

# Heavy metal contamination in water, sediments, and fauna of selected areas along the Kenyan coastline

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**Abstract.** Mwatsahu SH, Wanjau R, Tole M, Munga D. 2020. Heavy metal contamination in water, sediments, and fauna of selected areas along the Kenyan coastline. *Ocean Life 4*: 37-47. Every year millions of tons of industrial waste and municipal sewage are dumped into the world's oceans as rivers carrying agricultural wastes discharge their waters into the ocean. The Mombasa inshore (Kilindini and Portreiz) waters and Sabaki/Malindi bay, Kenyan coastline, complex are characterized by rapid urbanization and industrial activities, including shipping, agriculture, and tourism. As a result, the coastal fauna, sediments, and seawater are polluted with heavy metals, raw sewage, and organochlorine pesticides. Heavy metals such as Cadmium (Cd), Copper (Cu), Chromium (Cr), Lead (Pb), Iron (Fe), Manganese (Mn), Mercury (Hg), and Zinc (Zn) have threshold limits (USEPA) above which they are toxic. The aim of this study was to assess the levels of heavy metals Cd, Cu, Cr, Fe, Mn, Hg, and Zn in selected areas along the Kenyan Coastline. The analysis was done during the dry and wet seasons. The levels of the heavy metals were determined using Atomic Absorption spectro-photometry flameless Atomic Absorption Spectrophotometry (Mercury cold vapor), and Energy Dispersive X-ray fluorescence. The levels of the metals were as follows: In sediments, Hg: nd, Cr: nd, Cu: 9.912-40.412 µg/g, Fe: 3,195.667-35,435.981 µg/g, Mn: 135.467-228.780 µg/g, Zn: 54.700 -181.725 µg/g. Biota: Hg: nd, Cr: nd, Cu: 43.963-229843 µg/g, Mn: 29.770-486.611 µg/g, Fe: 379.853-35,277.752 µg/g, Zn: 99.476-872.852 µg/g, Cd: nd, Pb: 135.407-833.111 µg/g. Sea water: Cr: 0.015-0.026 µg/mL, Fe: 0.062-16.524 µg/mL, Cu: 0.010-0.033 µg/mL, Zn: 0.028-0.066 µg/mL, Pb: 0.006-0.010 µg/mL. Cd and Hg levels were not detected in seawater, sediments, and fauna. In contrast, Cr was not detected in sediments and fauna but had levels above USEPA guidelines at Kilindini, Malindi Bay, and Sabaki estuary sites. Cu had levels above USEPA guidelines at Sabaki in the water and sediments at most sites. Pb levels were above USEPA guidelines at most sites of the Kenyan Coastline, while Zn levels indicated moderate pollution in seawater, sediments, and fauna. These findings indicated that seawater sediments and fauna from the Kenyan Coastline are moderately polluted with Cu, Pb, and Zn according to USEPA guidelines. It is recommended that regular assessments of pollution levels be done and measures put in place to prevent increased pollution of the Kenyan Coastline.

**Keywords:** Heavy metal, industrial, ocean, waste

## INTRODUCTION

Human beings greatly impact the environment since they manipulate it for their benefit. The components of the ecosystem, namely air, water, and soil, are greatly affected by pollution. Therefore, pollution in the world is a major health and environmental concern. This concern is a priority for action since environmental pollution affects the well-being of all organisms in their habitats (Magothe 2009; Anderson et al. 2012; Vikas and Dwarakish 2015; Manisalidis et al. 2020). Marine pollution has been defined as the introduction of substances or energy into the marine environment resulting in such deleterious effects as harm to living resources, hazards to human health and hindrance to maritime activities, and reduction of amenities. Further point source pollution is contamination that enters the environment through discernible, confined, and discrete conveyance (Advameg Inc. 2011). Non-point sources, on the other side, are those that spread over a large area and have no specific outlet or discharge point (NOAA 2011).

Mombasa is the largest coastal city, an island surrounded by Kenyan coastal waters, with an estimated

population of 939,370 people (Kenya National Bureau of Statistics 2009). That is a source of large quantities of domestic sewage, which contribute loads of Biological Oxygen Demand (BOD), nutrients, and microbial contaminants to surface and groundwater, including coastal waters (Mwaguni and Munga 1997). The city's water run-offs are a significant source of pollution to the marine environment. In addition, inefficient collection, inadequate treatment, and disposal of solid waste are potential sources of groundwater and coastal water pollution (Munga et al. 2005; Brand et al. 2017; Lestari and Trihadiningrum 2019).

However, to increase food productivity in farms, sewage sludge and agricultural chemicals such as inorganic fertilizers, herbicides, and pesticides have been used on crops and soils (Magothe 2009; Lestari et al. 2017; Mokaya et al. 2018). Commercial phosphate fertilizers and sewage sludge contain small amounts of heavy metals, which may accumulate in soil with repeated fertilizer applications, thus contaminating the soil. In addition, some elements such as Cu, Zn, and Mo are essential for plant growth (Greaney 2005; Tsonev and Lidon 2012; Hafeez et al. 2013; Sturikova et al. 2018). In the Kenyan coastal region

farming along Athi-Galana – Sabaki river basin and on steep slopes enhance soil erosion and result in the transportation of high loads of suspended sediments downriver which discharge into the Sabaki estuary and Malindi Bay. The heavy loads of sediments eventually discharge into the Indian Ocean and are a potential source of nutrients, pesticides, residues, and heavy metals (Kithiia 2006).

Tourism is also one of the factors that significantly contribute to marine pollution. The cruise ships carrying tourists produce hazardous waste (toxic) from several on-board activities and processes, including silver, mercury, lead, and cadmium through dry cleaning, photographic processing, print shops, painting activities, equipment cleaning, and other sources (Smart Guide to World Cruise Ship 2011). Kenya's Coastal tourism is estimated to account for about 60% of the national tourism industry, with some urban centers attributing their rapid development to tourism, namely Malindi, Watamu, and Diani. Tourism development and activities have impacted wetlands, contributing to beach erosion. In addition, they are directly responsible for the over-exploitation of marine resources. At the same time, poor waste management practices at tourist establishments and tourist-satellite centers are responsible for declining water quality and loss of aesthetic value of some destinations (Mwaguni and Munga 1997).

Urbanization, industrialization, tourism, shipping (harbor), and agricultural run-offs are key and feared to cause marine environment pollution. Sabaki estuary, Malindi Bay, and Kilindini harbor are some areas along the Kenyan Coastline that are at risk of high levels of heavy metal pollutants due to surrounding activities. Through the

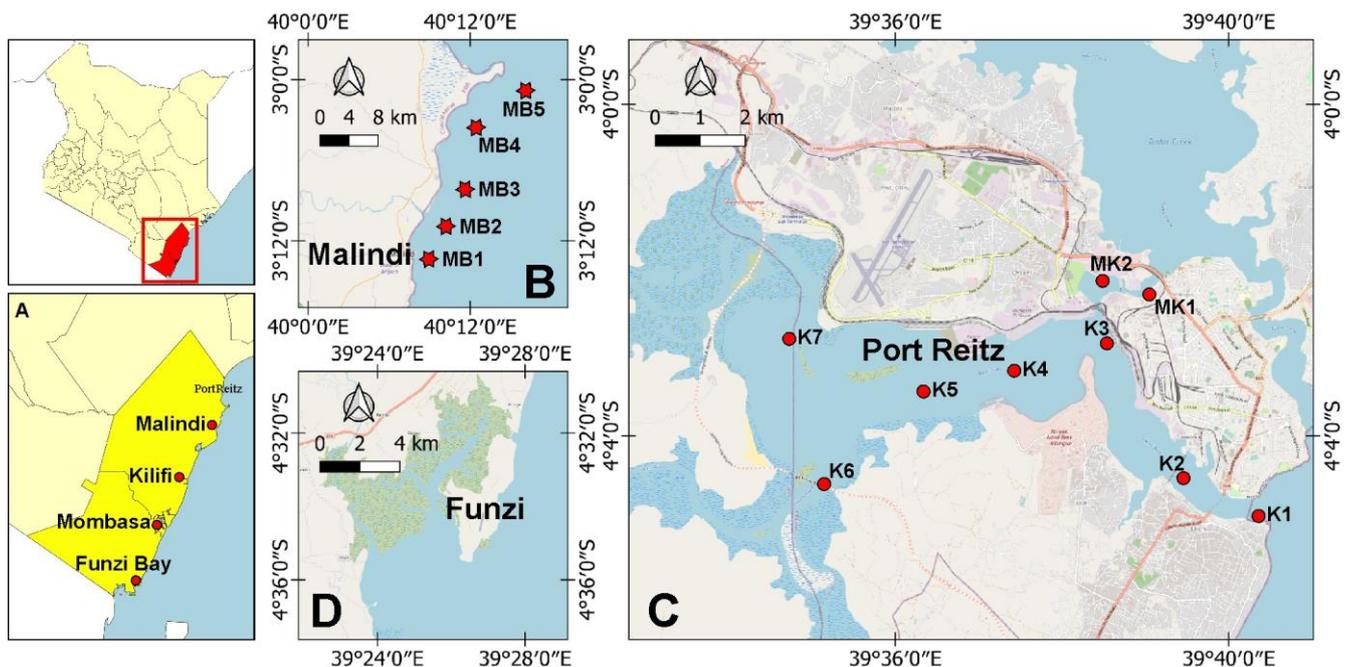
food chain-heavy metals, including Pb, Cd, Zn, Mn, Cr, Cu, and Hg in seawater, sediments, fish, and other marine fauna affect the health of human beings. There is, therefore, the need to assess these heavy metals in the Kenyan coastline.

