**UNIVERSITY OF NAIROBI**

# IMPACTS OF INORGANIC POLLUTION ON MARINE BENTHIC COMMUNITIES

BY

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**DECLARATION**

**Student**

I ***Charity Wanjohi*** of registration number I56/82907/2015 hereby declare that the work reported herein is, to the best of my knowledge, my original and has been carried out by me. This thesis has not been submitted in any other university.

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## ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| PCB | Polychlorinated biphenyls |
| DDT | Dichlorodiphenyltrichloroethane |
| BOC | Biological Oxygen Consumption |
| DO | Dissolved Oxygen |
| PAH | Polycyclic Aromatic hydrocarbons |
| BOD | Biological Oxygen Demand |
| TOM | Total Organic Matter |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |
| WFD | Water Framework Directive |
| REDD | Reduced Emissions from Deforestation and Degradation |
| EDXRF | Energy Dispersive X-ray Fluorescence |
| EEZ | Exclusive Economic Zone |
| ANOVA | Analysis of Variance |
| ANOSIM | Analysis of Similarity |
| PCA | Principal Component Analysis |
| SAMS | Scottish Association of Marine Science |
| IAEA | International Atomic Energy Agency |
| Ti | Titanium |
| Mn | Manganese |
| Fe | Iron |
| Zn | Zinc |
| Rb | Rubidium |
| Zr | Zirconium |
| Pb | Lead |

**ABSTRACT**

Anthropogenic pollution in marine ecosystems have greatly increased globally resulting to serious negative impacts on the lives of benthic communities (meiofauna and macrofauna). The impact of heavy metal pollution on these organisms was studied in two sites (Mikindani in Tudor creek and Dabaso in Mida creek) that had different levels of pollution. Samples were collected and analyzed during the dry season (January/February 2017) and wet season (November/December 2017) for dissolved oxygen (DO), biological oxygen demand (BOD), heavy metals, total organic matter (TOM), sediments grain size and macrofauna and meiofauna.

Results showed that TOM was significantly ($p=0.019$) higher in Dabaso (23.9±0.7%; 23.9±0.03%) than in Mikindani (6.6±0.2%; 5.9±0.1%) ($p=0.03$) during dry and wet season respectively. BOD was significantly ($p=0.039$) higher in Mikindani (4.8±0.2 mg/L) than Dabaso (3.4±0.1 mg/L) in the dry season while in the wet season it was significantly ($p=0.041$) higher in Dabaso (3.5±0.03 mg/L) than Mikindani (2.8±0.03 mg/L). The concentration levels of all heavy metals identified (Ti, Mn, Rb, Zr, Fe, Zn, Pb) were higher in Mikindani as compared to Dabaso.

Macrofaunal densities were significantly (0.024) higher in Dabaso (14470±2049; 42489±2896) ind/$m^2$ compared to Mikindani (8879±376; 21507±1841) ind/$m^2$ ($p=0.013$). Similarly, meiofaunal densities were significantly ($p=0.027$) higher in Dabaso (2729±387; 2805±387) ind/$cm^2$ compared to Mikindani (604±114; 183±30) ind/$cm^2$ ($p=0.017$) in dry and wet seasons respectively.

A strong spatial variation between the two sites was exhibited in the structure of benthic communities. The study proves that heavy metals played a very significant role in structuring of benthic communities therefore contributing to better understanding of their response to marine inorganic pollution. Comprehensively, this study confirmed the assessment of impacts of marine inorganic pollution on benthic communities between two sites of different pollution levels. There is need to conduct further research to identify the exact source of sediments drained in Mikindani creek in order to determine whether heavy metals origin is from sediments in neighboring community or sewage.

**Key words:** ***Benthic communities, anthropogenic Pollution, Heavy Metals***

# 1. INTRODUCTION

## 1.1.Background

Marine pollution normally occurs as a result of harmful chemicals from industries, domestic and agricultural wastes disposed in the ocean. This might be non-point sources like surface run-off from farms, urban run-offs, roads, buildings, ports and harbors. Pollution may enter the ocean directly through sewage, drainages and rivers. Inorganic pollution by heavy metals results from human activities which alters their natural occurrence. These contaminants are among the most important pollutants that are disposed from commercial and residential areas within the urban and peri-urban environments (Prüss Ustün *et al.,* 2014). The main source of heavy metals are industrial wastes (batteries, wires, cables, alloys, dyes, pharmaceuticals, paints), waste waters, domestic effluents and agricultural wastes due to use of fertilizers and pesticides like DDT, diazinon, Malathion etc. They always settle in the sediments in higher concentration than in solution form.

In most developing countries, between 80% and 90% of domestic sewage within the coastal urban centers is discharged without treatment (Labadi, 2017). Coastal ecosystems are main recipients of effluents disposed from various industries and urban centers (Hourston *et al.,* 2009). This can be related to urbanization, increased development and food production as a result of the rising world's population causing serious environmental risks to marine ecosystems (Mayorga *et al.,* 2010; Thompson *et al.,* 2017). This also influences the water quality, concentration of dissolved oxygen, biological oxygen consumption, turbidity and conductivity thereby directly affecting marine life (Prüss Ustün *et al.,* 2014).

In Mombasa County, anthropogenic activities like industrial plant development, fishing activities, oil spills, construction of houses, effluent discharge, crop production and disposal of agrochemicals containing wastes are the main sources of inorganic pollution along Tudor creek ecosystems (Okuku *et al.,* 2011). For instance, use of heavy metals in numerous industries makes them the main source of toxicants discharged as effluents. They are released through sewage runoff as well as industrial discharges. Heavy metals like lead (Pb), mercury (Hg), zinc (Zn), nickel (Ni), arsenic (As), copper (Cu), iron (Fe), chromium (Cr) and cadmium (Cd) usually bio accumulate up in the food chain as they are not easily biodegraded in the environment (Okuku *et al.,* 2019a). They affect organisms' reproduction and the survival rates and can be

very dangerous when in toxic concentrations. Increase in their concentration above the mean allowable levels results to significant health and environmental risks to all living organisms in the ecosystem (Prüss Ustün *et al.*, 2014). The permissible levels according to Jamaican National Sewage Effluents standards, 1996 are iron (<3.5mg/L), Zinc (<15mg/L), Copper (<0.5mg/L), Lead (< 0.1mg/L), Cadmium (< 0.06mg/L), Mercury (< 0.1mg/L), Arsenic (<0.02mg/L), Chromium (<0.05mg/L).

Benthic macrofauna and meiofauna are organisms that inhabit the substrata of aquatic ecosystems. Their sedentary nature and close contact with sediments makes them vulnerable to pollution hence their importance in assessing the impacts of inorganic pollution and in the end determine the ecological status of an ecosystem. Presence of heavy metals in the sediments can lead to a wide range of effects ranging from molecular alterations, sharp reduction in benthic diversity, growth and reproduction rates (Massaquoi *et al.* 2015).

The present study was conducted on the distribution pattern of heavy metals in seawater, sediments and the predominant benthic organisms found in Tudor and Mikindani creeks in Kenya. Additionally, the study was to evaluate the heavy metals impacts to benthic organisms in a pristine environment (Mida creek) and polluted environment (Mikindani creek).

### 1.2.Problem statement and Justification

Marine pollution has been on the rise in the recent years resulted by anthropogenic activities hence considered as a global concern. This can be attributed to the increased discharge of sewage into the ecosystems. Rapid growth of population, urbanization and industrialization has excessively contributed to increased contamination of the ecosystems in Mombasa city. Much of the effluents contains persistent toxins such as PCBs, toxic heavy metals and DDT from industrial discharge; pesticides from farms; seepage from landfills as well as wastewaters from the city. Oil pollutants result from cars, heavy machineries, offshore oil drilling, natural seepage, shipping and oil tanker operations (Garcia-Gonzales *et al.,* 2019). The inadequacy and unavailability of proper sewage drainage systems has resulted to all these kinds of pollutants being improperly discharged into the coastal ecosystems. Impacts of environmental stress caused by this kind of pollution includes decline in biodiversity, increased mortality rates, destruction of habitats and breeding grounds. Additionally, exposure of marine organism to toxic levels of heavy metal contaminant results to damaged tissues and DNA, inhibited growth rates as well as incapacity to regenerate the damaged tissues.

Benthic communities (meiofauna and macrofauna) are drastically affected by pollution with some being very vulnerable while others can withstand high pollution levels (Zeppilli *et al.*, 2015). These studies are of great significance as they reveal needed information on evaluating nature of a habitat. They detect changes of the environmental conditions due to pollutants that affects their presence in the ecosystems (Emily & Scott, 2011). They are present in different trophic groups and have been intimately related to the sediments where they indicate high diversity and abundance. This makes their sampling simple thus a critical attribute to determine ecological status of a polluted area. Additionally, Water Framework Directive (Moreno *et al.*, 2011) proposed benthic organisms' usefulness as tools of evaluating polluted ecosystems.

Despite the significance of macrofauna and meiofauna to the littoral marine ecosystem, there is inadequate information on their importance, especially in detecting heavy metal pollution in nearshore marine ecosystems (Majdi & Traunspurger, 2015). Additionally, the effects of heavy metal pollution on key aspects of the benthic animal communities have not been adequately studied as many researchers have focused on impacts of organic pollution on these organisms (Masindi and Muedi, 2018).

Therefore, there is need for a continuous monitoring of the heavy metals due to their high potential of bioaccumulation in the marine ecosystem and thereby threatening the health of marine organisms (shellfish, crabs, prawns, worms and fish) consumers.

The findings of this study will help different governmental ministries, non-governmental organizations as well as other research institutions which are progressively trying to manage heavy metal pollution as well as establish relevant policies to eradicate pollution. This will be based on proper scientific knowledge from actual data on environmental impacts of pollution which is lacking (Okuku *et al.*, 2011).

## 1.3. Objectives

### 1.3.1. General objective

To determine the impacts of inorganic pollution (heavy metals) on benthic communities in marine environments.

### 1.3.2. Specific objectives

1. To assess the physico-chemical parameters of sediments at Tudor and Mida creeks.

2. To determine the levels of heavy metals at Tudor and Mida creeks.
3. To determine the density, distribution and diversity of benthic organisms at Tudor and Mida creeks in relation to sediment abiotic factors and heavy metals

## 2. LITERATURE REVIEW

### 2.1.Ocean ecosystems

Oceans covers about 70% of the earth's surface with average depth of 3.86 km where the deepest part is approximately 11 km deep (Rafferty, 2010). Oceans have immensely productive habitats including oxygenated continental slope, continental shelf, continental rise & basins, seamounts, abyssal plains, trenches, shorelines, salt marshes and saltwater bays. Submarine plateaus, mid-ocean ridges and few deep-sea trenches are some of the geomorphological features in the oceans (Dipper, 2016; Harris *et al.*, 2014). The Great Barrier Reef, one of the world's largest structure is also found in the ocean.

These habitats sustain high density and diversity of species consisting of invertebrates living in (infauna) and those living on (epifauna) sediments (Vanreusel *et al.*, 2010). Some of the invertebrates are large organisms (megafauna) such as crabs, mollusks, large fishes e.g. tunas, shark, billfishes, seabirds & rays, pinnipeds, sirenians, cetaceans, marine and estuarine reptiles (Estes *et al.*, 2016). The ocean also provides shelter to blue whale which grows up to 30 meters long and is the largest animal on earth.

Oceans are subdivided into three different zones based on the amount of sunlight they receive. The euphotic zone which is 200 m from the surface is the topmost zone. It receives maximum amount of sunlight thus having the ability to sustain marine life. The highest organic matter source is from phytoplankton blooms, river sediments, death of zooplanktons, big fish or turbulent eddies and upwelling which brings nutrients from ocean floor to the surface (Philips *et al.*, 2012; Zhang *et al.*, 2017). The marine plants such as sea grasses, sea weeds, phytoplankton and algae are found at the euphotic zone because they need sunlight for photosynthesis. The zone tends to host diverse benthic community (microfauna, meiofauna, macrofauna and megafauna), zooplankton, majority of commercial fisheries, protected marine mammals, corals, seals and sea turtles (Kasprak *et al.*, 2015). Mangrove trees found on the muddy tropical shores acts as carbon sinks. They too are part of the ocean ecosystem (Sigman & Hain, 2012). The second layer is referred to as disphotic zone or twilight zone which extends from 200m to 1000m below sea level. The zone receives less light to support photosynthesis with low temperature ranging from 3°C to 4°C (Scheffers *et al.*, 2012). Benthic communities exist in these stressful

environments and are well adapted to low temperatures, limited food and high pressure (Badrudin *et al.,* 2017).

The last layer in the ocean zonation is aphotic zone which has little or no sunlight penetrating therefore cannot sustain life and extends from 1000 m below sea level to the sea floor (Beale *et al.,* 2016). Very few organisms withstand the low temperatures, high pressure and limited food.

### 2.2.The Kenyan coastline and vegetation

The Kenya coastline is located on the Eastern African coast between latitudes 5°40´S and 4°4´S and longitudes 33°50´E and 41°45´E bordering Indian Ocean to the east. Kenyan coastline has a total length of 600 km extending from Kiunga in the north, bordering Somali and Vanga to the south bordering Tanzania. The Kenyan coastline accommodates several administrative counties including Lamu, Tana river, Kilifi, Mombasa and Kwale (Mwita *et al.,* 2013). Kenya has the seaward boundary of 200 nautical miles, Exclusive Economic Zone (EEZ), with approximately 230,000 $km^2$ surface area of sea water (Nordquist, 2011). Kenyan coastline is generally characterized by mangroves, tidal flats, sandy beaches, corals and seagrasses. Mangroves are the main vegetation on the Kenyan coastline in river deltas, estuaries, protected bays and creeks.

The world coverage of mangroves is 15 million hectares while Kenyan coastline covers approximately 54,000 ha widely distributed in Lamu and Tana River counties (Doute *et al.,* 1981; Giri *et al.,* 2011). There are 9 species of mangroves in Kenya, mostly dominated by *Rhizophora mucronata* and *Ceriops tagal* making 70 % of the coverage (Kirui *et al.,* 2013a). Other mangrove species includes *Avicennia marina, Bruguiera gymnorrhiza, Sonneratia alba, Xylocarpus granatum, Heritiera littoralis, Xylocarpus molucensis and Lumnitzera racemosa* (Huxham *et al.,* 2010).

Mangrove ecosystems are the most productive biotope along tropical and sub-tropical coastlines with a mean production of 8.8 t C/ha/yr (Jennerjahn & Ittekkot, 2002; Das, 2015). They provide broad range of ecosystem goods like construction materials, timber & firewood production, fish supply and medicine (Dahdouh-Guebas *et al.,* 2000; Aburto-Oropeza *et al.,* 2008). Additionally, mangroves provide ecosystem services which includes breeding grounds, habitat provision, carbon sequestration, sedimentation, sewage phytoremediation and coastal defense for local communities and animal survival (Kathiresan & Bingham, 2001; Wickramasinghe *et al.,* 2009;

Donato *et al.,* 2011; Zhang *et al.,* 2012; Duarte, 2017). Furthermore, mangroves have the ability to reduce carbon footprint while sheltering diverse communities of pelagic and benthic organisms thus contributing heavily to various schemes, for instance Reduced Emissions from Deforestation and Degradation (REDD+) and United Nations Educational, Scientific and Cultural Organizations (UNESCO) Biosphere Reserve respectively (Donato *et al.,* 2011).

Despite the vast benefits of mangroves in the world, the global coverage has suffered a decline of 23% in total area compared with 1990 (Bartolini *et al.,* 2011; Kirui *et al.,* 2013a). Over exploitation of mangrove goods by local communities has proven to be unsustainable due to population growth which has increased demand of the limited resources available (Dahdouh-Guebas *et al.,* 2000). Nevertheless, urban and industrial developments aggravated by ineffective government policies and human ignorance has resulted to intense pressure on mangrove ecosystems (Sutinen, 2010).

The diverse population of macrofauna and meiofauna studied in the marine biotope are sheltered in mangrove ecosystems due to enough food supply compared to sandy beaches (Mutua *et al.,* 2013; Sabeel, 2015). Mangroves overexploitation to different land use activities like aquaculture, agriculture, industrial development, urban growth, salt ponds and infrastructure development is the genesis of benthic organisms' diversity and density reduction and eventually extinction of some species. Exploitation of mangroves environments stipulates that short term economic profits are irrational since the overall holistic gains achieved when the ecosystem is intact is more compared to the value when destructed (Balmford *et al.,* 2004; Cullis-Suzuki & Pauly, 2010; McCrea-Strub *et al.,* 2011).

### 2.3.Inorganic pollution

Inorganic pollutants include heavy metals, mineral acids, cyanides, sulphates and metals with organic complexes. They are non-biodegradable and highly persistent in the ecosystems. They cohere to suspended particulates and collect in sediments in huge concentrations. Lead and mercury concentrations greater than 0.1mg/l are very toxic, carcinogenic, and mutagenic to both the benthos as well as the fish that feed on them (Fashola *et al.,* 2016). Reish & Gerlinger (1997) illustrated copper, along with mercury as the main toxic metals examined in their toxicological studies review using polychaetes.

These types of pollution have resulted from anthropogenic activities which have caused the recent alteration of marine benthic diversity in coastal and deep-sea zones (Wedding *et al.,* 2013). Toxic metals pollution in marine sediments is a progressively global issue (Kucuksezgin *et al.,* 2008; Fernandes *et al.,* 2008) which poses a consequential menace to marine environments derived from persistent nature, toxicity and bioaccumulation in the food chain, (Nobi *et al.,* 2010). Heavy metals in marine ecosystem are progressively classified as salient intermediate origin due to expeditious industrialization and urbanization (Paquin *et al.,* 2007; Castillo *et al.,* 2013). Heavy metals tend to appear in impermeable surfaces experiencing varying land uses (Zhao *et al.,* 2010). The metals concentrate in the sediments and they are immobilized through coagulation, flocculation, adsorption, combination in mineral structures e.g., metal oxides and insoluble fractionation formed by precipitation such as metal sulphides (Lin *et al.,* 2013). The smallest percentage of free metal ions are dissolved in water while 90% of metal ions in aquatic environment are related (Huo *et al.,* 2013) to sediments and suspended particles (Amin *et al.,* 2009; Zahra *et al.,* 2014). Metals distribution in sediments which are found in highly populated areas can offer verification of anthropogenic impact in aquatic ecosystems.

Various studies have been conducted on heavy metals pollution (Atkinson *et al.,* 2007; Saeedi *et al.,* 2013) and geochemical nature of metals in soil sediments (Simpson *et al.,* 2012). Heavy metals bioavailability to benthic organisms in marine sediments rely on both metals chemical form (Simpson, 2005), geochemical properties of sediments (Nobi *et al.,* 2010) and organisms exposure pathways (Simpson *et al.,* 2012).

