SECTION RESULTS

CHAPTER 4 ECOTOXICOLOGY

1. Introduction

Benthic macro fauna are those organisms that live on or inside the deposit at bottom of a water body (Odum, 1971; Barnes and Hughes, 1988; Andem et al., 2012). They constitute the link between the unavailable nutrients in detritus and useful protein materials in fish and shellfish (George et al., 2009). Most benthic organisms feed on debris that settle on the bottom of the water and in turn serve as food for a wide range of fishes (Adebisi, 1989; Ajao 1990; Idowu and Ugwumba, 2005). They also accelerate the breakdown of decaying organic matter into simpler inorganic forms such as phosphates and nitrates (Gallep et al*.,* 1978; Wang et al., 2011). All forms of aquatic plants, which are the first link of several food chains existing in aquatic environment, can utilize the nutrients. These organisms therefore form a major link in the food chain as most estuarine and marine fishes, birds and mammals depend directly or indirectly on the benthos for their food supply (Barnes and Hughes, 1988).Macrobenthic community composition, abundance and distribution can be influenced by water quality and soil quality (George et al., 2009) and thus, macrobenthic community are useful bio-indicatorsproviding a more accurate understanding of changing aquatic conditions than chemical and microbiological data (Ikomi *et al.,* 2005; Rombouts et al., 2013).

1.1 Water and Sediment Pollutant Analysis

In many aquatic systems, deposition of contaminants, including heavy metals, can lead to elevated sediment concentrations that have the potential to cause toxicity to aquatic biota (Yang and Rose 2003). Because of the importance of sediments to the overall quality of aquatic systems, sediment analysis is important in environmental assessment studies along with water analysis (Jain et al., 2005; Adekola and Eletta 2007). Sediments and suspended particulate matter (SPM) play an important role in the adsorption of dissolved heavy metals. They can also be a potential reservoir of metals, by releasing them to the water column under changing physical and chemical conditions (Karbassi et al., 2007). It is known that sediments play a significant role in controlling the metal concentrations in many of these aquatic environments and therefore the behavior of metals, including sedimentation and resuspension, have attracted the attention of many researchers (Bellucci et al., 2003; Betrolotto et al., 2003). It is generally believed that metals incarbonate, sulfide and organic compounds are more toxic due to higher bioavailability, and thus are more critical from an environmental risk assessment standpoint (Karbassi et al.,2008).In recent years, the contamination of aquatic systems has become a problem of great concern throughout the world.Sources of environmental contaminants to the coastal system are numerous and may enter the estuarine environment via a number of pathways. Metals may be present in the estuarine system as dissolved species, as free ions or forming organic complexes with humic and fulvic acids (Spencer and MacLeod, 2002). Consequently, sediments accumulate contaminants and may act as long-term stores for metals in the environment. Exposure of sediment-dwelling organisms to metals may then occur via uptake of interstitial waters, ingestion of sediment particles and via the food chain (Luoma, 1989).

1.2 Benthic Fauna as Bio indicator

Mussels have played a key role in the development of biomonitoring programmes for heavy metals, especially species of *Mytilus* as in the US Mussel Watch Program (Goldberg et al., 1978, 1983; Farrington et al., 1983; Lauenstein et al., 1990). Species of other mussel genera also used as biomonitors include *Septifer virgatus* in Hong Kong (Phillips andYim, 1981), *Trichomya hirsuta*in Australia (Klumpp andBurdon-Jones, 1982) and *Perna viridis* in the Far East, inThailand (Phillips and Muttarasin, 1985) and in HongKong (Phillips and Yim, 1981; Phillips,1985; Phillips andRainbow, 1988).Oysters represent the second group of bivalve molluscs widely employed as heavy metal biomonitors. Like mussels they are widespread suspension feeders in coastal waters, but unlike mussels they have the advantage of being strong net accumulators of zinc (George et al., 1978). Oyster species commonly used for heavy metal biomonitoring include *O. edulis* and species of *Crassostrea* such as *C. gigas, C. virginica, C. margaritacea* and *C. brasiliana* (Rainbow & Phillips, 1993).

In crustaceans, the important surface of the gill tissue constitutes a main avenue for exchange with the environmental medium (Malins and Ostrander, 1994). It can thus be assumed that this tissue is one of the first which may have to suffer from toxicity of heavy metals (Malins and Ostrander, 1994).It is long history that crustaceans were used as heavy metal biomarkers. Philips and Rainbow (1993) had started to investigate *Capitulum mitella* and *Balanus amphitrite* (Cirripedia, Crustacea) as a biomarker of heavy metals which was followed by Rainbow and Smith (1992) and Rainbow et al. (1993). Blackmore (1996) and Blackmore et al. (1998) had worked on *Balanus amphitrite* and *Tetraclita squamosa* to check bioaccumulation of heavy metals. Talitrid amphipods, *Orchestia gammerellus,* have been shown to be a suitable biomonitors for copper and zinc in British coastal waters (Rainbow et al., 1989; Moore et al., 1991).

The Advantage of using the benthic fauna as biomarkers is:

- The relatively sedentary life style ofsome epibenthic fauna can result inan in-place accumulation ofindicative pathogens and toxicantsin individuals while the communitycomposition reflects the averagesalinity, temperature and dissolvedoxygen of that site over anextended period of time.
- Ease of data collection by use ofsmall otter trawls or beam trawls.
- Relative ease of identificationbecause taxonomic lists of localcrustaceans, mollusks, and echinoderms can be fairly easily compiled.
- Sampling is as inexpensive as fishsurveys, and can often be done withthe same or similar equipment during the same survey.
- Decapod Crustacea are usually veryimportant prey for fish and areimportant components in benthicfood webs. Some (e.g., shrimp andcrabs) are harvested for humanconsumption.

Crustaceans have been observed as indicators of many ecological features. Crustaceans living in sediment were responsive to metal contamination and water quality. Additionally, crustaceans showed change in abundance and richness depending on changes in the fluvialhabitat and sediment (Tall et al. 2008). This illustrates that communities of crabs, among other crustaceans, are responsive to sedimentary change, and therefore can indicate sedimentaryconditions in benthic habitats.

Crabs not only show evidence of environmental features such as salinity and sediment types and content, but they also respond to anthropogenic factors, making them key bioindicators of human impact on benthic communities. For example, the behaviours of fiddler crab species Uca annulipes and Uca inversa are “strongly affected by domestic sewage dumping and have the potential to be used as bioindicators” (Bartolini et al. 2009).These behaviours were observed in juvenile fiddler crabs which experienced reduced ability to avoid predators, construct burrows, and feed adequately for survival (Cunninghan and Myers 1987). Brachyuran fauna can be used as indicator of pollution because they are benthic animals, have the ability to respond against environmental pollution and are widely distributed in the estuarine environment (Borja, et al., 2003; Arya et al., 2014). Crabs can tolerate high levels of disturbances in habitat and still able to maintain their existence so they can be better tool to check the long-term effect of pollutant on ecosystem.

1.3 Ex situ experiment of crab to check effect of heavy metals

There are list of study present describing effect of heavy metals on brachyuran crabs which are: Disruption of circulatory and respiratory activity due to accumulation of heavy metals in shore crabs *Carcinus maenas* was observed by Depledge (1984). Spicer and Weber (1992) observed respiratory impairment by water-borne copper and zinc in the edible crab *Cancer pagurus* during hypoxic exposure. Rtal et al. (1996) studied detoxification of exogenous copper by binding to hemolymph proteins in the shore crab, *Carcinus maenas*. Accumulation of zinc increased tissue total proteins, decreased glycogen, and decreased acid phosphatase activity in crabs, Portunus pelagicus (Hilmy et al. 1988); retardation of limb regeneration of fiddler crabs, Uca pugilator (Weis 1980). Heart rates and weight specific oxygen consumption increased with increasing copper concentration after a short exposure to 96 hrof the blue swimming crab, Portunus pelagicus (Linnaeus, 1766) (Ketpadung and Tangkrock-olan, 2006). Lauer et al. (2012) reported in the recent study that copper affects glycolysis and Krebs cycle enzymes, being more toxic to anterior gills of hyperosmoregulating estuarine crab Neohelice granulata.