This study aims to determine levels of heavy metals in water, sediments, and fauna in Mombasa inshore areas (Kilindini and PortReitz), the Sabaki estuary, and the Malindi Bay complex. Then, specific objectives are: (i) To determine the levels of Pb, Cd, Zn, Mn, Cr, Cu, Fe, and Hg in Mombasa inshore areas and Sabaki estuary/Malindi Bay complex during wet and dry seasons in seawater. (ii) To determine the levels of Pb, Cd, Zn, Mn, Cr, Cu, Fe, and Hg in Mombasa inshore areas and Sabaki estuary/Malindi Bay complex during wet and dry seasons in marine sediments. (iii) To determine the levels of Pb, Cd, Zn, Mn, Cr, Cu, Fe, and Hg in Mombasa inshore areas and Sabaki estuary/Malindi Bay complex during wet and dry seasons in marine fauna.

## MATERIALS AND METHODS

### Study area

The study area covered the Kenyan coastal area between Malindi Bay in the North and Funzi Bay on the South Coast, Kenyan coastline (Figure 1). Figure 1A shows the whole length of the study area while Figures 1B, C, and D shows the sampling sites of Sabaki estuary/Malindi Bay complex, Kilindini harbor/port Reitz creek, and Shirazi respectively. Figure 1C is an enlarged Kilindini/Port Reitz Creek map showing sampling sites.



**Figure 1.** A-D. Maps of the Kenyan coastline showing sampling sites.

### Research design

A quantitative research design was used in this study. Quantitative research design, where an environmental phenomenon, namely marine pollution, was accurately converted into numerical data. Samples of water, sediments, and fauna were collected from various points along the Kenyan coastline to analyze heavy metals (Cd, Cu, Mn, Fe, Cr, Pb, Zn, and Hg).

### Sampling design

Sampling was done during wet and dry seasons. Samples of marine sediments, fauna, and ocean water were collected from three sites along the Kenyan coast: Sabaki estuary/Malindi bay complex, Kilindini, and Port Reitz creek system, and Funzi bay/Shirazi, which served as the reference site. The sampling and sample analyses were conducted as a scheme shown in Figure 2.

### Description of sampling sites

Sampling points in the Sabaki estuary/Malindi bay complex were selected in the inshore/nearshore and 2 km from the shore. Four sampling points were selected within the bay and along the shoreline, and another 3 points were selected within the Sabaki estuary (Figures 1B, C and D).

Sampling points at Mombasa were on the Kilindini harbor and Port Reitz creek, where shipping activities, including bunkering and discharging crude oil, occur. There are also industries, the Kipevu oil terminal and the Kenya Naval base (Figure 1E). The reference site was located in Funzi bay at Shirazi, 70 Km south of Mombasa. The only activities were subsistence farming with low levels of agrochemicals used, artisanal fishing, and little tourist activities without heavy metal pollution.

### Cleaning

Teflon vessels, glassware, and plastic ware (including sampling bottles) were soaked in a soap solution overnight in a plastic bucket. The apparatus was rinsed in tap water and then with distilled de-ionized water. They were put and left to stand for six days in a 10% (v/v) concentrated HNO<sub>3</sub> solution at room temperature. They were then rinsed thoroughly with distilled de-ionized water and dried in the open air. The dried apparatus were put in closed plastic polythene bags and stored.

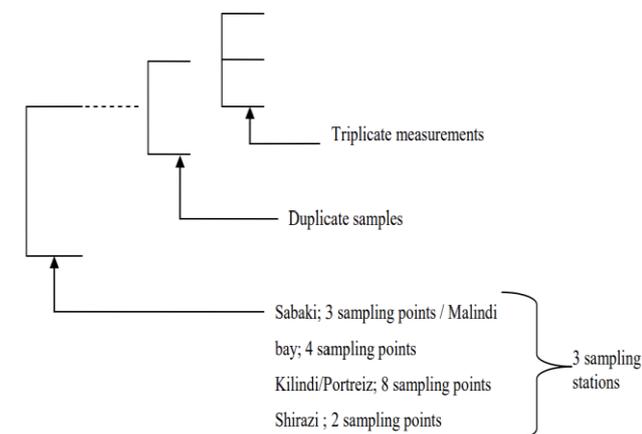


Figure 2. Sampling and sample analysis scheme used in this study

### Collection of samples

Water samples were collected from the ocean surface directly into plastic bottles by sub-merging the sample bottle just below the water surface. Samples were immediately acidified with 1 mL concentrated HNO<sub>3</sub> and stored at a temperature of 4°C. Surface sediments were collected using a Van Veen grab sampler and put into plastic bags, labeled, and transported to the laboratory. The sediments were dried at 50°C and stored. Fauna was picked manually, put in plastic bags, labeled, kept in ice during transport, and stored below 0°C. Then they were dried at 50°C. The flesh inside the shell was used for the heavy metal determination.

### Chemicals, reagents, and solvents

Chemicals, reagents, and solvents used were of Suprapur, analytical grade.

### Sample preparation

#### Digestion of sediment for AAS analysis

A sum of 0.2000 g portion of the dry sample was weighed accurately (Adam Equipment Co. Ltd, Model AAA 160/L, AE04876108) in labeled Teflon vessels. Next, 1 mL aliquot of aqua regia (HNO<sub>3</sub>: HCl, 1:3 v/v) was added slowly, followed by 6 mL of concentrated Hf, and left to stand at room temperature for 1 hour. Next, the Teflon vessels were closed, placed on a hot plate, and heated at 120°C for 2 hours and 30 minutes. Samples were allowed to cool to room temperature then the Teflon vessels were opened. Separately, 2.7000 g portions of boric acid were weighed, put in labeled volumetric flasks, and dissolved in 20 mL distilled de-ionized water. The sediment samples above were then transferred into the flasks and put in a water bath for 30 minutes until all boric acid was dissolved. They were then allowed to cool to room temperature and put in plastic containers (Azenard et al. 2006), labeled, and stored.

#### Digestion of fauna for AAS analysis

Portions of 0.2000g of dry fauna samples were weighed accurately in the labeled Teflon vessel. A 5 mL aliquot of concentrated HNO<sub>3</sub> was added and left at room temperature for 1 hour. The vessel was then closed and heated on a hot plate at 90°C for 3 hours. They were allowed to cool to room temperature and then transferred to a 50 mL volumetric flask, and the volume was adjusted to mark with distilled de-ionized water (Azenard et al. 2006).

#### Calculation of concentrations of sediment and fauna samples

The concentrations calculations were carried out using the calibration curve method and worked out as follows:

$$\mu\text{g/g} = \frac{\text{Measured concentration (ppm)} \times \text{Dilution} \times \text{Sample Volume (mL)}}{\text{Dry Weight of Sample (g)}}$$

### Preparation of water samples for EDXRF analysis

Sea water samples were analyzed using by EDXRF technique. First, a preconcentration procedure with Ammonium Pyrrolidine Dithiocarbonate (APDC) and analysis was done as follows: The seawater samples (100 mL of sample) were acidified with 5 mL dilute HNO<sub>3</sub> and pH adjusted to between 3.5-4.0 using dilute ammonia

solution. Next, 10 mL of freshly prepared 1% APDC solution was added, followed by 0.2000 g of Cd solution added as a carrier before precipitation. Next, they were thoroughly mixed by manually agitating after every 10 minutes for 40 minutes at room temperature, forming a suspension. The suspension was then filtered through a Nucleopore filter (0.45  $\mu\text{m}$  pore size). Finally, the Nucleopore filter was air-dried and irradiated to determine the elements (IAEA 1997).

#### Preparation of stock and standard solutions

Commercial standards of 1000  $\mu\text{g/g}$  strength were diluted using the formula  $V_1C_1=V_2C_2$ , and standards of concentrations of 0-10.0  $\mu\text{g/g}$  were prepared.

