997), hence leads to health hazards on humans and wildlife (Li and Zhang, 2010). The health hazards of heavy metals include cancer, damage of internal organs and interference with vital systems of the body of organisms. Dietary exposure to heavy metals through the food chain is a risk to the health and wellbeing of organisms (Davies et al., 2006; Kachenko and Singh, 2006; Yi et al., 2011). In the environment, heavy metals have been implicated in the reduction of species diversity and population densities of organisms as was the case with freshwater mussels in North America (Naimo, 1995). Although all heavy metals have the potential to cause problems, however the main threats to human health are associated with exposure to lead, cadmium, mercury and arsenic (Jarup, 2003).

The release of heavy metals in the environment can be through industrial and household waste discharges, agricultural and mining activities (Akcay et al., 2003; Wuana and Okieimen, 2011; Zeitoun and Mehana, 2014). According to Clements et al. (2000), mining activities contribute to significant heavy metal pollution of streams as is the case in the Rocky Mountains (USA). In rivers, the concentration of heavy metals tends to be higher downstream mostly due to agricultural activities, industrial effluents and anthropogenic wastes (Begum et al., 2009). Generally, more than 90% of the heavy metal load is bound to particulates like suspended matter and sediments (Calmano et al., 1993). In soil solution, heavy metals can form hydrolysis species and complexes with inorganic ligands such as Cl^- and SO_4^{2-}. The importance of the hydrolysis species and inorganic complexes depends on pH and the concentration of metal and ligands (Weng et al., 2002). In urban environments, motor vehicles through emissions and tyre wear can also contribute to heavy metal pollution (Brown and Peake, 2006). This is in addition to run-off from informal settlements and industries which can contribute significant levels of heavy metals in surface water bodies (Binning and Baird, 2001).

The fact that heavy metals cause environmental problems and also they can come from multiple sources, calls for continuous studies of these environmental contaminants. In Malawi a number of studies have been conducted to determine the concentrations of heavy metals in different environments such as soils, aquatic organisms and aquatic environments such as streams, rivers, lakes and ponds among others. However, appraisal of data from such studies has been either scanty or insignificant. It is imperative to have meaningful understanding and assessment of heavy metal pollution in Malawi to ensure sustainable management of water resources and the environment in general. In this paper therefore, a review of heavy metal studies in soil and aquatic systems of urban and semi-urban areas of Malawi is provided. Furthermore heavy metal concentrations in environmental samples are compared to studies conducted elsewhere. The paper also provides recommendations on possible remediation methods based on the evaluated studies conducted in the same area.

THE STUDY AREA

This study desk reviewed data on heavy metals conducted in soil and aquatic systems of urban and semi-urban areas of Malawi (13.25°S, 34.30°E). Malawi is a landlocked country bordered by Mozambique to the east, south and west, Tanzania to the northeast and Zambia to the northwest. It has an estimated population of 16 million people. The major cities are: Blantyre (commercial city), Lilongwe (capital city), Mzuzu (only city in the north) and Zomba (old capital city) (Figure 1). Malawi`s economy is characterized by a high dependence on agriculture, a narrow industrial base and weak intersectoral linkages (FAO, Food and Agricultural Organization, 2003).

HEAVY METAL ANALYSIS METHODS

Analysis of heavy metals and trace elements in drinking water, sediment, soil, solid wastes and several other types of samples are performed using various methods and equipment. These heavy and trace elements include calcium (Ca), magnesium (Mg), Iron (Fe), potassium (K), sodium (Na), lead (Pb), zinc (Zn), copper (Cu), cobalt (Co), cadmium (Cd), nickel (Ni), chromium (Cr), molybdenum (Mo), arsenic (As) and manganese (Mn) (APHA, American Public Health Association, 1998).

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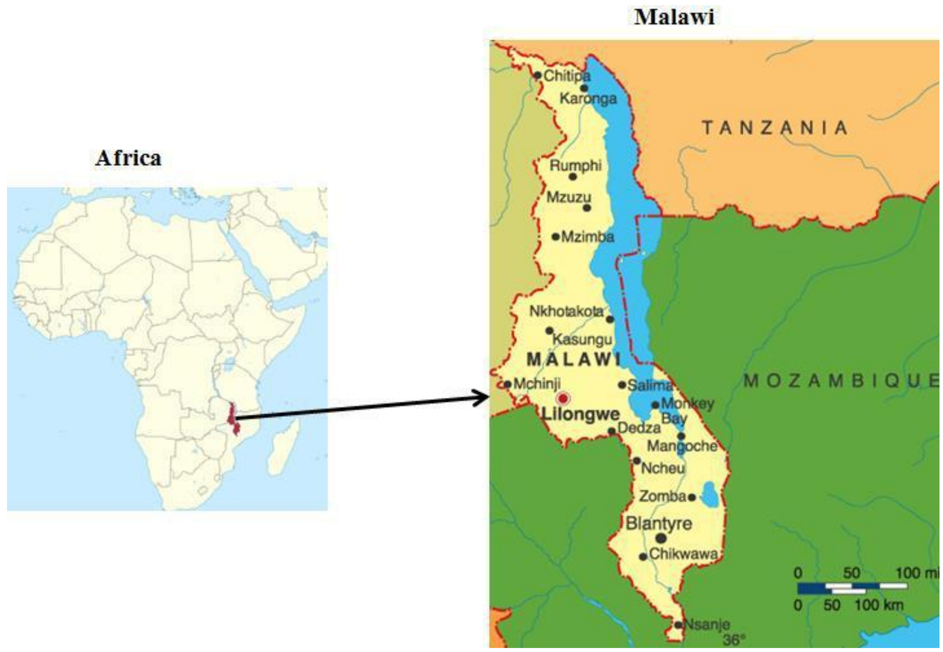

