Chapter

Decadal Pollution Assessment and Monitoring along the Kenya Coast

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Abstract

Marine contamination arising from land-based sources is on the rise along the Kenyan Coast. We carried out a decadal pollution survey between 2008 and 2018 to determine the levels of various pollutants (nutrients, trace metals, persistent organic pollutants, and ^{210}Po) in water, sediment, and biota collected from selected locations in Kenya. Nutrient levels in water ranged between <0.10 and 1560.00, <0.10 and 1320.00, and <0.10 and 3280.00 μg/L for PO_4^{3-}-P, (NO_2^- + NO_3^-)-N, and NH_4^+-N, respectively, while Chl-a values ranged between 0.02 and 119.37 mg/L. Total PAH, PCBs, and OCPs in sediment from the studied locations ranged from BDL-37800, 0.012–7.99 and BDL-6.10 ng/g. High level of PAH in Kilindini port was primarily from petroleum sources. DDD + DDE/DDT ratio was above 0.5 suggesting historical input. Sediment trace metal concentration from selected locations in Kenyan estuaries had various ranges, that is, Al (0.06–9804284.00 μg/g), Zn (3.82–367.20 μg/g), Cu (7.5–169.60), Cd (DL –2.40 μg/g), Mn (BDL-169.60 μg/g), Cr (2.55–239.10 μg/g), and Pb (BDL-135.60) μg/g dw. Surface sediment ^{210}Po activities ranged between 20.29 and 43.44 Bq kg^{-1} dw. Chl-a and PO_4^{3-}-P data revealed enhance primary productivity in Mombasa peri-urban creeks and estuarine areas. Although the reported concentrations of trace metals and POPs are low in most locations from Kenya, there is a potential risk of bioaccumulation of these contaminants in marine biota; thus, there is a need for continuous monitoring to protect both ecosystem and human health.

Keywords: marine pollution, nutrients, heavy metal

1. Introduction

Kenya is experiencing an increase in human population, urbanization, and industrialization which is characterized by massive utilization of natural resources coupled with an increase in waste production [1]. UNEP GEF-funded WIOLaB project identified that over 70% of pollutants entering marine and coastal ecosystems originate from the land [2]. Many pollutants from these land-based sources (such as sewage, oil hydrocarbons, sediments, nutrients, pesticides, litter, and plastics and toxic wastes) enter the sea via rivers and surface runoff [3]. For instance, sewage is still being indiscriminately discharged into peri-urban creeks of Mombasa [4].

Kenya's coastal waters are thus continuously enriched with large amounts of nutrients, particularly nitrogen (N) and phosphorus (P), silica (Si) and sulfur (S) from anthropogenic activities and wastewater from households and industries [4] despite the fact that effluent pollution had been identified as the most serious of all land-based threats to the marine environment and an area which requires more attention [5]. Excessive nutrient enrichment results in nutrient pollution and eutrophication with severe economic, environmental, and ecological implications to the marine environment due to the shift in the Redfield ratio [6]. Some of the impacts of nutrient enrichment include increased abundance and biomass of phytoplankton and macroalgae [7]; reduced light penetration; increased development of hypoxic, anoxic, and dead zones [8, 9]; changes in phytoplankton community structure and alteration of food chains and webs [10]; development of harmful algal blooms that may produce substances toxic to aquatic organisms or humans [11]; dieback of seagrasses, algal beds, and corals [12, 13]; loss of biodiversity; and increased incidences and duration of harmful algal blooms [14].

The other class of contaminants that are discharged through sewage, surface runoff, and industrial discharge includes heavy metals and persistent organic pollutants (POPs). Trace metals such as lead (Pb), cadmium (Cd), copper (Cu), chromium (Cr), nickel (Ni), mercury (Hg), arsenic (As), and zinc (Zn) are not easily degraded in the natural environment and are bioaccumulated along the food chain [15]. They are also known to affect productivity, reproduction, and survival of marine organisms and can be hazardous to human health at elevated concentrations [15].