#### Preparation of reference standard and blank

Reference material IAEA- 433 was used. The reference material solutions were prepared using the same procedure as the sediment samples. The blank was prepared using distilled/de-ionized water instead of a sample.

#### Analysis of samples by FAAS

The FAAS instrument used was Buck Scientific (1996) 210VGP Atomic Absorption Spectrophotometer. The machine operational parameters for the analysis are given in Table 1. The standards were first aspirated, and the absorbance was recorded. A calibration curve was obtained for each element analyzed. The sediments, fauna samples, and reference materials were then aspirated, and the absorbances were recorded. The samples' concentrations were calculated by extrapolating the individual samples' absorbances on the elements' graphs.

#### Analysis of samples by HGAAS

The cold vapor technique was used for the analysis of Hg. First, a mercury hollow cathode lamp was placed in the holder and allowed to warm up for about 15 minutes. Then, the burner head of the AAS was removed, and the absorption cell and holder were positioned. Next, the lamp current (6.5 MA) and wavelength (253.6 nm) were optimized, 50 mL of sample solution was pipetted into the reaction flask, and 5 mL of mixed acid solution (3:1HCl:H<sub>2</sub>SO<sub>4</sub>) was added.

A 10.0000 g portion of analytical grade stannous chloride was put in an empty acid-cleaned 100 mL plastic bottle, then 20 mL concentrated HCl, 2 grams tin metal, and 75 mL distilled de-ionized water was added. The bottle was swirled gently to dissolve the solids. Next, 5 mL of the 10% stannous chloride reductant solution, prepared as above, was injected into the septum of the flask stopper assembly with a syringe.

The argon gas was switched on, and the highest signal reading on the machine was taken. The reading was allowed back to zero, the Argon bubbles flow was turned off, and the reaction flask was removed. The flask was rinsed with 5% HCl / 5% H<sub>2</sub>O<sub>2</sub> solution, and also the bubbler tube was soaked in the same solution to remove traces of the SnCl<sub>2</sub>. Finally, it was reassembled for the next run. The analysis started with the reagent blank run, the standards, and, lastly the samples.

**Table 1.** Operational parameters of the AAS

Operational parameters	Elements						
	Cu	Cd	Cr	Ni	Pb	Zn	Mn
Wavelength	324.7	324.8	357.9	232.0	283.3	213.9	279.5
Slit width (nm)	0.7	0.7	0.7	0.2	0.7	0.7	0.7
Lamp current (ma)	3-8	5-10	5-10	7-15	3-7.5	3-10	5 -15
Detection limit ( $\mu\text{g/mL}$ )	0.02	0.005	0.05	0.04	0.1	0.005	0.01
Flame	Air-acetylen						
Flame temp.	2300 °C						

#### Method validation

The methods used in this study, the AAS and EDXRF, were validated using reference materials and commercial standards.

#### Data analysis

The data were analyzed using the student t-test and the Standard Statistical Package for Social Sciences (SPSS) Version 17.

## RESULTS AND DISCUSSION

#### Method validation

##### The EDXRF validation

The EDXRF level of accuracy and quality control comprised the measurement of ICP Multi-element standard solution 1 CertiPUR (Certified reference material). The results are presented in Table 2.

##### The AAS validation

The AAS level of accuracy and quality control was determined by certified reference material "IAEA 433" for trace elements and methyl mercury in marine sediments and certified reference material "IAEA 436" for Trace elements in the fauna. The comparison of means between the levels in the certified reference material and measured values is presented in Tables 2 and 3.

#### Levels of heavy metals in seawater

The levels of Pb, Cd, Zn, Mn, Cr, Cu, Fe, and Hg in seawater were determined using EDXRF and are presented in Table 4 for the wet and dry seasons, respectively.

##### Lead (Pb)

During the dry season, Pb levels ranged from < dl at MB1 at the Malindi marine park to 0.014  $\mu\text{g/g}$  at S1 at Sabaki river, 2 kilometers before the river water entered the sea. These levels were lower than the guide level set by USEPA, implying that the sea water is safe from Pb. However, Pb accumulation is known to be dangerous, resulting in the inhibition of enzyme-catalyzing formation of haem (UNEP 1984). Other studies of the Kenyan coastline also found levels of Pb in seawater to be lower than the USEPA guidelines (Oyugi et al. 2000), Mwashote (2003). Oyugi et al. (2000) reported a range from 0.012 to 0.06  $\mu\text{g/mL}$ , while Mwashote (2003) reported Pb levels of 0.05 to 0.62 in seawater at Mombasa, concluding that there was a need for constant monitoring of the region. A comparison of Pb between the dry and the wet seasons showed a difference ( $P < 0.05$ ).

**Table 2.** The EDXRF results for ICP Multi-element Standard Solution1CertiPUR

Element	Concentration in µg/g (n = 3)		t-test tcal
	Certified (mean ± SE)	Measured (mean ± SE)	
Cr	25.3 ± 0.50	19.754 ± 6.03	0.92
Fe	15.2 ± 0.50	15.336 ± 3.85	0.03
Cu	20.3 ± 0.50	19.444 ± 3.25	0.26
Zn	20.0 ± 0.50	20.525 ± 3.48	0.15
Pb	203 ± 4.00	182.902 ± 31.76	0.63
Mn	5.1 ± 0.20	5.00 ± 0.20	0.50
Cd	20.8 ± 0.50	20.40 ± 0.50	0.80

Note: Measured values were not significantly different from certified values since *t* -calculated values were less than the *t* -critical value (*t*<sub>crit</sub> = 4.303, df = 2, α = 0.05). Therefore the EDXRF method and hence the results presented in this study are accurate and reliable

**Table 3.** Comparison of mean levels of heavy metals in CRM IAEA433 and 436 and measured values

Element	Concentration in µg/g (n = 3)		t-test tcal
	Certified (mean ± SE)	Measured (mean ± SE)	
CRM IAEA433			
Cu	30.8 ± 2.60	30.3 ± 2.60	0.19
Zn	26.0 ± 2.70	25.5 ± 2.50	0.20
Mn	101 ± 8.00	103.37 ± 8.20	0.28
MeHg	316 ± 16.00	315.5 ± 15.90	0.03
Cd	136 ± 10.00	135 ± 9.50	0.10
Cr	0.17 ± 0.07	0.14 ± 0.06	0.50
Cu	0.153 ± 0.03	0.140 ± 0.03	0.43
CRM IAEA 436			
Cu	1.73 ± 0.19	1.70 ± 0.18	0.17
Zn	19.0 ± 1.30	19.0 ± 1.40	< 0.001
Mn	0.238 ± 0.04	0.250 ± 0.04	0.30
MeHg	3.67 ± 0.42	3.55 ± 0.04	3.00
Cd	0.052 ± 0.01	0.050 ± 0.01	0.20
Cr	0.194 ± 0.06	0.193 ± 0.06	0.02
Cu	1.73 ± 0.19	1.70 ± 0.18	0.17

Note: tcal = t calculated. Measured values were not significantly different from certified values since *t* -calculated values were less than the *t* -critical value (*t*<sub>crit</sub> = 4.303, df = 2, α = 0.05). The AAS results presented in this study are accurate and reliable

