

# An Overview of Heavy Metal Pollution in the Western Indian Ocean (WIO) region of Kenya: A Review

Nyamora Moraa Jane<sup>1,2\*</sup>,  Njiru James<sup>1</sup>,  Nyakeya Kobingi<sup>2,3</sup>, Getabu Albert<sup>2</sup> and  Muthumbi Agnes<sup>4</sup>

<sup>1</sup>Kenya Marine and Fisheries Research Institute (KMFRI), Mombasa Headquarters, P. O. Box 81651, Mombasa, Kenya

<sup>2</sup>Kisii University, Faculty of Agriculture and Natural Resource Management, P. O. Box 408-40200, Kisii, Kenya

<sup>3</sup>Kenya Marine and Fisheries Research Institute (KMFRI), Baringo Station, P. O. Box 31, Kampi ya Samaki, Baringo, Kenya

<sup>4</sup>University of Nairobi, School of Biological Sciences, P. O. Box 30197-00100, Nairobi, Kenya

## Abstract

This study is a review on heavy metal pollution in the Western Indian Ocean (WIO) region of Kenya. The review examines heavy metal pollution of copper, lead, cadmium, iron and zinc that are toxic to marine life and human health; and identifies gaps for future monitoring and assessment. Each pollutant was addressed in order to determine their status in the environment, sources and their effect on biological systems, marine organisms, and human health. Although the concentration levels of these metals are still low and within the recommended standards of global regulating bodies, there is little information in relation to their effects along the food web, human health and how they affect the population dynamics of fish species. Apart from regular monitoring and assessment further research on their effects in the food web and an assessment of human health is recommended.

**Keywords:** Heavy metals, WIO region of Kenya, biomagnification, human health, monitoring and assessment

**Correspondence:** [janenyamora8@gmail.com](mailto:janenyamora8@gmail.com)

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## Introduction

Heavy metals are ubiquitous in most aquatic ecosystems. Although they are required by plants and animals in a certain proportion for growth and development, they can be considered pollutants of serious menace to the living biota (Frayssé et al. 2006; Bervoets et al. 2005) in the aquatic environment if present in concentrations beyond background levels. Some of the heavy metals known to be important metabolically for aquatic organisms especially fish include copper, iron and zinc. On the other hand, however, such heavy

metals as mercury (Hg), lead (Pb), cadmium (Cd), and other metals have no known functions in the biological system of fish.

Marine environmental pollution as a result of heavy metals is a global phenomenon (Bryan 1976; Ober et al. 1987). Further, the situation is exacerbated by the non-biodegradable nature of these metals and the ability of marine ecosystems to bioaccumulate and biomagnify some metals within food chains (Watling 1983). They cause major environmental challenges because of their toxic nature, persistence, non-

biodegradable and bioaccumulation properties (Bervoets et al. 2005; Verhaert et al.

2013). The concentration of heavy metals in water and sediments make it accessible to marine

organisms, such as filter feeders, to take them up through their digestive systems. The filter feeders are consequently fed on by fish, which are eventually consumed by man as food thus posing potential human health risk (Sankar and Ashok Kumar 2014). Bioaccumulation of metals, therefore, increases within the food chain and exposure to them can cause irreversible health disorders in aquatic organisms including man, and can degrade the ecological quality of the environment.

Different factors are at play when it comes to the distribution and occurrence of metal pollution in aquatic ecosystems. Their presence and solubility in the aquatic environment is as a result of complex and ever changing physicochemical processes and factors (Lalah et al. 2008). While in the aquatic environment, they exist as inorganic and organic particulates in the sediments that act as sinks which leads to elevated levels (Liu et al. 2009; Ochieng et al. 2007). Any form of perturbation of the substratum will therefore result in metal remobilization that may lead to their release back to the water column thereby affecting aquatic fauna and flora (Liu et al. 2009). Their continued increase in the aquatic ecosystems globally is mainly due to anthropogenic activities although natural deterioration of soils and rocks can contribute to their bioavailability (Mdegela et al. 2009; Reichnberger et al. 2007).