Figure 1. Map of Malawi showing cities and some major towns.

Instrumental analysis methods like *Atomic Absorption Spectrometry* (AAS), *Inductively Coupled Plasma-Mass Spectrometry* (ICP-MS), *Inductively Coupled Plasma-Atomic Emission Spectrometry* (ICP-AES), and *Inductively Coupled Plasma- Optical Emission Spectrometry* (ICP-OES) are commonly used for the determination of heavy metals in environmental samples (APHA, 1998; US-EPA, United States Environmental Protection Agency, 2000). Several factors are considered when selecting the type of method and instrument for analysis of heavy metals and trace elements. These factors include sample type, sample processing, instrument sensitivity or detection limit, sample throughput, matrices or spectral interference, concentration range, ruggedness, regulation requirements, time and cost (APHA, 1998). On one hand, the atomic spectrometry instruments (such as Flame *Atomic Absorption Spectrometry*-FAAS or *Graphite Furnace Atomic Absorption Spectrometry*-GFAAS) are the most common and reliable techniques for trace metal and metalloids analysis in environmental samples. On the other hand, the ICP-MS and ICP-OES are suitable for trace-metal content analysis in water and wastewater samples. In cases where maximum detection is essential, the ICP-MS method is preferable. The ICP-OES is more rugged such that it can easily analyze samples with higher total dissolved solids (TDS) content. However, elements like lead (Pb) and arsenic (As) are well analyzed using ICP-MS because of their low regulatory limit in drinking water (US-EPA, 2000). Acid digestion (acid or acid mixtures) are often employed to ensure metal elements are totally dissolved in liquid or leached from solid samples. To ensure best digestion results and minimum (spectral) interferences, selection of acids or acid mixture is paramount and this is also dependent on the analyte of interest to be analyzed among other factors (APHA, 1998; US-EPA, 2000). The US-EPA 2007 and 2008 methods are often used for water sample preparation and analysis while 3050B, 3051A, and 3052 methods (total digestion) are used for preparation and analysis of soils, solid waste and sludge samples (APHA, 1998; US-EPA, 1994, 1992). Trace elements and metals in solution are readily measured by flame (direct aspiration) AAS, a simple and rapid method applicable to a variety of environmental samples (water, industrial wastes, soils, sludge and sediments) This may be achieved by following a revised method 7000B (SW-846) by US-EPA (US-EPA, 2007). The EPA 2007 method may be used for multi-elemental and some non-metal analyses in solution using ICP-AES. The method is considered a consolidation of prevailing methods for water, wastewater, and solid wastes (US-EPA, 1994, 1992). The revised method 3050B by US-EPA (1996) is used for acid digestion of sediments, sludges, and soils. The method gives two distinct procedures for preparation of sediments, sludge and soil samples for heavy metals and trace element analysis by FLAA or ICP-AES and by GFAA or ICP-MS. Similarly, the US-EPA (1998) method 6020A describes the multi-elemental determination of analytes by ICP-MS in environmental samples including

Table 1. International and national drinking water standards for trace elements and heavy metals.

Parameter (mg/L)	WHO (2011)	US-EPA (2012)		MBS (2005)
		MCL (P)	MCL (S)	
Na^+	NA. *200	NA	30-60	100-200
K^+	NA			25-50
Mg^{2+}	NA	NA	NA	30-70
Ca^{2+}	*100-300	NA	NA	80-150
Fe^{3+}	NA	NA	0.30	0.01-0.20
Cu^{2+}	2.00	1.3	1.0	0.5-1.0
Zn^{2+}	Nh	NA	5.0	3.0-5.0
Pb^{2+}	0.01 (A, T)	0.015 (lead action level)	NA	0.01-0.05
Cr^{3+}	0.05 (P)	0.10	NA	0.005-0.010
Ni^{2+}	0.07	NA	NA	0.05-0.15
Mn^{2+}	0.40	NA	0.05	0.05-0.10
Cd^{2+}	0.003	0.005	NA	0.003-0.005
As	0.01 (A, T)	0.01	NA	
Hg	0.006	0.002	NA	
Ba	0.7	2.0	NA	
Al	0.90 (health-based value)	NA	0.05-0.20	

MCL maximum contaminant levels. (P): Primary which refers to health-related effects; (S): Cosmetic (skin or tooth discoloration) or aesthetic (taste, odor or color) effects. Nh: Not of health concern at levels found in drinking water. NA: Data not available. *taste threshold value. A, T: Provisional guideline value.

water and waste extracts or digests. The revised method 6010C, in contrast, is applicable for analysis of trace elements in solution using ICP-AES (US-EPA, 2000).