1.4 Estuarine fauna and Heavy metal accumulation

McLusky et al. (1986) showed that temperature and salinity has a clear effect on copper toxicity, which in this study tended to increase as salinity decreased and temperature increased. These results seem to indicate that, for species living in estuaries, heavy metal toxicity increases as salinity decreases and as temperature increases. McLusky et al. (1986) also pointed out that toxicity values determined under fixed (or single) temperature and salinity regimes (e.g. in experimental conditions) are inappropriate for evaluating the effect of environmental factors in modifying the toxicity of metals for estuarine and marine species. Estuarine environment is dynamic and complexity of effect of biotic and abiotic factor on accumulation of heavy metals is hard to describe.

2. RESULTS

2.1 Pollutants in water sample of downstream of Mahi River

Affinity of metals to get accumulated in sediments at all the sites is as follows: (high concentration) Fe ≥ Zn ≥ Cd ≥ Pb ≥ Ni ≥ Mn ≥ Co ≥ Cr ≥ Cu (low concentration) at downstream of Mahi river (Table 1). Phenol concentration was recorded at Sarod and its downstream sites as well i.e. Nahar and Kamboi. Mean phenol concentration in water ranged between 0.042 ±0.007 mg/g (low tide, Kamboi) and 2.90 ±0.541 mg/g (low tide, Sarod) (Figure 1).

Oil and grease concentration was detected very high at Sarod and its downstream sites as well i.e. Nahar and Kamboi. Mean oil and grease concentration in water ranged between 6.933 ±1.007 mg/g (high tide, Kamboi) and 42 ±10 mg/g (low tide, Sarod) (Figure 1). Cadmium (Cd) concentration was recorded very low at all the four sites. Mean Cadmium (Cd) concentration in water ranged between 0.001 ±0.001 μg/g (high tide, Kamboi) and 0.015

±0.010 μg/g (low tide, Sarod) (Figure 2). Cobalt (Co) was detected in very less quantity during low tide at Sarod and Nahar. Mean Cobalt (Co) concentration in water ranged between 0.001 ±0.001 μg/g (low tide, Nahar) and 0.017 ±0.006 μg/g (low tide, Sarod). Mean Copper (Cu) Concentration in water, ranged between 0.002 ±0.001 μg/g (low tide, Kamboi) and 0.003 ±0.002 μg/g (Low tide, Sarod). Cu detected at Dabka during high tide (0.002 ±0.002 μg/g) which is an upstream site of Sarod. Chromium (Cr) was detected in very less quantity during low tide at Sarod (0.007 ±0.001 μg/g) and Nahar (0.001 ±0.001 μg/g). Mean Ferrous (Fe) concentration in water ranged between 0.016 ±0.009 μg/g (High tide, Kamboi) and 2.247 ±0.489 μg/g (High tide, Dabka) (Figure 2). Mean manganese (Mn) concentration in sediments ranged between 0.001 ±0.001 μg/g (High tide, Sarod) and 0.007 ±0.002 μg/g (low tide, Sarod) (Figure 3). Mean nickel (Ni) concentration in sediments ranged between 0.001 ±0.001 μg/g (low tide, Kamboi) and 0.010 ±0.001 μg/g (low tide, Sarod) (Figure 3). Mean Lead (Pb) concentration in sediments ranged between 0.003 ±0.001 μg/g (low tide, Kamboi) and 0.023 ±0.005 μg/g (low tide, Sarod) (Figure 4). Mean Zink (Zn) concentration in sediments ranged between 0.013 ±0.006 μg/g (high tide, Nahar) and 1.437 ±0.112 μg/g (low tide, Sarod) (Figure 4).

Effluent channel opens at Sarod hence, pollutants were recorded in higher quantity during low tide at Sarod. Nahar is downstream site to Sarod and hence, during low tide it receives pollutant load thus, pollutants were recorded in higher quantity. As Dabka is an upstream site of Sarod, metals were detected during high tide, at Dabka. Overall, lesser amount of metals recorded in water while phenol as well as higher amount of oil and grease were recorded at downstream of Mahi river.

2.2 Pollutants in Sediments

Affinity of metals to get accumulated in sediments at both the sites (i.e. Sarod and Kamboi) is as follows: (high concentration) Zn ≥ Pb ≥ Cd ≥ Fe ≥ Cu ≥ Co ≥ Mn ≥ Ni ≥ Cr (low concentration) (Table 2 & Table 3).

Sarod

Mean Cadmium (Cd) concentration in sediments ranged between 2 ±1 µg/g (60 cm depth, zone 3) and 40 ±14 µg/g (surface sediment, zone 3) at Sarod. Mean Cadmium (Cd) concentration was found to be decreased as depth increased (Figure 5). Mean Cobalt (Co) concentration in sediments ranged between 5 ±5 µg/g (20 cm depth, zone 2) and 30 ±11 µg/g (surface sediment, zone 3) at Sarod. Cobalt (Co) was detected in three samples (surface sediment, zone 3 and 20 cm depth, zone 2 and zone 3) out of 8 samples at various depths of two zones at Sarod (Figure 6). Mean Copper (Cu) concentration in sediments ranged between 5 ±2 µg/g (20 cm depth, zone 2) and 20 ±11 µg/g (surface sediment, zone 3) at Sarod. Cu was not recorded at any depth of zone 2 at Sarod (Figure 5). Mean Ferrous (Fe) concentration in sediments ranged between 1 ±1 µg/g (20 cm depth, zone 2) and 20 ±6 µg/g (surface sediment, zone 3) at Sarod (Figure 6). Mean manganese (Mn) concentration in sediments ranged between 1 ±1 µg/g (surface sediment, zone 2) and 22 ±3 µg/g (20 cm depth, zone 3) at Sarod (Figure 7). Mean nickel (Ni) concentration in sediments ranged between 10 ±6 µg/g (surface sediment, zone 2) and 20 ±3 µg/g (surface sediment, zone 3) at Sarod (Figure 7). Mean Lead (Pb) concentration in sediments ranged between 2 ±1 µg/g (40 cm depth, zone 2) and 40 ±10 µg/g (20 cm depth, zone 3) at Sarod (Figure 8). Mean Zink (Zn) concentration in sediments ranged between 6 ±3 µg/g (40 cm depth, zone 2) and 130 ±40 µg/g (surface sediment, zone 3) at Sarod (Figure 8).

Effluent channel opens at Sarod and effluent which passes through a small channel near zone 3 hence, metal concentration was detected significantly higher in the surface sediment samples of zone 3. Metal concentration was recorded in lesser amount as zone 2 comprises a slope hence diluted water reaches up to the zone during high tide.

Kamboi

Mean Cadmium (Cd) concentration in sediments ranged between 2.33 ±1.52 µg/g (60 cm depth, zone 2) and 40 ±15.28 µg/g (surface sediment, zone 5) at Kamboi (Figure 9). Cadmium (Cd) concentration was found to be decreased as depth increased except at zone 4 where highest concentration was recorded at the death of 40 cm. Mean Cobalt (Co) concentration in sediments recorded only in a single zone (i.e. zone 5) out of five zones which ranged between 10 ±5.41 µg/g (20 cm depth, zone 5) and 40 ±20 µg/g (surface sediment, zone 5) at Kamboi (Figure 10). Mean Copper (Cu) concentration in sediments ranged between 5 ±2.42 µg/g (40 cm depth, zone 3) and 18 ±4.16 µg/g (surface sediment, zone 5) at Kamboi. Cu was not recorded at any depth of zone 2 at Kamboi (Figure 9). Mean Ferrous (Fe) concentration in sediments ranged between 1 ±0.833 µg/g (40 cm depth, zone 2) and 29 ±6.24 µg/g (20 cm depth, zone 5) at Kamboi (Figure 10). Manganese was recorded in two zones only (i.e. zone 4 and zone 5). Mean manganese (Mn) concentration in sediments ranged between 5 ±2.77 µg/g (40 cm depth, zone 4) and 20 ±5.77 µg/g (surface sediment, zone 5) at Kamboi (Figure 11). Nickel was recorded only at zone 4 (i.e. on surface and at 20 cm depth) and zone 5 (on surface sediment). Mean nickel (Ni) concentration in sediments ranged between 5 ±2.89 µg/g (20 cm depth, zone 4) and 10 ±7.64 µg/g (surface sediment, zone 5) at Kamboi (Figure 11). Mean Lead (Pb) concentration in sediments ranged between 2.5 ±1.89 µg/g (20 cm depth, zone 2) and 60 ±24.11 µg/g (surface sediment, zone 5) at Kamboi (Figure 12). Mean Zink (Zn) concentration in sediments ranged between 2 ±0.58 µg/g (40 cm depth, zone 2) and 180 ±25.17 µg/g (surface sediment, zone 5) at Kamboi (Figure 12). Freshwater channel passes near by zone 5 so effluents come along fresh water during low tide hence metal concentration was recorded high. Due to the presence of slope and income of diluted water during high tide very less amount of metal concentration was recorded in upper intertidal zones (i.e. zone 2 and zone 3) (Table 3).