Oxidation of the organic matter in the wastewaters aerobically results to dissolved oxygen consumption present in the water body. Aquatic fauna and flora are greatly affected by dissolved oxygen (DO) depletion. Oils can naturally result from oil spills, leakages and wastewater from refineries. Oil causes reduction of DO in the water body through separating water and the air above. Oil spillage also cuts off light penetration into the water surface hence affecting photosynthetic activities of the aquatic plants. Polycyclic aromatic hydrocarbon (PAH) is a component in some oils and is very carcinogenic (Obini *et al.,* 2013).

Approximately eight million tons of marine litters are usually disposed into the oceans each year whereas; 5 million tons of these wastes (solid waste) are thrown overboard or lost from ships (Cheshire & Adler, 2009; Newman *et al.,* 2015).

### 2.4.Benthic organisms

Benthic communities are a key source of health status of an ecosystem which can be utilized to provide basic information of health status of an area. They include macrobenthos and meiobenthos. The macrobenthos are mostly comprised of annelids, crustaceans', mollusks and nematodes. Polychaetes (annelid phylum) are generally the most dominant family of macrobenthos in terms of density (Rehitha *et al.,* 2019). Correspondingly, mollusks and crustaceans form different taxonomic groups are the main organisms that colonize main marine habitats (Mosbahi *et al.,* 2019). Their communities' distribution is affected by sediments granulometry, dissolved oxygen, organic matter content, nutrients (ammonium, phosphates, nitrites and nitrates), pH, temperature, salinity and anthropogenic disturbances (Yoo *et al.,* 2019). It is crucial to understand marine sediments biodiversity regarding human influence on these ecosystems to successfully integrate conservation and management measures.

Meiofauna communities includes sipunculids, nematodes, polychaetes, isopods, amphipods, cladocerans, molluscs, tardigrads, ostracodes, halacaroids and oligochaetes. These organisms respond specifically towards different natural and human induced disturbances (Arezoo, 2019). They can survive in extreme conditions because they have short biological cycles, stable populations, and rapidly adapt to environmental changes in contrasting biotopes compared to macrobenthos (Semprucci & Balsamo, 2012). These factors influence their preference in determining ecological quality of an ecosystem within the Water Framework Directive (Moreno *et al.,* 2011).

The meiofauna are efficient, reliable and excellent gauge for status of coastal marine ecosystems (Materatski *et al.,* 2016*).* They show changes with environmental stress over a given period hence believed to be a collaborative metric indicating environmental quality due to distinct reactions to environmental disturbances (Arezoo, 2019). Most of the taxa such as ostracods, tardigrads, gastrotrichs and hydrozoa are very sensitive to pollution hence they end up disappearing resulting to lower diversity and lower richness. Nematodes dominate such environments because they are more resilient and can tolerate anoxic conditions that results from excessive nutrients pollution (Moreno *et al.,* 2011). Ostracods are highly sensitive to anoxic conditions and pollution by heavy metals. However, some of them are well adapted and can dominate highly polluted ecosystems (Yasuhara *et al.,* 2012). Meiofauna have several

generations per year allowing quick detection of pollutant effects on their longevity, growth rate and fecundity (Zeppilli *et al.,* 2015). Due to the different feeding strategies between species, information about the type and strength of pollutants can be obtained by determining adapted taxa of benthic organisms. Because of their sensitivity to the effects of pollution, they show effects of pollution faster and at lower concentrations than other organisms (Moreno *et al.,* 2008a; Brinke *et al.,* 2011).

Variations in marine soft sediments influence the structure of benthic organisms thus, affecting their assemblages (Bevilacqua *et al.,* 2011). Soft bottoms have unique ability in their components which have three-dimensional spatial structure and bioturbation effects changing the chemical and physical characteristics of their habitat (Giere, 2008).

In the benthic community, polychaetes and nematodes are often utilized when studying impacts of pollution due to their high diversity and density in benthic domain to assess variance. Nematodes are in addition relied on due to their key role in trophic chain and role in upholding shoreline disturbances (Whalen & Sampedro, 2010). They also survive in severe environments, as r strategists and have stable populations which respond rapidly in stressful conditions compared to other benthic communities (Moreno *et al.,* 2011; Vanaverbeke *et al.,* 2011; Semprucci & Balsamo, 2012). Polychaetes have been previously utilized as sensitive detectors of water quality majorly in terms of pollutants impacts on their life history characteristics. In addition, there is a possibility of utilization as general monitors of community diversity although different taxa may vary geographically. They are also used to indicate heavy metal contamination. Nonetheless, nematodes can dominate in osmotic stress because they regulate their water content by undergoing changes in their cuticle (Park *et al.,* 2007).

Resilient or opportunistic species regularly predominates polluted ecosystems while the sensitive species become rare or even disappear from such sites (Belan, 2003). A few species such as polychaetes (*Capitella capitata, Pseudopolydora paucibranchiata*), amphipods (Corophium sps) and mollusk (*Abra alba)* have been numerously recorded in polluted environments (Riera *et al.,* 2011).

When polluted beaches were compared with unpolluted beaches on the Brittany coasts in France during a field study, it was found that the diversity reduced, and species composition changed. shifts in community structures and very low diversity were recorded in sites that are polluted

unlike unpolluted (Arezoo, 2019). Benthos utilizes both biotic and abiotic parameters for their adaptation in an ecosystem thereby reliable in presenting accurate health status of an aquatic ecosystem (Casazza *et al.*, 2002).

## 3. MATERIALS AND METHODS

### 3.1.Study site

The study was conducted at Mikindani (MIK) in Tudor Creek and Dabaso (DAB) in Mida Creek which acted as the control site (Fig 3.1).

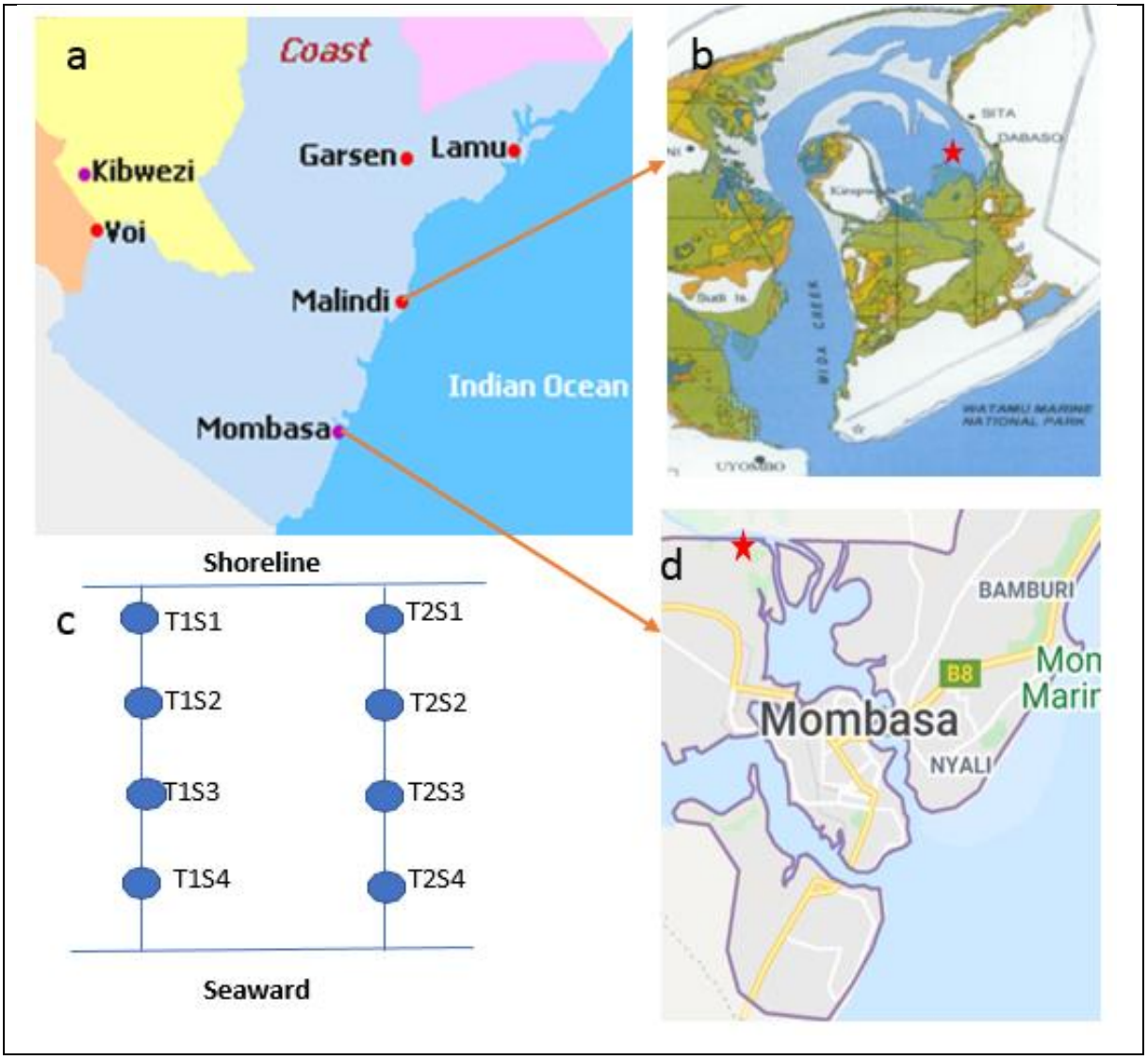


Figure 3.1: Map of study area showing a) Kenya Coast and the sampling sites b) Dabaso (Mida creek); c) sampling strategy d) Mikindani (Mombasa)

Tudor Creek is located at $4^0$2’ S, $39^0$40’ E and borders Mombasa Island on the northwest side. It stretches roughly 10km inland and passes underneath the Nyali Bridge. It is bordered by Makupa Causeway on the western facet. Three seasonal streams (Mtsapuni, Kombeni and Tsatu) enters

the creek close to Mariakani, roughly 32 km north-west of the Port (Harifi *et al.*, 2014). The mangrove forest is composed of *Rhizophora mucronata* and *Avicennia marina* covers approximately 8km$^2$ of the creek. The mangrove forest however does not display any defined zonation. *A. marina* covers the middle zone while *R. mucronata* covers the landward zone (Kirui et al., 2013b). The mangrove system is extremely polluted by raw sewage that is mainly released into the creek from Tudor, Mikindani, and the Old Town settlements.

Tudor creek is often loaded with sewage in every tidal cycle with the discharge decreasing away from the source (Amaral *et al.,* 2009). The sewage passes through channels cutting across Mikindani forest to the ocean (Kelly, 2011). Some parts of the creek are covered by sand while others are covered by muddy sediments. There have been increased encroachment in the land neighboring the creek to create space for subsistence farming and informal settlements. The vegetation has been cleared with coconut plantation put in place as well as grazing which has greatly degraded the creek (Kirui et al., 2013b). The creek supports a very large population that resides in Mikindani, Bangladesh, Burukenge, Mishomoroni, Changamwe, Tudor, Kibarani, Kongowea, Moroto, Kenya Meat commission and the old town.

Mida Creek (3°20'S, 39° 58' E) in Watamu, Kilifi County stretches inland to Arabuko Sokoke forest from the sea. It is 32km$^2$ wide with the forest being the main source of water. The estimated terrain elevation is 6metres above the sea level. The average monthly temperatures range between 23°C to 27°C but the maximum temperatures are 34°C during dry season. The total annual precipitation is between 1000mm and 1600mm. The short rains are between November and December while the long rains take place from April to June. The creek is composed of different habitats which are influenced by tides. It is characterized by muddy and shallow sandy soils which makes its water retention low. Mangroves, sea grasses and coral reefs act as water purifiers and nutrient cycling in marine ecosystems. The mangrove and sea grasses also help in trapping sediments allowing healthy growth of the coral reefs. *R. mucronata, A. marina* and *C. tagal* are the most dominant mangrove species. The creek provides feeding and development area for sea turtles. It is home and breeding ground for many different species of marine organisms including fish. There is less settlement surrounding the creek compared to

Mikindani hence minimal anthropogenic activities that would result to pollution. Nevertheless, the creek supports the local communities both ecologically and economically.

### 3.2.Field sampling

Sampling was conducted at low tide during dry season (January/February 2017) and wet season (November/December 2017). Two transects perpendicular to the shoreline were identified within the intertidal zone in each site where 4 stations were selected at 15 m interval in each transect (Fig 3.1).

In Mikindani, transect 1 was laid away from the sewage channel while transect 2 was laid within the sewage channel. In each station, two replicates' samples were collected comprising of the following parameters: macro- and meio-fauna, heavy metals, sediments grain size, Dissolved Oxygen (DO), Total Organic Matter (TOM), and Biological Oxygen Demand (BOD).

Benthic fauna samples were collected using corers of transparent perspex tubing of diameter 6.4 cm for macrofauna and 3.6 cm for meiofauna to a sediments depth of 10 cm and placed in well-labeled sample bottles. The samples were fixed with 8% buffered formaldehyde solution to preserve them in their original structure. Samples for TOM and sediments granulometry were sampled using the 6.4 cm diameter corer and stored in Ziplock bags.

Dissolved Oxygen was measured following the Winkler protocol. A 300 ml BOD bottle was filled with interstitial water, which was acquired by scooping out sediments from the creek floor using corers and allowing the holes to fill with water. Sample bottles were closed with a stopper. This was done gradually ensuring no air bubbles were trapped inside the bottle. The sample was fixed by adding 2ml of manganese sulfate immediately after sampling. This was done by slowly squeezing a calibrated pipette below the liquid surface followed by 2ml of alkali-iodide-azide. The bottle was thoroughly stoppered ensuring no air passed through and the sample mixed evenly by inverting the bottle severally. Concentrated sulphuric acid (2ml) was added using a pipette after which the bottle was closed tightly and inverted several times to dissolve any flocculant formed. The samples were then wrapped with aluminum foil. They were stored in a cooler box for transportation to the lab.

BOD samples were collected, fixed and stored using the same procedure as that of DO where 300 ml BOD bottles were filled with interstitial water acquired though scooping out sediments

using corers and allowing the holes fill with water. The sample bottles were gradually closed with stoppers guaranteeing absence of air bubbles. The samples were fixed by adding 2ml of Manganese sulfate followed by 2ml of alkali-iodide-azide. The bottle was thoroughly closed ensuring absence of external air and the sample mixed by severally inverting the bottle. Concentrated sulphuric acid (2ml) was added after which the bottle was stoppered and mixed a few times to dissolve any flocculant formed. The samples were then wrapped with aluminum foil. They were stored in a cooler box for transportation to the lab.

Sediments samples for heavy metals analysis were collected from the surface using corers to a depth of 10cm and preserved with concentrated nitric acid to below pH 2. They were stored in zip lock bags and labelled with month of collection, replicate number, site, and station details before transporting them to the laboratory.

Table 3.1: Location of transects (T), station (S) and sampling sites at Dabaso and Mikindani in Kilifi and Mombasa County respectively.

| Station | Transect (T) | Station(S) Code | | Longitude | Latitude | Number of replicates |
|---|---|---|---|---|---|---|
| Dabaso | T1 | S1 | DT1S1 | 39° 59' 19.7808" E | 3° 20' 41.7732" S | 2 |
| | | S2 | DT1S2 | 39° 59' 19.1076" E | 3° 20' 41.586" S | 2 |
| | | S3 | DT1S3 | 39° 59' 18.4776" E | 3° 20' 41.5896" S | 2 |
| | | S4 | DT1S4 | 39° 59' 17.8548" E | 3° 20' 41.4924" S | 2 |
| | T2 | S1 | DT2S1 | 39° 59' 19.77" E | 3° 20' 42.8208" S | 2 |
| | | S2 | DT2S2 | 39° 59' 19.1076" E | 3° 20' 42.7308" S | 2 |
| | | S3 | DT2S3 | 39° 59' 18.2976" E | 3° 20' 42.6408" S | 2 |
| | | S4 | DT2S4 | 39° 59' 17.4444" E | 3° 20' 42.5328" S | 2 |
| Mikindani | T1 | S1 | MT1S1 | 39° 38' 16.2852" E | 4° 0' 25.5852" S | 2 |
| | | S2 | MT1S2 | 39° 38' 17.016" E | 4° 0' 25.4448" S | 2 |

| | | | | | |
|---|---|---|---|---|---|
| | S3 | MT1S3 | 39° 38' 18.1716" E | 4° 0' 25.2108" S | 2 |
| | S4 | MT1S4 | 39° 38' 18.9852" E | 4° 0' 24.9624" S | 2 |
| T2 | S1 | MT2S1 | 39° 38' 13.9488" E | 4° 0' 23.2956" S | 2 |
| | S2 | MT2S2 | 39° 38' 15.1728" E | 4° 0' 22.4928" S | 2 |
| | S3 | MT2S3 | 39° 38' 15.8172" E | 4° 0' 21.708" S | 2 |
| | S4 | MT2S4 | 39° 38' 16.5552" E | 4° 0' 20.9268" S | 2 |

### 3.3.Laboratory Analysis

#### 3.3.1. Benthic communities

Macrofauna samples were rinsed with tap water over the sieves of 2mm and 0.5mm. The 2.0mm sieve was used to remove large sediments and organisms. The 0.5mm sieve was used to retain and collect the macrofauna which were preserved in 5% formalin solution and 3 drops of Rose Bengal added overnight to stain. Samples were rinsed off formalin and the stain the following day and then observed under dissecting microscope, enumerated and identified to the sub-class taxonomic level.

Meiofauna samples were washed over 1mm and 38µm sieves sizes and those sediments collected in the 38µm sieve were preserved using 5% formalin. The following day the samples were rinsed off formalin and washed into the centrifuge tubes of 50ml using magnesium sulphate ($MgSO_4$) of 1.28 specific densities, to separate nematodes and dirt, and centrifuged at 6000 rpm for ten minutes. The procedure was repeated thrice for each sample to ensure achievement of 95% extraction efficiency of meiobenthos from the sediments by density separation (Hodda and Abebe, 2006). The supernatant was collected over the 38µm after every centrifugation and rinsed off the sieves using filtered water. The samples were fixed in 4% buffered formaldehyde and stained with Rose Bengal overnight. Specimens were observed under a dissecting microscope at magnification x10 and identified to the highest taxonomic level using Platt & Warwick (1988) classification guide.

This analysis was conducted in the biological laboratory at The University of Nairobi.

### 3.3.2. Total Organic Matter

Organic matter samples were processed according to Hoogsteen et al., (2018) using the method of 'loss on ignition'. They were dried in an oven at $60^0$C until there was no change in weight. A small portion of each dried sediments samples weighing 25g was put in a porcelain dish and burned in the furnace at 600°C for 3 hours, cooled and weighed. Organic matter content was computed as the percentage of the weight loss over total sample ashed (%OM).