For protection of the environment, animal and human health and other species, stringent guidelines and regulations have been set in Europe, Japan, United States (US) and in many other countries around the world that call for greater precision in heavy metal and trace elements analysis (US-EPA, 1996; WHO, 2008). Regulatory bodies such as World Health Organization (WHO) and United States Environmental Protection Agency (US-EPA) set maximum contaminant levels (MCL) for various heavy metals and trace elements in drinking water sources. In Malawi, the maximum and allowable levels of contaminants in drinking water are set by the government institutions namely Malawi Standards Board and Malawi Bureau of Standards (MBS). Table 1 shows standards of selected heavy metals in drinking water by WHO (2011), US-EPA (2012) and MBS (2005).

HEAVY METAL STUDIES IN MALAWI

Studies in surface water samples

Table 2 show results of heavy metal studies conducted in Malawi and worldwide. In Malawi, Kaonga et al. (2008) assessed Cd, Mn and Pb in Blantyre City streams. These streams pass through industrial areas and also they are frequent recipients of raw sewage by virtue of broken sewer lines apart from farming activities taking place along their banks. The data show that Cd levels (0.07 to 0.111 mg/L) reported by Kaonga et al. (2008) were higher than those reported elsewhere. However, Mn (n.d-0.626 mg/L) and Pb (0.011 to 0.23 mg/L) concentrations found in the same study were within the range of similar environments reported elsewhere. In the same area, Kaonga et al. (2012) reported that concentrations of Cu, Fe, Zn, Cr and Ni were within the range reported elsewhere (Tables 1 and 2). Furthermore, these results, compared well with studies done in the same area by Sajidu et al. (2006) and Kumwenda et al. (2012). Another study done in Malawi by Chidya et al. (2011) on Likangala River, Zomba City reported maximum concentrations of Cd (0.05 mg/L) and Pb (0.71 mg/L) to be higher than those from other countries. However the values found for these analytes were lower than those found in Blantyre City as reported by Kaonga et al. (2008) and Kaonga et al. (2012). This is due to the fact that Blantyre City is a commercial and industrial capital of Malawi hence more activities which could lead to stream pollution. The sources of Cd in Blantyre City were mainly attributed to metal processing operations, phosphate fertilizers and deposition of metal products. It was also noted in the studies done in Blantyre City that in the dry season, the concentrations of heavy metals were generally higher than in the rainy season which was mainly attributed to dilution. On the other hand, a study

Table 2. Cd, Cr, Cu, Fe, Mn, Pb, Ni and Zn in surface water in Malawi as compared to other countries.

Metal	Conc. (ppm)	Area	Author
Cadmium	0.0001-0.001	Greece	Simeonov et al., 2003
	n.d-0.0013	Turkey	Turgut, 2003
	n.d	India	Singh et al., 2005
	n.d-0.015	Malawi	Sajidu et al., 2006
	n.d-0.00049	Turkey	Demirak et al., 2006
	n.d-0.01	Turkey	Karadede-Akin and Unlu, 2007
	0.07-0.111	Malawi	Kaonga et al., 2008
	0.001-0.003	India	Kar et al., 2008
	n.d-0.00004	Greece	Papafilippaki et al., 2008
	0.0024-0.0241	India	Suthar et al., 2009
	0.007-0.012	Bangladesh	Ahmad et al., 2010
	0.0003-0.006	China	Li and Zhang, 2010
	0.0004-0.04	India	Reza and Singh, 2010
	n.d-0.05	Malawi	Chidya et al., 2011
	n.d-0.02	Malawi	Kumwenda et al., 2012
	n.d-0.049	Malawi	Msika et al., 2014
Chromium	0.011-0.028	Turkey	Akcay et al., 2003
	0.001-0.018	Greece	Simeonov et al., 2003
	n.d-0.0026	Turkey	Turgut, 2003
	0.0007-0.1183	Iran	Diagomanolin et al., 2004
	0.001-0.0057	India	Singh et al., 2005
	0.013-0.479	Malawi	Sajidu et al., 2006
	n.d-0.0004	Turkey	Demirak et al., 2006
	0.001-0.044	India	Kar et al., 2008
	n.d-0.32	India	Begum et al., 2009
	0.0312-0.3309	Iran	Suthar et al., 2009
	0.489-0.645	Bangladesh	Ahmad et al., 2010
	0.001-0.005	Greece	Papafilippaki et al., 2008
	n.d-0.39	Malawi	Chidya et al., 2011
	n.d-0.419	Malawi	Kaonga et al., 2012
	0.10-0.46	Malawi	Kumwenda et al., 2012
Copper	0.010-0.013	Turkey	Akcay et al., 2003
	0.002-0.007	Greece	Simeonov et al., 2003
	n.d-0.01668	Turkey	Turgut, 2003
	0.0005-0.0703	Iran	Diagomanolin et al., 2004
	n.d	India	Singh et al., 2005
	0.010-0.046	Malawi	Sajidu et al., 2006
	n.d-0.0013	Turkey	Demirak et al., 2006
	0.011-1.3	Turkey	Karadede-Akin and Unlu, 2007
	0.003-0.032	India	Kar et al., 2008
	0.001-0.013	Greece	Papafilippaki et al., 2008
	0.00024-0.0016	Turkey	Kucuksezgin et al., 2008
	0.0024-0.0027	China	Yi et al., 2008
	0.03-1.12	India	Begum et al., 2009
	n.d-4.3725	India	Suthar et al., 2009
	0.107-0.201	Bangladesh	Ahmad et al., 2010
	n.d-0.046	China	Li and Zhang, 2010