2.3 Heavy metals in crab muscle tissue (*Ilyoplax sayajiraoi)* and vegetation (*Aeluropus lagopoides)*

Affinity of metals to get accumulated in sediments at both the sites is as follows: (high concentration) Fe ≥ Cr ≥ Zn ≥ Cd ≥ Co ≥ Pb (low concentration) at Sarod and Kamboi (Table 4). Mean cadmium (Cd) concentration was recorded 0.073 ±0.07 µg/g in muscle tissue of crabs and 0.025 ±0.01 µg/g in vegetation (grass leaf) tissue collected from Sarod (Figure 13). Mean cobalt (Co) concentration was recorded 0.018 ±0.007 µg/g in muscle tissue of crabs and 0.034 ±0.011 µg/g in vegetation (grass leaf) tissue collected from Sarod (Figure 13). Chromium (Cr) concentration was recorded surprisingly high in crab and vegetation tissue collected from Sarod. Mean Chromium (Cr) concentration was recorded 2.78 ±1.62 µg/g in muscle tissue of crabs and 7.59 ±2.231 µg/g in vegetation tissue collected from Sarod (Figure 13). Ferrous (Fe) concentration was also recorded high in crab and vegetation tissue collected from Sarod. Mean Ferrous (Fe) concentration was recorded 16.52 ±4.28 µg/g in tissue of crabs and 86.53 ±34.21 µg/g in vegetation tissue collected from Sarod (Figure 13). Mean Lead (Pb) concentration was recorded 0.019 ±0.012 µg/g in tissue of crabs and 0.011 ±0.007 µg/g in vegetation tissue collected from Sarod (Figure 13). Mean Zink (Zn) concentration was recorded 0.36 ±0.12 µg/g in tissue of crabs and 0.33 ±0.056 µg/g in vegetation tissue collected from Sarod (Figure 13).

Since effluent channel opens at Sarod, Heavy metals were present in animal and vegetation tissue while negligible in animal and vegetation tissue collected from Kamboi.

3. DISCUSSION

Concentration of oil & grease was recorded very high at effluent releasing site, Sarod. Otokunefor and Obiukwu (2005) stated that high oil and grease concentration along with other pollutants could be responsible for depletion of fish communities and other aquatic life at the point of the effluent. Compare to other effluent releasing site concentration of oil and grease was recorded very high at Sarod (Table 6.5). Concentration of Phenol was recorded very high (2.9 ±0.541 mg/g) at effluent releasing site. Phenol have been observed to be very toxic to fish and other aquatic organisms. They have a unique property of tainting the taste of fish if its concentration ranges between 0.1 to 1.0 mg/l (Staples et al., 1998). At study sites, all metals were recorded below the safe values for water quality standards in India (CPCB, IS 2296:1992).

Heavy metal analysis of sediment of Sarod site shows high accumulation of Zinc (Zn), Cobalt (Co) and Cadmium (Cd) at lower intertidal area whereas, in lower intertidal area of Kamboi Cadmium (Cd), Cobalt (Co), Lead (Pb) and Zinc (Zn) were recorded with higher concentration. Accumulation of heavy metals recorded up to 40 cm depths at both the sites. Thus it can be concluded that the accumulation of heavy metals in sediments is due to the effluent passing along with fresh water channel through lower intertidal area. Concentration of Chromium (Cr) and Ferrous (Fe) recorded high in crab muscle tissue and vegetation tissue collected from Sarod. Vey negligible amount of Chromium was detected in water and not detected in sediment. Surprisingly, it was noticed in higher amount in crab and vegetation tissue however, further study is required to draw a conclusion.

The concentrations of heavy metals varied among water, soil, crab muscle tissue (Ilyoplax sayajiraoi) and vegetation tissue (Aeluropus lagopoides) collected from study sites. Accumulation of metals was in following order; soils > crabs > vegetation >water which matches with the work carried out by Zhang et al. (2010), they observed following order; soils > plants > water by studying the heavy metal accumulation in water, soil and riparian plants at Pearl River estuary, South China. Table 6 shows the comparison of accumulation of heavy metal in crustacean fauna of different region and confirms that study site contained low accumulation of heavy metals except chromium in animal tissues. In the case of vegetation tissue, present site shows the high accumulation of chromium and ferrous compare to other sites (Table 7). Concentration of Chromium also detected high in benthic macrofauna by Chiba et al., (2011) at Southeast Brazil. They stated that due to its high toxicity, the metal indicate risk to the ecosystem. Significant bio concentration of certain elements in plant tissue occurs as a result of the lack of regulatory mechanisms concerning the uptake of metals, particularly when the concentration of an element in the environment is markedly increased (Stankovic et al., 2000; Pajevic et al., 2002). If the metal concentration in organisms found to be exceeded than the concentration of metals found in water and sediment, indicates bioaccumulation in the ecosystem (Klavins et al. 1998). There was no consistent relationship between the physico-chemical variables of water, metals in water, metals in the sediment and metals in animal and vegetation tissues. Probably, the patterns of accumulation are associated with complex relationships of the environment. Environmental factors such as temperature, pH, dissolved oxygen, sediment grain size and hydrological features of the system also influence the bioavailability of metal to the marine animals (Safahieh et al., 2011; Salahshur et al., 2014).

As demonstrated by Rybak et al. (2013), Cu and Zn accumulation in genus *Ulva* from the Maltanski Reservoir was positively correlated with total dissolved solids content, but negatively with water temperature. Therefore both, the aqueous chemistry and the physiology of the living organisms can be important in affecting metal bioavailability (Rzymski et al., 2014). So, interacting of physical, chemical and biological processes that affect the fate and bioavailability of metals which are shown in figure 6.14. The bioavailability of dissolved Cu, Cd, Pb or Zn correlates with the activity of the free ion (or the chemical potential of the metal) and not with total metal present in water and sediment (Sunda and Guillard, 1976; Sunda et al., 1978; Campbell and Tessier, 1989).

Cu as well as Fe, Mn, and Zn, are essential elements for bivalves although their demand and bio concentration appears to be controlled by biological processes (Moura et al., 2000). Cu forms hemocyanin, Fe binds to ferritin, an important detoxification protein, Mn is a cofactor for enzymes including manganese superoxide dismutase and Zn is required with more than 200 metalloenzymes for maximum catalytic activity (van Holde et al., 2001).

Table 1. Water pollutants in the downstream of Mahi estuary

Sites	Tide	Phenol	Oil & Grease	Cd	Co	Cu	Cr	Fe	Mn	Ni	Pb	Zn
Dabka	L.T.	0	0	0	0	0	0	1.443 ±0.209	0.005 ±0.11	0	0.005 ±0.001	0.015 ±0.005
	H.T.	0	0	0.003 ±0.002	0	0.002 ±0.002	0.000	2.247 ±0.489	0.004 ±0.002	0	0.004 ±0.002	0.025 ±0.010
Sarod	L.T.	2.900 ±0.541	42.000 ±14.000	0.015 ±0.010	0.017 ±0.006	0.003 ±0.002	0.007 ±0.001	0.507 ±0.260	0.007 ±0.002	0.010 ±0.001	0.023 ±0.005	1.437 ±0.112
	H.T.	1.263 ±0.341	36.000 ±9.165	0.013 ±0.007	0	0	0	0.395 ±0.177	0.003 ±0.001	0.004 ±0.002	0.008 ±0.002	0.520 ±0.113
Nahar	L.T.	0.045 ±0.008	21.333 ±4.619	0.005 ±0.002	0.001 ±0.001	0	0.001 ±0.001	0.366 ±0.053	0.001 ±0.001	0.004 ±0.001	0.006 ±0.002	0.026 ±0.009
	H.T.	0.548 ±0.178	17.000 ±3.000	0	0	0	0	0.630 ±0.281	0.001 ±0.001	0.005 ±0.003	0.004 ±0.002	0.013 ±0.006
Kamboi	L.T.	0.042 ±0.007	8.867 ±1.026	0.003 ±0.001	0	0.002 ±0.001	0	0.019 ±0.004	0	0.001 ±0.001	0.003 ±0.001	0.247 ±0.061
	H.T.	0.220 ±0.087	6.933 ±1.007	0.001 ±0.001	0	0	0	0.016 ±0.009	0	0	0	0.233 ±0.153