### 3.3.3. Grain size

Sediments grain size samples, each weighing 100gms, were passed through an electric shaker with 63 µm, 125 µm, 250 µm, 500 µm, 1000 µm and 2000µm sieves for 10 minutes. Each sieve proportion was weighed in a microbalance and the percentage proportion of each of the different grain sizes calculated over the total weight. The samples were then grouped into 7 classes using the Wentworth size class: silt and clay (pan) (<63µm), very fine sand (63µm-125µm), fine sand (125µm-250µm), medium sand (250µm -500µm), coarse sand (500µm -1000µm), very coarse sand (1000µm-2000µm) and granule (>2000µm).

### 3.3.4. DO

The DO samples were analyzed by titrating 200 ml of the sample with sodium thiosulfate to a pale straw color. The titrate was slowly added into the solution while stirring continuously. A solution of 2ml of starch was added to form a blue color. Titration proceeded until the sampled turned clear with only one drop eliminating the blue color as the experiment neared the end point. The DO concentration in the sample is equal to amount of titrant (sodium thiosulfate) used in milliliters. Each ml added is equivalent to 1 mg/L dissolved oxygen.

### 3.3.5. BOD

To determine Biological Oxygen Demand (BOD), the initial DO was assessed after which the samples were incubated using 300ml incubation bottles where buffered dilution water dosed with seed microorganism was added and the samples stored in the dark for 5 days at 20 degrees Celsius. After the five days, the final DO content was determined and the difference between the final reading and the initial reading was calculated. BOD was determined by;

$$\text{BOD (mg/L)} = (\text{Initial DO} - \text{Final DO}) \div \text{Volume of sample/Volume of bottle}$$

TOM, grain size, DO and BOD analysis was conducted at Kenya Marine and Fisheries Research Institute laboratories, Mombasa.

### 3.3.6. Heavy Metals

For heavy metal analysis, sediments samples were dried in the oven at $105^0$C for 24 hours then ground and sieved with a 63µm sieve. Starch was added to allow binding together of the sediments after which three replicates' pellets of each subsample (0.5g) were prepared. Sediments samples total metal content was estimated using Atomic Absorption Spectroscopy (AAS). Air-acetylene flame at optimum instruments operating conditions was used. The values obtained from the samples were corrected and results reported on dry weight basis. AAS and Energy Dispersive X-ray Fluorescence (EDXRF) techniques were used for comparison. Replicate analysis of selected samples was carried out to evaluate precision and repeatability. The analysis method was evaluated using soil 7 certified reference material known as International Atomic Energy Agency (IAEA).

Heavy metals analysis was carried out at the Institute of Nuclear Science, University of Nairobi

### 3.4. Data analysis

The benthos' densities, diversities, relative abundances and their community assemblages were analyzed. Means and standard errors in all the variables were determined and recorded. The macrofauna densities were determined as individuals per meter square (ind/$m^2$) while for meiofauna densities were determined as individuals per 10-centimeter square (ind/$10cm^2$). Densities data was transformed (square root) to enhance normality in distribution. The data was tested for homogeneity of variances before choosing a parametric test (St Pierre et al., 2018).

PAST Statistical Programme was used to determine the Shannon Wiener diversity indices in both macrofauna and meiofauna. SPSS was used to test for significant difference between the sampling sites in all abiotic and biotic factors using ANOVA. Turkey HDS (Honestly Significant Difference) test was further used to partition any other observed differences between the sampling stations in each site. Graphs were created using SPSS and excel. Community analysis was done using Plymouth Routines in Multivariate Ecological Research (PRIMER v5.2.9) where Bray Curtis Cluster analysis on similarity (ANISOM) and Simper compared the similarities between sites and stations. ANOSIM tests were to assess if there were differences in the community structure acquired from nMDS ordination. If R value calculated was significant, pairwise comparisons were done between treatments. The R values fell between -1 to +1 where zero (0) represented the null hypothesis (no significant difference between samples). R values

greater than 0.75 indicated well separated sites while R>0.5 showed clear difference between sites, but they were overlapping. Value of R<0.25 was indicative of barely separable groups. nMDS graphs were then plotted based on the similarities using Primer.

Normalized Principal Component Analysis (PCA) was used to assess the variability of meiofauna and macrofauna densities with environmental variables. Pearson's Product-Moment correlation (Statistica program) analysis was conducted to evaluate the association or correlation between abiotic and biotic factors as well as spatial variations.

# 4. RESULTS

## 4.1.Physico-chemical parameters of marine sediments at Dabaso and Mikindani

### 4.1.1. Total Organic Matter

During the dry season (Fig 4.1), the mean TOM content was significantly higher (p=0.019) in Dabaso (23.7 ± 0.7%) compared to Mikindani (6.6± 0.2 %). Similarly, in the wet season, Dabaso (23.9±0.03%) recorded a significantly higher (Appendix 7.1, P=0.03) TOM content compared to Mikindani (5.9 ± 0.1%).

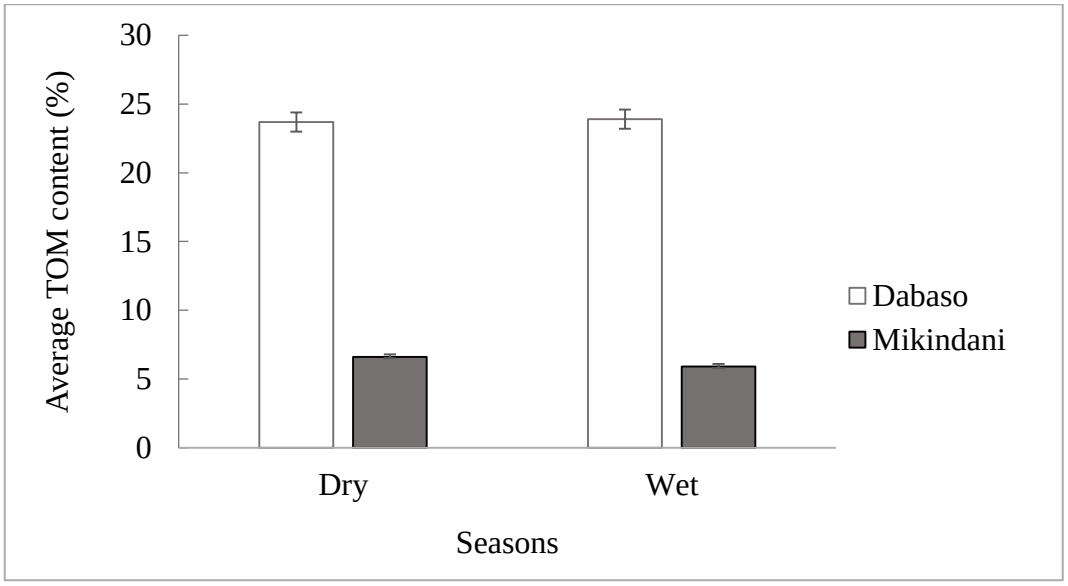


Figure 4.1: Mean TOM content of sediments at Dabaso and Mikindani during dry and wet seasons

In Mikindani, there was a slight difference (Appendix 7.1, p = 0.293) in the TOM content in the sediments between the dry (6.6 ± 0.2%) and the wet season (5.9 ± 0.1%) but it was not significant. Similarly, in Dabaso, there was no difference between the dry (23.7±0.7%) and the wet (23.9± 0.03%) season, p = 0.827). However, total organic matter content was significantly higher at Dabaso than at Mikindani in both wet and dry season.

### 4.1.2. Sediment's size

During the dry season (Fig 4.2), coarse and medium sand fractions were higher in Dabaso (29.7%, 30.3%) compared to Mikindani (20.7%, 23.3%) respectively. On the other hand, fine sand, very fine sand and silt/clay had higher proportions observed in Mikindani compared to Dabaso. Similarly, very coarse sand and granules were also higher in Mikindani compared to Dabaso. Silt/clay had the lowest proportion in both sites.

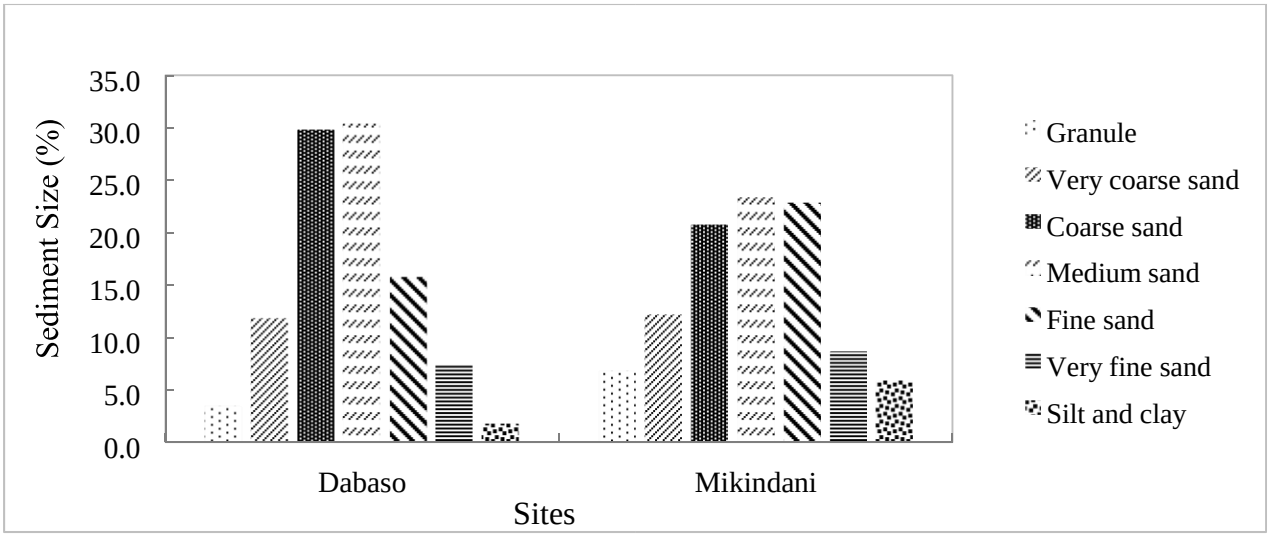


Figure 4.2: Dry season variation in sediments size at Dabaso and Mikindani

During the wet season (Fig 4.3), coarse, medium and fine sand had the highest proportions in both sites although they were higher in Dabaso (28.3%, 25.0%, 20.6%) compared to Mikindani (23.3%, 23.9%, 19.7%) respectively. Granules and very coarse sand had higher fractions in Mikindani compared to Dabaso. Clay had the lowest proportion in both sites although it was slightly higher in Mikindani than in Dabaso.

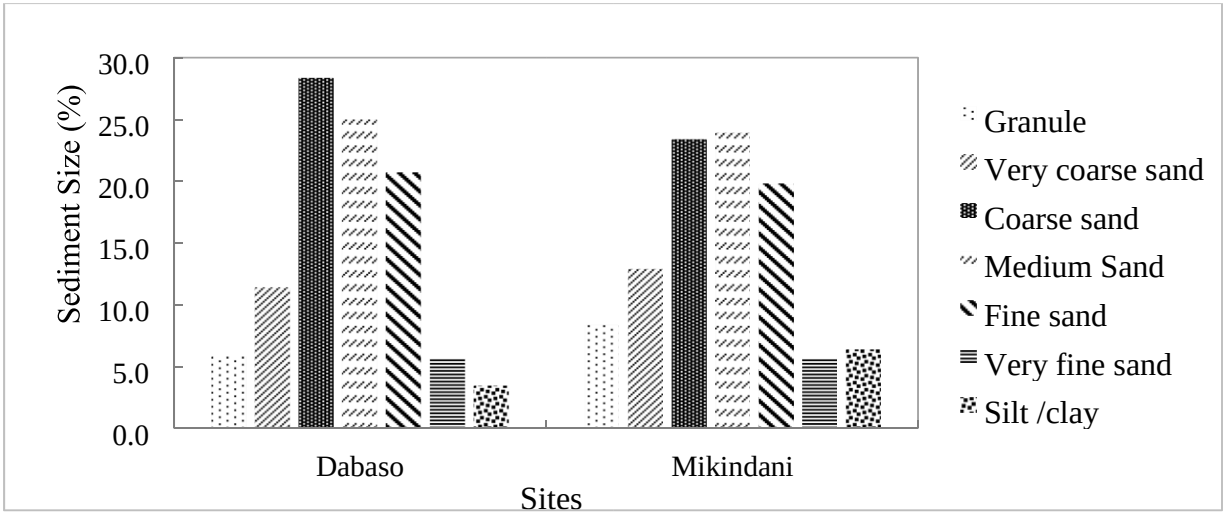


Figure 4.3: Wet season variation in sediments size at Dabaso and Mikindani

### 4.1.3. Dissolved Oxygen Concentration and Biological Oxygen Demand

During the dry season (Fig 4.4), Dabaso recorded significantly higher (Appendix 7.1, p=0.048) DO concentrations (4.0±0.1mg/L) compared to Mikindani (3.8 ± 0.02 mg/L). Likewise, in the wet season, DO concentrations were significantly higher (Appendix 7.1, p=0.013) in Dabaso (5.3± 0.03 mg/L) compared to Mikindani (2.1 ± 0.04 mg/L).

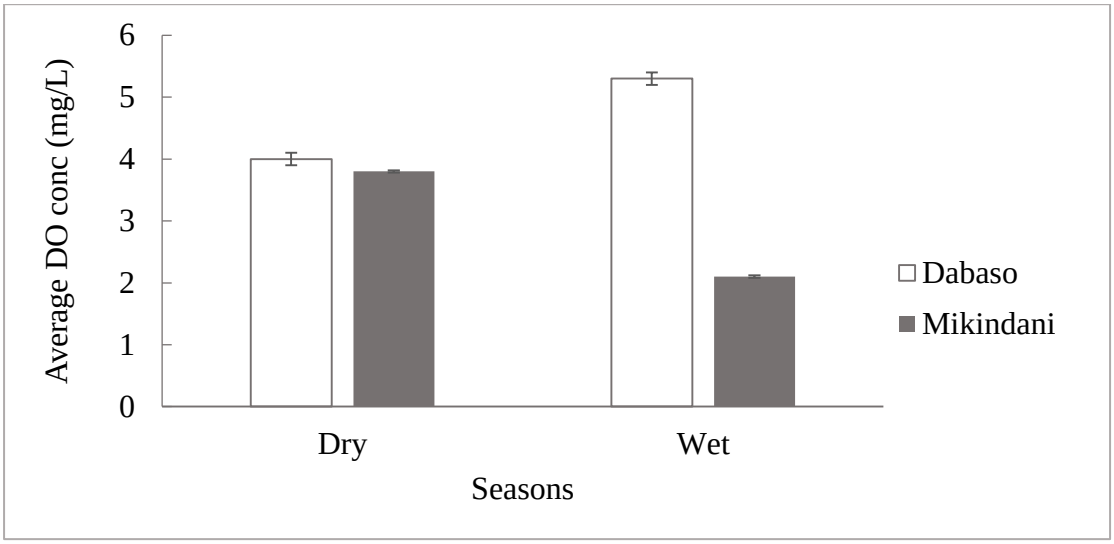


Figure 4.4: Mean DO concentrations (mg/L) in the sediments at Dabaso and Mikindani during dry and wet seasons

The DO concentrations were significantly (p=0.025) higher in the wet season (5.3 ± 0.03 mg/L) compared to the dry season (4.0 ± 0.05mg/L) in Dabaso. In contrast, DO they was significantly higher (p=0.021) in the dry season (3.8 ± 0.02 mg/L) compared to the wet season (2.1 ± 0.03 mg/L) in Mikindani (Appendix 7.1).

The mean BOD (Fig 4.5) was significantly (Appendix 7.1, p=0.039) higher in Mikindani (4.8± 0.2mg/L) compared to Dabaso (3.4 ±0.10 mg/L) during the dry season. In contrast, during the wet season (Fig 4.5B), the BOD was significantly higher (p=0.041) in Dabaso (3.5 ± 0.03 mg/L) than at Mikindani (2.8± 0.03mg/L).

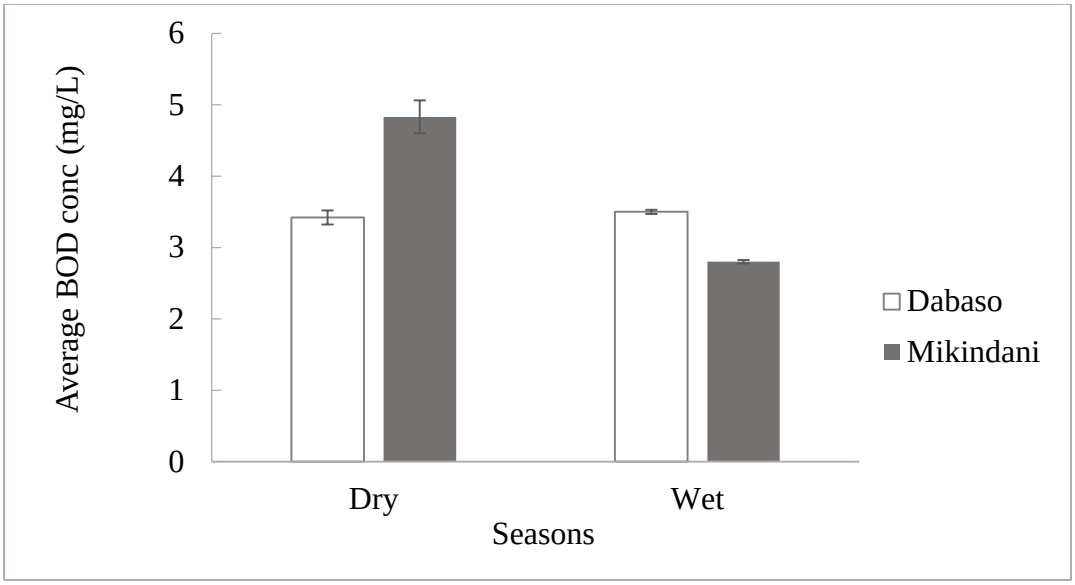


Figure 4.5: Mean BOD concentrations (mg/L) in the sediments at Dabaso and Mikindani during dry and wet seasons

When the concentrations between seasons were compared, a slight increase from the dry season (3.4±0.10mg/L) to the wet season (3.5±0.03mg/L) was recorded in Dabaso with no significant difference (Appendix 7.1, p>0.5). Contrastingly, Mikindani recorded a significant (p=0.003) decrease in BOD between the dry season (4.8±0.2mg/L) and the wet season (2.8±0.03mg/L).