Persistent contamination of organic pollutants (POPs), such as organochlorine pesticides (OCPs), polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs) in the aquatic environment is a worldwide problem [16]. The anthropogenic input of these POPs in the Indian Ocean includes industrial and sewage effluents, storm water drains, shipping activities, spillage, rivers, atmospheric fallout, coastal activities, and natural oil seeps. For instance, these compounds have been used extensively in Kenya for various applications in industries and agriculture [17]. They are characterized by long-term stability (not easily degradable in the environment and can persist in sediments for decades or even centuries), bioaccumulative nature, long-range transport capability, and may have high toxic effects on aquatic living organisms [18, 19]. These chemicals have since been replaced with organophosphate and carbamate, which are less persistent in the environment under the Stockholm Convention on Persistent Organic Pollutants [20, 21]. However, their residues are still present in the marine environment.

Among the natural radionuclides, alpha emitters (e.g. ^{210}Po) have been reported to have significant radiological effects resulting from their accumulation in organisms [22]. ^{210}Po is a naturally occurring radioactive material (NORM) alpha-emitter occurring in very low concentrations in the environment as a part of the uranium decay chain. ^{210}Po has a radioactive half-life of 138.4 days and is produced in the marine environment from the decay of ^{210}Pb (which is a daughter isotope derived from ^{226}Ra dissolved in seawater). ^{210}Pb can also be introduced into marine environment directly from the atmosphere from the decay of ^{222}Rn [22, 23]. It is ubiquitously distributed in rocks, soils, making up earth's crust, in the atmosphere and in natural waters [24]. It can also be derived in insignificant quantities from lead-containing wastes from uranium, vanadium, and radium refining operations [25]. The activity of ^{210}Po in the environment has increased in the past due to human activity such as fossil fuel combustion, use of phosphate fertilizers in agriculture, and discharge of domestic and industrial sewage.

UNEP-GEF WIO-LaB Project identified municipal and industrial effluents, contaminated surface runoff including groundwater and agricultural runoff [2] as the major sources of land-based pollution and microbial contamination, suspended solids, chemical pollution, marine litter (including debris), and eutrophication

(harmful/nuisance algal blooms) as priority pollution categories in the WIO region. In Kenya, limited action has been taken to control or manage pollution. For instance, only a couple of studies have been carried out to determine long-term pollution status or their impacts on marine and coastal ecosystems and the potential human health.

During the assessment and monitoring program, water matrix was analyzed for nutrient pollution whereas sediments were analyzed for trace metals, radionuclides, and POP contamination. Sediment was the preferred matrix for persistent pollutants given that it a known sink and an archive of pollutants brought into the aquatic environment from direct discharges, surface runoff, atmospheric fallout, and nonpoint source [19, 26, 27]. The distribution of these contaminants in sediments can serve as a useful index of pollution and potential environmental risks [17, 28].

2. Materials and methods

Water and sediment samples were collected from the estuarine areas of Ramisi-Vanga system in the Kenyan South Coast; peri-urban creeks of Mombasa; and estuarine areas of the North Coast (**Figure 1**). Ramisi-Vanga system (Ramisi, Mwena, and Umba) is a low-lying coastal plain submergent complex (below 30 m contour) with extensive cover of mangrove forest, intertidal areas covered with seagrass beds and shallow water lagoons harboring the coral reefs. These critical systems are interlinked through the exchange of water, nutrients, and carbon by the tidally controlled circulation and river discharge [29]. The Kisite-Mpunguti Marine Protected Area (KMMPA) and Shimoni are situated approximately 90 km south of Mombasa with very few scattered fringe mangrove cover on the shoreline though there is no river input into this system apart from sewage and runoff [30]. The area constitutes an important tourist attraction and important resource for the surrounding communities [31]. The main characterizing features of interest around Mombasa peri-urban creeks (Makupa, Kilindini, Mtwapa, and Tudor creeks) include the Kilindini port and the Mombasa Municipal refuse dumpsite, (Kibarani), both of which are found in the vicinity of the Makupa creek stations and the Kenya Meat Commission (KMC) beef factory located within the vicinity of the Tudor creek [32]. Mtwapa creek is situated 25 km north of Mombasa. It is a tidal creek lined by mangrove forests and extensive mud banks. The creek receives freshwater input through seasonal rivers and it is reported to be relatively eutrophic due to direct release of raw sewage into the creek at the vicinity of Shimo la Tewa government prison [30]. These peri-urban creeks were chosen due to anthropogenic activities in the adjacent areas while riverine estuarine systems were chosen given that river-derived material like water, sediments, and pollutants have a tremendous ecological and toxicological influence on coastal zones [35]. North Coast sites comprised of estuarine areas of River Tana which arises from Aberdare range and Mount Kenya passing through the arid and semiarid areas of the eastern part of the country and finally drain into the Indian Ocean in a fan-shaped delta [34] while Sabaki river originates from Athi river where it joins Tsavo river and forms river Galana where it also discharges into the sea. These two rivers affect the marine ecological conditions of Watamu, Malindi, and Lamu [33].