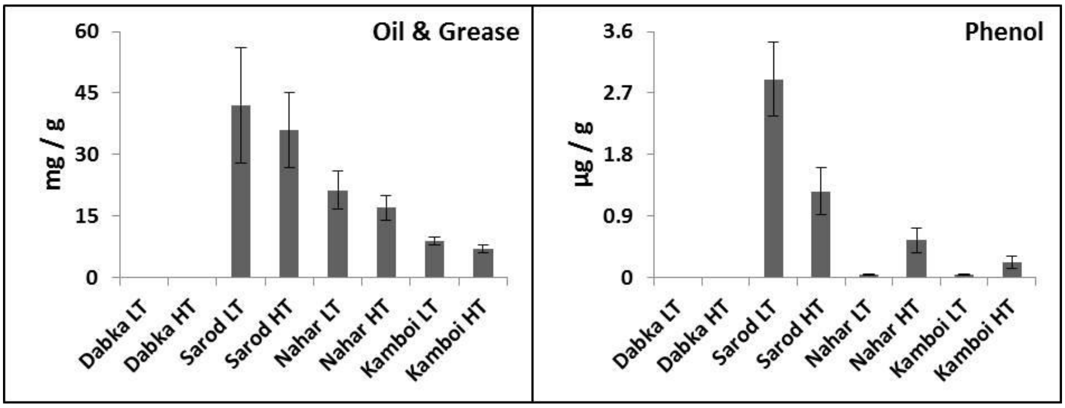

Figure 1. Concentration of Oil-Grease and Phenol in the downstream of Mahi estuary

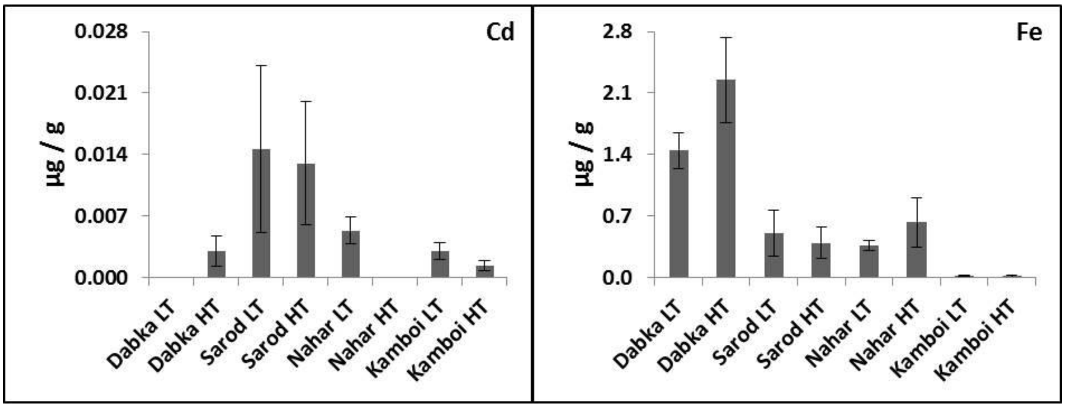

Figure 2. Concentration of Cadmium and Ferrous in the downstream of Mahi estuary

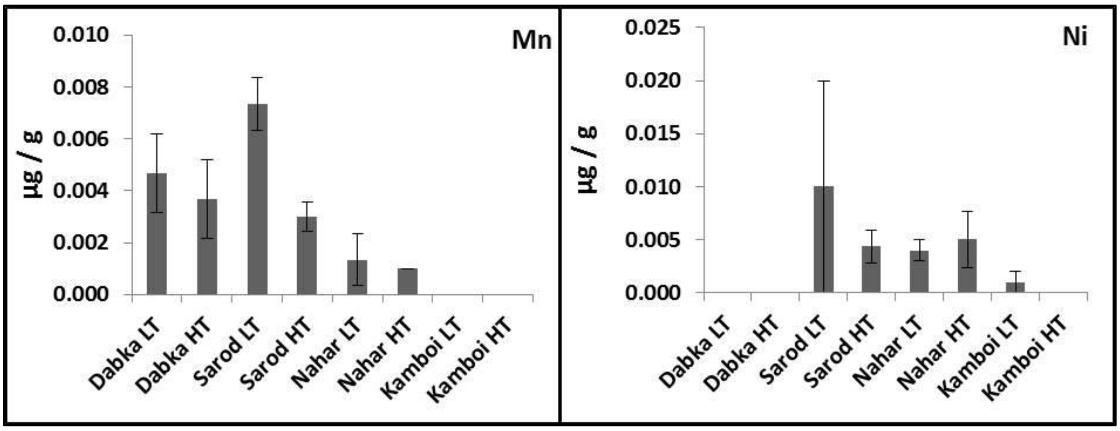

Figure 3. Concentration of Manganese and Nickel in the downstream of Mahi estuary