### 4.2. Heavy metal concentrations

The heavy metals that were found in the surface sediments at Dabaso and Mikindani study sites were Titanium (Ti), Manganese (Mn), Iron (Fe), Zinc (Zn), Rubidium (Rb), Zirconium (Zr) and Lead (Pb). The metals were concentrated on the surface sediments and decreased in the following order: Fe> Ti > Zr > Mn > Rb > Zn > Pb. Iron (Fe) was the most abundant heavy metal in Mikindani (Appendix 1).

#### 4.2.1. Titanium (Ti)

The average concentration levels for Ti were generally high in both sites (Fig 4.6). During the dry season, the concentrations were significantly (Appendix 7.2, P=0.04) higher in Mikindani (2677±122 mg/kg) compared to Dabaso (897±10.4 mg/kg).

Similarly, during the wet season, the concentrations were significantly (Appendix 7.2, 0.03) higher in Mikindani (3133±86.3 mg/kg) compared to Dabaso (807±65 mg/kg). The difference

between the dry (2677±122 mg/kg) and the wet season (3133±86.3 mg/kg) was significant (p=0.05) in Mikindani. In Dabaso, the concentrations slightly decreased from the dry season (897±10.4 mg/kg) to the wet season (807±65 mg/kg) but the difference was not significant (p=0.342).

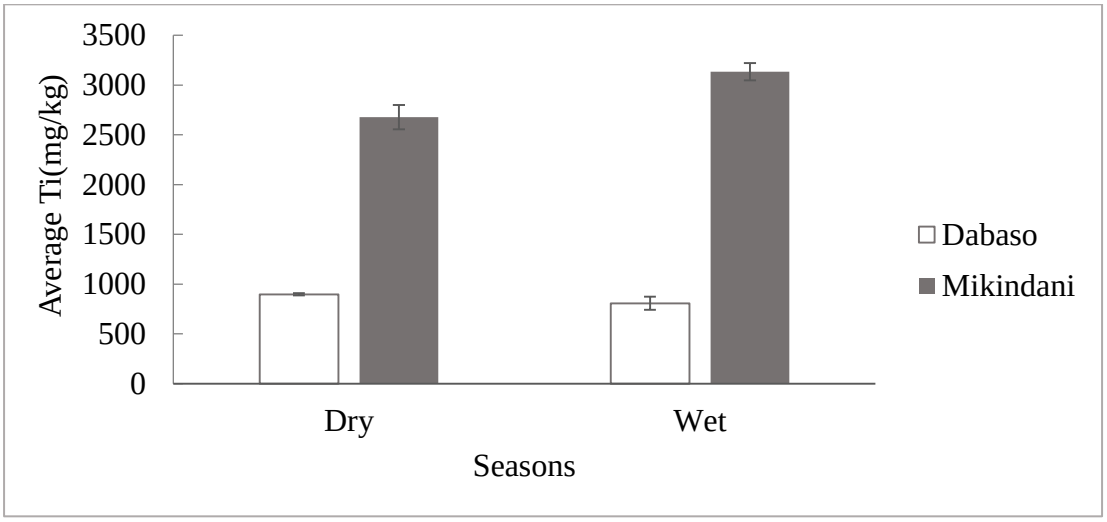


Figure 4.6: Mean Titanium concentrations (mg/kg) in the sediments at Dabaso and Mikindani during dry and wet seasons

### 4.2.2. Manganese (Mn)

Generally, the average Mn concentration levels were low in both sites (Fig 4.7). In the dry season, the levels were significantly higher in Mikindani (164.1±8.9 mg/kg) compared to Dabaso (127.5±0.4 mg/kg) (Appendix 7.2, p=0.034).

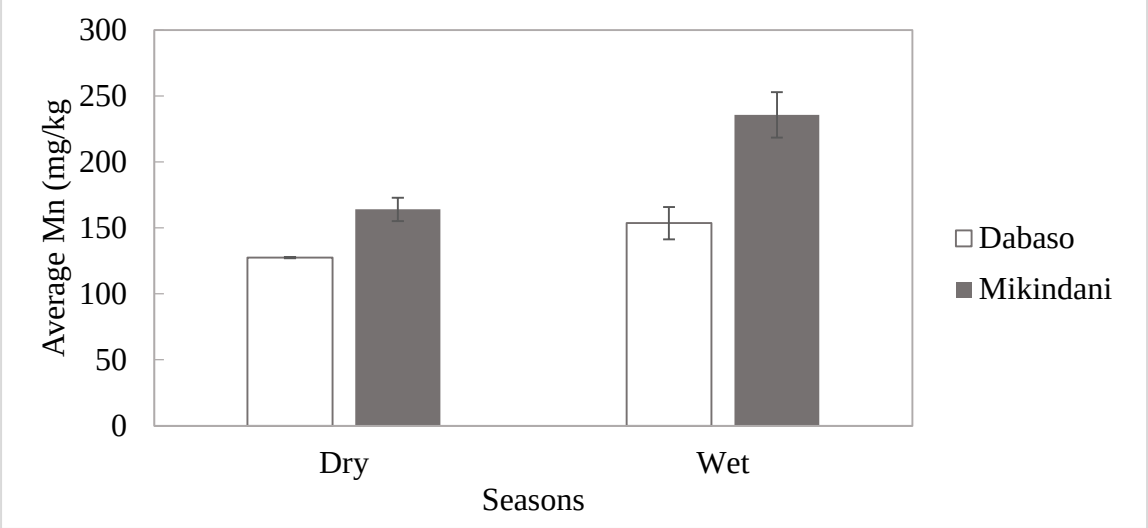


Figure 4.7: Mean Manganese concentrations (mg/kg) in the sediments at Dabaso and Mikindani during dry and wet seasons

Likewise, in the wet season the concentrations were significantly higher in Mikindani (235.8±17.2 mg/kg) compared to Dabaso (153.6±12.3 mg/kg), p=0.018).

The Mn concentrations significantly increased from dry to wet season in both Mikindani (p=0.012) and Dabaso (p=0.032).

### 4.2.3. Iron (Fe)

The levels for the average concentration of Fe (Fig 4.8) were significantly (Appendix 7.2, p=0.01) higher in Mikindani (17147±585 mg/kg) compared to Dabaso (4146±1831 mg/kg) during the dry season. The concentrations during the wet season were also significantly (p=0.017) higher in Mikindani (21633±886.3 mg/kg) as compared to Dabaso (5240±257.2 mg/kg). In both Dabaso and Mikindani, the levels increased significantly from dry to wet season (Appendix 7.2, p=0.043; p=0.024) respectively.

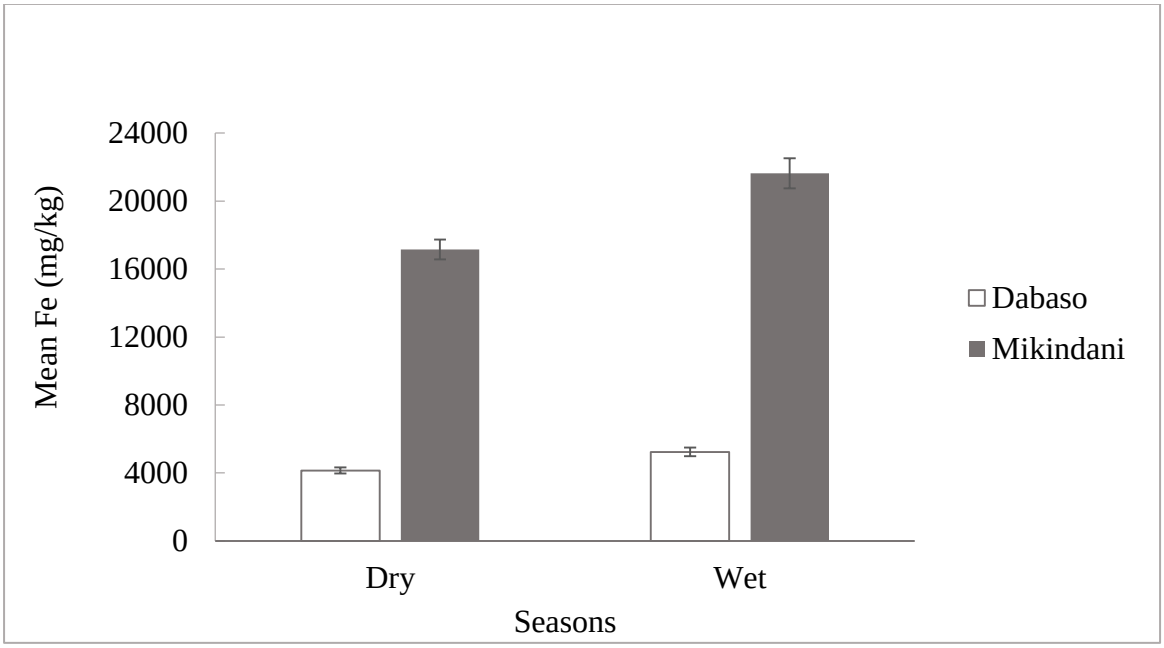


Figure 4.8: Mean Iron concentrations (mg/kg) in the sediments at Dabaso and Mikindani during dry and wet seasons

### 4.2.4. Zinc

The average concentration levels for Zn (Fig 4.9) were roughly low in both sites and seasons. Mikindani (70.5±3.7 mg/kg) recorded significantly (Appendix 7.2, p=0.016) higher levels compared to Dabaso (16.4±2.3 mg/kg) during the dry season while in the wet season no significant difference was recorded between the two sites although in Mikindani (70.1±7.6 mg/kg) the concentrations were higher than in Dabaso (12.5±0.7 mg/kg).

Temporal differences were very minute but non-significant in both Dabaso (p=0.262) and Mikindani (p=0.92). The levels were a bit lower in the wet season compared to the dry season.

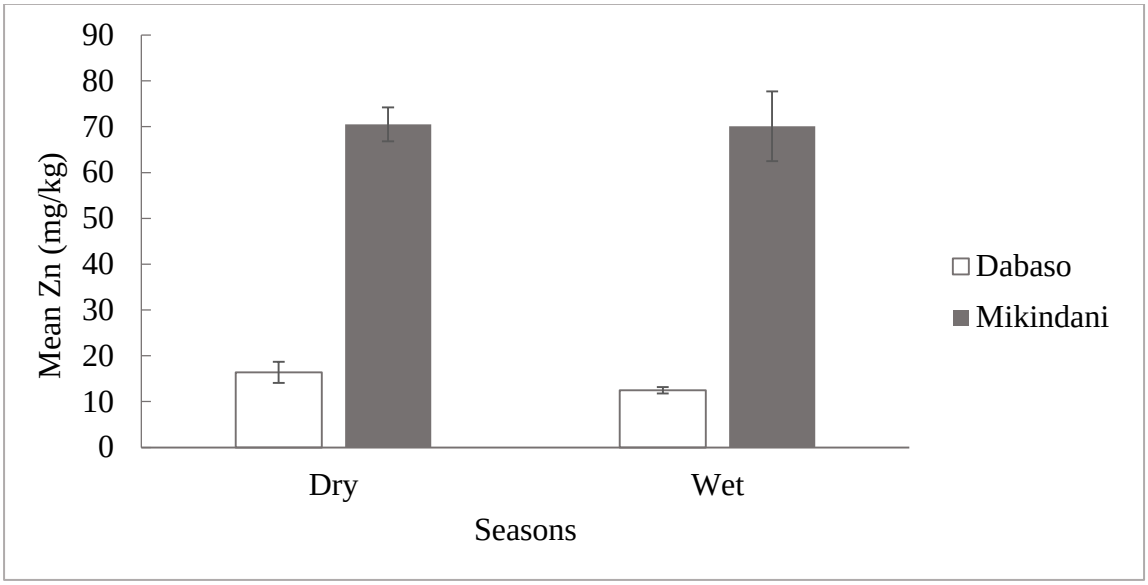


Figure 4.9: Mean Zinc concentrations (mg/kg) in the sediments at Dabaso and Mikindani during dry and wet seasons

### 4.2.5. Rubidium (Rb)

The average concentration levels for Rb were significantly (Appendix 7.2, p=0.02) higher in

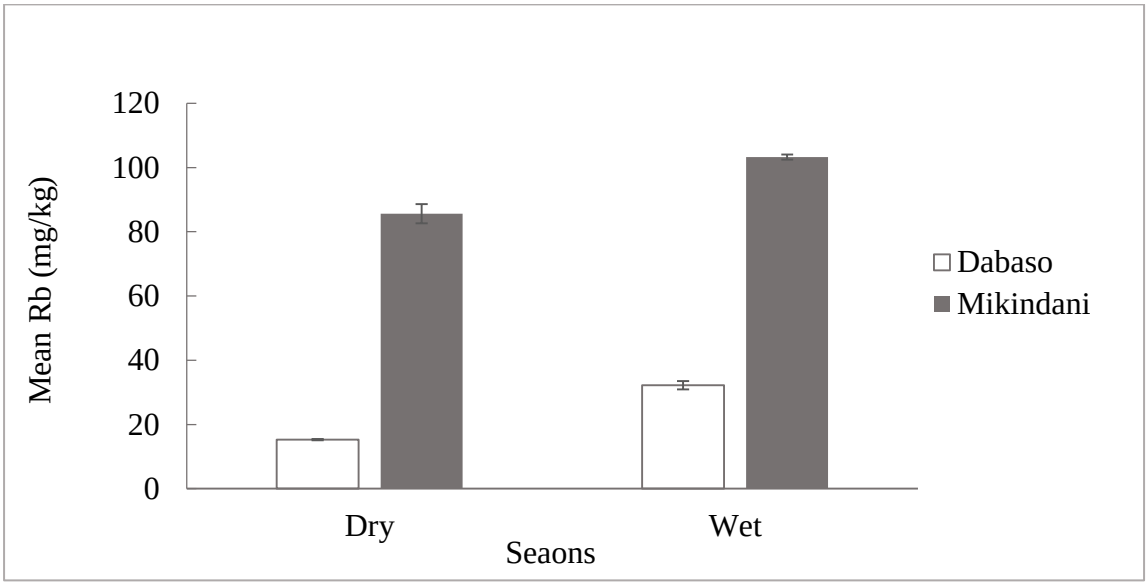


Figure 4.10: Mean Rubidium concentrations (mg/kg) in the sediments at Dabaso and Mikindani during dry and wet seasons

Mikindani (85.6 ±3 mg/kg) compared to Dabaso (15.32± 0.2 mg/kg) (Fig 4.10). Likewise, during the wet season, the concentrations were significantly (p=0.018) higher in Mikindani (103±0.8) compared to Dabaso (32.2±1.3 mg/kg).

When seasons were compared, both Dabaso and Mikindani recorded slightly higher Rb levels during the wet season compared to the dry season. Although the differences between the two seasons were minimal, they were significant in both sites.

### 4.2.6. Zirconium (Zr)

During the dry season, Mikindani (877±36.3mg/kg) recorded significantly (Appendix 7.2, p=0.027) higher levels compared to Dabaso (309±5.2 mg/kg) (Fig 4.11).

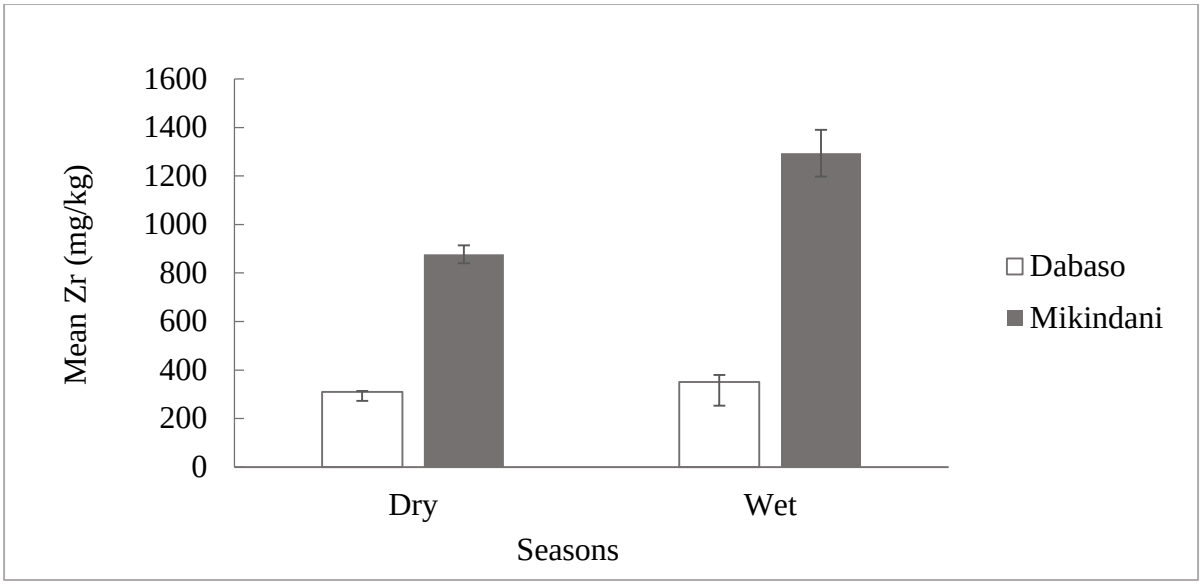


Figure 4.11: Mean Zirconium concentrations (mg/kg) in the sediments at Dabaso and Mikindani during dry and wet seasons

Likewise, in the wet season, the concentration levels were significantly (p=0.016) higher in Mikindani (1294±96.7mg/kg) compared to Dabaso (350±29.1 mg/kg). The concentration levels in wet season were higher than in the dry season in both sites. The difference was significant in Mikindani (p=0.04) but not significant in Dabaso (Appendix 7.2, p=0.132).

### 4.2.7. Lead (Pb)

In general, the average levels for Pb concentration were very low in both sites (Fig 4.12). During the dry season, Mikindani (25.1±3.3 mg/kg) recorded significantly (Appendix 7.2, p=0.039) higher concentration levels compared to Dabaso (15.2±3.8 mg/kg) as well as during the wet season (p=0.024). The levels significantly increased from the dry season to the wet season in Mikindani (p=0.045) but in Dabaso the differences were not significant (Appendix 7.2, p=0.402).