Nutrient sample collection, preservation, shipment, storage, and analysis were done following procedures described by Parsons [36], APHA [37] and measured using Genesys 10S Vis spectroscopy (Thermo Scientific™). Sediment samples were collected using Uwitec corer (fitted with a 50-cm plastic sampler, Ø 8 cm) following the procedures provided in IAEA TECDOC-1415. The samples were transported to the laboratory awaiting analysis.

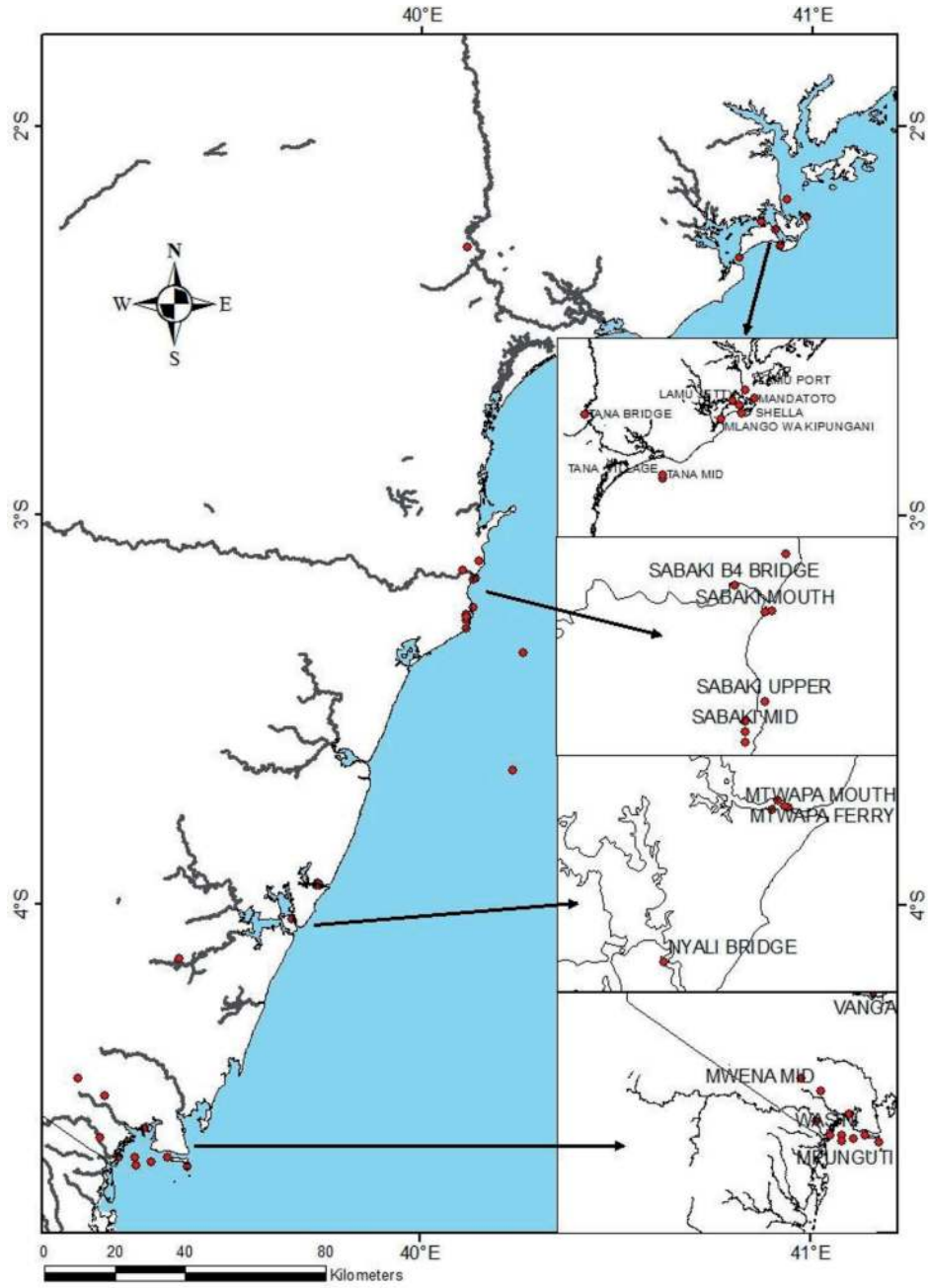

Figure 1.
Map showing sampling sites: Estuaries (Umba, Ramisi, Sabaki, Mwena, and Tana); north coast (Kilifi, Malindi, and Lamu); south coast (Kibuyuni, Shimoni, Wasini, Sii Island, Gazi, and Kisite); and peri-urban creeks of Mombasa (Mtwapa, Tudor, and Makupa).

For analysis of trace metals and alpha-emitter ^{210}Po radionuclide, top 5 cm of sediment for each site were pooled, mixed by hand, and freeze-dried, homogenized sieved, dry-weighed, and then digested in a microwave (Microwave Accelerated Reaction system). Elemental analysis of Cu, Zn, Mn, Pb, Cd, and Cr was carried out using inductively coupled plasma mass spectrometer (ICP-MS) (Varian, Australia) while ^{210}Po activity was measured using alpha-spectrometry with silicon surface barrier detectors (EG and G) coupled to a PC running Maestro TM data acquisition software [38].

PCBs, OCPs, and PAH were analyzed as described by Thompson et al. [39] where wet samples were freeze-dried using Heto powerdry LL3000 freeze dryer (Thermo

Scientific), then known weight of the sediment sample was spiked with internal standard for PCBs (PCB 30, PCB 103, PCB 155, PCB 198 from Promochem, Dr. Ehrenstorfer GmbH, France), OCPs (d8 4,4′ DDT from Cambridge Isotope Laboratory, France), and PAH (per-deuterated PAHs; Phenanthrene-d10, benzo [a]pyrene- d12, benzo [e] pyrene d12 