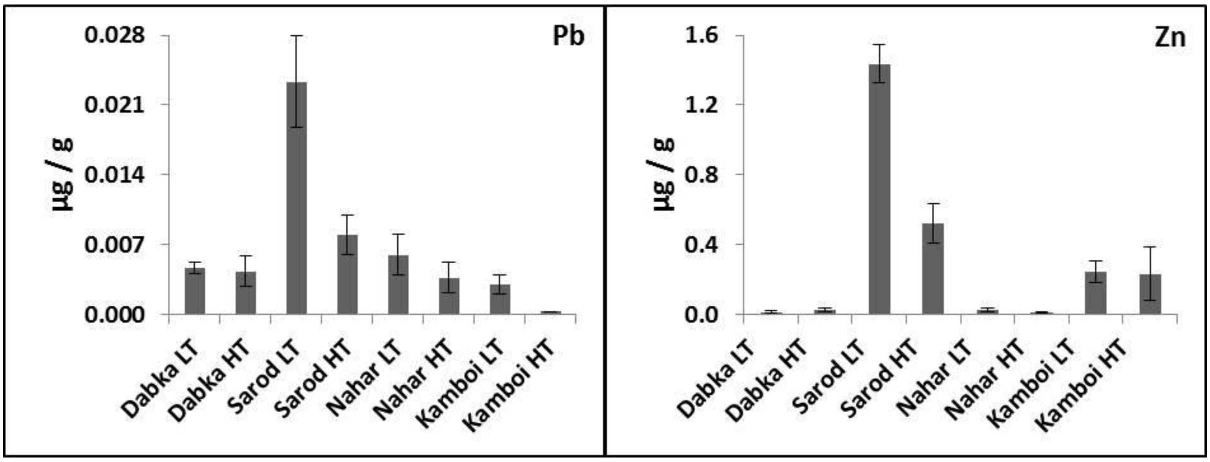

Figure 4. Concentration of Lead and Zink in the downstream of Mahi estuary

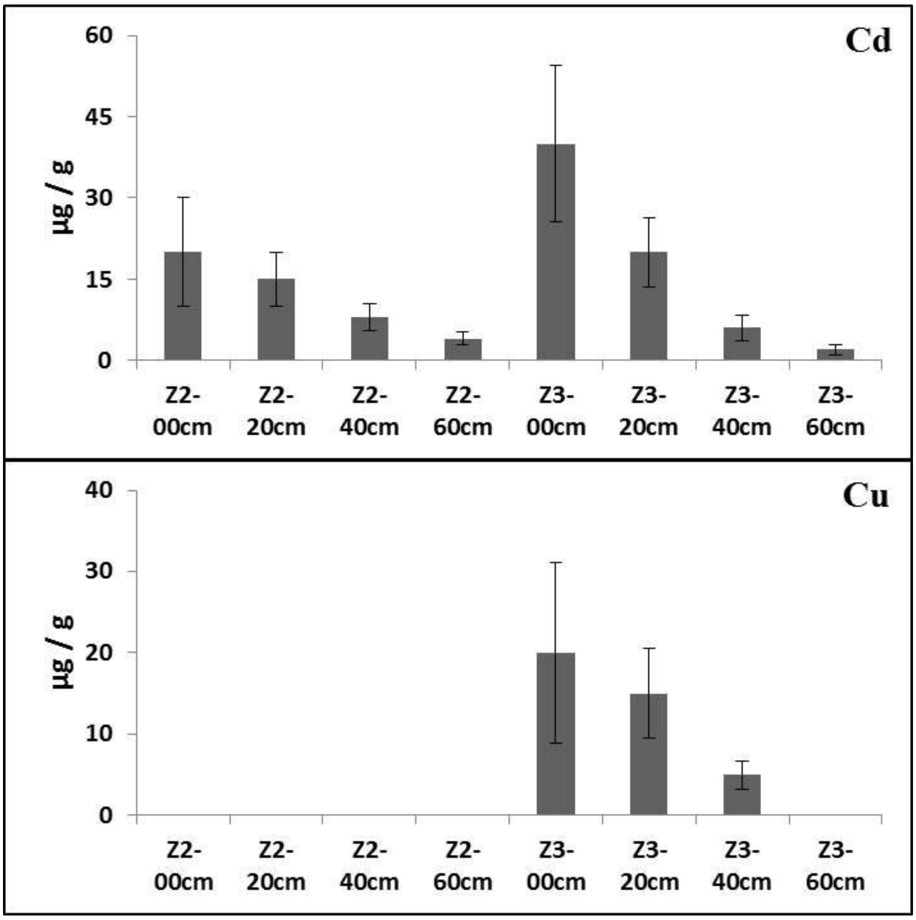

Figure 5. Concentration of Cadmium and Copper in the sediment samples of Sarod

Table 2. Sediment pollutants at different depths of two zones at Sarod

Sarod	**Depth**	**Phenol**	**Oil & Grease**	**Cd**	**Co**	**Cu**	**Cr**	**Fe**	**Mn**	**Ni**	**Pb**	**Zn**
Zone 2	00 cm	0	0	20 ±10	0	0	0	2 ±2	1 ±1	10 ±6	5 ±1	18±2
	20 cm	0	0	15 ±5	5 ±5	0	0	1 ±1	3 ±2	0	4 ±3	10±1
	40 cm	0	0	8 ±3	0	0	0	0	0	0	2 ±1	6±3
	60 cm	0	0	4 ±1	0	0	0	0	0	0	0	0
Zone 3	00 cm	0	0.003 ±0.003	40 ±14	30 ±11	20 ±11	0	20 ±6	10 ±5	20 ±3	15 ±2	130±40
	20 cm	0	0.001 ±0.001	20 ±6	20 ±15	15 ±6	0	12 ±4	22 ±3	10 ±2	40 ±10	28±11
	40 cm	0	0	6 ±2	0	5 ±2	0	10 ±8	5 ±3	0	22 ±10	12±4
	60 cm	0	0	2 ±1	0	0	0	0	0	0	0	0