Bioavailability and absorption of metal compounds by aquatic organisms depends on their solubility properties (Jadhav 2010). These pollutants enter the food web through direct uptake of water through the gills and skins or when fish consumes aquatic organisms such as

zooplankton, phytoplankton and benthic fauna and the pollutant may accumulate in edible fish in aquatic ecosystem. The bioavailability of metals in organisms at the base of the food webs is biomagnified at higher trophic levels (Bard 1999). Also, water pH can cause acidic conditions of aquatic environment by releasing free divalent ions of many heavy metals to be absorbed by fish gills (Part et al. 1985).

Fish has been used in toxicological studies as indicators of contamination in aquatic environments, because they are top consumers and they biomagnify pollutants in their tissues posing a potential risk to man who depend on it as food (Bervoets and Blust 2003). Accumulation of pollutants in various fish tissues is therefore used as a measure of exposure and effect (Evans et al. 1993) with higher accumulation of pollutants being found in demersal compared to pelagic fish. This is because demersal fish are in direct contact with polluted sediments that has high concentrations of contaminants and through feeding on benthic organism (Yi et al. 2011; Anandkumar et al. 2018). However, many studies on metal pollution have not been conducted on fish because of its sensitivity to pollution but by virtue of fish and fisheries products being an essential component of human food (Mitral et al. 2000; Sankar et al. 2006; Sivaperumal et al. 2007; Prabhu Dass Batvari et al. 2008; Uysal et al. 2008; Akan et al. 2012; Kumar et al. 2012; Prabhu Dass Batvari et al. 2012; Elnabris et al. 2013; Heidarieh et al. 2013; Javed and Usmani 2013; Murthy et al. 2013; Usha and Vikram Reddy 2013; El-Moselhy et al. 2014; Velusamy et al. 2014; Kulawik et al. 2016).

**Table 1:** Minimum allowable limits (ppm/mg/kg) of common heavy metals in fish as set out by different regulatory bodies/countries

Body/Country	Heavy metals				Reference
	Cd	Cu	Zn	Pb	
FAO	0.005	30.0	30.0	0.5	FAO (1983)
FAO/WHO	0.5	30.0	100.0	0.5	FAO/WHO (1989)
European Commission	0.5	-	30.0	0.3	EC (2008, 2014)
FSSAI	0.3	-	-	0.3	FSSAI (2015)
FDA for crustaceans	3.0	-	-	1.5	FDA (2001)
Codex Stan	2.0	-	-	0.3	Codex Stan (1993-1995)
Turkey guidelines	0.1	20.0	50.0	1.0	Dural et al. (2007)
England	0.2	20.0	50.0	2.0	MAFF (2000)

In the Western Indian Ocean (WIO) region of Kenya extensive research on metal pollution has been conducted. Most of the studies have

reported on the general occurrence, distribution in

sediments and water (Oteko 1978; Onyari 1985; Everaarts and Nieuwenhuize 1995; Okuku et al. 2012, 2010). Despite discovery of high levels of toxic heavy metals (particularly cadmium and lead) in seafood and other living organisms in the Kenya Coast (Oteko 1987; Onyari 1985; McConchie et al.

1988) little has been reported in terms of their occurrence and how they affect organisms in the food chain. Data and information on human health assessment and the risks associated to the consumption of infected fish by heavy metals is also lacking. Because such heavy metals as Cu, Zn, Cd, Fe and Pb are the most common metals that have been reported to contaminate seafood products and their allowable minimums recommended by different world regulating bodies (Table 1), this review zeroed on these metals. This study therefore, reviews studies undertaken in the Kenyan Coast on heavy metal pollution (i.e. Cu, Zn, Cd, Fe and Pb) to identify gaps for future studies and monitoring.

### **Studies on heavy metals (i.e. Cu, Zn, Fe, Cd and Pb) in the Kenya Coast**

#### **Copper**

Copper is known to play an essential role in human body (Demirezen and Uruc 2006). It is an essential mineral in that assists the body to produce blood cells, acts as a catalyst in the production of iron to form haemoglobin, and also in the strengthening of bones. If consumed in excess, however, can result in human health complications and in some cases it can be fatal. According to FAO (1983) 30 ppm of copper is the maximum permissible limit. Consequently, its regular monitoring in the environment is key.