and benzo [g, h, i]perylene-d12 from Cambridge Isotope Laboratories, Andover, USA; and Fluoranthene-d10, chrysene-d12 and pyrene-d10 from MSD isotopes, Division of Merck Frost Canada INC, Montreal, CND) to quantify the recoveries. The samples were then extracted using START E microwave-assisted extraction system (Milestone, Italy). The extract was concentrated using Rapidvap LABCONCO (Serlabo Technologies, France) and then concentrated samples were subjected to the clean-up process. Thereafter, the extracts were finally concentrated under nitrogen, transferred to 100-μl container and analyzed using GC-MS.

3. Pollutants' source identification and risk assessment

To determine the possible pollution sources of DDT, the approach by Kilunga et al. and Mohammed et al. [18, 40] (that classified sediments with (DDD +DDE)/DDT ratio greater than 0.5 as historic and ratio less than 0.5 as recent input) was applied. The ratio of DDE to DDD was used in this study to give an idea of the degradation pathway of DDTs in the sediment [41]. DDE/DDD ratio greater than 1 was indicative of anaerobic degradation of DDT into DDD while the ratio less than 1 implies DDT conversion into DDE via aerobic degradation [42].

The pollution data obtained compared with effects range-low (ER-L) and effects range-median (ER-M) values (sediment quality guidelines, SQGs) provided by MacDonald et al. and MacDonald and Ingersoll [43, 44] were used to evaluate the ecotoxicological significance/potential impacts of trace metals, PAH, PCBs, and DDT on benthic organism. ER-L represents the value at which toxicity may be observed in sensitive marine species (i.e., pollution is at a level that may not cause harm to aquatic environment) and ER-M represents the concentration below which adverse effects are expected to occur.