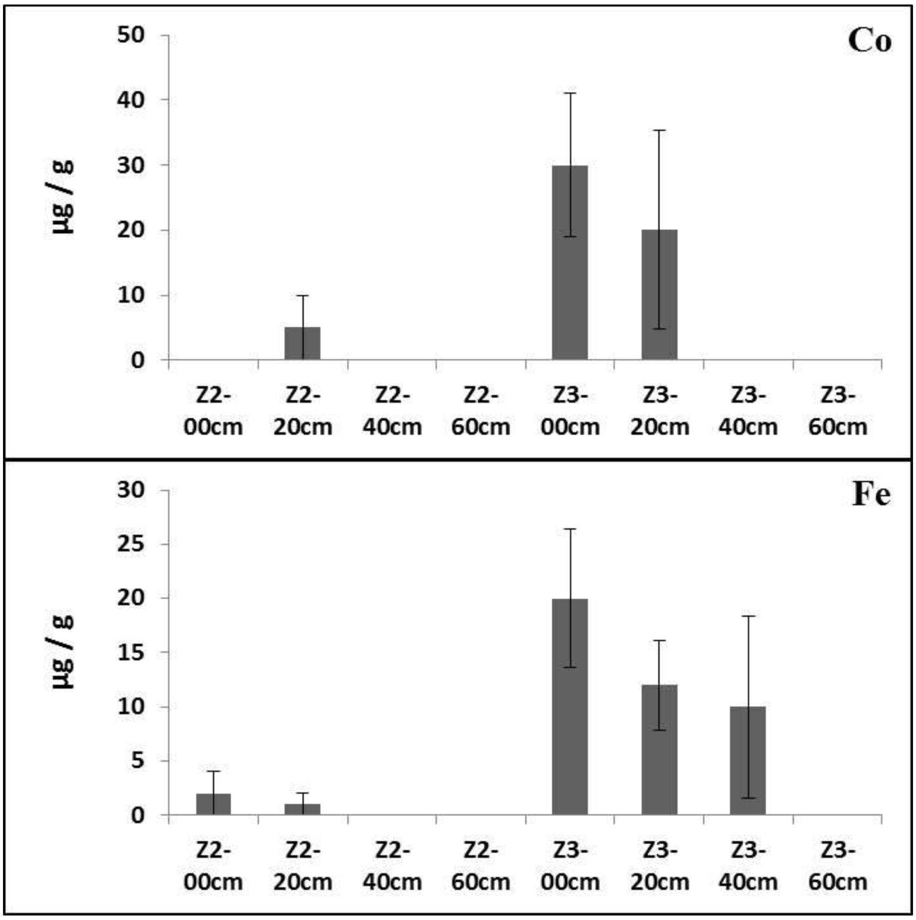

Figure 6. Concentration of Cobalt and Ferrous in the sediment samples of Sarod

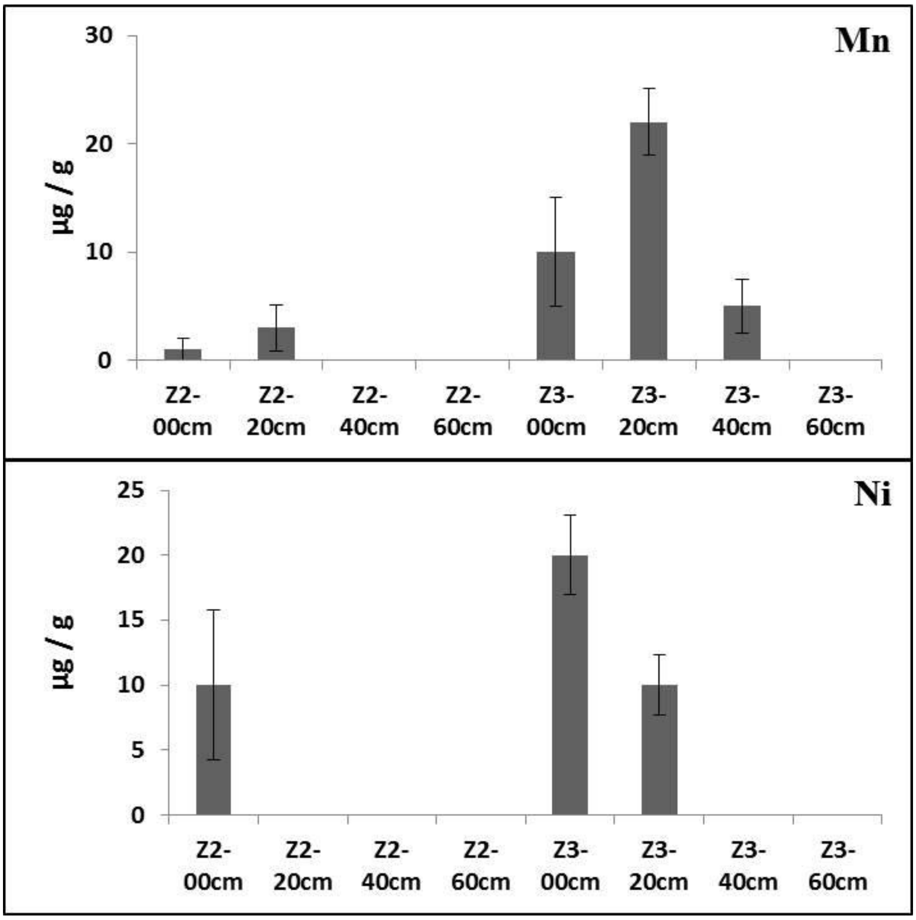

Figure 7. Concentration of Manganese and Nickel in the sediment samples of Sarod

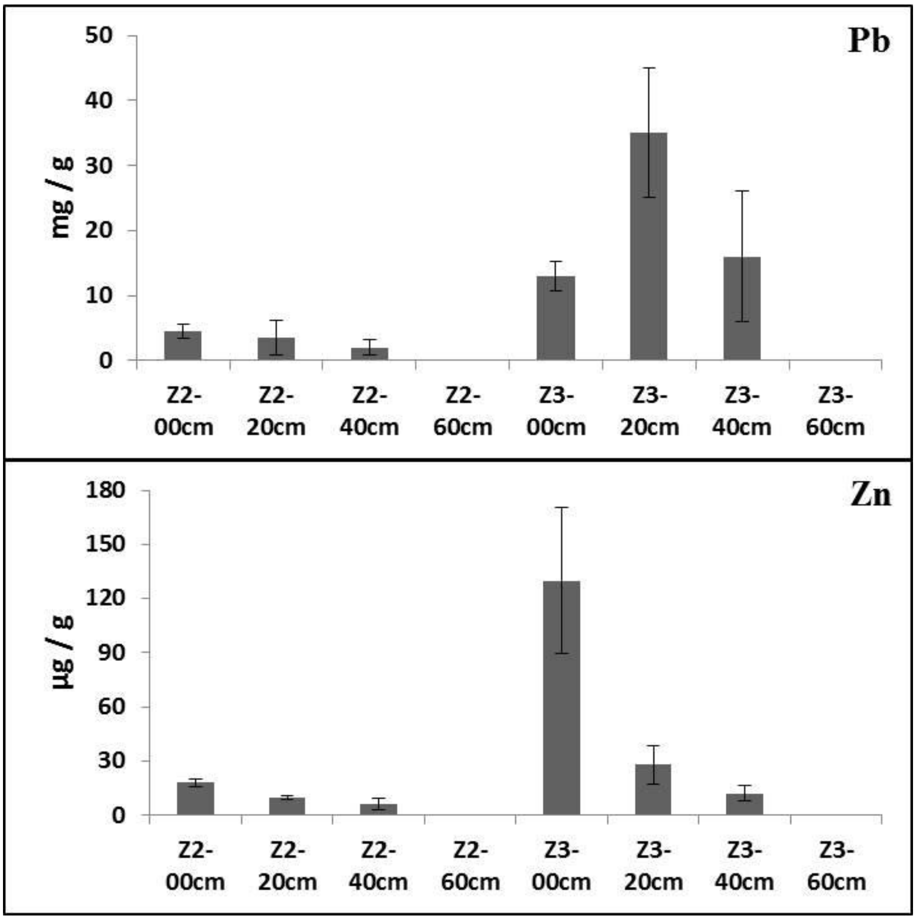

Figure 8. Concentration of Lead and Zink in the sediment samples of Sarod

Table 3. Sediment pollutants at different depths of four zones at Kamboi

	Depth	Phenol	Oil & Grease	Cd	Co	Cu	Cr	Fe	Mn	Ni	Pb	Zn
Zone 2	00 cm	0	0	5 ±1.53	0	0	0	6 ±3.06	0	0	10 ±2.88	12 ±5.29
	20 cm	0	0	3 ±2.65	0	0	0	4 ±1	0	0	2.5 ±1.89	6 ±1.53
	40 cm	0	0	3.66 ±2.08	0	0	0	1 ±0.833	0	0	0	2 ±0.58
	60 cm	0	0	2.33 ±1.52	0	0	0	0	0	0	0	0
Zone 3	00 cm	0	0	11 ±3	0	10 ±5.77	0	20 ±8.33	0	0	30 ±10	30 ±10
	20 cm	0	0	8 ±2.52	0	10 ±5.77	0	19 ±4.41	0	0	42 ±9.02	40 ±7.64
	40 cm	0	0	4 ±3.79	0	5 ±2.42	0	8 ±2	0	0	10 ±2.89	40 ±5
	60 cm	0	0	3.00 ±2.27	0	0	0	0	0	0	8.00 ±2.00	5.00 ±5.00
Zone 4	00 cm	0	0	3.33 ±2.77	0	11 ±5	0	12 ±5.3	10 ±10	10 ±5.77	15 ±10.41	30 ±11.01
	20 cm	0	0	0	0	18 ±6	0	16 ±2	10 ±0.0	5 ±2.89	22 ±5.3	180 ±50.33
	40 cm	0	0	14 ±10.26	0	7 ±3.61	0	12 ±1	5 ±2.77	0	18 ±5.3	30 ±15.276
Zone 5	00 cm	0	0	40 ±15.28	40 ±20	18 ±4.16	0	15 ±5	20 ±5.77	10 ±7.64	60 ±24.11	180 ±25.17
	20 cm	0	0	10 ±5.77	10 ±5.41	10 ±7.64	0	29 ±6.24	5 ±2.89	0	15 ±5	40 ±10