Copper has been studied in the WIO region of Kenya by many researchers. In their findings Munyao and Maritim (2013) who studied the assessment of trace metals in sediment and water from Sabaki River Mouth, Kenya reported elevated levels in the sediments during the dry season compared to all the sampled stations in the Athi-Sabaki river mouth where the highest mean of 8.33g/kg was observed at the last point to the ocean while 0.38 g/kg was recorded at the furthest station upstream. Similar results were documented during the wet spell but in low levels (below 0.5 g/Kg for all the stations). Therefore, their results confirmed variations in copper levels in sediment in both seasons an indication of different sources of copper pollution in sediments during dry and wet seasons. However, there were no significant differences ( $p = 0.773$ ) that were observed in water, in both dry and wet seasons. In terms of their distribution, copper levels increased downstream towards the estuary during the dry season. Similarly, they reported that copper levels did not differ significantly ( $p = 0.773$ ) between the sediments and water during both seasons.

In another study conducted by Kamau (2001) in which he compared three different

ecological zones in Mombasa namely Makupa creek (a dumping site), Kilindini creek (harbor) and Likoni (undisturbed), high concentrations (i.e. 114  $\mu\text{g/g}$  dry weight) of Cu in sediments at Makupa creek compared to those measured at the Kilindini creek were recorded. He attributed this to poor flushing of water that favoured the trapping of pollutants. In a similar study conducted by Maritim et al. (2016) on speciation of trace metals Pb, Zn, Cu and Cd in superficial sediments from Makupa Creek Mombasa, Coastal Kenya, Cu was reported to have originated from urban runoff and is in most cases organically bound in the sediments (Muohi et al. 2003; Ramirex et al. 2005).

In a study on metal bioaccumulation from Fort Jesus Mombasa, copper was found to be high in *Acanthopleura gemmata* and was attributed to high usage in the organism (Swaleh et al. 2016).

#### **Zinc**

Zinc is an essential element that plays an important role in human health by disintegrating macromolecules in food eaten by man. It is also a crucial enabler in healing wounds. It forms part of human cells, enzymes, and cofactors hence one of the most important trace and microelements for the human body (Demirezen and Uruc 2006). Its persistent concentration in the environment can find itself in human body through food chain magnification thus causing health challenges. Its regular monitoring in the environment is important.

High levels of Zn have been reported at Makupa Creek, Mombasa Kenya (Kamau 2001; Maritim et al. 2016). Its presence has been attributed to leaching from Kibarani Dumpsite situated at the shore of the creek and urban effluent discharge from Maritini area. This was associated also with the Fe-Mn oxides Maritim et al. (2016), which have high stability constants than carbonates (Abdallah 2007). Elsewhere, elevated concentration levels of Zn bounded on Fe-Mn oxides have been associated with polluted sediments (Yuan et al. 2004; Singh et al. 2005). The highest concentration level recorded by Kamau (2001) was 1429  $\mu\text{g/g}$  dry weight and was linked with the then Kibarani municipal dumping site [53].

In Munyao and Maritim (2013) study on the contribution of Sabaki River in trace metals in Malindi Bay, high levels of zinc were witnessed in sediments during the wet season. Temporal variations were therefore observed between the seasons. In water, however, they observed low levels in both seasons hence there were no significant differences ( $p=0.594$ ) in temporal variations recorded.

### **Cadmium**

Cadmium has no known essential role in marine organisms including fish. It is toxic with no meaningful biological activity in man. It can therefore be passed to human beings via the consumption of seafood and cause serious health complications (Velusamy et al. 2014). Cd has been studied in different stations and media along the Kanya coast (Kamau 2003, 2001; Mwashote, 2003; Muohi et al. 2005, 2003; Okuku et al. 2011; Munyao and Maritim 2013; Maritim et al. 2016). Below detectable levels to 1.14 g/kg were recorded in sediments during the wet season whereas detectable to 0.12 g/kg levels were reported in the dry season (Munyao and Maritim 2016). Low levels were, however, recorded in water temporary, with slightly elevated levels occurring during the dry seasons. According to Kamau (2001), Cadmium concentration levels did not display distinct trends between the sampled stations along Kilindini and Makupa creeks, Mombasa Kenya. Of significance here, is that whatever results he reported, they were similar with those observed by Munyao and Maritim (2016). Cadmium levels at Makupa Creek, Mombasa have also been reported to be below the detection limits (Muohi et al. 2003; Maritim et al. 2016).