**Table 4.** Mean levels of heavy metals in seawater during the dry and wet season

SITE	Concentration µg/mL±SE (n=3)					
	Pb	Zn	Mn	Cr	Fe	Cu
<b>Dry season</b>						
K1	0.007±0.001 <sup>bc</sup>	0.072±0.029 <sup>b</sup>	0.010±0.001 <sup>abc</sup>	0.014±0.000	0.174±0.013 <sup>a</sup>	0.006±0.001 <sup>a</sup>
K2	0.007±0.000 <sup>bc</sup>	0.044±0.014 <sup>a</sup>	0.008±0.004 <sup>ab</sup>	0.015±0.003	0.260±0.068 <sup>a</sup>	0.015±0.004 <sup>ab</sup>
K3	0.008±0.001 <sup>bc</sup>	0.013±0.000 <sup>a</sup>	0.011±0.002 <sup>abc</sup>	0.013±0.002	0.171±0.056 <sup>a</sup>	0.011±0.001 <sup>ab</sup>
K4	0.010±0.002 <sup>bc</sup>	0.031±0.001 <sup>ab</sup>	0.013±0.000 <sup>abc</sup>	0.014±0.002	0.159±0.005 <sup>a</sup>	0.013±0.002 <sup>ab</sup>
K5	0.009±0.001 <sup>bc</sup>	0.013±0.002 <sup>a</sup>	0.011±0.001 <sup>abc</sup>	0.012±0.001	0.220±0.013 <sup>a</sup>	0.014±0.002 <sup>ab</sup>
K6	0.012±0.001 <sup>bc</sup>	0.029±0.000 <sup>ab</sup>	0.011±0.000 <sup>abc</sup>	0.056±0.042	0.339±0.035 <sup>a</sup>	0.011±0.001 <sup>ab</sup>
K7	0.008±0.001 <sup>bc</sup>	0.024±0.002 <sup>ab</sup>	0.016±0.002 <sup>bc</sup>	0.013±0.002	0.459±0.017 <sup>a</sup>	0.016±0.001 <sup>b</sup>
K8	0.009±0.000 <sup>bc</sup>	0.023±0.000 <sup>ab</sup>	0.019±0.003 <sup>c</sup>	0.019±0.001 <sup>b</sup>	0.787±0.021 <sup>b</sup>	0.010±0.001 <sup>ab</sup>
MB1	0.000±0.000 <sup>a</sup>	0.025±0.004 <sup>ab</sup>	0.010±0.000 <sup>abc</sup>	0.060±0.049	0.079±0.013 <sup>a</sup>	0.012±0.002 <sup>ab</sup>
MB2	0.006±0.003 <sup>bc</sup>	0.034±0.009 <sup>ab</sup>	0.005±0.003 <sup>a</sup>	0.009±0.005	0.430±0.255 <sup>a</sup>	0.017±0.004 <sup>b</sup>
MB3	0.013±0.003 <sup>c</sup>	0.033±0.006 <sup>ab</sup>	0.008±0.004 <sup>ab</sup>	0.017±0.001	0.196±0.070 <sup>a</sup>	0.013±0.000 <sup>ab</sup>
MB4	0.005±0.002 <sup>b</sup>	0.021±0.001 <sup>ab</sup>	0.014±0.003 <sup>abc</sup>	0.008±0.004	0.343±0.293 <sup>a</sup>	0.015±0.003 <sup>b</sup>
S1	0.011±0.000 <sup>bc</sup>	0.072±0.000 <sup>ab</sup>	0.089±0.000 <sup>d</sup>	0.013±0.013	17.613±0.006 <sup>d</sup>	0.036±0.000 <sup>ab</sup>
S2	0.009±0.000 <sup>bc</sup>	0.070±0.000 <sup>b</sup>	0.036±0.000 <sup>e</sup>	0.032±0.000	20.351±0.014 <sup>c</sup>	0.036±0.000 <sup>d</sup>
S3	0.010±0.001 <sup>bc</sup>	0.057±0.000 <sup>b</sup>	0.045±0.000 <sup>abc</sup>	0.033±0.001	11.609±0.003 <sup>a</sup>	0.027±0.001 <sup>d</sup>
SH1	0.007±0.000 <sup>bc</sup>	0.054±0.028 <sup>ab</sup>	0.013±0.001 <sup>abc</sup>	0.017±0.002	0.063±0.003 <sup>a</sup>	0.009±0.000 <sup>ab</sup>
SH2	0.009±0.001 <sup>bc</sup>	0.034±0.001 <sup>ab</sup>	0.015±0.001 <sup>abbc</sup>	0.013±0.002	0.061±0.004 <sup>a</sup>	0.011±0.001 <sup>ab</sup>
<b>Wet season</b>						
K1	0.005±0.001 <sup>ab</sup>	0.044±0.005 <sup>abc</sup>	0.012±0.001 <sup>a</sup>	0.012±0.000 <sup>a</sup>	0.068±0.007 <sup>a</sup>	0.011±0.001
K2	0.006±0.000 <sup>ab</sup>	0.040±0.002 <sup>ab</sup>	0.011±0.002 <sup>a</sup>	0.022±0.002 <sup>a</sup>	0.061±0.002 <sup>a</sup>	0.012±0.001
K3	0.006±0.000 <sup>ab</sup>	0.040±0.002 <sup>ab</sup>	0.011±0.002 <sup>a</sup>	0.022±0.002 <sup>a</sup>	0.061±0.002 <sup>a</sup>	0.012±0.001
K4	0.006±0.000 <sup>a</sup>	0.040±0.002 <sup>ab</sup>	0.011±0.002 <sup>a</sup>	0.022±0.002 <sup>a</sup>	0.061±0.002 <sup>d</sup>	0.012±0.001
K5	0.005±0.001 <sup>ab</sup>	0.045±0.000 <sup>abc</sup>	0.009±0.000 <sup>a</sup>	0.011±0.001 <sup>a</sup>	0.094±0.006 <sup>bcd</sup>	0.008±0.000
K6	0.007±0.001 <sup>ab</sup>	0.042±0.001 <sup>abc</sup>	0.010±0.001 <sup>a</sup>	0.014±0.001 <sup>a</sup>	0.150±0.005 <sup>f</sup>	0.010±0.001
K7	0.008±0.001 <sup>b</sup>	0.023±0.002 <sup>a</sup>	0.009±0.001 <sup>a</sup>	0.019±0.002 <sup>a</sup>	0.098±0.005 <sup>cd</sup>	0.036±0.001
K8	0.006±0.000 <sup>ab</sup>	0.046±0.000 <sup>abc</sup>	0.009±0.000 <sup>a</sup>	0.015±0.000 <sup>a</sup>	0.307±0.000 <sup>h</sup>	0.009±0.000
MB1	0.005±0.000 <sup>a</sup>	0.038±0.000 <sup>ab</sup>	0.010±0.000 <sup>a</sup>	0.012±0.000 <sup>a</sup>	0.082±0.000 <sup>abc</sup>	0.008±0.000
MB2	0.008±0.001 <sup>b</sup>	0.032±0.002 <sup>ab</sup>	0.010±0.001 <sup>a</sup>	0.013±0.001 <sup>a</sup>	0.079±0.005 <sup>abc</sup>	0.010±0.000
MB3	0.005±0.000 <sup>a</sup>	0.041±0.001 <sup>ab</sup>	0.012±0.001 <sup>a</sup>	0.022±0.001 <sup>a</sup>	0.096±0.002 <sup>cd</sup>	0.012±0.000
MB4	0.007±0.001 <sup>ab</sup>	0.064±0.000 <sup>c</sup>	0.013±0.001 <sup>a</sup>	0.117±0.052 <sup>b</sup>	0.093±0.004 <sup>bcd</sup>	0.018±0.000
S1	0.014±0.001 <sup>e</sup>	0.158±0.020 <sup>e</sup>	0.024±0.003 <sup>c</sup>	0.024±0.000 <sup>a</sup>	4.326±0.007 <sup>j</sup>	0.019±0.005
S2	0.014±0.000 <sup>e</sup>	0.177±0.001 <sup>f</sup>	0.027±0.000 <sup>d</sup>	0.023±0.001 <sup>a</sup>	4.323±0.006 <sup>j</sup>	0.024±0.001
S3	0.010±0.000 <sup>c</sup>	0.086±0.000 <sup>d</sup>	0.065±0.001 <sup>e</sup>	0.053±0.001 <sup>a</sup>	15.610±0.002 <sup>k</sup>	0.037±0.000
SH1	0.006±0.000 <sup>ab</sup>	0.027±0.000 <sup>ab</sup>	0.011±0.000 <sup>a</sup>	0.016±0.000 <sup>a</sup>	0.071±0.000 <sup>ab</sup>	0.011±0.000
SH2	0.014±0.000 <sup>a</sup>	0.012±0.000 <sup>d</sup>	0.011±0.000 <sup>a</sup>	0.194±0.000 <sup>g</sup>	0.012±0.000	0.039±0.000 <sup>ab</sup>

Note: Mean values followed by the same letter(s) within the same column are not significantly different. (Oneway ANOVA, SNK-test, α = 0.05)

### Zinc (Zn)

Zinc levels in seawater in the dry ranged from 0.013 µg/mL at sampling point k3 at oceanic sampling at Kilindini harbor to 0.072 µg/mL at K1 next Mombasa industrial area at Kilindini harbor. Zn was also detected at all other sampling points. These levels were lower than the guidelines of 81.0 µg/L set by USEPA. That implies that the results show that the seawater was polluted by zinc, except at Sabaki during the wet season.

Previous studies of the Kenyan coastline reported levels lower than the USEPA guidelines (Oyugi et al. 2000 Hashim 2001). Oyugi et al. (2000) reported a range of 0.03 µg/g at Mombasa to 0.07 at Vanga, while Hashim (2001) reported 0.57 µg/L to 8.10 µg/L at Mombasa. Other water bodies worldwide reported 0.5-27.6 µg/L in seawater at Port Elizabeth, South Africa. That indicated pollution attributed to industrial-runoff sources (Fatoki and Mathabatha 2001). In the wet season, Zn levels in seawater were higher, 0.177 µg/L at Sabaki. In a non-statistical comparison, Kenyan Coastline seawater's Zn levels are lower than the USEPA guidelines. A comparison between the Zn levels in the dry and wet seasons showed a significant difference ( $P < 0.05$ ). The wet season had higher levels than the dry season.

