Original Article

Meiofauna as bioindicators of organic and inorganic pollution of estuarine sediments in Kenya

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Abstract
Meiofaunal density, diversity, and community assemblages were studied at the highly contaminated Tudor Creek and the less contaminated Mida Creek in Kenya to assess their potential as bioindicators of marine pollution. Sampling during the dry (January/February 2017) and wet (November/December 2017) seasons indicated a significantly greater total organic matter content at Mida (23.7 and 23.9 %) than at Tudor Creek (6.6 and 5.9 %) in the dry and wet seasons. Heavy metal concentrations were always greater at Tudor Creek. Meiofaunal densities were greater at Mida (2729 and 2804 ind.10 cm^{-2}) than Tudor Creek (612 and 183 ind.10 cm^{-2}) during both seasons. Meiofauna at Mida Creek (10 and 7 taxa in the dry and wet seasons) were dominated by nematodes, copepods, and turbellarians. Meiofauna at Tudor Creek (8 and 6 taxa) were dominated by nematodes, turbellarians and ostracods. Meiofaunal diversity was greater at Tudor Creek, but dominance was highest at Mida Creek. Community dissimilarities between the two sites were shown in a Bray-Curtis cluster analysis. There is a high likelihood that heavy metals affect meiofauna density and diversity in the sediments of the two studied creeks in Kenya.

Keywords: pollution, heavy metals, meiobenthos, Dabaso, Mikindani

Introduction
Marine pollution arises when harmful chemicals find their way into the ocean. The chemicals can have non-point sources, such as surface runoff from farms and urban roads and buildings, and point sources, such as sewage treatment works discharges, factories, and oil refineries. Pollution by metals results from anthropogenic activities, causing them to increase to toxic levels for organisms under certain circumstances. Metals are important pollutants arising from industrial and residential areas in urban and peri-urban environments (Prüss-Ustün *et al.,* 2014). In most developing countries, between 80 % and 90 % of domestic sewage in coastal urban centers is discharged without treatment (Labadi, 2017). This can be linked to urbanization, increased infrastructure development, and food production as a result of the rising world population, posing serious environmental risks to marine ecosystems (Mayorga *et al.,* 2010; Thompson *et al.,* 2017). This also influences water quality in terms of dissolved oxygen concentration, biological oxygen demand, turbidity, and conductivity, directly affecting marine life.

In Mombasa County, Kenya, anthropogenic activities, such as industrial plant development, fishing, construction of houses, wastewater discharge, crop production, and the disposal of agrochemical containing wastes, are major causes of pollution in Tudor Creek (Okuku *et al.,* 2011). The use of metals by different industries makes them important toxicants in many effluents. They are also released through sewage and surface runoff. Metals such as mercury (Hg) and arsenic (As) often bio magnify in the food chain (Okuku *et al.,* 2019). They affect organism reproduction and survival rates and can be toxic at high concentrations. An increase in their concentration above acceptable levels results in serious environmental health risks (Prüss-Ustün *et al.,* 2014).

There is, therefore, a need for biomonitoring to assess the impacts from these types of pollution (El Zrelli *et al.,* 2015). Biomonitoring has proved to be more effective than certain other methods of environmental monitoring since the level of toxicity of a substance is judged by its biological effects, not its concentration in the environment alone. Biota provide direct information about pollution hazards occurring over a long period, while chemical monitoring provides results based on the sampling time and does not provide a measure of bioavailability. Current research focused on the optimization of biological organisms, mostly meiofauna, to conduct biomonitoring programmes while including measurement of physio-chemical properties of the sediments and metal analysis to render the study more robust. Biological indicators can be defined as communities, organisms, or species whose presence or absence is indicative of environmental condition. Meiofauna are usually believed to be vulnerable to stress in the marine environment and can be excellent biological indicators. Some meiofauna are highly sensitive, while others are tolerant of high pollution levels. They are, therefore, effective indicators of environmental change (Orlando-Bonaca *et al.,* 2008).

Meiofauna are good bioindicators because of their small size, fast generation, widespread distribution, direct benthic development, and high diversity and density (Zeppilli *et al.,* 2015; Balsamo *et al.,* 2012). Their community structure reflects oxygen levels, organic matter content, and contaminant concentrations at a site (Moreno *et al.,* 2008b). Additionally, being constrained to the sediment through their life cycle (Sutherland *et al.,* 2007) and being susceptible to pollutants (Danovaro *et al.,* 2009), they are good for assessing environmental quality (Moreno *et al.,* 2008a). A few taxa (tolerant/opportunistic) dominate the community while those that are less tolerant become rare or disappear as a result of high organic matter content and low oxygen levels (Dal Zotto *et al.,* 2016). Meiofauna are assumed to have the highest level of sensitivity to disturbance in soft sediments (Penha-lopes *et al.,* 2014). This study was carried out to identify the potential of meiofaunal communities as indicators of pollution in estuaries at Dabaso and Mikindani in Kenya, which have different levels of anthropogenic disturbance.