In an assessment of levels of cadmium and lead in water, sediments and selected fish species in Mombasa, Kenya Mwashote (2003) reported cadmium concentration levels in water below detectable limits. Concentration levels in the sediments on the other hand ranged from not detectable to 1.0 mg/kg whereas in fish they ranged from not detectable to 3.7 mg/kg. The elevated levels occurred mainly during the rainy season. Although the findings of Mwashote (2003) are comparable with other studies undertaken in the same area (e.g. Onyari 1985; Oteko 1987; Kamau 2001), his findings were much lower. This could probably be due to differences in laboratory analytical procedures as well as the exact locations of the sampling sites. However, the recorded high concentration levels of Cd in the samples compared to water and sediment samples could easily explain the effect of biomagnification of heavy metals in the trophic structure. Of paramount in Mwashote (2003) findings is that the concentration levels in fish were within the FAO (1983) food regulatory standards.

An assessment study of heavy metal bioaccumulation in marine biota from Fort Jesus Mombasa, Kenya was conducted by Swaleh et al. (2016). The authors investigated heavy metals in *Acanthopleura gemmata*, algae, sediments and

water. Cd was one of the metals investigated and found to be of high concentrations in both flesh and shell samples of *A. gemmata*. The flesh samples recorded the highest concentration levels of 13.92 µg/g compared with the allowed limits by WHO of 1 µg/g on edible shell fish (FAO/WHO, 1984). High concentration levels of some heavy metals can cause mortalities, stunted growth, respiratory problems and muscle dysfunctions in organisms [43]. Metals such as Cd accumulate in high quantities in the liver and kidney of aquatic organisms (Chiarelli and Roccheri 2014).

### **Iron**

Iron is an abundant metal in the earth's crust it is also bonded in sediments. In their study (Swaleh et al. 2016) observed elevated levels of Fe in the water, algae and sediment samples along Fort Jesus Mombasa. As much as iron can be abundant in the earth's crust, it is also readily bonded in sediments. It can also be washed from different points such as farms and rock quarries via surface run off during spates (Adu 2010). Municipal wastes from Mombasa old town and its environs are disposed of near Fort Jesus. The elevated concentrations therefore could also be due to municipal waste disposal.

According to Munyao and Maritim (2016) high concentration levels of iron in sediments is likely to occur upstream in rivers during the wet season than during the dry season. This is according to their study on the assessment of trace metals in sediment and water from Sabaki River Mouth, Kenya. They explained this occurrence to be indicative of possible control of geology. Another possible reason is as a result of surface runoff from point and non-point sources (Adu 2010).

In a study conducted by Kamau (2002) on heavy metal distribution and enrichment at Port-Reitz Creek, Mombasa Kenya, very high concentration levels (32,260 µg/g dry wt) of iron were reported towards the harbor of Mombasa port. Such a trend was attributed to some ships undergoing repair and, in the process, chipping off of the corroded parts before painting. In other sampled stations within the Port-Reitz, low levels were observed and were attributed to anoxia which emitted smells of hydrogen sulphide resulting to the dissolution of hydrated manganese oxide (Förstner and Patchineelam, 1976).

### **Lead**

Lead has been documented to occur in fish along the coast of Kenya. According to Mwashote (2003) concentration levels ranging

between no detectable to 18.5 and not detectable to 58.3 mg/kg wet weight, for muscle and gill tissues of fish respectively were recorded in Makupa and Tudor creeks, Mombasa Kenya. Samples with elevated concentration levels in water and sediments corresponded with those in fish. These levels were associated with anthropogenic activities such as dumping of municipal waste at Kibarani dumpsite, Mombasa Port and the meat-processing factory, Kenya Meat Commission.