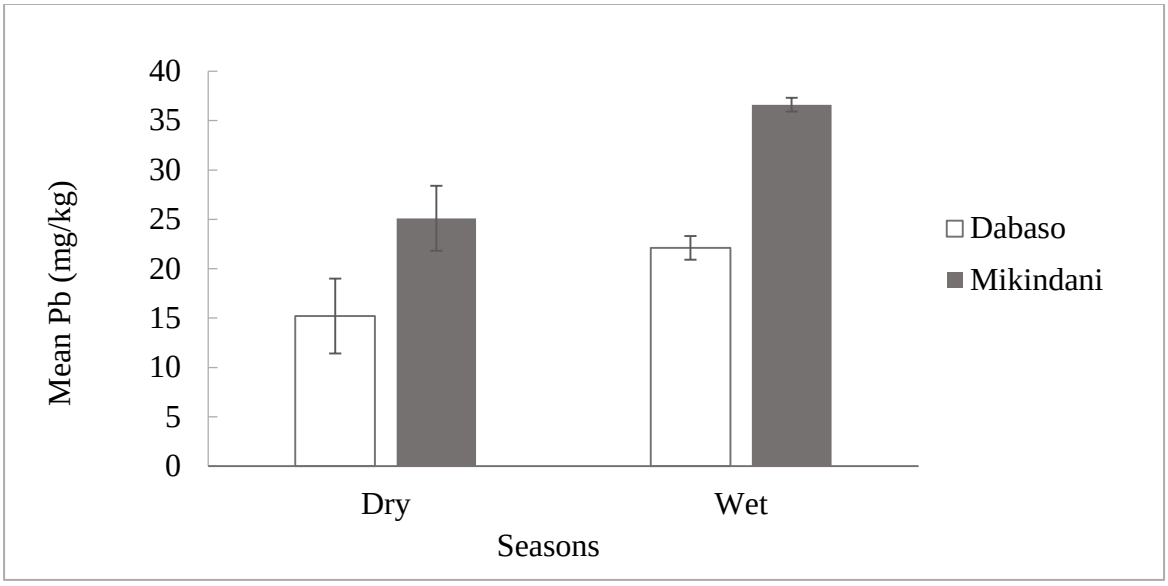


Figure 4.12: Mean Lead concentrations (mg/kg) in the sediments at Dabaso and Mikindani during dry and wet seasons

### 4.3. Biotic Factors

#### 4.3.1. Macrofauna

##### 4.3.1.1. Density and distribution

Overall mean macrofauna densities were significantly higher (Appendix 7.3, p=0.036) in both Dabaso (42489±2896 ind.m$^{-2}$) and Mikindani (21507 ±1841ind.m$^{-2}$) (p=0.02) during the wet season compared to the dry season (14470±2049 ind.m$^{-2}$) (8879±376) ind.m$^{-2}$) respectively. During the dry season the mean macrofauna densities were significantly (p=0.024) higher in Dabaso (14470±2049 ind.m$^{-2}$) compared to Mikindani (8879±376 ind.m$^{-2}$) (Fig 4.13).

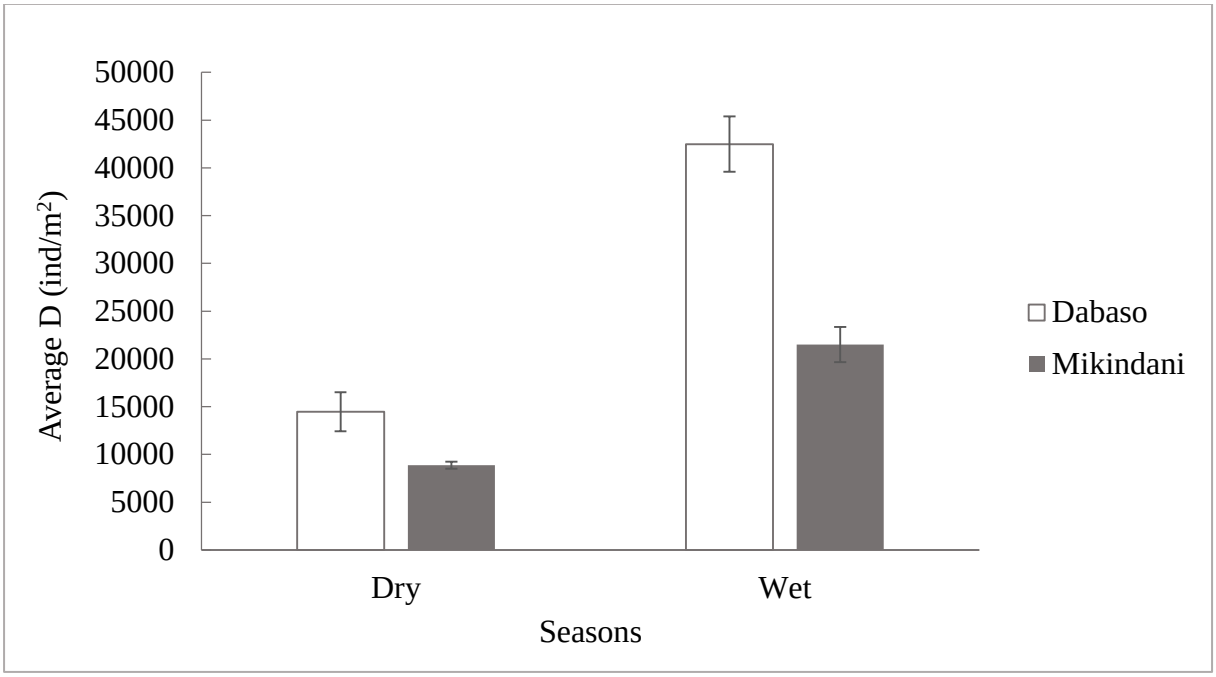


Figure 4.13: Mean macrofauna densities (Ind.m-$^{2}$) at Dabaso and Mikindani during dry and wet seasons

Similarly, during the wet season the macrofauna densities were significantly higher (p=0.013) in Dabaso (42489 ±2896 ind.m$^{-2}$) compared to Mikindani (21507 ± 1841 ind.m$^{-2}$) (Fig 4.13).

The macrobenthic faunal community was composed of 7 groups in both Dabaso and Mikindani during the dry season while during the wet season there were 7 groups in Dabaso and 8 groups in Mikindani (Appendix 7.4). The community assemblage varied between the two sites in that nematodes (50.1%, 63.4%), Polychaetes (24.3%, 13.4%) and amphipods (12.1%, 7.6%)

dominated in Dabaso in both the dry and the wet season, respectively. On the other hand, Polychaetes (36.1%, 56.1%), Oligochaetes (42.9%, 12.5%) and copepods (6.3%, 18.1%) dominated in Mikindani in both seasons (Fig 4.14). In the wet season, Oligochaetes greatly decreased in Mikindani while Amphipods disappeared completely. Gastrotrichs were only present in Mikindani during the wet season at 0.8%. Bivalves were only found in Dabaso at 1.6% and 0.4% in dry and wet season respectively. Both taxa together with ostracods had very low representation (<10%) and were therefore grouped as 'other groups' (Fig 4.14).

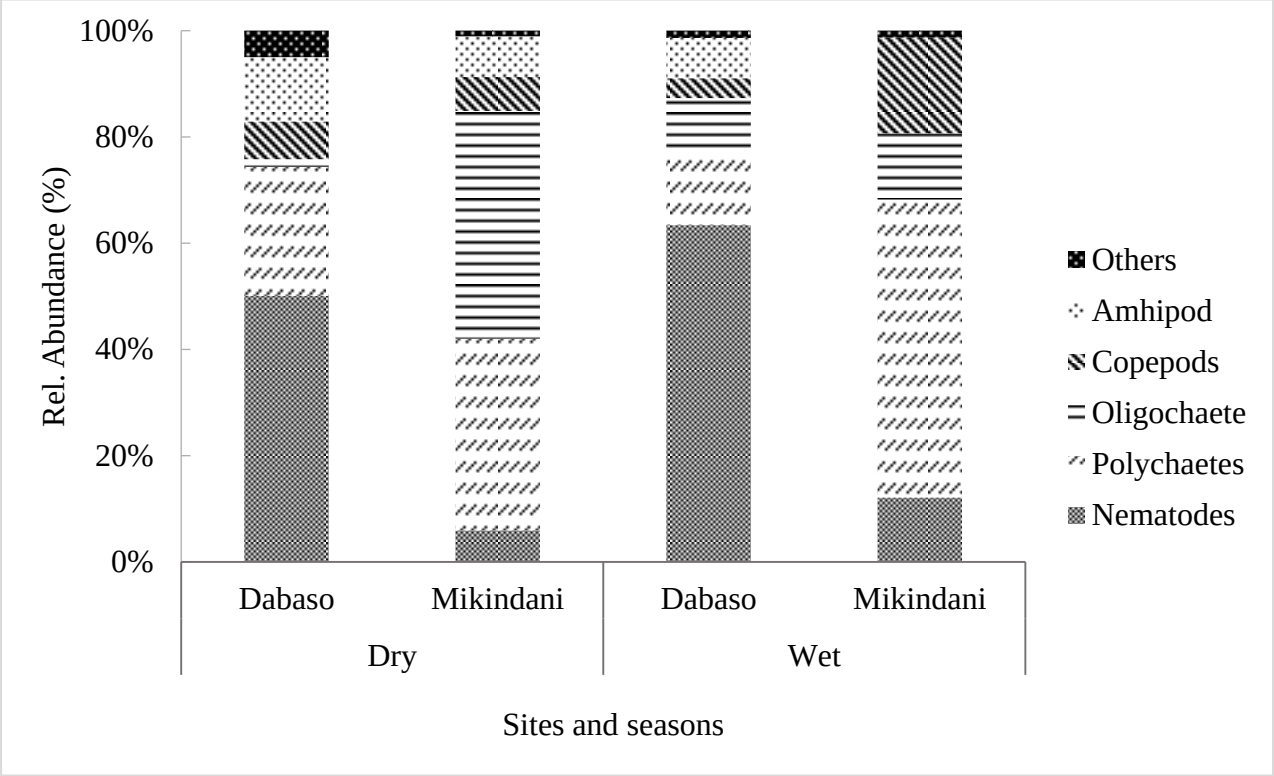


Figure 4.14: Relative abundance (%) of major macrobenthic groups at Dabaso and Mikindani during dry and wet seasons

#### 4.3.1.2. Seasonal Taxa Diversity

The macrofauna taxa richness S was equal (7) in the two sites during the dry season and higher in Mikindani (8) during the wet season compared to Dabaso (7). The dominance was higher in Mikindani (0.66) compared to Dabaso (0.44) in the dry season while during the wet season it was higher in Dabaso (0.53) compared to Mikindani (0.44) (Table 4.1). Nevertheless, no significant difference was found between the two sites in both dry and wet seasons (0.06, 0.2). Both Simpson and Shannon diversity indices showed higher macrofauna diversity in Mikindani (0.60, 1.10) compared to Dabaso (0.47, 0.94) during the wet season. Contrary, during the dry

season both indices indicated a higher diversity in Dabaso (0.56, 1.08) compared to Mikindani (0.34, 0.66). Species evenness was high in Mikindani (0.72, 0.72) compared to Dabaso (0.65, 0.54) in both the wet and dry seasons, although the difference between the sites in both dry ((p=0.49) and wet seasons (p=0.06) was not significant.

Table 4.1: Diversity indices of macrofauna at Dabaso and Mikindani during dry and wet seasons

| | Study sites | | | |
|---|---|---|---|---|
| | Season | Mikindani | Dabaso | P value |
| Dominance | Dry | 0.66 | 0.44 | 0.06 |
| Dominance | Wet | 0.4 | 0.53 | 0.2 |
| Simpson | Dry | 0.34 | 0.56 | 0.06 |
| Simpson | Wet | 0.6 | 0.47 | 0.2 |
| Shannon | Dry | 0.66 | 1.08 | 0.06 |
| Shannon | Wet | 1.09 | 0.94 | 0.39 |
| Evenness | Dry | 0.72 | 0.65 | 0.49 |
| Evenness | Wet | 0.72 | 0.54 | 0.06 |
| Taxa | Dry | 7 | 7 | 0.2 |
| Taxa | Wet | 8 | 7 | 0.32 |

#### 4.3.1.3. Macrofaunal Community assemblages

The Bray-Curtis cluster analysis of major macrofauna taxa based on standardized samples by total did not show any defined pattern during the dry season. Dabaso and Mikindani transect samples were close to each other irrespective of different pollution levels in the two sites. ANOSIM recorded a P Value of 31.7% indicating no significant difference between the two sites.

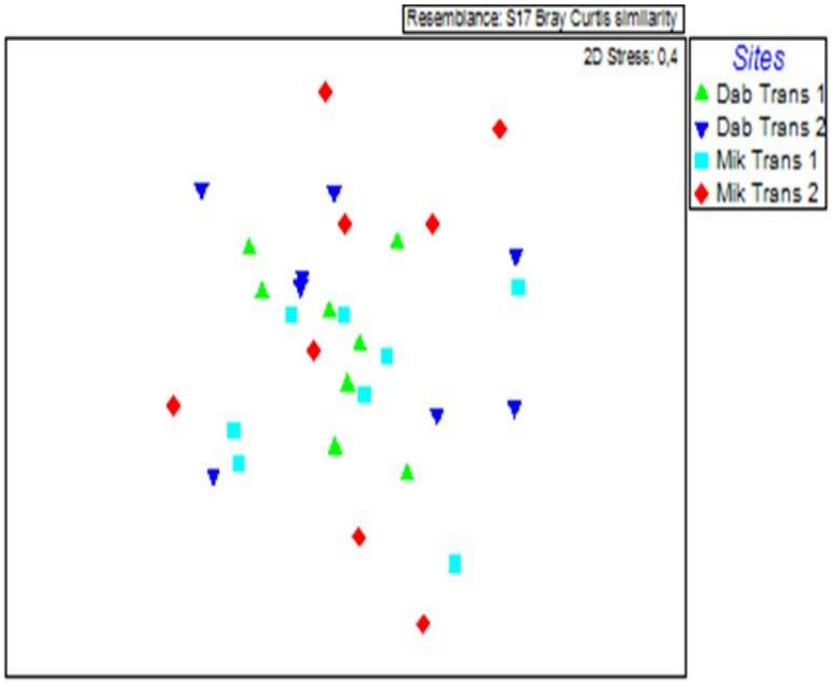


Figure 4.15: nMDS plot on macrofaunal community structure at Dabaso and Mikindani during dry season

During the wet season, however, the macrofaunal samples formed 2 major clusters; a cluster for stations from Dabaso that had all the replicate samples in both T1 and T2 clustered together and a cluster that included nearly all the replicate samples from Mikindani except 2 samples from transect T1 and T2. ANOSIM showed a significant difference between sites (r=0.509) (p=4.8%). SIMPER analysis showed a dissimilarity of 63% between the sites. This indicated that communities between the two sites were dissimilar. The replicate samples that were separate in Mikindani shows some dissimilarity (Fig 4.16).

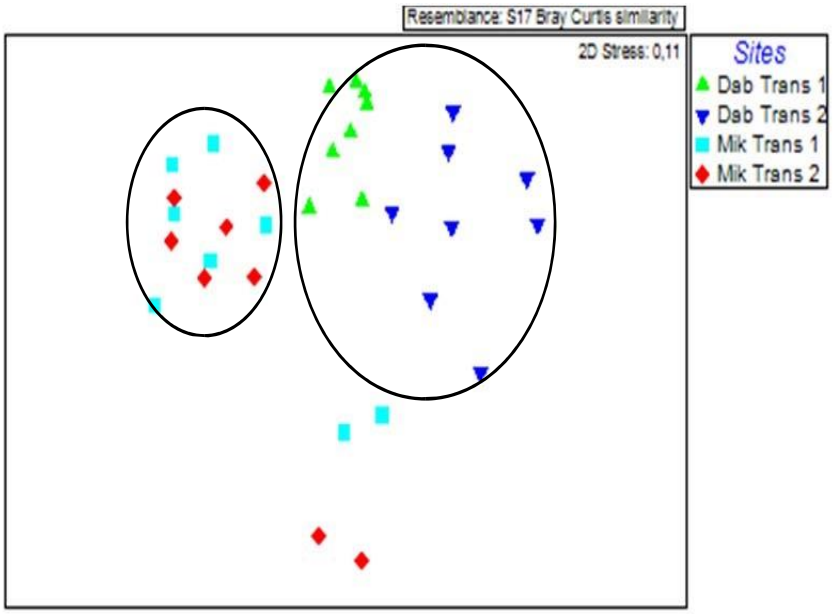


Figure 4.16: nMDS plot on macrofaunal community structure at Dabaso and Mikindani during wet season

### 4.3.2. Meiofauna

#### 4.3.2.1. Density and distribution

Overall meiofaunal densities were significantly (p=0.027) higher in both dry and wet seasons in Dabaso (2729±387ind.10cm$^{-2}$, 2804±11ind.10cm$^{-2}$) compared to Mikindani (604±114 ind.10cm$^{-2}$, 183±30ind.10cm$^{-2}$) (p=0.017) respectively (Fig 4.18). The densities in Dabaso were slightly higher during the wet season than the dry season with no significant difference (p= 0.171). Contrastingly, in Mikindani the densities were higher, but not significantly so (p>0.05) in the dry season compared to the wet season (Appendix 7.5).

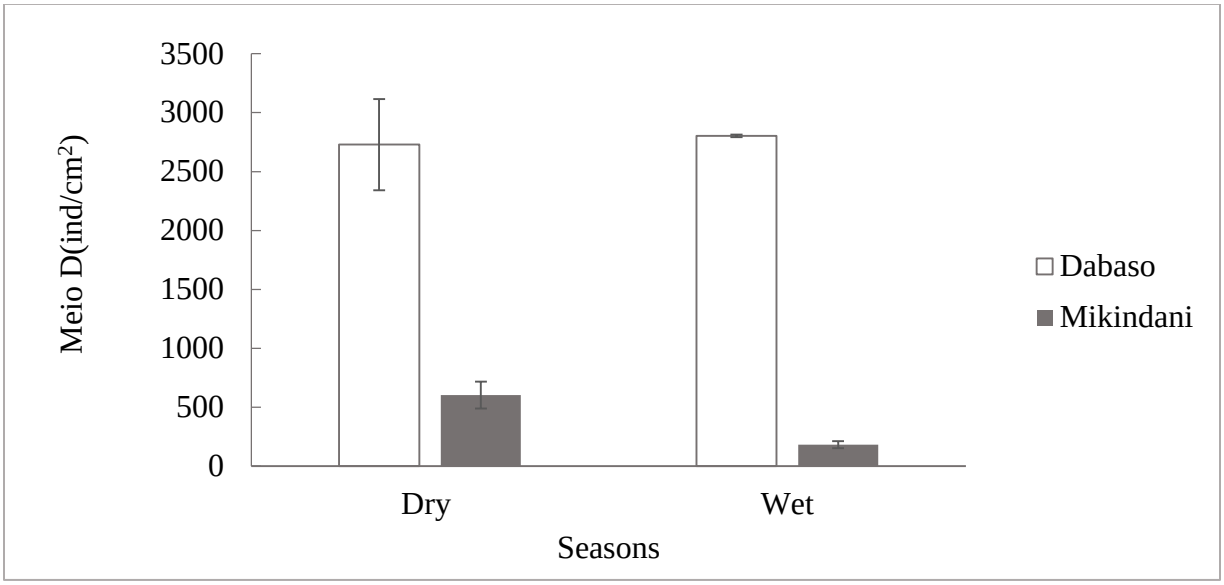


Figure 4.17: Mean meiofaunal densities (Ind.10cm-$^{2}$) at Dabaso and Mikindani during dry and wet season

The meiofauna community composed of 11 and 8 groups in Dabaso while in Mikindani the communities consisted of 9 and 8 groups in both dry and wet seasons respectively (Appendix 7.6).