4. Results and discussion

4.1 Nutrient pollution

Results of this study showed high values of nutrient concentration in stations within estuaries compared to oceanic water stations (**Figure 2a–d**). The highest value of phosphate concentration was recorded in Kisite (304.82 μg/L) followed by River Sabaki (205.79 μg/L) and the least was in Kilifi (7.52 μg/L) whereas the highest values of ammonium were, however, recorded in Mombasa stations of Tudor creek (81.71 μg/L). The stations in Mombasa were also observed to have high nutrient levels compared to Malindi and Lamu (**Figure 2d** and **b**), a condition that can be attributed to the high population associated with municipal and industrial wastes in Mombasa compared to the other towns. It was observed that the nutrient levels for stations in Tana river estuary, which was hypothetically thought to be receiving higher nutrient input from the agricultural and residential population in the river catchment, were strikingly low (**Figure 2a**). This observation of low nutrient and chlorophyll-a concentration can be explained by the presence of several dams, which form the Seven Folks Dams Scheme. These dams are known to settle down suspended materials with adsorbed nutrients [45], therefore reducing the transportation of these sediments and nutrients downstream. Nutrient ranges recorded

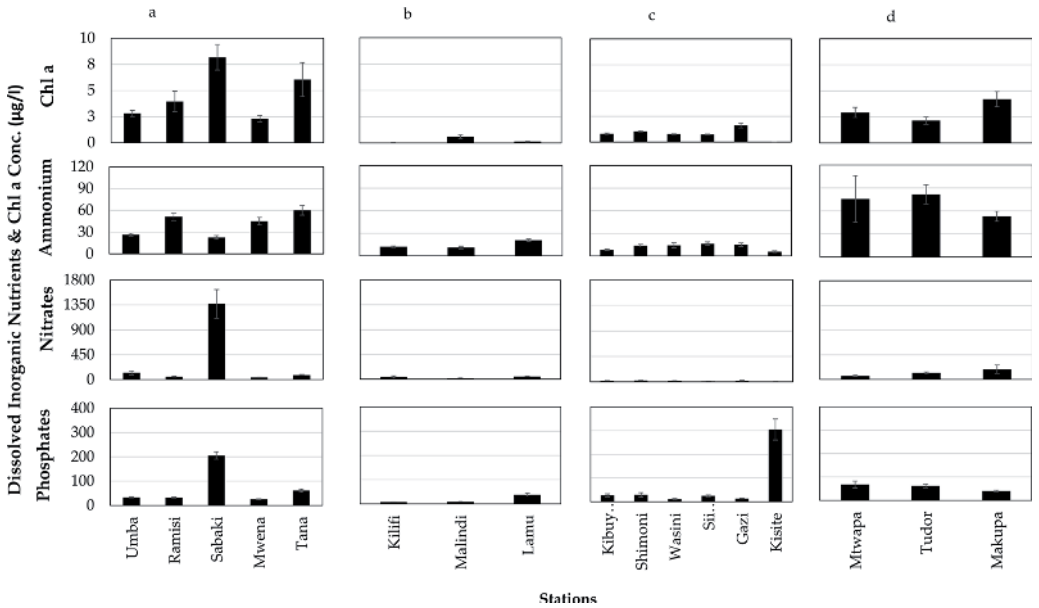

Figure 2.
Showing nutrient phosphates (µg/L), nitrates (µg/L), ammonia (µg/L), and chlorophyll-a (µg/L) distribution pattern observed in: (a) south coast estuaries: Umba, Ramisi, Sabaki, Mwena, and Tana; (b) north coast open water, stations: Kilifi, Malindi, and Lamu; (c) south coast shoreline area: Kibuy (Kibuyuni), Shimoni, Wasini, Sii Island, Gazi, and Kisite; and (d) peri-urban stations of Mombasa: Mtwapa, Tudor, and Makupa.

in this study are similar to those realized by [46, 47] in the Indian Mangroves of 14–600 and 1.00–80 µg/L for nitrates and phosphates respectively. Chlorophyll-a showed a distribution pattern almost similar to that of nutrients with low values recorded in Kilifi (0.03 µg/L) while the highest ranges were observed in River Sabaki (8.19 µg/L).