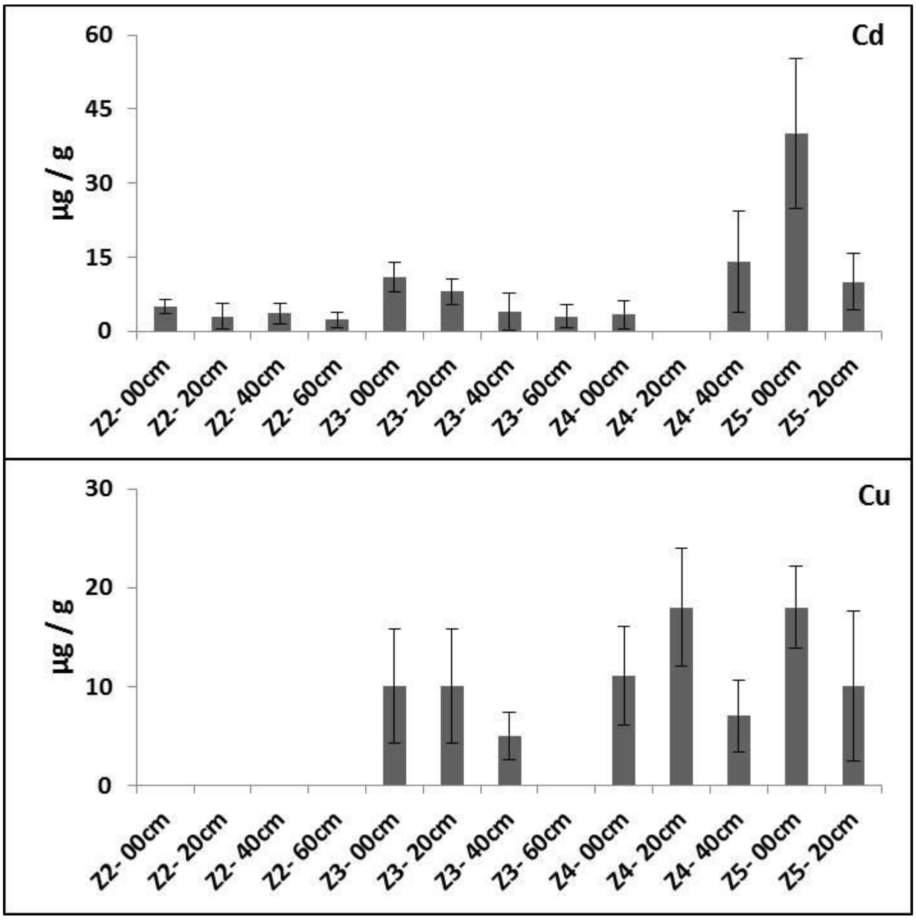

Figure 9. Concentration of Cadmium and Copper in the sediment samples of Kamboi

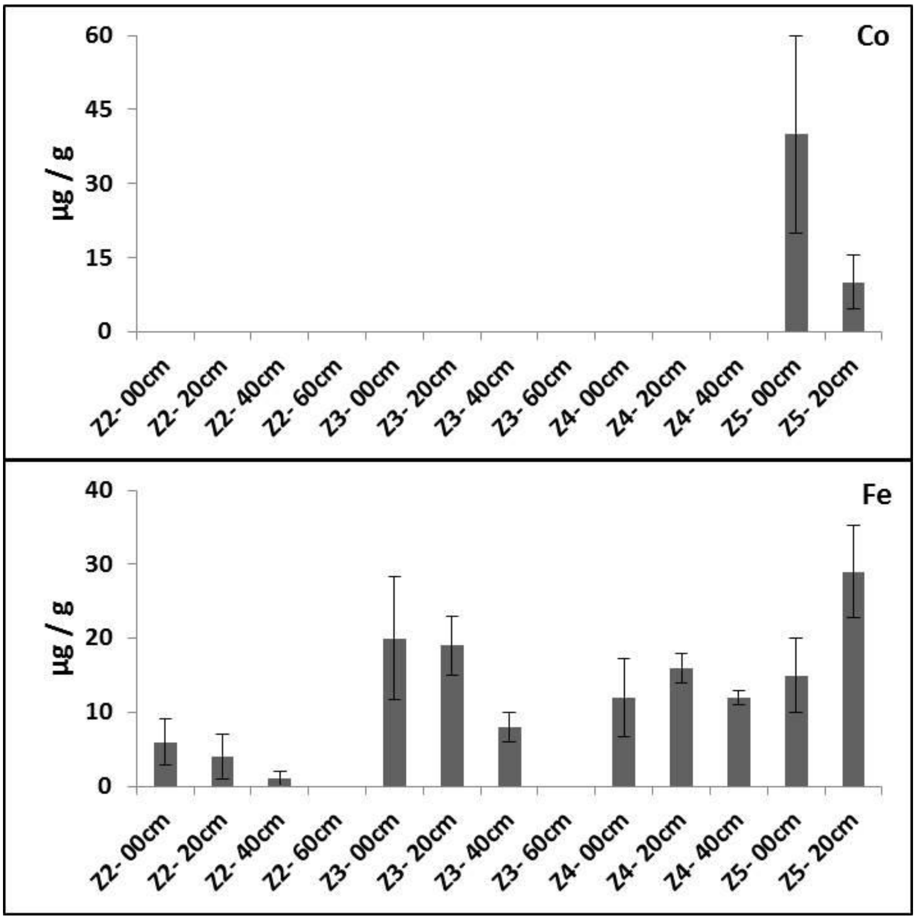

Figure 10. Concentration of Cobalt and Ferrous in the sediment samples of Kamboi

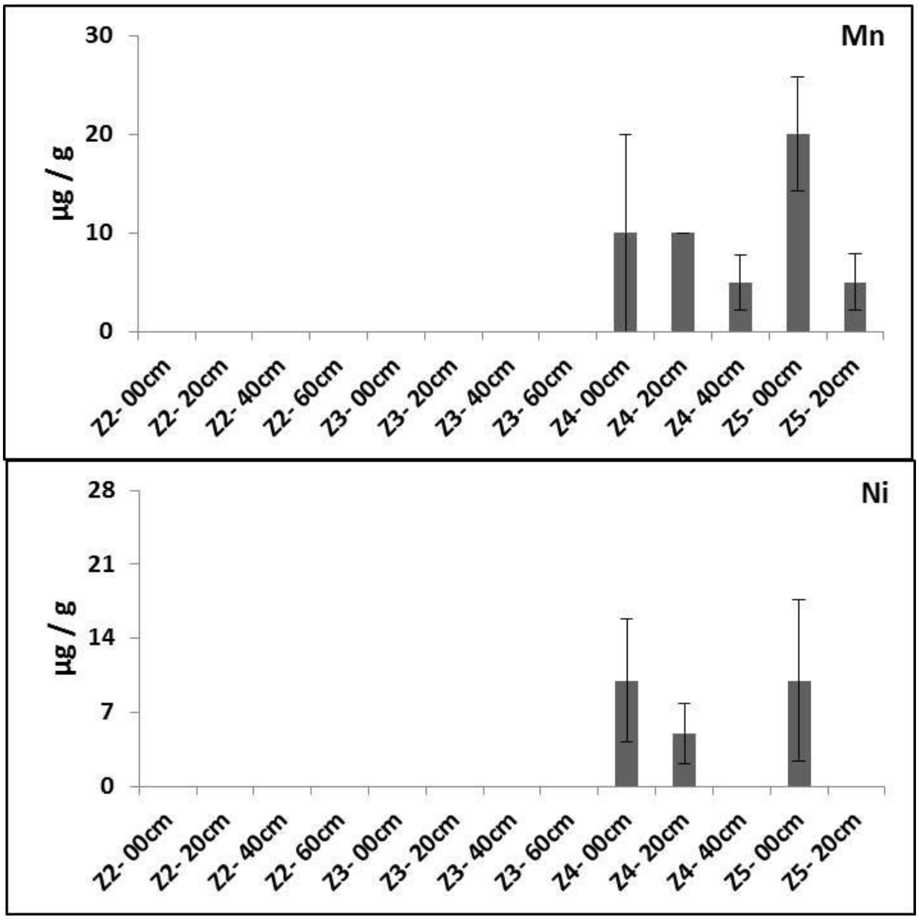

Figure 11. Concentration of Manganese and Nickel in the sediment samples of Kamboi

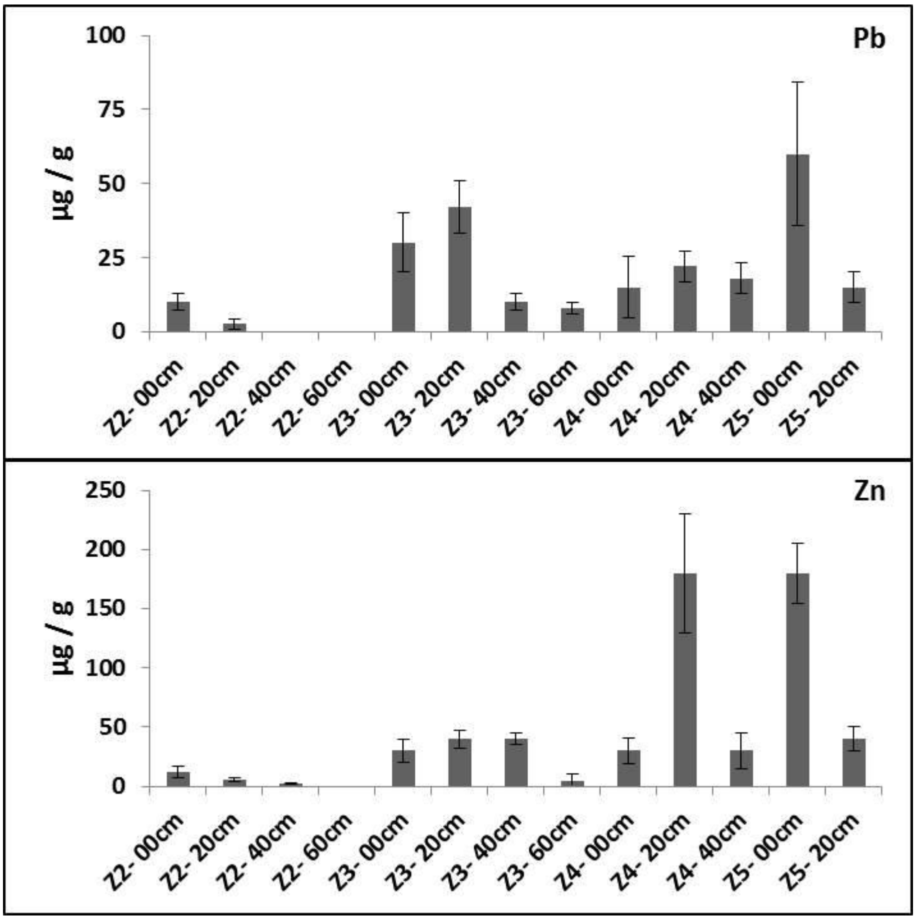

Figure 12. Concentration of Lead and Zink in the sediment samples of Kamboi

Table 4. Pollutants in crab and vegetation tissue of Sarod and Kamboi

		Phenol	Oil & Grease	Cd	Co	Cu	Cr	Fe	Mn	Ni	Pb	Zn
Sarod	Crab tissue	0	0	0.073 ±0.07	0.018±0.007	0	2.78 ±1.62	16.52 ±4.28	0	0	0.019 ±0.012	0.36 ±0.12
	Vegetation	0	0	0.025 ±0.01	0.034 ±0.011	0	7.59 ±2.23	86.53 ±34.21	0	0	0.011 ±0.007	0.33 ±0.056
Kamboi	Crab tissue	0	0	0	0.002 ±0.001	0	0	0.01 ±0.008	0	0	0	0
	Vegetation	0	0	0	0	0	0	0	0	0	0	0