Materials and methods

Study area

The study was conducted at two sites perceived to have different levels of contamination by virtue of their location relative to urban settlements, namely Mikindani in Tudor Creek and Dabaso in Mida Creek (Okuku *et al.,* 2011).

Tudor Creek, located at 4°2' S, 39°40' E, borders Mombasa Island on the northwest side. Three seasonal streams (Mtsapuni, Kombeni, and Tsatu) enter the Creek near Mariakani, roughly 32 km north-west of the port (Fig. 1). Sediments of Tudor Creek are predominantly mud and some parts are covered with sand (Kamau *et al.,* 2015). A mangrove forest composed of *Rhizophora mucronata* and *Avicennia marina* covers approximately 8 km^2 of the Creek. *A. marina* covers the mid zone while *R. mucronata* covers the landward zone (Kirui *et al.,* 2013). The mangrove forest is extremely polluted by raw sewage that is mainly discharged into the Creek from surrounding settlements at Mikindani, Tudor, and Old Town. The Creek is bordered by a large human population residing in settlements at Mikindani, Bangladesh, Burukenge, Mishomoroni, Changamwe, Tudor, Kibarani, Kongowea, Moroto, Kenya Meat Commission, and the Old Town.

Mida Creek, located at 3°20'S, 39 ° 58' E in Watamu, Kilifi County, stretches inland from the sea to the Arabuko Sokoke forest (Fig. 1). It is an extensive area of 31.6 km^2, consisting of a tidal inlet composed of sand and mud flats, located near Dabaso village (Kairo *et al.,* 2002). The estimated terrain elevation is 6 m above sea level. The Creek is characterized by muddy and shallow sandy soils (Wafula *et al.,* 2019). *R. mucronata, A. marina* and *Ceriops tagal* are the dominant mangrove species. The Creek provides a feeding and development area for sea turtles, birds, and fish amongst other biota. The area is less populated by humans than Tudor Creek and its surroundings, and there are thus fewer anthropogenic activities that result in pollution.

Sampling strategy

Sampling was conducted at Dabaso (3° 20' 41.77' S, 39° 59' 19.79'' E) and Mikindani (4° 0' 25.59'' S, 39° 38' 16.29'' E) during low tide in the dry (January/February 2017) and wet (November/December 2017) seasons (Fig. 1). The study collected eight samples along a transect perpendicular to the shoreline within the intertidal zone at each site. At Mikindani, the transect was laid alongside a sewage discharge channel, while at Dabaso, the transect was near the tidal inlet. The samples were tested for grain size, total organic matter (TOM), dissolved oxygen (DO), biological oxygen demand (BOD), metal, and meiofauna parameters.

Sample collection

Sediment for grain size and TOM analysis was sampled by inserting a 6.4 cm inner diameter corer into the sediment to a depth of 10 cm. The sediment was stored in Ziploc bags in a cooler box containing ice until transfer to the laboratory, to prevent degradation of the organic matter. Interstitial water for DO and BOD analysis was collected by excavating a shallow hole in the sediment and allowing pore water to drain into the hole. The water was transferred to Winkler bottles, 2 mL of concentrated sulfuric acid added to the sample surface and shaken several times. The sample was thereafter stored frozen prior to laboratory analysis (Helm *et al.*, 2012). Sediment for metal analysis was collected by inserting a 3.6 cm inner diameter corer into the sediment to a depth of 10 cm and the sediments stored in Ziploc bags. Meiofauna samples were collected using a 3.6 cm inner diameter corer inserted into the sediment to a depth of 10 cm. The sediment was placed in sample bottles and preserved using 8 % buffered formaldehyde.

Sediment grain size analysis

One hundred grams of oven dried sediment was transferred to an electric shaker with a stack of 63 µm, 125 µm, 250 µm, 500 µm, 1000 µm and 2000 µm mesh size sieves for 10 minutes. The fraction retained in each sieve was weighed on a microbalance and the proportion of the total start weight was used to calculated the proportion falling into each sediment grain size classes: granule (>2000µm), very coarse sand (1000µm - 2000µm), coarse sand (500µm - 1000µm), medium sand (250µm - 500µm), fine sand (125µm - 250µm), very fine sand (63µm - 125µm) and silt and clay (pan) (<63µm).

Total organic matter analysis

Samples were analyzed for organic matter using a 'loss on ignition' method as described by Hoogsteen *et al.* (2018). A 25 g portion of sediment from each replicate sample was placed into a porcelain dish and ashed in a furnace at 600 °C for 6 h, cooled, and weighed. The organic matter content was calculated as the percentage of the weight loss after ashing (% OM).