### Manganese (Mn)

Mn levels in seawater in the dry season ranged from 0.005 µg/mL at MB2 in front of the Malindi Jetty sampling point at Malindi Bay to 0.89 µg/mL at S1 at Sabaki river. Mn was also detected in all other sampling points. These levels are lower than the WHO recommended levels of 0.4 µg/L for drinking water (WHO 2000). The Mn levels indicated the Mn pollution of the seawater at Sabaki. In the wet season, seawater levels ranged from 0.009 µg/mL at K8 at Mwache to 0.065 µg/mL at the S3 sampling point at the Sabaki river. These levels are higher than the WHO-recommended level of 0.4 µg/L. Previous studies of the Kenyan Coastline, Hashim (2001) reported a range from 0.24-0.51 µg/mL at Mombasa and 0.12-0.19 µg/g at Malindi. The above levels were indicative of Mn pollution of the seawater of the Kenyan coastline.

Studies from other regions of the world, in the North sea, the northeast Atlantic Ocean, the English channeled, and the Indian Ocean, Mn levels were reported to range from 0.3 to 4.0 µg/L (Howe et al. 2004).

A comparison between the Mn levels in the dry and wet seasons showed no significant difference,  $p > 0.05$ .

### Chromium (Cr)

Chromium levels in seawater in the dry season ranged from 0.008 µg/L at MB4 at Malindi Bay in front of Gongoni to 0.117 µg/mL at MB3 at Malindi Bay in front of Mambrui. The level at NB 3 is higher than the USEPA guidelines of 50 µg/L for Cr(vi); since the Cr level found was total Cr and not differentiated between Cr (III) and Cr(Vi), the pollution status of Cr pollution could not be inferred from above levels. Furthermore, Cr has not been reported in previous studies of the Kenyan Coast.

### Iron (Fe)

Seawater's iron levels in the dry season ranged from 0.061 µg/mL at SH2 at Shirazi to 20.351 µg/mL at 52 at Sabaki. Previous studies of the Kenyan Coastline reported comparable Fe levels in seawater. Oyugi et al. (2000) reported levels ranging from 0.11 µg/mL at Mombasa Marine park to 13.5 µg/mL at English point Mombasa, while Hashim (2001) reported iron levels of 0.44-1.33 µg/mL at Mombasa, 6.34 - 44.21 µg/mL at Malindi and 0.67-8.53 µg/mL at Gazi. These two previous studies reported higher levels than this study could be due to the difference in sampling sites. In unpolluted oceanic waters, iron levels ranging between 2.8 to 29 µg/L and 224-1228 µg/L have been reported (UK Marine Special Areas of Conservation 2011). USEPA quality criteria do not exist for iron as it is considered a non-priority pollutant (UK Marine Special Areas of Conservation 2011).

### Copper (Cu)

Copper levels in seawater in the dry season ranged from 0.006 µg/mL at K1 at the oceanic sampling point at Kilindini to 0.037 µg/mL at S1 and S2 at Sabaki river. In another study of the Kenyan coastline, Hashim (2001) reported Cu levels in seawater of 0.05-0.13 µg/mL at Mombasa, 0.05-0.11 µg/mL at Malindi and 0.04-0.08 µg/mL at Gazi. These figures are higher than those reported in this study, which could be due to the difference in sampling points. However, the levels also show a reduction in Cu indicative of a reduction in Cu pollution of the Kenyan coastline.

In the wet season, levels of Cu in seawater ranged from 0.011 µg/mL at KI at the oceanic sampling station at Kilindini to 0.037 µg/mL at S1 at Sabaki river. There is no significant difference in the levels during the dry and wet seasons. The levels of Cu in this study in this study are higher than the USEPA guidelines of 3.1 µg/L in seawater, indicating Cu pollution in the Kenyan coastline seawater.

### Levels of heavy metals in marine sediments

The Pb, Cd, Zn, Mn, Cr, Cu, and Fe levels in sediments were determined using AAS. The Hg levels in sediments were determined using the cold vapor method. The AAS calibration curve for Pb is shown in Figure 3. Calibration curves for other metals are in Appendix II. The results for dry and wet seasons are presented in Table 5. Site abbreviations are explained in the abbreviations and acronyms list. Cd, Cr, and Hg, however, were not detected in marine sediment samples.