Table 2. Cont'd.

	0.001-0.0047	India	Reza and Singh, 2010
	n.d	Malawi	Chidya et al., 2011
	n.d-0.076	Malawi	Kaonga et al., 2012
	0.04-0.12	Malawi	Kumwenda et al., 2012
	0.113-0.833	Greece	Simeonov et al., 2003
	0.034–0.117	India	Singh et al., 2005
	0.837-7.280	Malawi	Sajidu et al., 2006
	0.08-1.98	Malawi	Chavula and Mulwafu, 2007
	n.d-5	Turkey	Karadede-Akin and Unlu, 2007
	0.025-5.49	India	Kar et al., 2008
Iron	0.0013-0.687	Turkey	Kucuksezgin et al., 2008
	n.d-1.2474	India	Suthar et al., 2009
	n.d-0.086	China	Li and Zhang, 2010
	0.005-0.095	India	Reza and Singh, 2010
	n.d-10.25	Malawi	Chidya et al., 2011
	n.d-3.209	Malawi	Kaonga et al., 2012
	n.d-27.23	Malawi	Msika et al., 2014
	0.050-0.098	Turkey	Akcay et al., 2003
	0.045-0.291	Greece	Simeonov et al., 2003
	0.0013-0.0053	India	Singh et al., 2005
	0.045-0.747	Malawi	Sajidu et al., 2006
	n.d-3	Turkey	Karadede-Akin and Unlu, 2007
	n.d-0.626	Malawi	Kaonga et al., 2008
Manganese	0.025-2.72	India	Kar et al., 2008
	0.03-0.17	Turkey	Kucuksezgin et al., 2008
	n.d-1.25	India	Begum et al., 2009
	0.0017-0.8675	India	Suthar et al., 2009
	0.015-0.085	China	Li and Zhang, 2010
	0.0015-0.102	India	Reza and Singh, 2010
	n.d-2.73	Malawi	Chidya et al., 2011
	0.009-0.013	Turkey	Akcay et al., 2003
	0.002-0.012	Greece	Simeonov et al., 2003
	0.00149-0.01075	Turkey	Turgut, 2003
	0.041-0.1107	Iran	Diagomanolin et al., 2004
	0.009-0.017	India	Singh et al., 2005
	0.123-0.338	Malawi	Sajidu et al., 2006
	0.01-0.4	Turkey	Karadede-Akin and Unlu, 2007
Nickel	0.012-0.375	India	Kar et al., 2008
	0.00039-0.009	Turkey	Kucuksezgin et al., 2008
	0.05-5.25	India	Begum et al., 2009
	0.007-0.010	Bangladesh	Ahmad et al., 2010
	0.0001-0.006	China	Li and Zhang, 2010
	0.009-0.052	India	Reza and Singh, 2010
	n.d	Malawi	Chidya et al., 2011
	0.101-0.578	Malawi	Kaonga et al., 2012
Lead	0.020-0.048	Turkey	Akcay et al., 2003

Table 2. Cont'd.