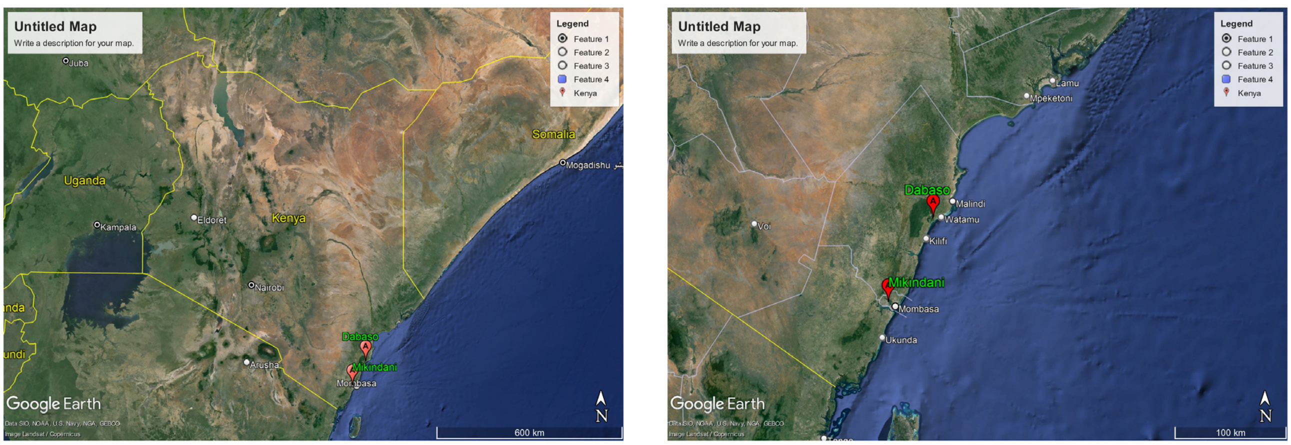

Figure 1. Map showing the Kenyan coastline with sampling sites - Dabaso (3° 20' 41.77' S, 39° 59' 19.79'' E) (Mida Creek) and Mikindani (4° 0' 25.59'' S, 39° 38' 16.29'' E) (Tudor Creek).

Dissolved oxygen (DO) and biological oxygen demand (BOD) analysis

DO was analyzed by titrating 200 ml of the sample with sodium thiosulfate to a pale straw colour. The titrate was slowly added into the solution using a pipette while stirring continuously. A solution of 2 ml of starch was added to form a blue color. Titration continued until the sample turned clear. The DO concentration in the sample was equal to the amount of titrant (sodium thiosulfate) used in milliliters.

To determine the BOD, the initial DO concentration was determined using the Winkler protocol (Helm *et al.*, 2012). The samples were then incubated in 300 ml incubation bottles with buffered dilution water dosed with seed microorganisms. The samples were stored in the dark for 5 days at 20 ^{0}C. The final DO concentration was determined as:

BOD (mg/L) = (Initial DO-Final DO) ÷ Volume of sample/Volume of bottle

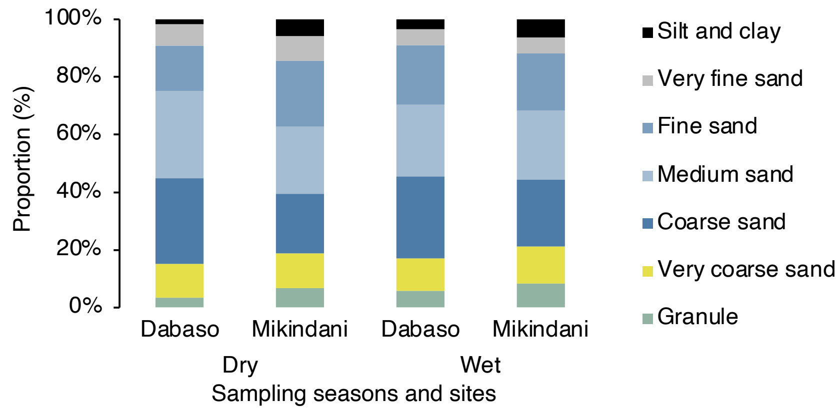

Figure 2. Grain size composition of sediment at Dabaso (Tudor Creek) and Mikindani (Mida Creek) in the dry and wet seasons.

Metal analysis

The samples were first air-dried for two weeks, and then oven-dried at 60 °C for eight hours to remove any remaining moisture. The dried samples were crushed into fine powder and sieved to grain sizes less than 60 µm. Approximately 1.4 g of the fine sample was mixed with 0.4 g of cellulose to achieve a 20 % dilution. Three pellets, each weighing approximately 350 mg, were prepared using a hydraulic press from each sample, and were ready for Energy-dispersive X-ray fluorescence (EDXRF) analysis.