4.2 Spatial distribution of heavy metals

The aluminum (Al) levels in the peri-urban creeks had a higher concentration range: 0.06–17483.66 µg/g) compared to estuaries (range: 719484.00–9804284.00 µg/g) and pristine area Gazi Bay (335.00 µg/g). The metal concentration seemed normal since aluminum concentrations are not likely to be significantly affected by anthropogenic aluminum sources [47].

Cr concentration levels in estuaries were higher (range: 101.10–239.10 µg/g) compared to Gazi Bay (1.58 µg/g), Lamu port (range: 2.55–7.58 µg/g), and peri-urban creeks (range: 11.53–24.43 µg/g) with an exception of Kilindini harbor that had Cr concentration of 42,338.00 µg/g. The relatively high concentration of Cr in the river could have been caused by mining activities upstream whereas the high level observed in one of the stations in Kilindini could have resulted from the cement bulk storage at Kilindini harbor which is adjacent to the station [48].

Pb concentration in estuaries was higher (range: 45.70–135.60 µg/g) compared to the peri-urban creeks (range: 2.75–40.65 µg/g). These high concentrations could be attributed to both natural and anthropogenic Pb point-source discharges, primarily from its use as a fuel additive, which has made it a pervasive and persistent pollutant worldwide [49]. The concentration reported in this study was, however, lower compared to Pattani Bay (range: 79.00–97.00 µg/g), Thailand Laptev, Russia (range: 16.00–22.00 µg/g; Nolting in press) and the levels previously reported for the Kenyan Coastal Zone (range: 0.13–0.56 µg/g; by [50].

The concentration of Zn was higher in the peri-urban creeks (range: 23.36–264.30 μg/g) compared to the estuaries (range: 144.20–367.20 μg/g) and Gazi Bay (3.82 μg/g). High levels of Zn are associated to the dissolution of sacrificial zinc anodes used in marinas, ships, and on leisure boats at the Kenya ports and water sports areas; the adjacent Kibarani dumpsite is also a contributor since most types of wastes in the dumpsite find their way into Makupa creek [51].

Mn level in estuaries had higher concentrations (range: 3809.00–6781.00 μg/g) compared to peri-urban creeks (range: 16.10–58.50 μg/g) and Gazi Bay (0.77 μg/g). The same trend was observed in Cu levels in which estuaries had the highest concentration (range: 63.30–169.60 μg/g) compared to peri-urban creeks (range: (0.51–52.16 μg/g) and Gazi Bay which was BDL. Cd levels in peri-urban creeks were higher (range: BDL-2.40 μg/g), compared to the pristine area Gazi Bay (0.03 μg/g) (**Table 1**). These values may be attributed to historical industrial activity around the estuaries, that is, gypsum mining in Tana River County; five cement manufacturing companies located in Athi River: Athi River Mining, Bamburi Portland Cement, East African Portland Cement, Savanna Cement, and Simba Cement; and small landfill along Sabaki river [52, 53].

The mean ^{210}Po activities determined in the surface sediment from the three peri-urban creeks ranged between 20.29 and 43.44 Bq kg^{-1} dw. Mtwapa creek had the highest mean (37.56 ± 2.14 Bq kg^{-1} dw) compared to Makupa creek (30.42 ± 2.16 Bq kg^{-1} dw) and Tudor creek (28.64 ± 2.86 Bq kg^{-1} dw). These results are comparable to those of surface sediments from the Venice lagoon ecosystem in Italy in the range of 26–45 Bq kg^{-1} [54].

The high levels of ^{210}Po activity in Mtwapa creek could have originated from the seasonal river (River Mto Mkuu) which flows into the creek discharging finer sediment from the mainland agriculture activities. In addition, high levels of silt and organic matter were found in Mtwapa creek and this may have resulted in high levels of ^{210}Po activity since ^{210}Po tends to adsorb on a finer particle of silt (<63 μm) due to its specific surface area compared to coarse particles (>63 μm) [49, 50]. The same observation was made by Aközcan and Uğur Görgün [57] in Izmir Bay and Didim who attributed high levels of ^{210}Po to Buyuk Menderes river.