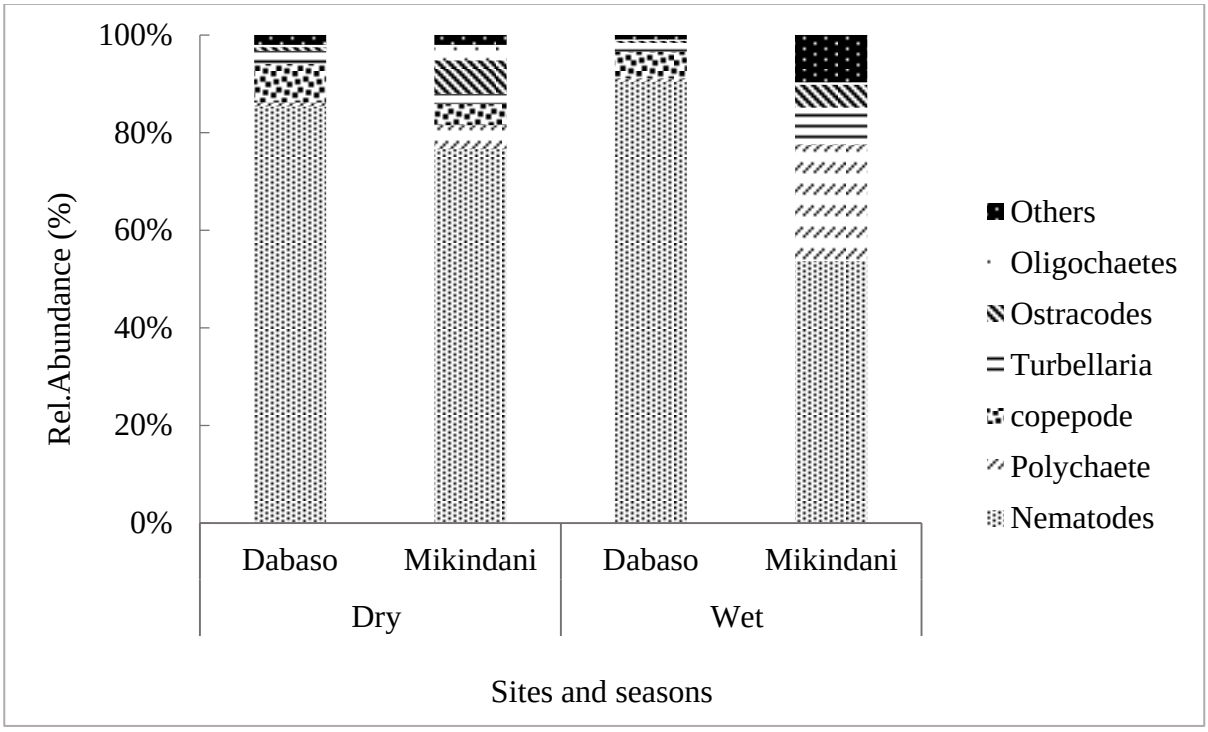


Figure 4.18: Relative abundance (%) of major meiofauna groups at Dabaso and Mikindani during dry and wet season

The meiofaunal community assemblage showed that nematodes dominated in both dry and wet seasons for Dabaso at 85.4% and 90.4% while in Mikindani they were 76.6% and 53.7% respectively. Polychaetes were also relatively abundant in Mikindani during the wet season at 23.8% but were much less abundant during the dry season at 4.9%. The rest of the taxa were less abundant having less than 10% representation in both sites during the two seasons (amphipods, isopods, kinorhynchs, sipunculids, halacaroids, gastrotrich and tunicates). Copepods occurred majorly in Dabaso during the dry and wet season at 7.9% and 5.4% respectively and in much less abundance in Mikindani during the dry season at 4.3% (Appendix 7.6). Ostracods were only present in Mikindani at 6.8% and 4.7% relative abundance during the dry and wet season respectively.

#### 4.3.2.2. Diversity

Taxa richness (S) was highest in Dabaso (10, 8) compared to Mikindani (7, 6), being higher during the wet compared to the dry season (Table 4.2).

Table 4.2: Diversity indices of meiofauna at Dabaso and Mikindani during wet and dry seasons

| | Season | Mikindani | Dabaso | P value |
|---|---|---|---|---|
| Dominance | Dry | 0.55 | 0.68 | 0.07 |
| Dominance | Wet | 0.4 | 0.81 | 0.16 |
| Simpson | Dry | 0.45 | 0.32 | 0.6 |
| Simpson | Wet | 0.6 | 0.19 | 0.7 |
| Shannon | Dry | 0.971 | 0.707 | 0.5 |
| Shannon | Wet | 1.157 | 0.445 | 0.02 |
| Evenness | Dry | 0.43 | 0.22 | 0.01 |
| Evenness | Wet | 0.56 | 0.21 | 0.02 |
| Taxa | Dry | 7 | 10 | 1.0 |
| Taxa | Wet | 6 | 8 | 0.9 |

Dominance was higher in Dabaso compared to Mikindani in both seasons and consequently evenness was higher in Mikindani compared to Dabaso.

According to both Simpson and Shannon Wiener diversity indices Mikindani (0.45, 0.97; 0.60, 1.12) had higher species diversity compared to Dabaso (0.32, 0.707; 0.2, 0.45) in both dry and wet seasons (Table 4.2). There was significant difference between sites according to Shannon Weiner diversity indices during the wet season. Similarly, evenness displayed significance differences between Dabaso and Mikindani in both seasons.

#### 4.3.2.3. Meiofaunal Community structure

During the dry season (Fig 4.19), the Bray-Curtis cluster analysis of the major meiofaunal taxa produced 3 major clusters; Dabaso, Mikindani T1 and a few from T2 and finally T2. T2 of Mikindani was distinctively apart from the rest stipulating dissimilarity from the other communities. On the other hand, T1 of Mikindani and a few from T2 were close to the Dabaso cluster showing some similarity of the communities. However, ANOSIM showed significant difference (P=16.7%) between Dabaso (T1 & T2) and Mikindani (T1).

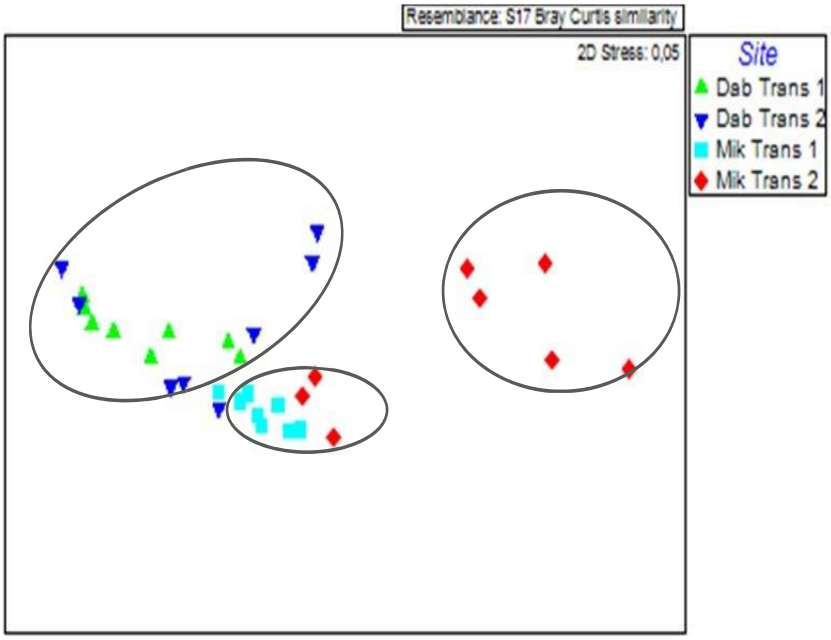


Figure 4.19: MDS plot for meiofauna community structure at Dabaso and Mikindani during Dry season

During the wet season (Fig 4.20), The Bray-Curtis cluster analysis of the major meiofaunal taxa produced 2 major clusters, cluster 1 that had communities in both transects (Dabaso) clustered together and cluster 2 that had both transects (Mikindani) clustering together although T2 communities were a bit distant but close to T1 within this site. This indicated that the meiofaunal composition in each site; Dabaso and Mikindani was highly similar. The clusters of each site were highly separated from each other showing very high dissimilarity. Analysis of Similarities (ANOSIM) indicated high similarity of samples within the groups (r=1, p=1.2%) while percentage of similarity (SIMPER) analysis indicated that dissimilarity between the two sites was very high (72%).

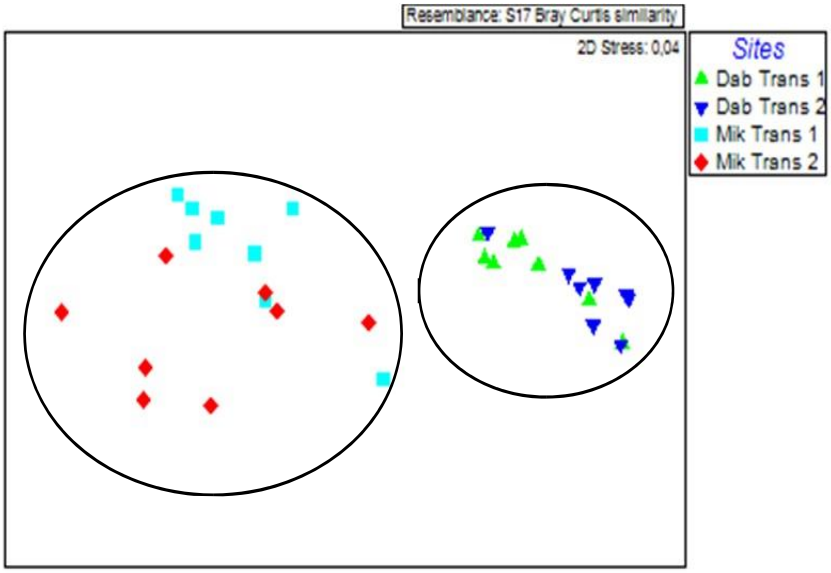


Figure 4.20: MDS plot for meiofauna community structure at Dabaso and Mikindani during wet season

### 4.4. Variability of abiotic and biotic factors

A principal component analysis was performed to identify which variable contributed the most to the description of pollution status of the two sites. Benthic community variability with HM was determined. In the dry season, the first two components accounted for the 80.9% of the total variability of the factors with 61.6% loaded on PC1 and 19.3% loaded on PC2. Ti, Zn, Rb nad Zr have a high positive loading on PC1 while Fe have a high negative Loading on the same axis. Pb have a high positive loading on PC2 while Mn and Zr had very high negative loadings on the same axis (Appendix 7.7). Mikindani samples were influenced by Mn, Zr, Zn, Ti and Rb (Fig 4.21).

PCA for benthos and abiotic factors (HM and Physiochemical parameters combined) recorded the first two components accounting for 74.3% of the total variability of the factors with 59.7% loaded on PC1 and 14.6% loaded on PC2 (Appendix 7.8). DO had a low negative loading on PC1 while TOM and Fe had a higher negative loading on the same axis. BOD, Ti, Mn, Zn, Rb, Pb and Zr had positive loading on the same axis. DO, BOD and Pb had a very high positive loading on PC2 while TOM, Ti, Mn, Zr and Fe had a negative loading on same axis (Appendix 6). There was a clear separation of samples between the two sites. The samples for Dabaso were majorly influenced by TOM and DO while those in Mikindani were influenced by BOD, Mn, Zr, Ti, Rb, Pb and Zn (Fig 4.22).

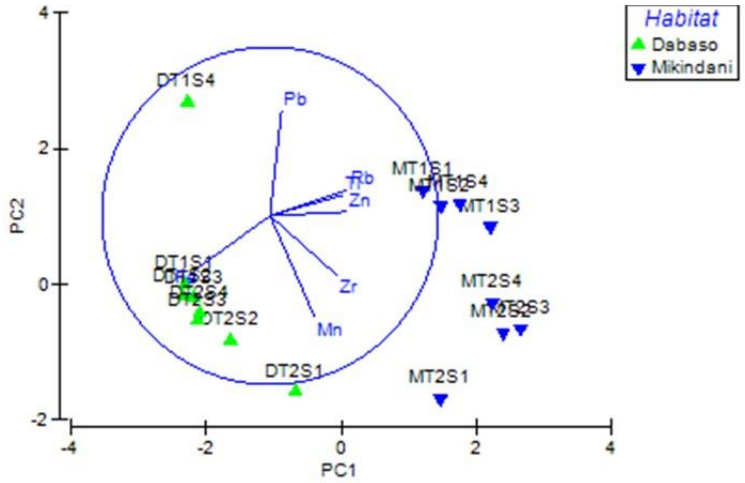


Figure 4.21: PCA loading plots for Heavy metals and benthos during the dry season

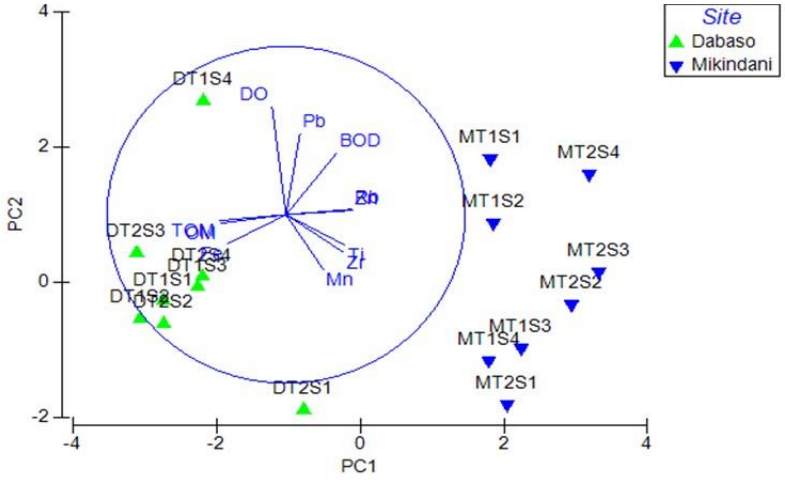


Figure 4.22: PCA loading plots for biotic factors (Heavy metals and Physiochemical parameters combined) and benthos during dry season

During the wet season (Fig 4.23), PCA for benthos and HM had the first two components accounting for 94.3% of the total variability of the factors with 89.8% loaded on PC1 and 4.5% on PC2. Fe positively loaded on PC1 while Ti, Mn, Zn, Pb, Zr and Rb negatively loaded the same axis. Ti and Zr positively loaded on PC2 while Mn and Rb negatively loaded on the same axis (Appendix 7.9).

PCA for benthos and abiotic factors (HM and physiochemical parameters) recorded the first two components accounting for 92.4% of the total variability of the factors with 86.6% loaded on PC1 and 5.8% loaded on PC2. Ti, Mn, Zr, Zn and Rb had a low positive loading on PC1 while DO, BOD and TOM had a low negative loading on this component. Therefore, this component primarily measures heavy metal positively influencing benthic communities' densities. Ti, Fe, Zr

and TOM had positive loading on PC2 while Mn, Zn, Rb, Pb, BOD and DO had a negative loading on this component although for BOD it was high (Appendix 7.10). The samples in each site were distinctively separated where the samples for Dabaso were majorly influenced by BOD, DO and TOM while those in Mikindani were influenced by Mn, Ti, Zn, Zr and Rb (Fig 4.24).

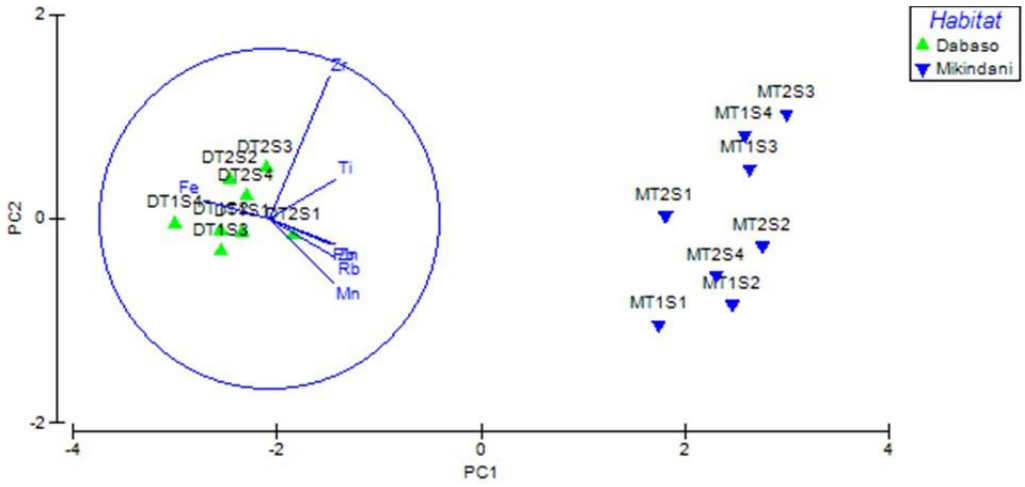


Figure 4.23: PCA loading plots for Heavy metals and benthos during the wet season

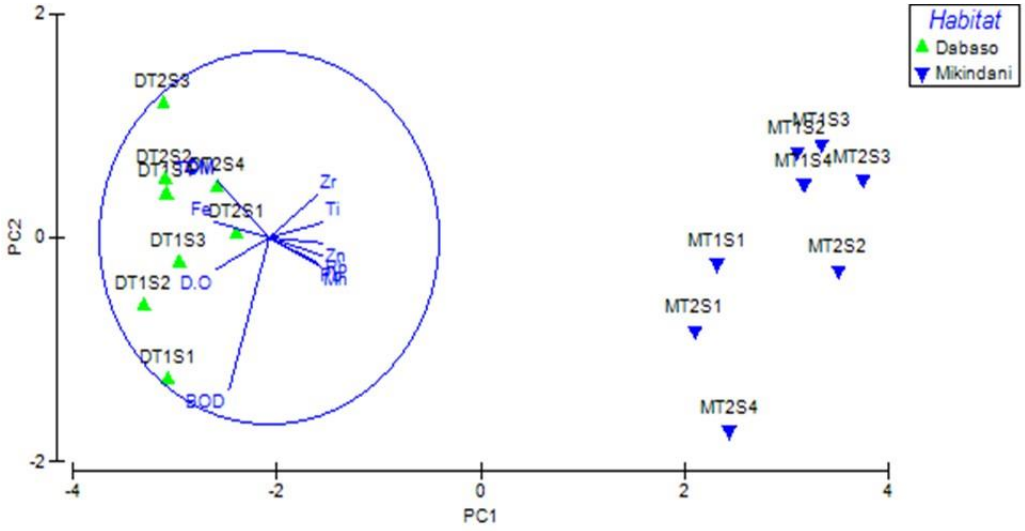


Figure 4.24: PCA loading plots for biotic (Heavy metals and Physiochemical parameters) and benthos during the wet season

### 4.5. Correlations between abiotic and biotic factors

In Dabaso (Appendix 7.11), DO had significant positive correlations with Fe (r = 0.674**) and Rb (r = 0.803**). Similarly, macrofaunal densities had significant positive correlations with DO

(0.438**) and Rb (0.463**). However, no correlation was found between Meiofaunal densities and any abiotic parameter in Debaso.