Meiofauna extraction and identification

In the laboratory, sediment samples were washed through a 1 mm mesh size sieve and retained on a 38 µm mesh size sieve to extract the meiofauna. The contents retained by the 38 µm mesh size sieve were centrifuged three times (Hodda and Abebe, 2006) using magnesium sulphate ($MgSO_4$) of 1.28 specific density at 6000 rpm for ten minutes. The supernatant was passed through a 38 µm sieve, rinsed using filtered tap water, preserved using a 4 % buffered formaldehyde solution, and stained with Rose Bengal overnight. The samples were observed under a dissecting microscope at magnification x10. Meiofauna were identified to the highest taxonomic level.

Statistical analysis

One-way Analysis of Variance (ANOVA) was used to test for differences in TOM, DO, BOD, metals, and meiofauna amongst sites. The PAST Statistical Programme was used to determine Shannon Wiener diversity, dominance, and evenness indices for meiofauna (Hammer *et al.,* 2001). Meiofauna densities were square root transformed for community assemblage analysis using Multidimensional Scaling (MDS) on Plymouth Routines in Multivariate Ecological Research (PRIMER v5.2.9) software (Clarke and Warwick, 2001). Pearson's Product-Moment correlation analysis was conducted using Statistica to determine the correlation between abiotic factors and meiofauna densities.

Results

Abiotic Factors

Coarse and medium sand contributed more to the sediment weight at Dabaso (29.7 %, 30.3 %) than at Mikindani (20.7 %, 23.3 %) in the dry season (Fig. 2). Other grain size classes had a higher contribution at Mikindani than Dabaso. In the wet season, coarse, medium, and fine sand had the highest contribution at both sites, but this was slightly higher at Dabaso (28.3 %, 25.0 %, 20.6 %) compared to Mikindani (23.3 %, 23.9 %, 19.7 %). Granules and very coarse sand had a higher contribution at Mikindani compared to Dabaso. Silt and clay made the lowest contribution at both sites, although this was slightly higher at Mikindani than at Dabaso (Fig. 2).

DO concentrations were significantly higher ($p < 0.05$) at Dabaso compared to Mikindani in the dry and wet seasons combined (Table 1). The DO concentration was significantly higher at Dabaso in the wet season ($p = 0.02$) and at Mikindani in the dry season ($p = 0.02$).

The BOD was significantly higher ($p = 0.039$) at Mikindani compared to Dabaso in the dry season, while in the wet season it was significantly higher ($p = 0.041$) at Dabaso (Table 1). When concentrations within sites are compared between seasons, a slight increase from the dry (3.4 ± 0.10mg/L) to wet (3.5 ± 0.03mg/L) season was recorded at Dabaso, but the difference was not significant ($p = 0.5$). In contrast, at Mikindani there was a significant decrease ($p = 0.003$) from the dry (4.8 ± 0.2mg/L) to wet (2.8 ± 0.03mg/L) season.

Table 1. Physio-chemical parameters (mean ± standard error) for sediment porewater at Mikindani and Dabaso in the dry and wet seasons. DO = dissolved oxygen, BOD = biological oxygen demand, TOM = total organic matter.

Parameter	Site	Dry season	Wet season
DO (mg/L)	Mikindani	3.8 ± 0.02	2.1 ± 0.04
	Dabaso	4.0 ± 0.1	5.3± 0.03
BOD (mg/L)	Mikindani	4.8 ± 0.23	2.8± 0.03
	Dabaso	3.4 ±0.10	3.5 ± 0.03
TOM (%)	Mikindani	6.6 ± 0.2	5.9 ± 0.1
	Dabaso	23.7±0.7	23.9± 0.03

The TOM content was significantly higher ($p < 0.05$) at Dabaso compared to Mikindani in the dry and wet season combined. TOM content in the sediment was not different between seasons at either site (Table 1).

Metal concentrations

Seven metals were analysed in the sediment, namely iron (Fe), titanium (Ti), zirconium (Zr) manganese (Mn), rubidium (Rb), zinc (Zn), and lead (Pb), in that order in terms of concentration. All metals exhibited higher concentrations at Mikindani compared to Dabaso in both seasons (Table 2). Iron, Ti, Zr, Rb and Zn concentrations were nearly threefold higher at Mikindani compared to Dabaso. Manganese and Fe concentrations significantly increased from the dry to wet season at Dabaso, but not Ti ($p = 0.342$), Zr ($p = 0.132$), Rb ($p = 0.295$), Zn ($p = 0.262$), or Pb ($p = 0.402$). All metals increased significantly in concentration from the dry to wet season at Mikindani apart from Zn ($p = 0.920$) (Table 2).

Meiofaunal density and distribution

Overall, meiofaunal density was significantly higher at Dabaso (2729 ± 387 ind.10 cm^2, 2804 ± 11 ind.10 cm^2) compared to Mikindani in the dry and wet seasons (604 ± 114 ind.10 cm^2, 183 ± 30 ind.10 cm^2) respectively (Fig. 3). The density was particularly low at Mikindani in the wet season, being more than 10 times lower than at Dabaso. The density at Dabaso was slightly higher in the wet season, but the difference was not significant ($p = 0.081$). In contrast, at Mikindani the density was significantly higher in the dry compared to wet season ($p = 0.048$).