4.3 Organic pollutant pollution

PAH concentration in the surface sediment from Ramisi, Sabaki, and Tana rivers was in the range of BDL-0.16, 0.06–7.98, and 0.78–13.20 ng/g, respectively. Higher concentration of PAH in Tana river could be as a result of rapid urbanization, industrialization, gasoline or diesel fuel from fishing boats, and high erosion activities in their catchment areas. The concentrations were, however, lower compared to those reported by Chen and coworkers [58] who recorded concentration ranges of 362.00–15, 667.00 ng/g (dw) for Weihe river, a river draining arid and semiarid regions as Tana river.

The surveyed sites in Lamu, namely, Wange Fish Port, proposed Lamu Port, and Mokowe Fish port, had PAH concentration of less than 10.00 ng/g (dw). This is because the port is still under construction and un-operational. The PAH levels were lower than the levels observed in Kilindini port (range: <50.00–37,800.00 ng/g dw) with a mean concentration of 6086.00 ng/g dw. The PAH level in Kilindini was, however, higher than levels reported by Saleem et al. [59, 53] in Karachi harbor (mean: 27.52 ng/g dw) and [54, 60] in Kaohsiung harbor, Taiwan (range: 472.00–16,201.00 ng/g; mean 5764.00 ng/g). High level of PAH was observed in Kilindini due leakage of combusted and un-combusted fuel from intense shipping activities, oil spills experienced in Makupa creeks, and oil terminal activities in Kilindini

	Pristine environment	Estuaries		Peri-urban			SQG	
Sampling site	**Gazi Bay**	**Sabaki mouth**	**Tana mouth**	**Lamu port**	**Makupa creek**	**Kilindini harbor**	**ER-L**	**ERM-**
Al	335.00	9804284.00	719484.00	659.50–1674.90	17483.66	0.06–2.85	—	NA
As	—	—	—	BDL-3.54	—	<0.01–2.99	33	NG
Cd	0.027	—	—	BDL-0.13	2.4	<0.02–0.11	5	9.6
Co	0.072	—	—	—	—	—	—	—
Cr	1.576	101.10	239.10	2.55–7.58		11.53–42,338	80	370.00
Cu	BDL	63.30	169.60	0.51–2.98	52.16	6.57–15.3	70	270.00
Hg	4.623	—	—	BDL	—	<0.01	0.15	—
Mn	0.757	3809.00	6781.00	16.10–58.5	90.47	—	—	NG
Ni	—	4.90	13.10	—	—	8.47–16.22	30	—
Pb	—	45.70	135.600	BDL	40.65	2.75–11.46	35	218.00
Zn	3.82	144.20	367.20	—	264.3	23.36–38.45	120	410.00

NG: no guideline.
BDL: below detection limit.

Table 1.
Decadal comparison of trace metals of the Kenyan coastal sediment with the set international standards for sediment quality.

port as well as ferry services. This port serves many shipping vessels involved in cargo importation for Kenya as well as the landlocked countries in East Africa. The total OCPs namely HCN, Heptachlor, Hepoxide, 2,4′ DDE, Cis chlordane, Trans Nonachlor, 4,4'DDE, 2,4' DDD, 4,4' DDD, 2,4′ DDT, 4,4′ DDT, and Mirex in sediments from Ramisi, Sabaki, and Tana estuarine areas ranged between ND-0.13, 0.37–1.81, and 0.03–3.94 ng/g respectively. The concentration of OCP reported by this study (range: 0.03–3.94 ng/g) was lower compared to the levels reported for Tana estuary by Lalah et al. [61, 55] (range: <0.003–108.51 ng/g). This confirms the reduction in utilization of the products containing OCPs in Kenya.

The DDT and its metabolites 2,4′ DDE, 4,4′ DDE, 2,4' DDD, 4,4' DDD, 2,4′ DDT, and 4,4′ DDT were detected in the surface sediment in both Sabaki and Tana river estuaries. The highest concentrations of ∑6 DDTs were recorded in Tana river (11.57 ng/g dw) compared to Sabaki (2.34 ng/g dw) and Ramisi (0.23 ng/g dw). This suggests that even though DDT was banned in Kenya in 1986, there could still be illegal use of DDT in Kenya [56].