	n.d-0.00313	Turkey	Turgut, 2003
	0.019-0.039	India	Singh et al., 2005
	n.d-0.116	Malawi	Sajidu et al., 2006
	n.d-0.0007	Turkey	Demirak et al., 2006
	n.d-0.05	Turkey	Karadede-Akin and Unlu, 2007
	0.011-0.23	Malawi	Kaonga et al., 2008
	0.001-0.250	India	Kar et al., 2008
	0.00059-0.0015	Turkey	Kucuksezgin et al., 2008
	n.d-0.013	Greece	Papafilippaki et al., 2008
	0.0301-0.9021	India	Suthar et al., 2009
	0.058-0.072	Bangladesh	Ahmad et al., 2010
	0.08-9.95	India	Begum et al., 2010
	n.d–0.026	China	Li and Zhang, 2010
	0.01-0.027	India	Reza and Singh, 2010
	n.d-0.71	Malawi	Chidya et al., 2011
	0.21-0.93	Malawi	Kumwenda et al., 2012
	0053-0.080	Turkey	Akcay et al., 2003
	0.020-0.157	Greece	Simeonov et al., 2003
	n.d-0.29392	Turkey	Turgut, 2003
	0.011-0.032	India	Singh et al., 2005
	0.123-0.630	Malawi	Sajidu et al., 2006
	n.d-0.0022	Turkey	Demirak et al., 2006
	0.04-5	Turkey	Karadede-Akin and Unlu, 2007
	0.012-0.37	India	Kar et al., 2008
Zinc	0.00019-0.0029	Turkey	Kucuksezgin et al., 2008
	n.d-0.142	Greece	Papafilippaki et al., 2008
	<0.001-0.0021	China	Yi et al., 2008
	0.000501-0.8364	India	Suthar et al., 2009
	n.d–10.70	India	Begum et al., 2010
	0.0004-0.0801	India	Reza and Singh, 2010
	n.d-0.14	Malawi	Chidya et al., 2011
	0.102-2.614	Malawi	Kaonga et al., 2012
	0.05-0.18	Malawi	Kumwenda et al., 2012

n.d: not detected.

done on water from geothermal springs in Nkhata Bay District, Northern Malawi by Msika et al. (2014) found the concentration of Fe (≤27.23 mg/L) to be higher than that found in surface water bodies in Malawi as shown in Table 2. Some of the geothermal spring samples had Fe concentration higher than WHO and MBS safe limits (Fe, 0.20 mg/L). However the concentration of Cd was within the range of that found in streams of Malawi. A study by Branchu et al. (2010) detected heavy metals at nanomolar concentration in Lake Malawi (Africa's second largest lake). It was noted in this study that the lake annual chemical budget showed that the northern watershed generates the main elemental input to the lake. The northern watershed of Lake Malawi is hilly and there are some mines (coal and uranium) which could potentially be contributing to heavy metals into the lake. Lake Malawi lies in a region of savanna and a sub-tropical forest (Brown et al., 2000). There was also a study by Chavula and Mulwafu (2010) in Likangala River catchment, Zomba, Malawi in which they detected Fe (0.08-1.98 mg/L). It was noted that this concentration of Fe did not pose any threat to human beings based on comparisons between this study and standards.

The heavy metal concentrations found in Malawi were comparable to those found elsewhere as indicated in Table 2. The highest concentrations of heavy metals recorded in water samples both in Malawi and elsewhere were for Fe. The sources of this metal are varied and include iron rich mineral soils and also industrial inputs. Also the issue of having streams that pass through industrial areas being polluted by heavy metals is not peculiar to Blantyre City alone. For example, a study done in India by Gaur et al. (2005), found that the River Gomti became highly polluted after passing through the city of Lucknow where it received industrial and domestic wastes through mainly drainage systems. The degradation of water resources by heavy metals in Malawi and other countries compromises sustainability of water bodies and vital aquatic ecosystems, hence negatively impacting Integrated Water Resource Management (IWRM) efforts.

Studies in industrial effluent

A study was conducted on effluent from a match stick factory in Blantyre, Malawi by Schutz (2013). In this study the concentration ranges were: 13.5 to 33.33 mg/L Cr, 438-3693 mg/L K and 7-3450 mg/L Zn. The concentrations of Cr and Zn exceeded the tolerance limits (0.05 mg/L Cr and 5 mg/L Zn) set by Malawi Bureau of Standards for wastewater.

Kuyeli (2007) analysed industrial effluents in Blantyre city, Malawi. In this study, the concentration ranges of heavy metals in industrial effluents were as follows: 0.002-0.005 mg/L Cd, 17.81-56.12 mg/L Cr, 0.026-2 mg/L Cu, 0.074-14.08 mg/L Fe, 0.001-9.01 mg/L Mn, 0.143-2.6 Pb, 0.07-1.11 Ni and 0.01-30.83 mg/L Zn. The concentration of heavy metals found in industrial effluents in this study, were at least six times higher than the corresponding levels in surface water bodies (streams) in the same area. It was generally observed that the effluents from industries in Blantyre City have a high potential of polluting surface water bodies and if they are not properly managed by good wastewater treatment systems, they could result in gross impairment of water quality of streams in Blantyre City.

Heavy metal studies in soils

A study by Kaonga and Monjerezi (2012) in river bank soils along streams that pass through industrial areas in Blantyre, Malawi, reported maximum concentrations of heavy metals to be as follows: Cd 0.18 mg/kg dw, Cr 8.19 mg/kg dw, Cu 10.13 mg/kg dw, Fe 82.82 mg/kg dw, Mn 31.43 mg/kg dw, Ni 4.32 mg/kg dw, Pb 3.49 mg/kg dw and Zn 17.45 mg/kg dw. In same study, the concentration of the heavy metals in soils was higher in dry season than in rainy season. This was attributed to the dilution effect. There are no established standards for heavy metals in soils in Malawi however a comparison with standards from other countries indicated that these values were lower than the maximum permissible limits of Europe and Canada (Bohn et al., 1979; Alloway and Ayres, 1997).