The meiofauna community was comprised of 10 and 7 taxa at Dabaso and 8 and 6 taxa at Mikindani in the dry and wet seasons respectively. Nematodes dominated in dry and wet seasons at Dabaso (85.4 % and 90.4 %) and Mikindani (76.6 % and 53.7 %) respectively. Other taxa were less abundant, contributing <10 % of the total density at both sites in each season. Copepods

Table 2. Metal concentrations (mg/kg dry weight; mean ± standard error) in Mikindani and Dabaso sediments in the dry and wet seasons. Fe = iron, Ti = titanium, Zr = zirconium, Mn = manganese, Rb = rubidium, Zn = zinc, Pb = lead.

Metals	Sites	Dry season	Wet season
Fe	Mikindani	17147±585.0	21633±886.2
	Dabaso	4146±183.1	5240±257.2
Ti	Mikindani	2677±122.0	3133±86.28
	Dabaso	897.0±10.4	807.0±65.0
Zr	Mikindani	870.0±36.3	1294±96.7
	Dabaso	309.0± 5.2	350.0±29.1
Mn	Mikindani	164.1±8.9	325.8± 17.2
	Dabaso	127.5±0.4	153.6±12.3
Rb	Mikindani	85.6±3.0	103.3±0.8
	Dabaso	15.3±0.2	32.2±1.3
Zn	Mikindani	70.5±3.7	70.0±7.6
	Dabaso	16.4±2.3	12.5±0.7
Pb	Mikindani	25.1±3.3	36.6±4.8
	Dabaso	15.2±3.8	22.7±1.5

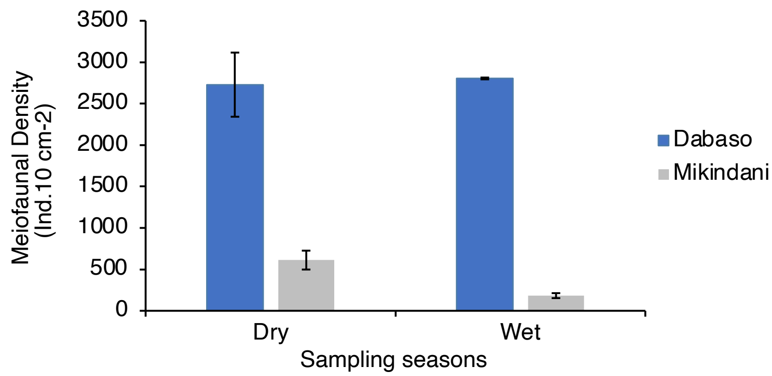

Figure 3. Meiofaunal densities (mean ± standard error) at Dabaso (Tudor Creek) and Mikindani (Mida Creek) in the dry and wet seasons.

contributed 7.9 % and 5.4 % of the total density at Dabaso in the dry and wet seasons respectively but were much less abundant at Mikindani in the dry (4.3 %) and wet (0.1 %) season. Ostracods were only present at Mikindani, at 6.8 % and 4.7 % contribution in the dry and wet seasons respectively (Fig. 4). Other meiofauna, like Isopods, Kinorhynchs, Tunicates, Halacaroids, Sipunculids, and Amphipoda, contributed <2 %. Isopods were only recorded at Dabaso while Halacaroids were recorded only at Mikindani.

Meiofaunal diversity

Taxa richness (S) at Dabaso (10, 7) and Mikindani (8, 6) was higher in the wet compared to dry season respectively (Table 3). Dominance and evenness were higher at Dabaso compared to Mikindani in both seasons. Simpson and Shannon Wiener diversity indices indicated higher species diversity in Mikindani compared to Dabaso in both seasons (Table 3), but there was no significant difference between sites and season for all indices.

Meiofaunal Community structure

Non-Metric Multidimensional scaling (nMDS) on meiofauna communities in the dry season produced two major clusters (Fig. 5a). Four samples from Mikindani were distinctively dissimilar to the other four samples, and the eight Dabaso samples. Analysis of Similarity (ANOSIM) showed a significant difference between Mikindani and Dabaso samples ($p < 0.05$). On the other hand, Dabaso samples clustered together, showing similarity of the meiofaunal communities ($p > 0.05$).

In the wet season, Bray-Curtis cluster analysis of the major meiofaunal taxa produced two major clusters, cluster 1 that had communities from Dabaso and cluster 2 that had communities from Mikindani (Fig. 5b).