The DDE-to-DDD ratio for Ramisi, Sabaki, and Tana river estuaries were 0.20, 0.16, and 0.17 respectively, suggesting an aerobic degradation of DDT to DDD in the areas via dehydrochlorination and oxidation processes [18, 62]. The study revealed high ratios (above 0.5) for Ramisi (3.38), Sabaki (2.82), and Tana rivers (2.10), indicating a historical input of DDT into the estuaries. The historical input of DDT into marine environment has similarly been reported by Aly Salem et al. [63] for Egyptian Mediterranean Coast, as well as Lu et al. [28] for Poyang Lake, China. This shows the reduced application of DDT in some part of the world.

High concentration of PCBs was observed in River Tana estuary (range: 4.94–7.99 ng/g dw) compared to concentration in Ramisi (ND-0.15 ng/g dw) and Sabaki (0.58–2.40 ng/g dw) which could be attributed to leakage or inadvertent disposal of materials used in transformers and capacitors along the Tana river channel since Tana river holds the Seven Folks hydropower dams which generate approximately 49% of Kenyan electricity.

4.4 Ecological risk assessment of pollution along the Kenyan Coast

According to [64], some of the estuaries and peri-urban stations (Mwena, Ramisi, Sabaki, Umba, Lamu, Kibuyuni, Sii Island, and Makupa) could be classified as eutrophic given that they have phosphates levels >0.021 mg/L whereas Shimoni and Gazi could be classified as oligotrophic. Trace metal concentrations in estuaries (River Sabaki and Tana mouth) except for Pb and Cr (**Table 1**) in the sediments were below the effect range-low (ER-L)/effect range-median (ER-M). This indicates that high concentration may pose adverse effects [65].

Sediment quality criteria and concentration ranges of PAHs, PCBs, and DDT contaminants are summarized in (**Table 2**). The ∑PAHs, ∑PCBs, and ∑DDT concentration in sediment from Ramisi, Sabaki, and Kilindini were below ER-L and ER-M suggesting the low ecological risk of these compounds to sediment-dwelling

	Ramisi	Sabaki	Tana	Kilindini	Lamu	ER-L	ER-M
∑PAH	0.01–0.16	0.79–3.75	0.78–13.2	<50–37,800	<10	4000	35,000
∑PCB	0.12–0.15	0.58–2.40	4.99–7.99	<10	—	50	400
∑DDT	0.01–0.128	0.22–1.57	0.25–5.23	—	—	3	350

Table 2.
Comparison of PAH, DDT, and PCB (ng/g dw) concentrations in sediments of the study area with the sediment quality guidelines (SQG).

organisms. However, the concentration level of ∑DDT was higher than ER-L in Tana estuary but was significantly lower than the ER-M values suggesting that the accumulated DDT in sediments in Tana estuary could have a potential ecotoxicological impact on the benthic fauna.

5. Conclusion

From the study, it is evident that human influences like urbanization and agricultural activities are the major nutrient contributors to the marine environment through continuous discharge of untreated sewage effluents and agricultural runoffs delivered by rivers. Trace metal concentrations in estuaries, peri-urban creeks, and Lamu port were below the ER-L and ER-M indicating that there are no potential adverse effects on marine biota with an exception of Kilindini harbor that had a higher Cr concentration that may pose adverse effects. The concentrations of PAH, PCB, and OCP were generally high in Tana estuary as compared to the other estuaries in this study; however, the concentrations were lower than ER-L suggesting no potential impacts on organisms. It was also observed that the concentration level of ∑DDT was higher in Tana estuary than ER-L and lower for ER-M values suggesting that the accumulated persistent organic pollutants in sediments from Tana estuary could have a potential ecotoxicological impact on the benthic fauna. It is therefore important to put in place effective sewage and wastewater management strategies and implement good agricultural practices to manage the emerging pollution problem along the Kenyan Coast. A monitoring program for these pollutants is also important so as to always have an early warning.

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