Maritim et al. (2016) observed high levels of Ld of 31.5 µg/g at Makupa creek, Mombasa that was attributed to formation of stable complexes with Fe and Mn oxides [54]. High levels of Ld bounded on Fe and Mn oxides have been cited by Turki (2007) and Peng et al. (2004). However, the major sources of lead into the environment around Makupa Creek is from the point source pollution from Mombasa harbor and traffic crossing Kibevu bridge.

#### Health risk assessment

Metal pollution is a potential human health risk. Therefore, linking metal pollution and human health is important. In spite of this, there is data and information paucity in relation to the specific effects of metal environmental contaminants on human health in the WIO region of Kenya. Based on the current review, there is hardly any information on metal pollution effects on human health. In order to come up with a sound monitoring programme in the WIO region of Kenya, we recommend here that goals be set in the evaluation of health risk associated with metal pollution. In addition, while setting out these goals the following ought to be taken into account as recommended by Freije (2014):

- Identify major health problems that result from all sorts of pollution.
- Develop monitoring and surveillance programs for affected communities.
- Establish regional management plans in corporation with international authorities.
- Adopt effective control measures that involve local and international cooperation.
- Utilize available research knowledge in formulating legislation, and regulation.
- Gather extensive and effective research and baseline information.
- Identify objectives, classify issues and formulate management plans.

#### Conclusions and recommendation

The high levels of metal contaminants (Pb, Cu, Zn) in the environment in most parts of Kenyan coast depict a high possible human health risk that may

be associated with the consumption of seafood. This is evident from the studies that were undertaken at Kilindini, Makupa, Port Reitz, Mtwapa and Shirazi creeks along the Kenyan coastline (Kamau 2001; Muohi et al. 2003; Muohi et al. 2005), which clearly demonstrated the presence of trace metals. The significance of bioaccumulation and transfer of contaminants in the food chain is poorly understood in the Kenya Coast. Although Okuku and Peter (2012) on their study on choose of heavy metals pollution biomonitors: a critic of the method that uses sediments total metals concentrations as the benchmark indicated that *Ulva lactuca* efficiently bioaccumulated Cd and Cu whereas *Sargassum* spp. bioaccumulated Al, Co, Cr, Fe and Mn, there isn't much information on how these metals are transferred to fish that happen to be on the apex of the food chain. The effects of long-term stress on marine organisms, especially fish, and their ability to adapt to chronic stress of heavy metal pollutants, is a critical factor in the management of point and non- point source discharges. There is therefore a need for the development of laboratory test systems to evaluate chronic stress. Efforts should concentrate on chronic level effects and on bioaccumulation studies. The methods should have the ability to predict such effects under field conditions and be able to predict between lower and higher levels of biological organization. In addition to the foregoing, we recommend as follows:

- Environmental assessment and monitoring aimed at quantifying the biologically available heavy metals, and understanding how bioaccumulation and biomagnification of a metal is related to the specific fish species, age, feeding habit and locality, and how all these factors interrelate at the spatial and temporal scales should be evaluated. This will help shed light on the long-term, low-level contaminant input to coastal systems and the resultant changes in species composition and abundance.
- Studies on the effects of metal pollution on fish population dynamics be undertaken. According to Arulkumar et al. (2017), the length and weight of fish determine the accumulation levels of trace metals in their muscles. This forms the basis of knowing the relationship between the length and weight of fish and the absorption of both essential and nonessential elements. Whereas similar studies have been conducted elsewhere (Velusamy et al., 2014; Arulkumar et al., 2017), there is no single study that has been undertaken in the Kenya coast. We therefore

recommend for similar studies in the Kenya coast.

- There is need to carry out studies on biomagnification of metals along the food web. Metal concentrations in the apex of the food web are likely to be higher despite the fact that at the base it is low. This will ascertain the cause of cancer cases reported in Kenya, which have to some extent been associated with heavy metal contamination of seafood (fish).
- Timely and regular assessment and monitoring of heavy metal pollution with validated protocol or standards in the Kenya coast ought to be put in place. This will provide reliable data that will be used to guide policy. Unlike data reported in this review that is not based on certain monitoring procedures, agreeable standards of operation in the assessment and monitoring will help dispel studies reporting metal pollution in an isolated manner.

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