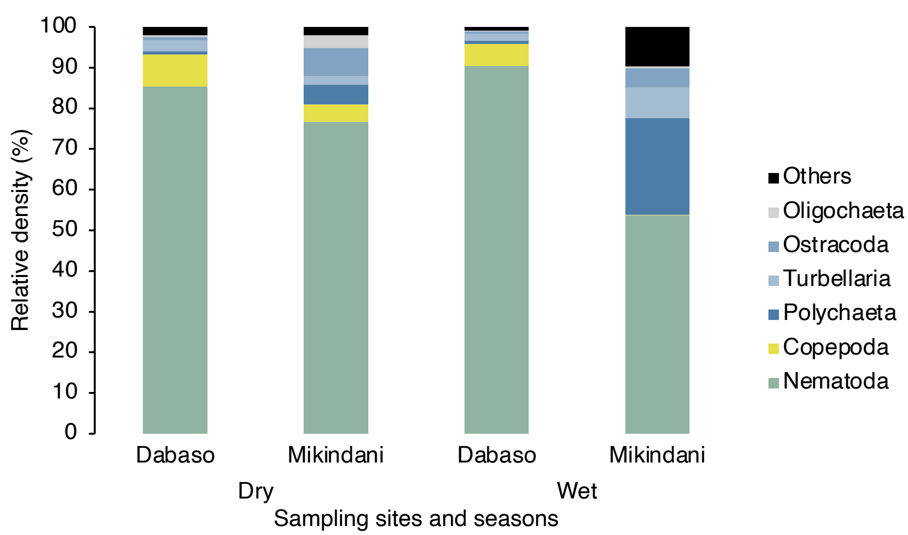

Figure 4. Relative density of meiofaunal taxa at Dabaso (Tudor Creek) and Mikindani (Mida Creek) in the dry and wet seasons.

Table 3. Meiofauna taxa, dominance, Simpson and Shannon Weiner diversity indices, and evenness at Dabaso (Tudor Creek) and Mikindani (Mida Creek) in the dry and wet seasons.

	Dry season		Wet season	
	Dabaso	Mikindani	Dabaso	Mikindani
Taxa	10	7	8	6
Dominance	0.68	0.55	0.81	0.40
Simpson	0.32	0.45	0.19	0.60
Shannon	0.71	0.97	0.45	1.16
Evenness	0.22	0.43	0.21	0.56

This indicated that the meiofaunal composition at each site was similar, but different between sites. The samples at Mikindani were highly separated from one another, showing high dissimilarity. Analysis of Similarity (ANOSIM) showed high similarity of samples within the groups (p = 1.2 %), while the percentage similarity (SIMPER) analysis showed that dissimilarity between the sites was high (72 %).

Correlation between abiotic factors and meiobenthos

At Dabaso, no meaningful correlation was found between meiofaunal density and any abiotic parameter. At Mikindani, meiofaunal density was significantly positively correlated to TOM (r = 0.497**) and DO (r = 0.404**). Density displayed a significant negative correlation with Mn (r = -0.657**), Rb (r = -0.440*), Zr (r = -0.476**) and Pb (r = -0.416*). Density was negatively correlated with Ti (-0.080) and Zn (-0.242) and positively correlated with Fe (0.265), but the correlations were not significant. Density was positively, but not significantly, correlated with BOD. Different metals also showed positive but not significant correlations with one another; 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) (Table 4).

Discussion

Previous studies have shown the Mikindani area to be polluted (Okuku *et al.,* 2011; Kamau *et al.,* 2015) while the Dabaso area was semi-pristine (Kairo *et al.,* 2002; Waweru *et al.*, 2022). The present study highlighted the occurrence of meiobenthic fauna in relation to physio-chemical parameters and metal pollution. The findings show higher metal concentrations at Mikindani (near a sewage disposal point) than at Dabaso (pristine environment).

Physico-chemical parameters showed differences between Mikindani and Dabaso. In Dabaso, coarse and medium sand contributed the most to the sediment size, which may be due to dense mangrove forest stands acting as filters to trap sediments. Mangroves trap sediments like sand but they are less efficient in trapping mud compared to mudflats (Van Santen *et al.*, 2007). Conversely, at Mikindani the higher proportion of fine sand, very fine sand, and silt/clay could be attributed to over a decade of runoff from a large residential estate with a population of more than 20,000 inhabitants (Kamau *et al.,* 2015).