In Mikindani (Appendix 7.11), TOM had a significant negative correlation with Zr (r=-0.455**). DO recorded a significant positive correlation with Mn (r=0.702**) but had negative significant correlations with Ti (r=-0.451**), Rb (r=-0.527**), Zr (-0.402*) and Pb (r=-0.666**). On the other hand, BOD recorded a significant positive correlation with Pb (r=0.619**) but had significant negative correlations with Ti (r=-0.538**), Mn (r=-0.621**), Pb (-0.619**) and Rb (r=-0.514**). Meiofaunal densities had significant positive correlation with TOM (r=-0.497**) and DO (r= 0.404**) but had significant negative correlation with Mn (r=-0657**), Rb (r=-0.440*), Zr (r=0.476**) and Pb (r=-0.416*). The densities had a positive correlation with BOD although it was not significant. However, macrofaunal densities had no significant correlation with any abiotic parameter. Different metals also showed positive correlations with each other; Ti with Zr (r= 0.353), Ti with Rb (r= 0.392), Mn with Zr (r=0.496), Mn with Rb (r=0.417) and Zr with Pb (r=0.314).

# 5. DISCUSSION, CONCLUSION AND RECOMMENDATION

## 5.1. Discussion

Previous research in the study have shown Mikindani to be a polluted site (Kamau *et al.,* 2015) while Dabaso remained semi-pristine in relation to variation in mangrove forest distribution and meiobenthic & macrobenthic communities. The present study was more detailed, highlighting benthic communities' densities, distribution, composition and assemblages over gradient in a polluted and non-polluted site while incorporating physiochemical parameters and heavy metals. The findings illustrated high level of inorganic pollution in Mikindani (located in densely populated industrial area) compared to Dabaso.

Physiochemical parameters showed significant differences between Mikindani and Dabaso site. Higher TOM in Dabaso was attributed mainly to autochthonous and allochthonous processes mainly during rainy season (Boyd & Osburn, 2004). Dense mangrove forest in Dabaso contributed heavily to leaf litter, which was the main source of TOM while at Mikindani, mangrove forests were scattered and smaller in size reducing autochthonous processes while

allochthonous processes were limited to the sewage from land. Fine sediments in Dabaso supported dense mangrove trees serving as sieves to trap sediments. Similarly, in Mikindani very fine, fine sand, sand and silt/clay were in higher proportions which could be attributed to over a decade of deposition because of runoff from large residential estate with more than 20,000 people (Kamau *et al.,* 2015).

Dissolved oxygen (DO) was generally higher in Dabaso compared to Mikindani in both seasons. This could be attributed to the fact that no inflow of pollution from land at Dabaso. In Mikindani, the low concentration levels could be due to high input of oxygen-demanding wastes from the sewage discharge. Phytoplankton and heavy metals consume a lot of DO during decomposition and oxidation in the process known as Carbonaceous Biochemical Oxygen Demand (CBOD) resulting to reduction of DO concentrations (Leeson *et al.,* 2002). CBOD is the biochemical oxygen demand from carbonaceous and nitrogenous compounds in wastewater as well as oxidation of inorganic compounds such as ferrous iron and sulfide.

BOD readings were generally high in Mikindani during the dry season, which was caused by increased inflow of high oxygen demanding wastes from the sewage effluents as well as algal decomposition process that requires a lot of oxygen hence elevating the oxygen demand (Okuku *et al.,* 2011). In addition, Vaquer-Sunyer & Duarte (2008) illustrated that abundant production of OM (from organic waste) increased oxygen demand in coastal ecosystems hence high BOD levels. Low values of BOD in Mikindani during the wet season resulted from dilution effect from rainwater. Higher BOD in Dabaso, mostly in the wet season, could be credited to higher accumulation of OM from mangroves leaf fall.

Heavy metals are usually immobilized in the aquatic sediments (Kamau, 2002). This study showed that different heavy metals (Zr, Zn, Ti, Rb, Pb, Mn and Fe) were higher in Mikindani than in Dabaso. This can be attributed to the high inflow of anthropogenic pollutants in Mikindani Creek from the neighboring households as well as industries in Mikindani village. Additionally, fine sediments found in this site harbors elevated levels of these metals (Pająk *et al.,* 2017). This confirms (Okuku *et al.,* 2019b) research that showed high levels of heavy metals in Tudor creek. Zinc and lead are heavily used in leisure boats and ship due to their high density and resistance to corrosion. High Zn levels in our results could be associated with dissolution of zinc anodes along the creek as well as use of galvanized metals and automobile tyres within the

urban area. The deposited metals accumulate in the street dust and later finds their way into the creek through storm water run-off (Muohi *et al.*, 2003). High Mn levels can be accredited to discharge from the adjacent cement factory while high lead levels can be associated with remnants of lead in the soil from boats and vehicles used along the creek in the past. High Pb could be attributed to use of leaded gasoline in boats and ships as well as spillage during shipment. Some heavy metals displayed a positive correlation with each other while others showed a negative correlation. This can be allotted to reduction and oxidation reactions of the metals as well as the chemical properties of the existing sinks of metal.

Independent correlations revealed that all the metals except Pb had notable correlations with Mn and, Fe. These results illustrated possible metals adsorption to oxides–hydroxides of Mn and Fe. No correlations of Pb with most metals could be attributed to various biological processes and external inputs taking place in the mangrove and estuarine sediments (Kossoff *et al.*, 2012).

Different correlations were also observed between the metals and other physico-chemical parameters. Positive significant correlation between OM and Zr illustrated possibility of sediments organic matter acting as metal carrier while also playing a vital role in zirconium distribution patterns (Balkıs & Çağatay, 2001). Heavy metals in sediments relate to organic matter which provides binding elements and transported through biological uptake and adsorption like in humic substances (Dhanakumar *et al.*, 2013).

The macrofaunal densities were higher in Dabaso compared to Mikindani. This can be attributed to differences in heavy metal concentration levels, TOM, DO, BOD and grain size between the two sites. Dabaso was characterized by food availability in form of high TOM as well as DO which are critical for the survival of the organisms. The densities positively correlated with DO matching with the study in Gooday *et al.*, (2009) on oxygen gradient along Pakistan margin. Additionally, granulometric composition played a key role in Dabaso where coarse and medium sand had the highest proportions. Dabaso did not receive pollutants because of its geographical location and the less development as well as settlements adjacent to the site. Therefore, the organisms had favorable conditions hence high densities. Contrary, Mikindani which received elevated levels of pollutants recorded very low DO and TOM hence low densities. Temporal variability was observed in both sites being associated with increased sedimentation rates and organic matter (Danovaro & Fraschetti, 2002). Adverse biological effects on benthic

communities in Mikindani were mostly due to decrease in oxygen content in the water (Fiege *et al.,* 2010). The low densities could also be attributed to the high heavy metal concentration levels recorded in Mikindani which affects the growth and even cause high mortality rates to some sensitive macrofaunas.

Macrofauna distribution also displayed a spatial variation in that nematodes highly dominated in Dabaso. This is because large-bodied nematodes could be more sensitive to harsh environmental conditions hence easily eliminated in Mikindani. Dabaso with limited pollution provided favorable conditions for nematode to survive and regenerate. Polychaetes were also notably numerous in Dabaso. This can be linked to some species in the taxa like members of Lumbrineridae, Maldanidae (Belan, 2004) and Terabellidae (Olsgard *et al.,* 2003) being very sensitive to poor environmental conditions.

On the other hand, oligochaetes, copepods and Polychaetes were predominant in Mikindani in both wet and dry season. Polychaetes present in Mikindani could be the more tolerant taxa since they were also present in Dabaso. These findings were aligned with results of the previous study (Labrune *et al.,* 2012) where polychaetes abundance positively correlated with mean annual inflow. Additionally, the high relative abundance in Mikindani could also be linked to high organic matter and loose textured sediments (silt and high sand) as described by (Musale & Desai, 2011). In Dabaso, high polychaetes during the dry season could be because of higher proportions of coarse sand in the area. This environment favored different groups of filter feeders like polychaetes (Mohamed et al., 2018). Bivalves were only found in Dabaso, species indicators of low pollution, high DO and low concentration of heavy metals (Lima *et al.,* 2012) which are conducive factors to boost their abundance.

Oligochaetes were very numerous in Mikindani which could be attributed to some opportunistic species, such as (*Tubifex tubifex* and *Limnodrilus hoffmesteri*, which are very tolerant to high pollution and low dissolved oxygen levels. Additionally, the respiratory physiology of some species in the taxa are well adapted to anaerobic conditions linked to high inflow of pollutants hence they have high survival rates. These results aligned with the previous study by Ragi & Jaya, (2014). Oligochaete's abundance however increased with heavy input of sewage effluent during the wet season as compared to the dry season explaining that oligochaetes could be bio indicators of pollution. (Lin & Yo, 2008). Copepods increased their abundance in Mikindani in

the wet season compared to dry season. This could relate to their tolerance to low pollution levels in wet season resulted by dilution effect from rainwater and sedimentation of suspended solids from storm water. However, some species of copepods like *Acanthocyclops robustus* can be used as inorganic pollution indicators while *Thermocyclops minutus* are more sensitive to polluted sites (Perbiche-Neves *et al.*, 2016).

Macrofauna diversity was highest in Dabaso compared to Mikindani which was limited by low DO, high heavy metals and low TOM. Therefore, it was realized that macrobenthic biodiversity was associated with dissolved oxygen and organic matter quantity in the sediments which aligned to Tabatabaie & Amiri (2011) research. El-Sammak (2001) found that extreme levels of pollution in Dubai Creek caused decrease in macrobenthic diversity which aligned with Mikindani diversity. Long *et al.,* (2008) additionally expounded that reduced DO caused species' richness and diversity decrease and macrofauna composition is largely influenced by oxygen tolerance. Reiss *et al.,* (2011) recorded higher species diversity, abundance and richness in fine and medium sediments which aligns with the results for Dabaso in this present study.

The community assemblage of macrofauna did not show any defined pattern in the dry season in the MDS (refer to the figure) graph, which was supported by ANOSIM analysis, which showed no significant difference between the sites (what this quantity refers to % similarity? p=31.7%). Nevertheless, there was a distinction of the communities between the two sites in the wet season as displayed by bray Curtis analysis and dissimilarities in the SIMPER analysis (63%). This according to (Tarhan *et al.,* 2013) can be linked to the abundance of taxa specific to a particular site. Mikindani cluster was attributed to polychaetes and oligochaetes that were the dominant taxa while for Dabaso, nematodes were the most dominant. This study highlighted that Mikindani was highly affected by pollution.

Meiofaunal densities also displayed a spatial and seasonal variability. Dabaso had higher abundance than Mikindani which can be attributed to different sediments characteristics (Levin *et al.,* 2010), pollution levels, TOM and DO which influence the composition of communities in a site (Schmid-Araya & Schmid, 1995). According to Ingels *et al.,* (2014) and Carvalho *et al.,* (2017), food proximity in form of organic matter plays a vital role in regulating the abundance of meiofaunal densities as exhibited by the results of this study where Dabaso with high OM had higher abundance than Mikindani. Additionally, the densities decreased in Mikindani during the

wet season because of extreme reduction in oxygen levels (hypoxic conditions) which was caused by increased sewage effluent discharge hence disappearance of many sensitive groups (Rabalais *et al.,* 2002). Nonetheless, this is not always the case as the densities may not change in a short period of time due to influence of highly dominant and tolerant nematodes as described by (De Troch *et al.,* 2013). The densities decreased with increased input of sewage with high Mn, Rb, Zr and Pb as displayed in Mikindani.

Meiofaunal distribution varied between the sites and seasons. Dabaso recorded nematodes and copepods as the most abundant meiofauna which confirms the study by Thiel & Higgins, (1988). Mikindani recorded nematodes and polychaetes as the most dominant group. Nematodes being the most abundant taxa in both sites can be attributed to being able to adapt to both polluted and non-polluted ecosystems. Our results are similar to Hourston *et al.,* (2009) research that recorded 70% to 90% nematode density of all meiofauna groups in both sites. Nevertheless, their dominance was more in Dabaso (unpolluted site) compared to Mikindani (polluted site). In Mikindani, nematodes abundance decreased with increased inflow of sewage effluents in the wet season. This is however contrasting with the previous study by Vanreusel *et al.,* (2010) which indicated that nematode thrive in extreme pollution levels. Polychaetes were seen to be tolerant to high pollution in Mikindani. Their abundance increased in the wet season compared to dry season. This could be associated to lack of competition for food because of disappearance of other taxa that could not withstand increased inflow of heavy contaminants through sewage effluents. Previous studies have shown that polychaetes, being most abundant in Mikindani, are indicators of polluted site (Lima *et al.,* 2012).

Copepods found in coarse sand sediments were abundant in Dabaso and are comparatively sensitive (Moore & Bett, 2008) to poor oxygen supply. They are the most susceptible meiofauna group to limited oxygen concentration levels (De Troch *et al.,* 2013) hence they disappeared in Mikindani during the wet season due to increased release of industrial and domestic effluents. Turbellaria, ostracods and Oligochaetes were numerous in Mikindani compared to Dabaso because they are resilient to high pollution. Halacaroids were only found in Mikindani showing they are excellent positive indicators of pollution. Other groups of meiobenthos were less abundant in both sites which aligns with the study by (Hoste et al., 2007). Amphipods, isopods,

tunicates (few) and sipunculids were only able to thrive in a pristine site (Dabaso) because they are intolerant to pollution.

Meiofaunal diversity was low in Dabaso as compared to Mikindani in both seasons which can be attributed to high dominance of few opportunistic species in Dabaso contributing to the high densities yet low diversity (Somerfield & Warwick, 1996). This study confirms (Schratzberger *et al.,* 2010); (Pusceddu *et al.,* 2013) results which links decreased diversity to high dominance of opportunistic taxa. According to a study by Mohamed *et al.,* (2018) meiofaunal diversity were higher in coarse and medium sized sediments which is not the case for Dabaso with similar granulometric composition. High dominance in Dabaso during both seasons can be linked to very high abundance of nematodes (Mohamed *et al.,* 2018).

Meiofaunal community assemblage displayed two major clusters in the dry season which was greatly influenced by the sediment's characteristics, TOM, DO, taxa distribution, and the pollution levels in each site. The clusters were distant from each other indicating dissimilarity of the communities. However, T1 of Mikindani was close to Dabaso cluster. This pattern can be attributed to the fact that the samples in T1 in Mikindani were collected away from the sewage channels unlike T2 which were collected direct at the channels. In the wet season, the 2 clusters were distinctively away from each other. T1 and T2 of Mikindani were close to each unlike in the dry season which can be attributed to pollution dilution during the wet season making the site homogenous. This pattern can also be attributed to nematodes that greatly dominated the meiofaunal communities hence aligning with the results of (Flach *et al.,* 2002). The community structure is indeed a good indication of difference in the sites therefore would be used as a bio indicator of heterogeneity of ecosystems.

### 5.2. Conclusions

In conclusion, the study revealed that excessive pollution of marine ecosystems is very detrimental to meiofaunal and macrofaunal densities, diversity, composition and community assemblages. It was evident that the differences observed in the biotic factors were majorly influenced by the abiotic parameters (DO, TOM, BOD, sediments size, heavy metals) which were because of heavy inflow of pollutants in Tudor creek (Mikindani). According to the results of this study, Mikindani had very high levels of heavy metal concentrations which greatly affected vulnerable benthic communities. The assemblages of benthic communities were majorly

attributed to sediments characteristics and food availability. Some taxonomic groups in both meiofaunal and macrofauna showed sensitivity to contamination by either being absent from the contaminated site or in low abundance. It is clear that both abiotic factors and benthic communities (meiofauna and macrofauna) can be used as metrics to regularly monitor the environmental quality of marine ecosystems.

However, macrofauna organisms are relatively slow in responding to change in water and sediments conditions compared to meiofauna. This character makes their densities, diversities and distribution be studied to show the impacts of inorganic pollution over a long period of time. Additionally, this study has shown that oxygen significance in the water matrix and OM quantity in sediments are crucial factors in the distribution of benthic communities.

The study has also shown that a dynamic relationship exists between abiotic and biotic factors. Good understanding of that relationship is fundamental for effective monitoring and management of inshore marine ecosystems that experience increased anthropogenic pollution. This knowledge will help the relevant authorities to better manage these important ecosystems and provide alternative ways of managing both small scale (households) and large scale (municipal and industrial) discharge of sewage and other types of pollutants from the terrestrial environment to the oceans.

### 5.3. Recommendation

#### 5.3.1. Recommendations for further study

There is need to conduct further research to identify the exact source of sediments drained in Mikindani creek. This will explain whether heavy metals origin is from sediments in neighboring community or sewage. Additionally, the sediments should be tested to determine whether they are loaded with heavy metals or are persistent in the marine sediments and possible ways to reduce the concentrations.

There also need to further analyze macrofaunal and meiofaunal samples to species level to identify the specific species that are tolerant to high heavy metal pollution levels and those that very sensitive. Previous studies have shown some species of the same group as oligochaetes can be bio indicators of pollution because they are more sensitive to pollution. This will bring out more knowledge on those species that can be used in biomonitoring of inorganic pollution and can be targeted for bioremediation of the same in marine ecosystems.

There is need to identify other indices that can be used to better determine those that are indicator species such as family biotic index (FBI).

### 5.3.2. Recommendations for conservation and management actions

There should be application of precautionary principle in management of marine environments. Respective governing bodies in marine ecosystems should pay more attention to disposal of untreated waste in the ocean both from commercial companies and residential areas. This will assist in reduction of heavy metals concentration in marine sediments gradually thus beneficial in the long run to stabilize benthic communities which plays a critical role in the food chain. The overall output of well-organized management will be to increase marine goods and services.