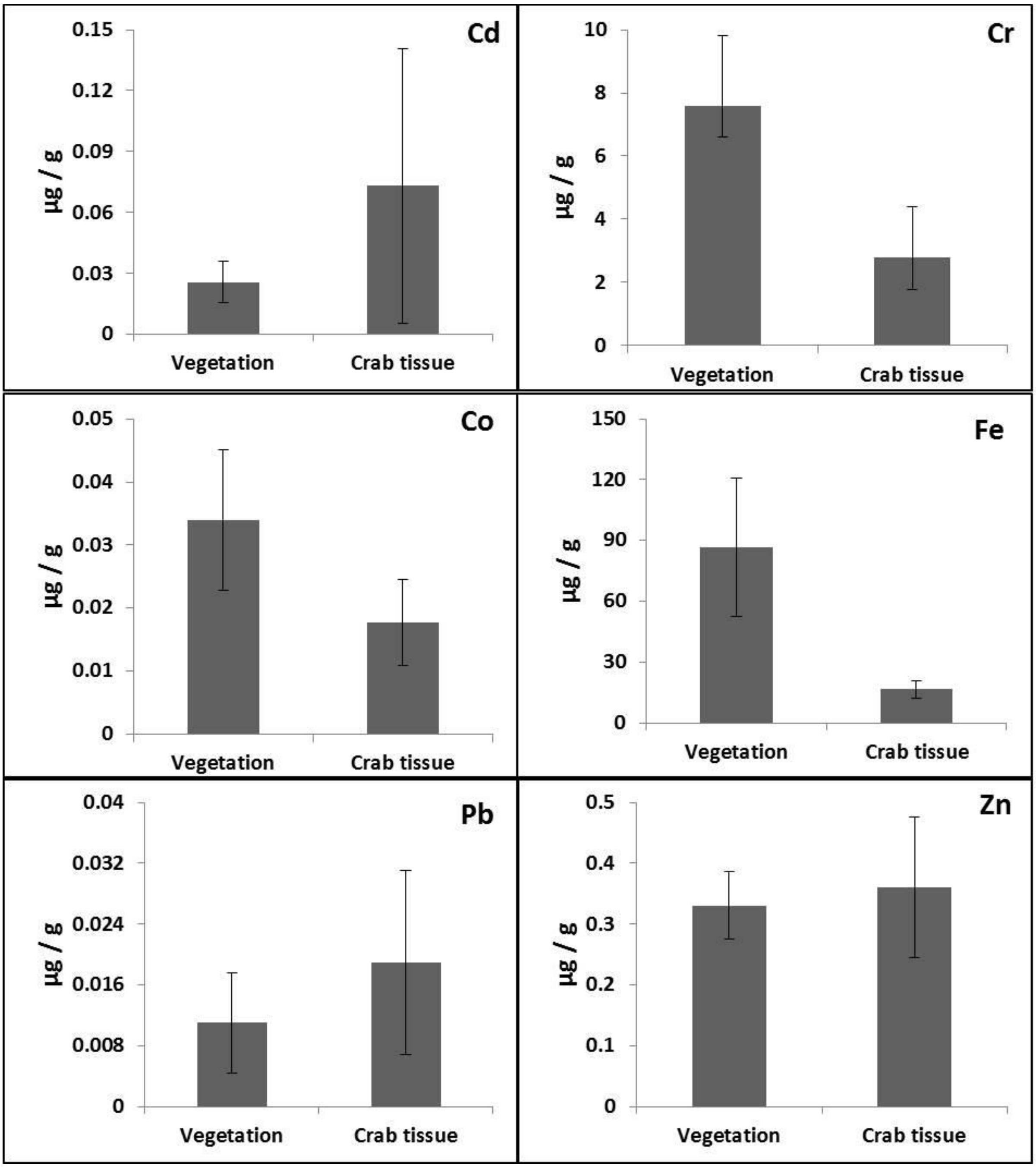

Figure 13. Concentration of heavy metals in crab and vegetation tissue collected from Sarod

Table 5: Water quality of effluent release site at different regions

Location	References	Oil & Grease	Phenol	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Mahi estuary (Sarod, Low tide)	Present Study	42.00	2.9	0.015	0.017	0.007	0.003	0.507	0.007	0.01	0.023	1.437
Niger Delta, Nigeria	Otokunefor and Obiukwu, 2005	7.52	11.06	NS	NS	0	0.001	0.241	NS	0.001	0.01	0.11
Ubeji creek Warri, Southern Nigeria	Uzoekwe and Oghosanine, 2011	NS	0.01	0.0	0.74	0.54	NS	4.29	NS	0.0	0.01	0.56

Table 6. Concentration of Heavy metals in crustaceans in different estuaries

Location	References	Cd	Co	Cr	Cu	Fe	Pb	Zn
Mahi estuary	Present Study	0.073	0.018	2.78	0.0	16.52	0.019	0.36
Kuwait Bay	Bu-Olayan and Thomas, 2005	NS	NS	NS	5.21	28.12	2.05	22.93
UK estuaries	Bryan and Langston,1992	NS	NS	NS	7.10	45.80	2.30	35.12
Bidasao estuary	Saiz-Salinas et al., 1996	0.8	4.6	NS	NS	464	42	1140

Table 7. Comparison of Concentration of Heavy metals in marine vegetation

Location	References	Cd	Co	Cr	Cu	Fe	Pb	Zn
Mahi estuary, India	Present Study	0.025	0.034	7.59	0	86.52	0.011	0.33
Tisza river, Serbia	Strbac et al., 2014	0.56	1.89	0.33	0.97	0.15	1.92	0.82
Malta lake, Poland	Rzymski et al., 2014	0.11	0.20	4.5	5.23	325.2	1.67	62.32
Pearl River Estuary, South China	Zang et al., 2010	0.02	NS	13	19	NS	7	69

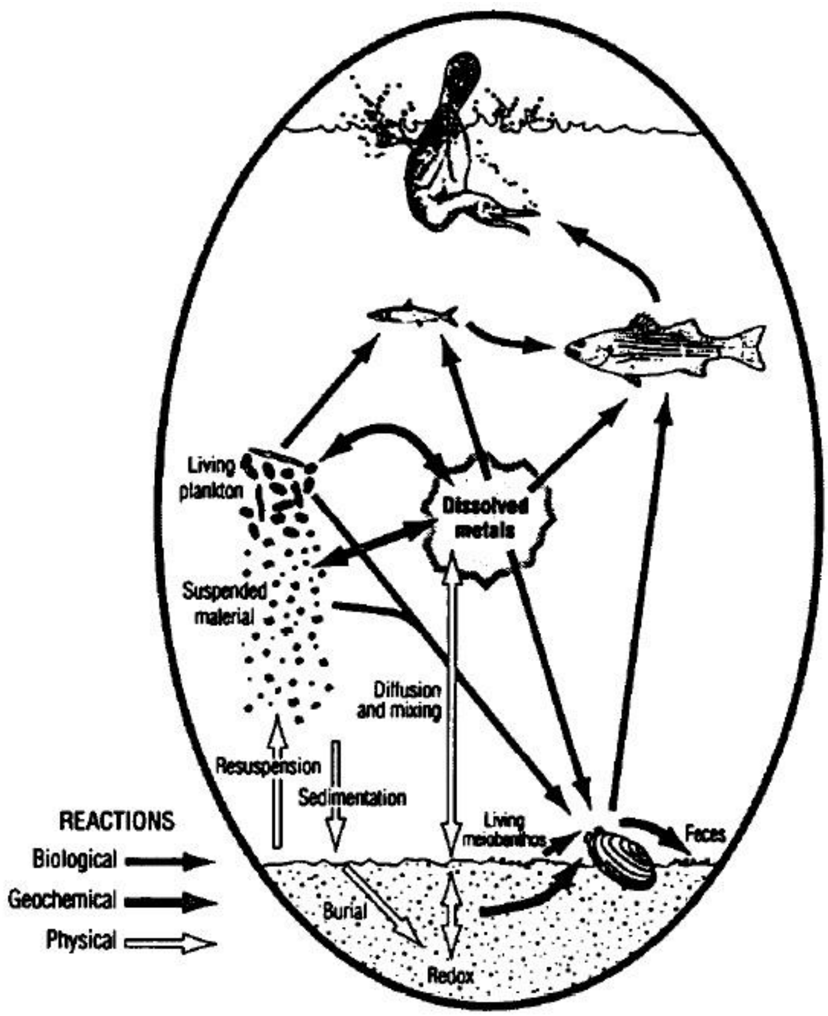

Figure 14. A simplified overview of the interacting physical, chemical and biological processes that affect the fate and bioavailability of metals (Luoma, 1996)