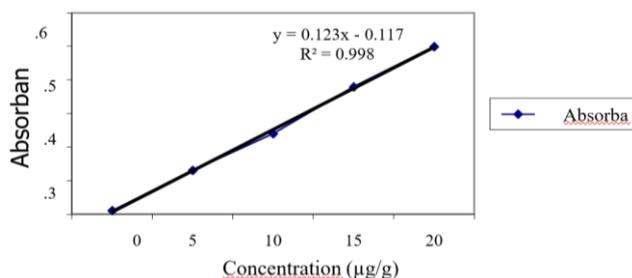


Figure 3. Calibration curve for lead

**Table 5.** Mean levels of heavy metals in sediments during the dry and wet season

Site	Concentration in $\mu\text{g/g} \pm \text{SE}$ ( $n = 3$ )				
	Pb	Zn	Mn	Fe	Cu
<b>Dry season</b>					
K1	170.769 $\pm$ 0.116 <sup>g</sup>	140.859 $\pm$ 0.335 <sup>k</sup>	460.674 $\pm$ 0.163 <sup>g</sup>	46314.705 $\pm$ 0.103 <sup>l</sup>	43.034 $\pm$ 0.034 <sup>g</sup>
K2	170.769 $\pm$ 0.116 <sup>g</sup>	141.093 $\pm$ 0.052 <sup>i</sup>	460.840 $\pm$ 0.160 <sup>g</sup>	46315.705 $\pm$ 0.103 <sup>m</sup>	41.064 $\pm$ 0.032 <sup>f</sup>
K3	133.400 $\pm$ 0.100 <sup>b</sup>	145.169 $\pm$ 0.037 <sup>m</sup>	400.917 $\pm$ 0.220 <sup>c</sup>	40554.153 $\pm$ 0.078 <sup>j</sup>	43.034 $\pm$ 0.034 <sup>g</sup>
K4	133.400 $\pm$ 0.100 <sup>b</sup>	145.093 $\pm$ 0.001 <sup>m</sup>	400.917 $\pm$ 0.220 <sup>c</sup>	40554.153 $\pm$ 0.078 <sup>h</sup>	43.034 $\pm$ 0.034 <sup>g</sup>
K5	134.417 $\pm$ 0.209 <sup>c</sup>	137.288 $\pm$ 0.006 <sup>j</sup>	450.075 $\pm$ 0.038 <sup>e</sup>	35129.710 $\pm$ 0.095 <sup>k</sup>	44.077 $\pm$ 0.033 <sup>i</sup>
K6	160.673 $\pm$ 0.163 <sup>e</sup>	145.077 $\pm$ 0.038 <sup>m</sup>	455.717 $\pm$ 0.148 <sup>f</sup>	41500.185 $\pm$ 0.094 <sup>i</sup>	32.902 $\pm$ 0.004 <sup>e</sup>
K7	230.556 $\pm$ 0.067 <sup>j</sup>	332.507 $\pm$ 0.004 <sup>o</sup>	420.979 $\pm$ 0.226 <sup>d</sup>	35203.435 $\pm$ 0.219 <sup>f</sup>	28.027 $\pm$ 0.002 <sup>d</sup>
K8	185.700 $\pm$ 0.153 <sup>h</sup>	137.281 $\pm$ 0.000 <sup>j</sup>	450.323 $\pm$ 0.007 <sup>e</sup>	33351.784 $\pm$ 0.045 <sup>c</sup>	28.027 $\pm$ 0.001 <sup>d</sup>
MB1	290.800 $\pm$ 0.115 <sup>k</sup>	83.592 $\pm$ 0.001 <sup>g</sup>	130.117 $\pm$ 0.060 <sup>a</sup>	9351.835 $\pm$ 0.017 <sup>c</sup>	10.133 $\pm$ 0.002 <sup>b</sup>
MB2	290.833 $\pm$ 0.120 <sup>k</sup>	83.104 $\pm$ 0.058 <sup>f</sup>	130.450 $\pm$ 0.275 <sup>ab</sup>	9351.835 $\pm$ 0.017 <sup>g</sup>	10.134 $\pm$ 0.001 <sup>b</sup>
MB3	230.667 $\pm$ 0.176 <sup>j</sup>	101.495 $\pm$ 0.005 <sup>h</sup>	750.547 $\pm$ 0.227 <sup>k</sup>	33425.595 $\pm$ 0.298	27.018 $\pm$ 0.009 <sup>c</sup>
MB4	165.700 $\pm$ 0.153 <sup>f</sup>	101.495 $\pm$ 0.005 <sup>h</sup>	1050.853 $\pm$ 0.074 <sup>ai</sup>	83425.609 $\pm$ 0.304	94.595 $\pm$ 0.003 <sup>k</sup>
MB5	165.900 $\pm$ 0.208 <sup>f</sup>	102.496 $\pm$ 0.004 <sup>i</sup>	1051.187 $\pm$ 0.292 <sup>ai</sup>	83425.275 $\pm$ 0.327 <sup>p</sup>	94.597 $\pm$ 0.007 <sup>k</sup>
MK	220.509 $\pm$ 0.065 <sup>i</sup>	311.154 $\pm$ 0.001 <sup>n</sup>	460.261 $\pm$ 0.069 <sup>g</sup>	52520.900 $\pm$ 0.153 <sup>o</sup>	60.510 $\pm$ 0.006 <sup>j</sup>
S1	131.167 $\pm$ 0.083 <sup>a</sup>	52.343 $\pm$ 0.001 <sup>a</sup>	520.670 $\pm$ 0.165 <sup>i</sup>	12231.387 $\pm$ 0.202 <sup>d</sup>	43.916 $\pm$ 0.003 <sup>h</sup>
S2	135.445 $\pm$ 0.028 <sup>d</sup>	58.208 $\pm$ 0.004 <sup>e</sup>	540.677 $\pm$ 0.162 <sup>j</sup>	14907.500 $\pm$ 0.323 <sup>e</sup>	43.903 $\pm$ 0.009 <sup>h</sup>
S3	135.445 $\pm$ 0.028 <sup>d</sup>	56.308 $\pm$ 0.004 <sup>d</sup>	480.393 $\pm$ 0.018 <sup>h</sup>	48240.730 $\pm$ 0.015 <sup>n</sup>	43.916 $\pm$ 0.003 <sup>h</sup>
SH1	135.497 $\pm$ 0.088 <sup>d</sup>	55.250 $\pm$ 0.000 <sup>c</sup>	130.677 $\pm$ 0.162 <sup>ab</sup>	3250.533 $\pm$ 0.291 <sup>b</sup>	9.912 $\pm$ 0.006 <sup>a</sup>
SH2	135.467 $\pm$ 0.067 <sup>d</sup>	54.147 $\pm$ 0.013 <sup>b</sup>	131.038 $\pm$ 0.221 <sup>b</sup>	3140.800 $\pm$ 0.416 <sup>a</sup>	9.912 $\pm$ 0.006 <sup>a</sup>
<b>Wet season</b>					
K1	187.767 $\pm$ 0.145 <sup>c</sup>	142.192 $\pm$ 0.004 <sup>j</sup>	471.813 $\pm$ 0.094 <sup>h</sup>	47314.705 $\pm$ 0.103 <sup>l</sup>	43.913 $\pm$ 0.006 <sup>i</sup>
K2	187.667 $\pm$ 0.167 <sup>c</sup>	142.164 $\pm$ 0.033 <sup>j</sup>	471.810 $\pm$ 0.146 <sup>h</sup>	47315.705 $\pm$ 0.103 <sup>m</sup>	40.810 $\pm$ 0.005 <sup>h</sup>
K3	135.646 $\pm$ 0.180 <sup>b</sup>	146.093 $\pm$ 0.001 <sup>k</sup>	442.718 $\pm$ 0.034 <sup>d</sup>	41754.153 $\pm$ 0.078 <sup>i</sup>	43.913 $\pm$ 0.006 <sup>i</sup>
K4	135.646 $\pm$ 0.180 <sup>b</sup>	146.093 $\pm$ 0.001 <sup>k</sup>	443.051 $\pm$ 0.351 <sup>d</sup>	41754.153 $\pm$ 0.078 <sup>i</sup>	43.913 $\pm$ 0.006 <sup>i</sup>
K5	135.639 $\pm$ 0.182 <sup>b</sup>	138.288 $\pm$ 0.006 <sup>i</sup>	464.664 $\pm$ 0.168 <sup>g</sup>	37129.710 $\pm$ 0.095 <sup>g</sup>	43.913 $\pm$ 0.006 <sup>i</sup>
K6	187.820 $\pm$ 0.160 <sup>c</sup>	146.077 $\pm$ 0.038 <sup>k</sup>	462.756 $\pm$ 0.172 <sup>f</sup>	41759.185 $\pm$ 0.094 <sup>j</sup>	33.309 $\pm$ 0.004 <sup>g</sup>
K7	239.789 $\pm$ 0.120 <sup>e</sup>	333.507 $\pm$ 0.004 <sup>m</sup>	428.177 $\pm$ 0.089 <sup>c</sup>	36203.435 $\pm$ 0.219 <sup>f</sup>	27.028 $\pm$ 0.001 <sup>d</sup>
K8	239.789 $\pm$ 0.120 <sup>e</sup>	138.281 $\pm$ 0.000 <sup>j</sup>	457.197 $\pm$ 0.103 <sup>e</sup>	34351.784 $\pm$ 0.045 <sup>e</sup>	28.024 $\pm$ 0.002 <sup>e</sup>
MB1	291.778 $\pm$ 0.111 <sup>f</sup>	84.110 $\pm$ 0.006 <sup>f</sup>	138.269 $\pm$ 0.134 <sup>a</sup>	19400.407 $\pm$ 0.348 <sup>c</sup>	11.215 $\pm$ 0.010 <sup>c</sup>
MB2	291.778 $\pm$ 0.111 <sup>f</sup>	84.110 $\pm$ 0.006 <sup>f</sup>	139.035 $\pm$ 0.201 <sup>b</sup>	19500.407 $\pm$ 0.348 <sup>d</sup>	10.896 $\pm$ 0.017 <sup>b</sup>
MB3	231.121 $\pm$ 0.140 <sup>d</sup>	100.497 $\pm$ 0.004 <sup>g</sup>	725.254 $\pm$ 0.127 <sup>i</sup>	53300.373 $\pm$ 0.190 <sup>o</sup>	30.167 $\pm$ 0.017 <sup>f</sup>
MB4	187.700 $\pm$ 0.153 <sup>c</sup>	101.495 $\pm$ 0.005 <sup>h</sup>	1210.890 $\pm$ 0.059 <sup>k</sup>	95420.100 $\pm$ 0.058 <sup>q</sup>	95.204 $\pm$ 0.004 <sup>k</sup>
MB5	187.667 $\pm$ 0.167 <sup>c</sup>	101.495 $\pm$ 0.005 <sup>h</sup>	1210.890 $\pm$ 0.059 <sup>k</sup>	95422.100 $\pm$ 0.058 <sup>r</sup>	95.204 $\pm$ 0.004 <sup>k</sup>
MK	239.563 $\pm$ 0.054 <sup>e</sup>	310.153 $\pm$ 0.002 <sup>l</sup>	464.698 $\pm$ 0.201 <sup>g</sup>	53796.092 $\pm$ 0.099 <sup>p</sup>	60.808 $\pm$ 0.004 <sup>j</sup>
S1	239.589 $\pm$ 0.006 <sup>e</sup>	65.700 $\pm$ 0.005 <sup>c</sup>	1710.890 $\pm$ 0.059 <sup>l</sup>	40833.144 $\pm$ 0.099 <sup>h</sup>	43.912 $\pm$ 0.006 <sup>i</sup>
S2	187.671 $\pm$ 0.165 <sup>c</sup>	67.972 $\pm$ 0.008 <sup>e</sup>	1783.198 $\pm$ 0.117 <sup>l</sup>	45462.908 $\pm$ 0.030 <sup>k</sup>	43.613 $\pm$ 0.306 <sup>i</sup>
S3	187.873 $\pm$ 0.127 <sup>c</sup>	66.937 $\pm$ 0.022 <sup>d</sup>	1015.216 $\pm$ 0.009 <sup>j</sup>	51943.400 $\pm$ 1.224 <sup>n</sup>	43.870 $\pm$ 0.035 <sup>i</sup>
SH1	130.493 $\pm$ 0.194 <sup>a</sup>	56.250 $\pm$ 0.000 <sup>b</sup>	138.272 $\pm$ 0.136 <sup>a</sup>	6582.777 $\pm$ 0.400 <sup>b</sup>	10.134 $\pm$ 0.001 <sup>a</sup>
SH2	130.340 $\pm$ 0.070 <sup>a</sup>	54.240 $\pm$ 0.020 <sup>a</sup>	138.185 $\pm$ 0.093 <sup>a</sup>	6500.252 $\pm$ 0.144 <sup>a</sup>	10.134 $\pm$ 0.001 <sup>a</sup>

Note: Mean values followed by the same letter(s) within the same column are not significantly different. (One-way ANOVA, SNK-test,  $\alpha = 0.05$ )

#### Cadmium, Chromium and Mercury (Cd, Cr, Hg)

Cd, Cr, and Hg concentrations in the marine sediments were below detection limits in all stations sampled during both the dry and the wet seasons. Oyugi et al. (2000) had the same observations. However, Kamau (2002) and Mwashote (2003) reported concentrations of 1.0  $\mu\text{g/g}$  and 0.08  $\mu\text{g/g}$  of Cd in Makupa and Kilindini harbors, respectively. The difference could be due to sampling points, sampling time, and activities taking place. For chromium and mercury, no reports are available. However, cadmium levels are lower than those reported earlier by Oyugi (2000) and Kamau (2002), and Mwashote (2003), who studied cadmium in Kilindini Creek.