The dissolved oxygen concentration in sediment porewater was higher at Dabaso compared to Mikindani in

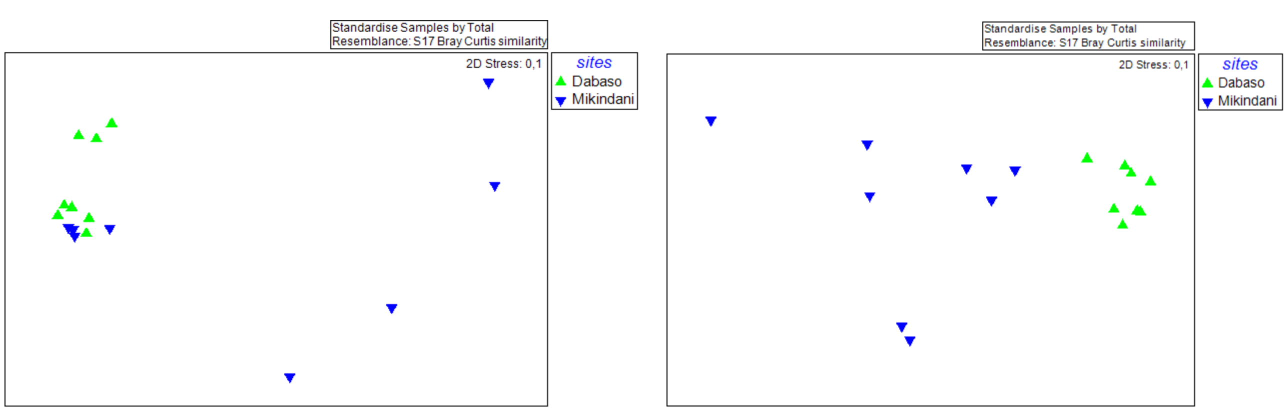

Figure 5. Non-Metric Multidimensional scaling plot of meiofauna community assemblages based on square root transformed data for Dabaso (Tudor Creek) and Mikindani (Mida Creek) in the dry (a) and wet (b) seasons.

Table 4. Pearson correlation coefficients for abiotic factors and meiofauna densities at Mikindani and Dabaso in the dry and wet seasons. Values represent R values for eight replicates. TOM = total organic matter, DO = dissolved oxygen, BOD = biological oxygen demand, Ti = Titanium, Mn = Manganese, Fe = Iron, Zn = zinc, Rb = rubidium, Zr = zirconium, Pb = lead, MeioD = Meiofauna density. Asterisks indicate significance levels (*P<0.05, **P<0.01).

	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	0.481**						
Fe	0.115	0.674**	0.028	0.027	0.421*					
Zn	0.128	-0.192	-0.182	-0.152	-0.320	0.069				
Rb	-0.049	0.803**	0.050	0.110	0.548**	0.788**	-0.362*			
Zr	-0.161	-0.100	-0.318	0.806**	0.401*	0.001	-0.308	0.236		
Pb	-0.213	0.237	0.126	-0.230	-0.069	0.105	0.205	0.018	-0.254	
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	0.964**								
Ti	0.134	-0.451**	-0.538**							
Mn	-0.340	-0.702**	-0.621**	0.346						
Fe	-0.014	0.049	0.073	-0.543**	-0.240					
Zn	-0.268	-0.018	0.044	-0.022	0.264	-0.019				
Rb	0.118	-0.527**	-0.514**	0.392*	0.417*	-0.442*	0.059			
Zr	0.455**	-0.402*	-0.330	0.353*	0.496**	-0.117	0.027	0.072		
Pb	-0.015	-0.666**	-0.619**	0.291	0.518**	-0.233	-0.200	0.394*	0.240	
MeioD	0.497**	0.404*	0.273	-0.080	-0.657**	0.265	-0.242	-0.440*	-0.476**	-0.416*

both seasons. This could be attributed to the fact there are limited land-based sources of pollution at Dabaso, while Mikindani had a nearby channel discharging sewage from surrounding settlements. In the wet season, the DO concentration increased at Dabaso, probably as a result of the inflow of oxygenated freshwater (Abril *et al.*, 2010). At Mikindani, the low DO concentration in the wet season could be due to high loads of oxygen-demanding wastes flushed from land to the mangroves. Such oxygen reducing agents include ferrous iron, some oxidizable substances, H_2S, ammonia, and nitrite (Verma and Saksena, 2010).

Biological oxygen demand was statistically higher at Mikindani in the dry season, probably caused by the high oxygen-demanding wastes from sewage and algal decomposition elevating the demand (Okuku *et al.,* 2011). In addition, Vaquer-Sunyer and Duarte (2008) showed that excessive production of OM (from organic waste) increased oxygen demand in coastal ecosystems, hence high BOD levels. Low BOD at Mikindani in the wet season resulted from dilution effect of rainwater. Higher BOD at Dabaso, mostly in the wet season, could be caused by the higher accumulation of OM from mangrove litter fall. Dense mangrove forest stands at Dabaso contributed to litter fall as a source of TOM (Omollo and Dharani, 2021) while at Mikindani mangrove forests were scattered and smaller in size, reducing autochthonous processes, while allochthonous processes were limited to effluent from the land.