Lakudzala and Khonje (2011) found traces of Pb from soil sampled in Blantyre and also the ones bought in Indian shops (Indian soils). These soils are consumed by mostly pregnant women. The Pb concentration in this study ranged from 0.05 to 0.07 mg/g dw. The concentration of Pb in Indian soils was higher than that of Blantyre soils however both soils pose a health hazard to individuals who consume them.

In Zomba City, Malawi a study by Orvestedt (2015) on dumpsite soils, found the following ranges of heavy metals: 4-10 mg/kg dw Cd, 5 to 69 mg/kg dw Cu, 14700 to 17600 mg/kg dw Fe and 130 to 210 mg/kg dw Zn. In this study, the values found were compared to the Swedish Environmental Protection guideline values of 2009. The concentration of Cd exceeded these guideline values (0.5 mg/kg). This poses a potential danger to human health since the areas close to dumpsites are used for growing crops.

A study by Braun (2015) on agricultural soils close to a dumpsite and wastewater treatment facility in Zomba City, Malawi found the following concentration of heavy metals: 4-11 mg/kg dw Cd, 5-69 mg/kg dw Cu, 14693-17592 mg/kg dw Fe and 183 to 231 mg/kg dw Pb. In this study, it was noted that the concentrations of Pb were much higher than expected as such this study called for a more detailed risk assessment of the metals in the area.

Pollution of soils by heavy metals is a worldwide problem (Tandy et al., 2004) with reports available in several countries. According to Wei and Yang (2010), heavy metal pollution in urban areas of China has become serious with rapid industrialization during the last two decades. This is supported by a study done by Khan et al. (2008) in Beijin who found that irrigating crops with wastewater caused significant contamination of soils by heavy metals. A study by Guo et al. (2012) in Yibin City, Sichuan Province, China found that the concentration of heavy metals (As, Cu, Pb and Zn) were higher in the vicinity of industrial areas as compared to parks. A study by Jung and Thornton (1996) found high concentrations of Cd, Cu, Pb and Zn in the vicinity of a Pb-Zn mine as compared to uncultivated sites, household garden sites and control sites. In Italy (Naples city), a study by Imperato et al. (2003) found that many surface soils from the urban area as well as from the eastern industrial district contained levels of Cu, Pb and Zn that largely exceeded the limits (120, 100 and 150 mg kg1 for Cu, Pb and Zn, respectively) set for soils of public, residential and private areas by the Italian Ministry of Environment. Also a study done by Kalbitz and Wennrich (1998) in wetland soils of the Mulde River in the industrial district of Bitterfeld-Wolfen (Germany) found concentrations of up to 1100 mg kg^{-1} for Zn, 800 mg kg^{-1} for Cr and 364 mg kg^{-}

^{1} for Cu. It was further revealed in this study that there was heavy metal translocation from top to bottom soils. This may potentially pose as a threat to ground water resources. In another study done in Damascus, Syria by Moller et al. (2005), it was found that Cr concentrations of up to 1800 mg kg^{-1} were found near a tannery industrial estate. In a study conducted by Manta et al. (2002) on urban top soil in Palermo (Sicily), Italy the ranges of heavy metals found were as follows; 10 to 344 mg kg^{-1} Cu, 0.27 to 3.8 mg kg^{-1} Cd, 12 to 100 mg kg^{-1} Cr, 57 to 2516 mg kg^{-1} Pb, 142 to 1259 mg kg^{-1} Mn, 7 to 38.6 mg kg^{-1} Ni and 52 to 433 mg kg^{-1} Zn. It was noted in this study that vehicular traffic was the main contributor of heavy metal pollution in this urban area. Another study that noted the contribution of vehicular traffic to heavy metal pollution was that done by Jaradat and Momani (1999) on a major highway connecting Amman with the Southern parts of Jordan. In that study, the concentrations of Cu, Cd, Pb and Zn were 29.7, 0.75, 188.8 and 121.7 µg g^{-1}, respectively 1.5 m east of the highway. It was further noted that the concentrations of the heavy metals dropped to background levels 60 m from the highway. Also Chen et al. (2005) in a study on 30 urban parks in China found that the maximum concentrations of Cu, Ni, Pb and Zn were 457.5, 37.2, 207.5 and 196.9 mg kg^{-1}, respectively. Further review of these concentrations pointed to the fact that they were contributed by vehicle traffic saves for Ni which was based on background levels. Anthropogenic activities can have a significant contribution to heavy metal pollution in soils as was seen in a study done by Chen et al. (1997) in Hong Kong. In that study, it was noted that while the concentrations of Cd, Cu, Pb and Zn in a forest (Country Park) were 0.697, 11.7, 45.7 and 44.6 µg g^{-1}, respectively; those of Cd, Cu, Pb and Zn in an industrial area were 1.31, 26.1, 87.7 and 62.8 µg g^{-1}, respectively. According to Sun et al. (2010), the modernization of industry and the presence of intensive human activities in urban areas have exacerbated the problem of heavy metal contamination in soils. This is because soils serve as both sinks and sources of heavy metal contaminants in the terrestrial environment. Excessive accumulation of heavy metals in urban soils may result not only in heavy metal contamination of the soils but also an increased exposure for human beings. In actual fact, the environmental risk of heavy metal pollution is pronounced in soils adjacent to large industrial complexes (Wang et al., 2007) which in most cases are located in urban areas.