A study in Algiers in the Mediterranean region (Soualili et al. 2008) reported sediment cadmium levels of 0.76  $\mu\text{g/g}$ . USEPA guidelines (PEL Indicators) for Cd is 4.21  $\mu\text{g/g}$ , for Cr is 160  $\mu\text{g/g}$  and for Hg is 0.7  $\mu\text{g/g}$  (Gidaracos and Hahladakis 2012).

#### Lead (Pb)

The results for Pb levels in marine sediments are given in Table 5. In the dry season, Pb levels in marine sediments ranged from 135.47  $\mu\text{g/g}$  at S2 at Shirazi to 290.83  $\mu\text{g/g}$  at MB 2 at Malindi Bay. In the wet season, Pb levels ranged from 13.4  $\mu\text{g/g}$  at S2 at Shirazi to 291.78  $\mu\text{g/g}$  at MB1 in Malindi Bay. There was a significant difference in the Pb levels during the dry and wet seasons ( $P$ -value > 0.05).

In earlier studies on Pb pollution in the Kenyan Coastline, Oyugi et al. (2000) and Hashim (2001) reported Pb levels of 7.76 $\pm$ 0.96 and 52.22 $\pm$ 7.92  $\mu\text{g/g}$ , respectively. In a study to the south, Sheikh et al. (2007) reported lead levels of 228-1150  $\mu\text{g/g}$  for Zanzibar port. These high lead levels may be due to the discharge of effluents from a tannery in the city. USEPA guidelines (PEL Indicators) for Pb is 8.1  $\mu\text{g/g}$  (Gidaracos and Hahladakis 2012).

Within the Sabaki estuary/Malindi bay complex, the lead concentrations increased from the Sabaki River (S1) towards the ocean at S3. At Malindi bay, there was an increase from MB1 at Malindi marine park toward M4, where the Sabaki River enters the ocean. The high concentrations could be due to pelagic activities bringing some pollutants from the open sea. In Kilindini, the high concentrations of lead could be due to the shipping activities at the port and the domestic and industrial wastes from the municipal treatment works, the Kipevu oil terminal, and other industries. Concentrations at Shirazi are due to the terrigenous activities of the region. Due to their geographical separation, there was no relationship between the concentrations at the Malindi/Sabaki complex and Kilindini.

#### Zinc

In the dry season, the Zn levels in sediments ranged from 52.34 µg/g at SH2 at Shirazi to 332.51 µg/g at K7 at Kilindini harbor. In the wet season, the Zn levels ranged from 54.24 µg/g at SH2 at Shirazi to 333.51 µg/g at K7 at Kilindini harbor.

There was no significant difference in concentrations between the dry and wet seasons,  $p$ -value  $>0.000$ . The high concentrations could have been due to industrial activities around Kilindini creek. These levels were comparable with Oyugi et al. (2000), at 27.68 µg/g at English Point Mombasa and 347.73 µg/g levels at Makupa creek. Another study by Hashim (2001) reported levels ranging from 60.97-5.38 µg/g at Malindi to 320.17±76.31 µg/g at Mombasa. In a study to the south, Sheikh et al. (2007) reported Zn levels of 339-3600 µg/g for Zanzibar port and 107-3190 µg/g for Dar es Salaam port. Zinc concentrations in the Sabaki river had no variations from S1 to S3. However, there was an increase in the Malindi Bay from 83.59±0.01 µg/g at the Malindi marine park (MB1) to 102.50±0.04 µg/g at the mouth of the Sabaki river (MB5). This rise could be due to pelagic activities at MB5. At Kilindini, the significantly high level was at K7 with a concentration of 332.51±0.04 µg/g. This concentration could be due to the local geochemical background.

USEPA guidelines (PEL indicators) for Zn is 81.0 µg/g (Gidakos and Hahladakis 2012); hence the Zn levels of the Kenyan coastline are indicative of Zn pollution.

#### Manganese (Mn)

The Mn levels in sediments in the dry season ranged from 130.68 µg/g at SH1 at Shirazi to 1051.19 µg/g at MB5 in Malindi Bay. In the wet season, Mn levels ranged from 138.19 µg/g at SH2 at Shirazi to 1783.20 µg/g at S2 at Sabaki river.

In earlier studies, Oyugi et al. (2000) reported Mn levels that were lower than those of this study, ranging from nd at Diani Beach to 1,100.02 µg/g at Vanga. Hashim (2001) found even lower Mn levels, from 97.54±19.33 µg/g at Gazi to 550.83-52.55 µg/g at Malindi. In their study, Sheikh et al. (2007) reported 537-812 µg/g for Zanzibar harbor and 277-725 µg/g levels - for Dar es Salaam port.

No trend in the sediment manganese concentrations was observed along the Sabaki and at Kilindini. But at Malindi Bay, there was an increase from MB5. That could be due to

marine activities in the open sea showing the highest levels at MB5 since the monsoons were strongest at that point. In addition, there was a significant difference in sediment manganese concentrations between the dry and wet seasons ( $P$  value  $> 0.05$ ), possibly due to siltation.

According to USEPA guidelines, sediment Mn levels  $> 500$  µg/g indicate heavy Mn pollution (Ahdy and Khaled 2009). Therefore, the Kenyan coastline could be considered heavily polluted with Mn.

#### Iron (Fe)

In the dry season, the Fe levels in sediments ranged from 3,14.80 µg/g at SH2 at Shirazi to 83,425.61 µg/g MB4 in Malindi Bay. In the wet season, Fe levels ranged from 6,500.25 µg/g at SH2 at Shirazi to 95,422.1 µg/g at MB 5 in Malindi Bay. Fe levels at Kilindini harbor ranged from 34,351.78 at K8 to 47,314.70 µg/g at K1. In earlier studies, Oyugi et al. (2000) reported iron levels ranging from 800.19 µg/g to 19,312.05 µg/g along the south coast to the Mombasa area. Kamau (2002) reported iron concentrations ranging from 4,268 µg/g to 42,660 µg/g at Port-Reiz creek, Mombasa.

A none-statistical comparison shows lower levels in Oyugi et al. (2000) and Kamau's (2002) studies than in this study. That could be due to differences in time and sampling points. Studies done in Zanzibar and Dar es Salaam ports by Sheikh et al. (2007) reported levels in the range of 67,500-12,400 µg/g and 43,300-7,040 µg/g, respectively. There was a trend in the Fe levels, as seen in Table 5, that the iron sediment concentrations increased from 12,231.39±0.20 µg/g at S1 to 48,240.73±0.02 µg/g. Also, at Malindi Bay, the Fe concentrations increased from 9,351.84±0.02 µg/g at MB1 at the Malindi Marine Park to 83,425.28±0.33 µg/g at MB5. That could be the effects of maritime activities at the open sea. Pollution is being transported towards the East African Coastal zone by the very strong currents of which the South East monsoon is the driving force (Everaats and Nieuwenhuize 1995). No trend was observed in the iron concentrations at Kilindini.

#### Copper (Cu)

Table 5 indicate Cu levels in Marine sediments in the dry season ranged from 9.91 µg/g at SH1 and SH2 at Shirazi to 94.6 µg/g at MB4 and MB5 in Malindi Bay. In the wet season, Cu levels ranged from 10.13 µg/g at SH1 and SH2 at Shirazi to 95.2 µg/g at MB4 and MB5 at Malindi Bay. These figures are comparable to those of an earlier study by Hashim (2001), with levels of 47.68±4.83 µg/g for the Mombasa area and 13.96±1.47 µg/g for the Gazi area, which is near Shirazi. Oyugi et al. (2000) also reported concentrations ranging from 18.70 µg/g at Mombasa Marine Park to 49.97 µg/g at Diani. Kamau (2002) reported concentrations ranging from 2.30 µg/g to 32.30 µg/g at Kilindini creek. Individual differences could be due to differences in sampling points. In studies for other water bodies, Sheikh et al. (2007) reported levels of 4-75 µg/g for Zanzibar port and 36 µg/g for Dar es Salaam harbor.