Metals are usually immobilized in sediment (Wan *et al.,* 2018). This study showed that different metals (Fe, Mn, Ti, Pb, Zr, Zn, Rb) were present at a higher concentration in sediment at Mikindani than at Dabaso. This could be attributed to the high inflow of anthropogenic pollutants in Mikindani Creek from the neighboring human community and industries in Mikindani village. However, it is paramount to normalize geochemical parameters of metals around the vast area of Mikindani and Dabaso in relation to chemical composition and chemical changes in the sediments to understand the huge differences reported. This study agreed with the study by Okuku *et al.* (2019) that showed high concentrations of metals in Tudor Creek. High Zn concentrations could be associated with dissolution of zinc anodes used in leisure boats as well as the use of galvanized metals and automobile tyres within the urban area. The deposited metals accumulate in street dust and later find their way into the aquatic systems through stormwater runoff (Hwang *et al.,* 2016). High Mn concentrations at Mikindani during the wet season could be attributed to discharge from the adjacent cement factory while high Pb concentrations could be associated with remnants of Pb in the sediment from boats used along the Creek and vehicles from the nearby villages.

Different correlations were observed between metals and other physio-chemical parameters. There was a significant positive correlation between DO-Rb and DO-Fe in Dabaso. This could be attributed by the fact that both DO, RB and Fe are influenced by similar environmental factors, such as water, temperature and salinity (Liu *et al.*, 2022). The negative correlation between biological oxygen demand and certain metals could be attributed to benthic organisms consuming metals for minerals intake (Xing *et al.,* 2022).

Meiofaunal densities showed seasonal variability. Density at Dabaso was higher than at Mikindani, which can be attributed to pollution levels, TOM and DO, which influence the composition of communities at a site (Schmid-Araya and Schmid, 1995). According to Ingels *et al.* (2014) and Carvalho *et al.* (2017), food availability in the form of organic matter plays an important role in regulating the density of meiofauna, as exhibited by the results of this study where Dabaso with high OM had higher density than at Mikindani. Additionally, the densities decreased at Mikindani in the wet season as a result of extreme reduction in oxygen concentrations (hypoxic conditions), caused by increased pollution and hence the disappearance of many sensitive taxa (Rabalais *et al.,* 2002). High inputs of metals can decrease the density of highly sensitive species, such as copepods (Pascal *et al.,* 2010), as at Mikindani. Nonetheless, this is not always the case as the densities may not change in a short period of time due to the dominance of highly tolerant nematodes, as described by De Troch *et al.* (2013).

Copepods, which are found in coarse sandy sediments and are sensitive to pollution (Uriarte and Villate, 2005; Moore and Bett, 2008) were present only at Dabaso. Additionally, they are the meiofauna most sensitive to low oxygen concentration (De Troch *et al.,* 2013), hence low density at Mikindani during the dry season and absent during wet season due to increased release of domestic and industrial effluents which caused low oxygen levels. This study showed copepods could act as good biological indicators when in significantly low densities or absent in polluted estuarine sediments. Turbellaria, ostracods and oligochaetes were more numerous at Mikindani compared to Dabaso because they are more resilient to pollution. A few halacaroids were found at Mikindani because they are well adapted to highly polluted and hypoxic environments and can be used as positive indicators of pollution (Bonaglia *et al.,* 2020). Navarro-Barranco *et al.* (2020) found that amphipods can be used as bioindicators of pollution which aligned with the current results where Mikindani lacked the presence of these meiofauna group compared to Dabaso, and are thus good indicators of pollution. However, the identification of nematodes to genus level could give better clarity to pollution indicators since some genera have been found to opportunistic or sensitive to organic or inorganic pollution.

Meiofauna diversity was higher at Mikindani compared to Dabaso in both seasons, which can be attributed to high opportunistic species contributing to the high diversity (Somerfield and Warwick, 1996). This study conforms with the results of previous studies by Schratzberger and Ingels (2018) and Pusceddu *et al.* (2013) that link increased diversity to the low dominance of opportunistic taxa. Mohamed *et al.* (2018) found a higher meiofaunal diversity in coarse and medium sized sediments, which was not the case for Dabaso with similar sediment size composition. High dominance at Dabaso during both seasons can be linked to very high density of nematodes (Mohamed *et al.,* 2018).

Excessive pollution in marine ecosystems is detrimental to meiofaunal density, diversity, composition, and community assemblages. It was evident that the differences observed in biotic factors were partly influenced by abiotic parameters (DO, TOM, BOD, grain size, metals), which were caused by the heavy inflow of pollutants at Mikindani. According to the results of this study, the sites were greatly affected by inorganic pollution. The meiofauna assemblages were attributed to sediment characteristics and food availability. Some taxa, like amphipods, showed sensitivity to contamination by being absent in Mikindani. The detrimental conditions due to high effluent discharge make it very difficult for some taxa to survive in these habitats.

Further studies should focus on a wider range of metals at Mikindani to ascertain if the higher concentrations here are attributed to the sediments grain size or to effluent discharge. Additionally, nematodes should be identified to the genus or species level to provide more information on opportunistic or sensitive taxa and to calculate a maturity index, thus providing insights on the sediment status at Dabaso and Mikindani.

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