Also when wastewater is used to irrigate crops, heavy metals tend to accumulate in soils. This was noted in a study by Mapanda et al. (2005) who found that the heavy metal concentrations (mg kg^{-}1) in soils ranged from 7.0 to 145 for Cu, 14 to 228 for Zn, 0.5 to 3.4 for Cd,<0.01 to 21 for Ni, 33 to 225 for Cr and 4 to 59 for Pb. It was concluded that the use of wastewater in urban horticulture enriches soils with heavy metals to concentrations that may pose potential environmental and health risks in the long-term.

Other studies on heavy metals in Malawi

Kaonga et al. (2008) studied Cd, Mn and Pb in algae, *Spirogyra aequinoctialis* in Blantyre City streams, Malawi. The maximum reported concentrations were: 0.91 mg/kg dw Cd, 16.13 mg/kg dw Mn and 0.97 mg/kg dw Pb. In a related study, Kaonga and Monjerezi (2012) found that the maximum heavy metal concentrations in *S. aequinoctialis* in the same streams were: 0.66 mg/kg dw Cr, 2.30 mg/kg dw Cu, 96.64 mg/kg dw Fe, 0.42 mg/kg dw Ni and 6.19 mg/kg dw Zn. These studies noted that *S. aequinoctialis* accumulated heavy metals from water. The bioconcentration factors (BCF) ranged from 1 to 42. Also Kaonga and Monjerezi (2012) determined the concentration of heavy metals in earthworms (*Apporectodea icteria*) found along the streams of Blantyre City, Malawi. The maximum concentrations were: 9.62 mg/kg dw Mn, 0.55 mg/kg dw Cd, 0.92 mg/kg dw Cu, 63.73 mg/kg dw Fe, 5.27 mg/kg dw Zn, 0.80 mg/kg dw Pb, 0.03 mg/kg dw Cr and 0.93 mg/kg dw Ni. This study noted that it was only Cd that was accumulated by *A. icteria* from stream soils therefore this organism cannot be used as a biological indicator for general heavy metal pollution in soils.

In another study done in Blantyre City, Kaonga and Monjerezi (2012) reported the concentrations of heavy metals in sewage sludge and sludge worms (*Tubifex tubifex*) sampled at Zingwangwa Wastewater Treatment Plant. The maximum concentrations on dry weight basis (in sludge and (*T tubifex*)) were: 2.31 mg/kg (2.18 mg/kg) Cd, 120.1 mg/kg (4.7 mg/kg) Cu, 22.4 mg/kg (0.95 mg/kg) Pb, 2301 mg/kg (3.69 mg/kg) Mn, 361.5 mg/kg dw (82.2 mg/kg) Zn. This study noted that *T. tubifex* did not show the ability to accumulate heavy metals (attributed to its high defecation and metabolic rate) except for Cd hence cannot be used as a bioindicator for general heavy metal pollution in sludge.

Ngonda (2014) assessed Pb, Cd, Mn, Zn, Cr, Cu and Fe in medicinal plants (*Trichodesma zeylanicumm, Securidaca longepedunculata and Vernonia glabra*) sampled from Zomba City and Machinga districts. Although all the heavy metals were detected in this study, however it was only in *S. longepedunculata* that the concentration of Cr exceeded the World Health Organization (WHO) permissible limit (Cr, 2.76 ppm).

A study on the concentration of heavy metals in cabbages irrigated with reservoir and tap water by Mumba et al. (2008) found the range of concentration to be as follows; 1.01-0.16 mg/L Cd, n.d -0.12 mg/L Pb and 0.05-0.09 mg/L Cr. In the same study, the concentrations of heavy metals irrigated with reservoir and tap water were; 0.71-1.25 mg/L Cd, 0.21-0.67 mg/L Pb and 0.11-0.12 mg/L Cr. In this study, it was shown that using contaminated water can increase the intake of heavy metals by vegetables. This is because the abundance of the heavy metals in the vegetables was related to the amounts in the water. The potential danger posed by heavy metals in agriculture is not only limited to the use of contaminated water and contamination of crops but also sludge. In a study done by Fliebbach et al. (1994) in Germany, it was found that sewage sludge contaminated by heavy metals (when added to agricultural soils) lowers both soil microbial biomass and microbial activity. The disturbances caused by heavy metals to microbial biomass and activity are known to be reflected in decreased litter decomposition and subsequently less-efficient soil nutrient cycling (Kandeler et al., 1996; Pennanen et al., 1996).