### 5.3.3. Recommendations for policy intervention

The laws that protect the marine ecosystems should be enhanced and applied to ensure optimum conservation measures. Prevent pollution from ships Act should be optimized to ensure heavy metals are not dumped from shipwreck and ship fuel bare reduced to minimal or no release. This will ensure controlled measures of containing harmful heavy metals and bio accumulation which eventually will reverse detrimental effects to marine organisms.

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## 7. APPENDICES

Appendix 7.1: Mean DO, BOD and TOM concentrations Dabaso and Mikindani during dry and wet season

| Parameter | Sites | Seasons | | |
|---|---|---|---|---|
| | | Dry | Wet | P-values |
| DO (mg/L) | Dabaso | 4.0 ± 0.1 | 5.3± 0.03 | 0.02 |
| | Mikindani | 3.8 ± 0.02 | 2.1 ± 0.04 | 0.02 |
| | P-value | 0.048 | 0.013 | - |
| BOD (mg/L) | Dabaso | 3.4 ±0.10 | 3.5 ± 0.03 | 0.5 |
| | Mikindani | 4.8 ± 0.23 | 2.8± 0.03 | 0.03 |
| | P-value | 0.039 | 0.041 | |
| TOM | Dabaso | 23.7±0.7 | 23.9± 0.03 | 0.827* |
| | Mikindani | 6.6 ± 0.2 | 5.9 ± 0.1 | 0.293* |
| | P-Value | 0.019 | 0.03 | - |

Appendix 7.2: Mean concentrations (mg/kg) of heavy metals in Dabaso and Mikindani during dry and wet season

| Heavy metal | Sites | Seasons | | |
|---|---|---|---|---|
| | | Dry | Wet | P-values |
| Ti | Dabaso | 897±10.35 | 807±65 | 0.342 |
| | Mikindani | 2677±122 | 3133±86.28 | 0.05 |
| | P-Values | 0.04 | 0.006 | |
| Mn | Dabaso | 127.5±0.38 | 153.6±12.3 | 0.032 |
| | Mikindani | 164.1±8.9 | 235.8± 17.2 | 0.012 |
| | P-Values | 0.034 | 0.018 | |
| Fe | Dabaso | 4146±183.1 | 5240±257.2 | 0.043 |
| | Mikindani | 17147±585 | 21633±886.23 | 0.024 |
| | P-Values | 0.139 | 0.175 | |
| Zn | Dabaso | 16.39±2.34 | 12.5±0.72 | 0.262 |
| | Mikindani | 70.52±3.7 | 70.01±7.64 | 0.920 |
| | P-Values | 0.016 | 0.076 | |
| Rb | Dabaso | 15.32±0.21 | 32.2±1.3 | 0.295 |
| | Mikindani | 85.64±3.01 | 103.3±0.77 | 0.018 |
| | P-Values | 0.103 | 0.018 | |
| Zr | Dabaso | 309± 5.22 | 350±29.1 | 0.132 |
| | Mikindani | 870±36.3 | 1294±96.72 | 0.04 |
| | P-Values | 0.027 | 0.016 | |
| Pb | Dabaso | 15.2±3.82 | 22.7±1.5 | 0.402 |
| | Mikindani | 25.1± 3.3 | 36.6±4.8 | 0.045 |
| | P-Values | 0.039 | 0.024 | |

Appendix 7.3: Mean macrofaunal densities (ind/$m^2$) in Dabaso and Mikindani during dry and wet season

| | | Seasons | | |
|---|---|---|---|---|
| Organisms | Sites | Dry | Wet | P-values |
| Nematodes | Dabaso | 7247±236 | 26927±606 | 0.021 |
| | Mikindani | 525±34 | 2603±67 | 0.018 |
| | P-Values | 0.033 | 0.024 | |
| Polychaetes | Dabaso | 3516±137 | 5712±785 | 0.349 |
| | Mikindani | 3206±684 | 12065±1716 | 0.127 |
| | P-Values | 0.839 | 0.381 | |
| Oligochaetes | Dabaso | 214±12 | 4468±449 | 0.112 |
| | Mikindani | 3808±471 | 2681±157 | 0.286 |
| | P-Values | 0.139 | 0.175 | |
| Copepods | Dabaso | 1030±168 | 1574±213 | 0.09 |
| | Mikindani | 563±56 | 3886±1099 | 0.317 |
| | P-Values | 0.251 | 0.373 | |
| Amphipods | Dabaso | 1749±112 | 3225±314 | 0.295 |
| | Mikindani | 680±11 | 0 | 0.018 |
| | P-Values | 0.103 | 0.106 | |
| Bivalves | Dabaso | 233±67 | 175±56 | 0.205 |
| | Mikindani | 0 | 0 | 0 |
| | P-Values | 0.295 | 0.323 | |
| Ostracods | Dabaso | 486±11 | 408±56 | 0.626 |
| | Mikindani | 97±34 | 97±11 | 1 |
| | P-Values | 0.063 | 0.356 | |
| Gastrotrichs | Dabaso | 0 | 0 | 0 |
| | Mikindani | 0 | 175±11 | 0.07 |
| | P-Values | 0 | 0.07 | |
| Overall densities | Dabaso | 14470±2049 | 42489±2896 | 0.036 |
| | Mikindani | 8879±376 | 21507±1841 | 0.02 |
| | P-Values | 0.024 | 0.013 | |

Appendix 7.4: Rel. Abundance (%) of macrobenthic communities in Dabaso and Mikindani during dry and wet season

| | Dry | | Wet | |
|---|---|---|---|---|
| | Dabaso | Mikindani | Dabaso | Mikindani |
| Nematodes | 50.1 | 5.9 | 63.4 | 12.1 |
| Polychaetes | 24.3 | 36.1 | 13.4 | 56.1 |
| Oligochaete | 1.5 | 42.9 | 10.5 | 12.5 |
| Copepods | 7.1 | 7.7 | 3.7 | 18.1 |
| Amhipod | 12.1 | 6.3 | 7.6 | 0.0 |
| Bilvalve | 1.6 | 0.0 | 0.4 | 0.0 |
| Ostracode | 3.4 | 1.1 | 1.0 | 0.5 |
| Gastrotricha | 0.0 | 0.0 | 0.0 | 0.8 |

Appendix 7.5: Mean meiofaunal densities (ind.10cm$^{-2}$) in Dabaso and Mikindani during dry and wet season

| Organisms | Sites | Seasons | | P-values |
|---|---|---|---|---|
| | | Dry | Wet | |
| Nematodes | Dabaso | 2331±124 | 2536±111 | 0.037 |
| | Mikindani | 469±15 | 98±19 | 0.023 |
| | P-Values | 0.02 | 0.041 | |
| Polychaetes | Dabaso | 22±6 | 21±2 | 0.931 |
| | Mikindani | 30±8 | 44±12 | 0.768 |
| | P-Values | 0.796 | 0.435 | |
| Copepods | Dabaso | 215±18 | 153±4 | 0.243 |
| | Mikindani | 26±4 | 0 | 0.185 |
| | P-Values | 0.08 | 0.021 | |
| Ostracods | Dabaso | 21±1 | 13±1 | 0.174 |
| | Mikindani | 42±8 | 9±1 | 0.28 |
| | P-Values | 0.402 | 0.373 | |
| Amphipods | Dabaso | 22±4 | 0 | 0.164 |
| | Mikindani | 0 | 0 | 0 |
| | P-Values | 0.105 | 0 | |
| Isopods | Dabaso | 2 | 0 | 0.07 |
| | Mikindani | 0 | 0 | 0 |
| | P-Values | 0.07 | 0 | |
| Oligochaetes | Dabaso | 12±1 | 8±1 | 0.524 |
| | Mikindani | 13±0 | 1±0 | 0.004 |
| | P-Values | 0.632 | 0.213 | |
| Turbellarians | Dabaso | 73±16 | 49±12 | 0.16 |
| | Mikindani | 13±0 | 14±6 | 0.874 |
| | P-Values | 0.279 | 0.307 | |
| Kinorhynchs | Dabaso | 4±1 | 9±1 | 0.042 |
| | Mikindani | 0 | 0 | 0.344 |
| | p-Values | 0.227 | 0.109 | |
| Sipunculids | Dabaso | 23±8 | 16±1 | 0.757 |
| | Mikindani | 0 | 0 | 0.344 |
| | p-Values | 0.372 | 0.067 | |
| Halacaroids | Dabaso | 0 | 0 | 0 |
| | Mikindani | 11±2 | 17±4 | 0.674 |
| | p-Values | 0.154 | 0.254 | |
| Gastrotrichs | Dabaso | 0 | 0 | 0 |
| | Mikindani | 0 | 1 | 0.126 |
| | P-Values | 0 | 0.126 | |
| Overall densities | Dabaso | 2729±387 | 2805±11 | 0.077 |
| | Mikindani | 604±114 | 183±30 | 0.02 |
| | P-Values | 0.027 | 0.017 | |

Appendix 7.6: Relative abundance (%) of meiofaunal communities in Dabaso and Mikindani during dry and wet season

| | Dry | | Wet | |
|---|---|---|---|---|
| | Dabaso | Mikindani | Dabaso | Mikindani |
| Nematodes | 85.4 | 76.6 | 90.4 | 53.7 |
| Polychaete | 0.8 | 4.9 | 0.7 | 23.8 |
| copepode | 7.9 | 4.3 | 5.4 | 0.1 |
| Ostracodes | 0.8 | 6.8 | 0.5 | 4.7 |
| Oligochaetes | 0.4 | 3.2 | 0.3 | 0.5 |
| Turbellaria | 2.7 | 2.1 | 1.7 | 7.5 |
| Amphipods | 0.8 | 0.0 | 0.0 | 0.0 |
| Isopods | 0.1 | 0.0 | 0.0 | 0.0 |
| Kinorhyncha | 0.2 | 0.2 | 0.3 | 0.0 |
| sipunculid | 0.8 | 0.0 | 0.6 | 0.0 |
| Halacaroidea | 0.0 | 1.9 | 0.0 | 9.2 |
| Gastrotricha | 0.0 | 0.0 | 0.0 | 0.4 |
| Tunicates | 0.1 | 0.0 | 0.0 | 0.0 |

Appendix 7.7: PCA for HM and benthos during the dry season

*Eigenvalues*

| PC | Eigenvalues | %Variation | Cumulative .%Variation |
|---|---|---|---|
| 1 | 4.31 | 61.6 | 61.6 |
| 2 | 1.35 | 19.3 | 80.9 |
| 3 | 0.824 | 11.8 | 92.7 |
| 4 | 0.253 | 3.6 | 96.3 |
| 5 | 0.163 | 2.3 | 98.6 |

*Eigenvectors*

(Coefficients in the linear combinations of variables making up PC's)

| Variable | PC1 | PC2 | PC3 | PC4 | PC5 |
|---|---|---|---|---|---|
| Ti | 0.431 | 0.122 | 0.252 | 0.348 | 0.763 |
| Mn | 0.266 | -0.601 | -0.460 | 0.249 | 0.015 |
| Fe | -0.408 | -0.294 | -0.322 | 0.308 | 0.304 |
| Zn | 0.453 | 0.024 | -0.227 | 0.348 | -0.458 |
| Rb | 0.460 | 0.155 | 0.162 | 0.125 | -0.203 |
| Zr | 0.394 | -0.350 | -0.101 | -0.750 | 0.200 |
| Pb | 0.068 | 0.625 | -0.731 | -0.149 | 0.189 |

Appendix 7.8: PCA for biotic (HM and Physiochemical parameters combined) and benthos during the dry season

*Eigenvalues*

| PC | Eigenvalues | %Variation | Cum. % Variation |
|---|---|---|---|
| 1 | 6.57 | 59.7 | 59.7 |
| 2 | 1.61 | 14.6 | 74.3 |
| 3 | 1.22 | 11.1 | 85.5 |
| 4 | 0.833 | 7.6 | 93.0 |
| 5 | 0.337 | 3.1 | 96.1 |

*Eigenvectors*

(Coefficients in the linear combinations of variables making up PC's)

| Variable | PC1 | PC2 | PC3 | PC4 | PC5 |
|---|---|---|---|---|---|
| DO | -0.078 | 0.641 | -0.434 | -0.147 | 0.101 |
| BOD | 0.283 | 0.366 | -0.339 | -0.215 | -0.237 |
| TOM | -0.369 | -0.035 | -0.025 | -0.149 | -0.406 |
| Ti | 0.332 | -0.183 | 0.330 | -0.174 | -0.208 |
| Mn | 0.210 | -0.327 | -0.546 | 0.370 | -0.328 |
| Fe | -0.328 | -0.173 | -0.215 | 0.396 | -0.069 |
| Zn | 0.369 | 0.026 | -0.039 | 0.124 | -0.447 |
| Rb | 0.369 | 0.033 | 0.151 | -0.218 | -0.209 |
| Zr | 0.320 | -0.224 | -0.291 | 0.062 | 0.454 |
| Pb | 0.077 | 0.479 | 0.365 | 0.698 | -0.103 |

Appendix 7.9: PCA for HM and benthos during the wet season

*Eigenvalues*

| PC | Eigenvalues | %Variation | Cum.%Variation |
|---|---|---|---|
| 1 | 6.29 | 89.8 | 89.8 |
| 2 | 0.16 | 4.5 | 94.3 |
| 3 | 0.255 | 3.6 | 98.0 |
| 4 | 0.767 | 1.1 | 99.1 |
| 5 | 0.365 | 0.5 | 99.6 |

*Eigenvectors*

(Coefficients in the linear combinations of variables making up PC's)

| Variable | PC1 | PC2 | PC3 | PC4 | PC5 |
|---|---|---|---|---|---|
| Ti | -0.392 | 0.234 | 0.064 | 0.227 | -0.161 |
| Mn | -0.379 | -0.377 | -0.042 | 0.789 | -0.042 |
| Fe | 0.391 | 0.110 | -0.135 | 0.185 | -0.861 |
| Zn | -0.384 | -0.148 | 0.411 | -0.363 | -0.450 |
| Rb | -0.390 | -0.229 | 0.251 | -0.252 | -0.112 |
| Zr | -0.351 | 0.834 | -0.031 | 0.081 | 0.007 |
| Pb | -0.356 | -0.148 | -0.862 | -0.300 | -0.122 |

Appendix 7.10: PCA for biotic (HM and Physiochemical parameters combined) and benthos during the wet season

*Eigenvalues*

| PC | Eigenvalues | %Variation | Cum. %Variation |
|---|---|---|---|
| 1 | 9.53 | 86.6 | 86.6 |
| 2 | 0.641 | 5.8 | 92.4 |
| 3 | 0.291 | 2.6 | 95.1 |
| 4 | 0.252 | 2.3 | 97.4 |
| 5 | 0.142 | 1.3 | 98.7 |

*Eigenvectors*

(Coefficients in the linear combinations of variables making up PC's)

| Variable | PC1 | PC2 | PC3 | PC4 | PC5 |
|---|---|---|---|---|---|
| Ti | 0.316 | 0.082 | 0.232 | -0.104 | -0.319 |
| Mn | 0.307 | -0.154 | -0.232 | 0.203 | -0.143 |
| Fe | -0.318 | 0.084 | 0.084 | 0.084 | 0.070 |
| Zn | 0.312 | -0.028 | -0.230 | -0.265 | -0.421 |
| Rb | 0.317 | -0.096 | -0.229 | -0.117 | -0.258 |
| Zr | 0.284 | 0.231 | 0.771 | -0.304 | 0.021 |
| Pb | 0.286 | -0.132 | 0.290 | 0.843 | -0.060 |
| D.O | -0.317 | -0.172 | 0.159 | -0.040 | -0.012 |
| BOD | -0.236 | -0.816 | 0.270 | -0.132 | -0.317 |
| TOM | -0.308 | 0.304 | 0.010 | 0.124 | -0.458 |

Appendix 7.11: Pearson's correlation coefficients for abiotic and biotic factors (seasons combined)

| | TOM | DO | BOD | Ti | Mn | Fe | Zn | Rb | Zr | Pb |
|---|---|---|---|---|---|---|---|---|---|---|
| a.Dabaso | | | | | | | | | | |
| TOM | | | | | | | | | | |
| DO | 0.022 | | | | | | | | | |
| BOD | 0.067 | 0.311 | | | | | | | | |
| Ti | 0.006 | -0.233 | -0.349 | | | | | | | |
| Mn | -0.040 | 0.295 | -0.216 | .481** | | | | | | |
| Fe | 0.115 | .674** | 0.028 | 0.027 | .421* | | | | | |
| Zn | 0.128 | -0.192 | -0.182 | -0.152 | -0.320 | 0.069 | | | | |
| Rb | -0.049 | .803** | 0.050 | 0.110 | .548** | .788** | -.362* | | | |
| Zr | -0.161 | -0.100 | -0.318 | .806** | .401* | 0.000 | -0.308 | 0.236 | | |
| Pb | -0.213 | 0.237 | 0.126 | -0.230 | -0.069 | 0.105 | 0.205 | 0.018 | -0.254 | |
| MacroD | -0.080 | .438* | -0.097 | -0.017 | 0.187 | 0.200 | -0.113 | .463** | 0.110 | 0.032 |
| MeioD | -0.219 | 0.030 | -0.251 | 0.201 | 0.246 | -0.188 | -0.146 | 0.080 | 0.202 | 0.194 |
| b. Mikindani | | | | | | | | | | |
| TOM | | | | | | | | | | |
| DO | -0.078 | | | | | | | | | |
| BOD | -0.159 | .964** | | | | | | | | |
| Ti | 0.134 | -.451** | -.538** | | | | | | | |
| Mn | -0.340 | -.702** | -.621** | 0.346 | | | | | | |
| Fe | -0.014 | 0.049 | 0.073 | -.543** | -0.240 | | | | | |
| Zn | -0.268 | -0.018 | 0.044 | -0.022 | 0.264 | -0.019 | | | | |
| Rb | 0.118 | -.527** | -.514** | .392* | .417* | -.442* | 0.059 | | | |
| Zr | .455** | -.402* | -0.330 | .353* | .496** | -0.117 | 0.027 | 0.072 | | |
| Pb | -0.015 | -.666** | -.619** | 0.291 | .518** | -0.233 | -0.200 | .394* | 0.240 | |
| MacroD | 0.278 | -0.326 | -0.313 | -0.026 | 0.231 | -0.006 | -0.314 | 0.080 | -0.195 | 0.312 |
| MeioD | .497** | .404* | 0.273 | -0.080 | -.657** | 0.265 | -0.242 | -.440* | -.476** | -.416* |