The sediment copper concentrations were the same along the Sabaki (43.92±0.03 µg/g). However, in Malindi

Bay, an increasing trend from  $10.13 \pm 0.02 \mu\text{g/g}$  at MB1 to  $94.60 \pm 0.07 \mu\text{g/g}$  at MB5, which could be due to the effects of the strong currents of the South East monsoon. There was no trend of sediment copper concentrations at Kilindini. USEPA guidelines (PEL indicators 0 for Cu sediments is  $\mu\text{g/g}$ ) (Gidaracos and Haliladakis 2012). Therefore the Kenyan coastline is free of sediments and Cu pollution.

#### Levels of heavy metals in marine fauna

The levels of Pb, Cd, Zn, Mn, Cr, and Cu analyzed in the fauna are shown in Table 6.

#### Cadmium, mercury, and chromium (Cd, Hg, Cr)

Cd, Hg, and Cr levels in the fauna samples were below the detection level in both wet and dry seasons. These levels are lower than those found by Bor (2000), who reported levels at Mombasa ranging from  $0.29 \pm 0.01 \mu\text{g/g}$  to  $2.36 \pm 0.70 \mu\text{g/g}$  for cadmium chromium and mercury levels in fauna had not been reported in previous studies of the Kenyan coastline.

#### Lead (Pb)

Table 6 show lead concentration levels for *Cerithidea decollata* (Nyambua) ranged from  $135.41 \pm 0.07 \mu\text{g/g}$  at Shirazi during the dry season to  $236.62 \pm 3.21 \mu\text{g/g}$  at Kilindini during the wet season. For *Saccostrea cucullata* (rock oyster), the levels ranged from  $135.507 \pm 0.058 \mu\text{g/g}$  to  $833.11 \pm 0.68 \mu\text{g/g}$  at Malindi Bay during the wet season. These levels are significantly higher than those found in another study (Bor 2000), which recorded levels for pearl oysters at Mombasa ranging from  $2.35 \pm 0.11 \mu\text{g/g}$  to  $121 \pm 0.02 \mu\text{g/g}$ .

The present study was done ten years after that of Bor, so it can be suggested that lead pollution has taken place in the subsequent period and that the sea animals have accumulated lead over time. However, t-statistics for temporal variations showed a  $p$ -value  $> 0.05$ , meaning there was no significant difference in lead concentrations of fauna between dry and wet seasons at the Kenyan coastline.

A study in the Middle East (Fowler et al. 1993) recorded levels for rock oysters ranging from  $0.08 \mu\text{g/g}$  to  $2.1 \mu\text{g/g}$ . Mostafa et al. (2009) reported lead concentrations of rock oysters in Yemen in the range of 2.6 – 15.4  $\mu\text{g/g}$ .

#### Zinc (Zn)

Zinc levels for *C. decollata* ranged from  $99.48 \pm 0.26 \mu\text{g/g}$  at Sabaki to  $381.48 \pm 0.01 \mu\text{g/g}$  at Shirazi during the wet season. Zinc levels for *S. cucullata* ranged from  $446.88 \pm 0.09 \mu\text{g/g}$  at Malindi during the dry season to  $873.07 \pm 0.19 \mu\text{g/g}$  at Shirazi during the wet season (Table 6). Bor (2000) reported zinc levels at Mombasa ranging from  $30.1 \pm 1.81 \mu\text{g/g}$  to  $119 \pm 1.4 \mu\text{g/g}$ . These are much lower levels of zinc than those found in this study. The high lead levels could be due to boating activities at Malindi, a busy tourist resort, and shipping activities at Kilindini harbor. The high zinc concentrations in oysters at Shirazi could be due to the biogeochemical environment. The zinc concentrations on the Kenyan Coast are high. The Australian National Health and Medical Research Council recommended 1,000  $\mu\text{g/g}$  (Brown and McPherson 2003).

Zinc tends to be bioaccumulated by bivalves. Oysters especially contain large amounts of zinc. For example, the highly contaminated English Restrongnet Creek oysters contain zinc concentrations above 10,000  $\mu\text{g/g}$  dry weight. However, like most heavy metals, zinc does not tend to biomagnify, so it causes little harm to sea birds or marine mammals (Kennish 1996).

#### Manganese (Mn)

Manganese levels for *C. decollata* ranged from  $29.77 \pm 0.12 \mu\text{g/g}$  at Sabaki during the wet season to  $486.61 \pm 0.22 \mu\text{g/g}$  at Kilindini during the dry season. For *S. cucullata*, the manganese levels ranged from  $210.92 \pm 0.04 \mu\text{g/g}$  at Shirazi during the dry season to  $334.29 \pm 0.16 \mu\text{g/g}$  at Malindi during the dry season.

#### Iron (Fe)

Iron levels for *C. decollata* ranged from  $379.85 \pm 0.18 \mu\text{g/g}$  at Sabaki during the dry season to  $35,278.09 \pm 0.35 \mu\text{g/g}$  at Kilindini during the wet season. For *S. cucullata*, the levels ranged from  $564.91 \pm 0.05 \mu\text{g/g}$  at Shirazi during the dry season to  $8343.03 \pm 0.32 \mu\text{g/g}$  at Malindi during the wet season (Table 6). Bor (2000) recorded much lower levels ranging from  $25.60 \pm 0.90 \mu\text{g/g}$  to  $242.00 \pm 14.50 \mu\text{g/g}$  at Mombasa. Elsewhere in the Middle East, Fowler et al. (1993) recorded Fe levels for rock oysters, ranging from 11 to 266  $\mu\text{g/g}$ .

**Table 6.** Levels of heavy metals in fauna during the dry and wet season

Site	Sample	Concentration ( $\mu\text{g/g}$ ) $\pm$ SE ( $n = 3$ )				
		Mn	Fe	Cu	Zn	Pb
<b>Dry season</b>						
Shirazi	<i>Cerithium decollata</i>	$37.002 \pm 0.049^b$	$565.576 \pm 0.289^c$	$145.323 \pm 0.039^c$	$380.480 \pm 0.010^c$	$135.407 \pm 0.007^a$
Shirazi	<i>Saccostrea cucullata</i>	$210.920 \pm 0.040^c$	$564.909 \pm 0.053^b$	$43.963 \pm 0.024^a$	$872.852 \pm 0.174^c$	$135.412 \pm 0.006^a$
malindi	<i>Saccostrea cucullata</i>	$334.286 \pm 0.162^d$	$8342.698 \pm 0.154^d$	$229.843 \pm 0.081^d$	$446.882 \pm 0.009^d$	$831.778 \pm 0.969^c$
Sabaki	<i>Cerithium decollata</i>	$29.770 \pm 0.119^a$	$379.853 \pm 0.176^a$	$128.382 \pm 0.009^{ab}$	$99.476 \pm 0.262^a$	$135.663 \pm 0.169^a$
Kilindini	<i>Cerithium decollata</i>	$486.611 \pm 0.222^e$	$35277.753 \pm 0.037^e$	$43.970 \pm 0.025^a$	$157.909 \pm 0.054^b$	$236.485 \pm 3.143^b$
<b>Wet season</b>						
Shirazi	<i>Cerithium decollata</i>	$35.669 \pm 0.285^b$	$565.909 \pm 0.524^b$	$145.474 \pm 0.074^c$	$381.480 \pm 0.010^c$	$135.507 \pm 0.058^a$
Shirazi	<i>Saccostrea cucullata</i>	$211.413 \pm 0.322^c$	$565.242 \pm 0.287^b$	$43.990 \pm 0.010^a$	$873.067 \pm 0.186^c$	$135.407 \pm 0.007^a$
malindi	<i>Saccostrea cucullata</i>	$333.200 \pm 1.604^d$	$8343.031 \pm 0.316^c$	$230.177 \pm 0.283^d$	$446.948 \pm 0.040^d$	$833.111 \pm 0.676^c$
Sabaki	<i>Cerithium decollata</i>	$29.867 \pm 0.133^a$	$380.187 \pm 0.260^a$	$128.546 \pm 0.023^b$	$99.737 \pm 0.263^a$	$135.997 \pm 0.274^a$
Kilindini	<i>Cerithium decollata</i>	$485.611 \pm 0.812^e$	$35278.086 \pm 0.348^d$	$44.037 \pm 0.042^a$	$158.038 \pm 0.085^b$	$236.624 \pm 3.214^b$

Note: Mean values followed by the same letter(s) within the same column are not significantly different. (One-way ANOVA, SNK-test,  $\alpha = 0.05$ )



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