Remediation strategies

According to Alkorta et al. (2004), phytoremediation, an emerging cost-effective, non-intrusive, and aesthetically pleasing technology, that uses the remarkable ability of plants to concentrate elements and compounds from the environment and to metabolize various molecules in their tissues, appears very promising for the removal of pollutants from the environment. The plants that have been identified to be hyper accumulators of heavy metals are as follows (metal is put in brackets): *Thlaspi caerulescens* (Zn and Cd), *Berkheya coddii* (Ni), *Astragalus racemosa* (Se), *Iberis intermedia* (Tl), *Ipomoea alpine* (Cu), *Haumaniastrum robertii* (Co) and *Pteris vittata* (As). Although the natural propensity of plants to take up metals serve as a tool for phytoremediation, on the other hand it is a drawback to human health especially when contamination (by heavy metals) of food crops is too high (Evangelou et al., 2007).

Studies on remediation strategies in Malawi mostly used Moringa species. These studies include the one done by Robertsson (2014) who conducted a study on the possibility of *Moringa oleifera* seed powder to remove Cr from wastewater collected from Liwonde Tannery, Malawi. The study found that a combination of 5 g of river sand and 2 g of unpeeled *M. oleifera* seed powder was able to remove 72 and 97% of total and dissolved Cr, respectively in 100 mL of wastewater. This study showed that *M. oleifera* has a potential as a natural Cr removal agent that can be applied in many developing countries at a low cost. Another study was that done by Mataka et al. (2006) who showed that *M. stenoptala* and *M. oleifera* were able to remove Pb from water. In this study, it was shown that *M. stenoptala* was more effective than *M. oleifera*. In fact, with an initial dosage of 7ppm Pb in water, *M. stenoptala* seed powder (dosage 2.5 g/100 mL) was able to remove 96% Pb. The study further showed the great potential of low cost methods in remediation of heavy metals especially in developing countries like Malawi.

Studies done in other countries have indicated other potential methods which can be used in the removal of heavy metals. For example, a study by Yantasee et al. (2007) in USA found that superparamagnetic iron oxide (Fe_3O_4) nanoparticles with a surface functionalization of dimercaptosuccinic acid (DMSA) are an effective sorbent material for metals and some metalloids such as As, Hg, Ag, Pb, Cd, and Tl, which effectively bind to the DMSA ligands and the iron oxide lattices. In another study conducted in Italy by Marchiol et al. (2004) *Brassica napus* and *Raphanus sativus* showed some potential in the removal of heavy metals in marginally polluted soils. However, these species showed relatively low phytoremediation potential in soils contaminated with many heavy metals. In another study done by Bech et al. (1997) on a copper mine in northern Peru, unusually high concentrations of metals were detected in *Bidens cynapiifolia* of up to 1430, 437, 620 and 6510 $\mu g g^{-1}$ for As, Zn, Cu and Al, respectively. Although this study was mainly on the assessment of heavy metal concentrations in the mine area, on the other hand it revealed the potential of *B. cynapiifolia* to accumulate heavy metals. In a study done by Meers et al. (2005) in Belgium, ethylene diamine tetraacetate (EDTA) and ethylene diamine disuccinate (EDDS) showed great potential to mobilise Cd, Cu, Pb, Ni and Zn from soils for easy uptake by plant shoots (*Helianthus annuus*). Another study done in Aznalcollar (Spain) by Clemente et al. (2005), found that *Brassica juncea* had the potential to accumulate Cu, Pb and Zn from soils especially at low pH levels. However, it is important to upscale these methods which are mostly laboratory based into full scale operations so as to remediate heavy metals in the environment.

CONCLUSION

Heavy metals especially Cd, Cr, Cu, Fe, Mn, Pb, Ni and Zn have been reported in Malawi in mainly water and soils. In most cases, the soils in urban areas especially those close to dumpsites have been found to be the most contaminated. Also surface water bodies seem to be contaminated by mostly industrial effluents. This is because studies in streams in Malawi, have shown that high concentrations of heavy metals are prevalent after they have passed though industrial areas. The results in Malawi compare well with studies done elsewhere in that urban streams and soils are mostly polluted by anthropogenic activities. In aquatic systems, studies have shown the potential of algae and earthworms to be used as biological indicators of metal pollution. On the other hand, sludge worms have high metabolic and excretion rates as such not good indicators of metal pollution.

Among the remediation strategies proposed, Moringa species have been favoured in the removal of heavy metals especially from water. These are also cheap since they are available locally. There is a need therefore for aggressiveness to environmental monitoring by relevant bodies both in Malawi and its region so that laboratory based methods should be upscaled (especially in developing countries) in remediation strategies for proper integrated water resources management.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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