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Coastal Marine Pollution in Dar es Salaam (Tanzania) relative to Recommended Environmental Quality Targets for the Western Indian Ocean

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Keywords: Dar es Salaam, environmental quality targets, heavy metals, marine pollution, microbial pollution, persistent organic pollutants.

Abstract—Pollution surveys were undertaken during 2007 and 2008 in the coastal marine environment of Dar es Salaam and the remote Ras Dege Creek. The objective was to determine the levels of microbial contamination, heavy metals and persistent organic pollutants and compare these with the recommended environmental quality targets (EQTs) for the West Indian Ocean (WIO). Levels of microbial pollution in urban coastal waters off Dar es Salaam were excessive, indicating that water within the port channel was not safe for contact recreation. Seafood from areas adjacent to Msimbazi Creek and the Ocean Road sewer outfall was unfit for human consumption. Conversely, the water quality of Ras Dege Creek was excellent for contact recreation as well as for the collection of seafood. Concentrations of heavy metals, even in the coastal marine environment off Dar es Salaam, were not significantly high compared with the recommended EQTs. Although some persistent organic pollutants exceeded the recommended EQTs in sediment and oysters along the coast of Dar es Salaam, this was not the case at Ras Dege. The lack of sufficient wastewater treatment facilities is the main cause of current levels of some pollution in the coastal marine environment off Dar es Salaam. The implementation of industrial and municipal wastewater management would greatly improve this situation. The results show that the proposed EQTs would constitute appropriate standards for coastal marine water quality in Tanzania.

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INTRODUCTION

The WIO region is composed of five mainland states (Somalia, Kenya, Tanzania, Mozambique and South Africa) and four island states (Comoros, Madagascar, Mauritius and Seychelles) with a combined coastline of more than 15,000 km. The region has a wide variety of marine habitats, such as coral reefs, estuaries, lagoons, sandy beaches, mangrove wetlands and seagrass meadows. For generations the coastal area has sustained coastal communities and fisheries have played a major role in their social and economic development. In recent years, coastal tourism and mariculture have become important economic activities in the WIO region. The sustainability of these activities and the coastal marine habitats and resources they depend on relies, to a large extent, on a healthy environment.

In Tanzania, about 80% of its industries are located in Dar es Salaam. These include: Food, beverage and animal feed processing; chemical and cosmetic production; metal product manufacture; paper product, printing and publishing industries; wood product manufacture and construction materials production; electrical appliance and battery industries; motor vehicle servicing; glass product manufacture; ginnery and tobacco processing; and mining. In addition, tourism and the hospitality industry are centred around the city's beaches. The marine environment off Dar es Salaam receives pollutants from these sources through streams, sewer and storm water outfalls. Some of the streams also drain the densely-populated areas of the city. Even though the level of industrialization is still low, untreated municipal and industrial wastewater discharges cause significant localised pollution (Machiwa, 1992, Machiwa,

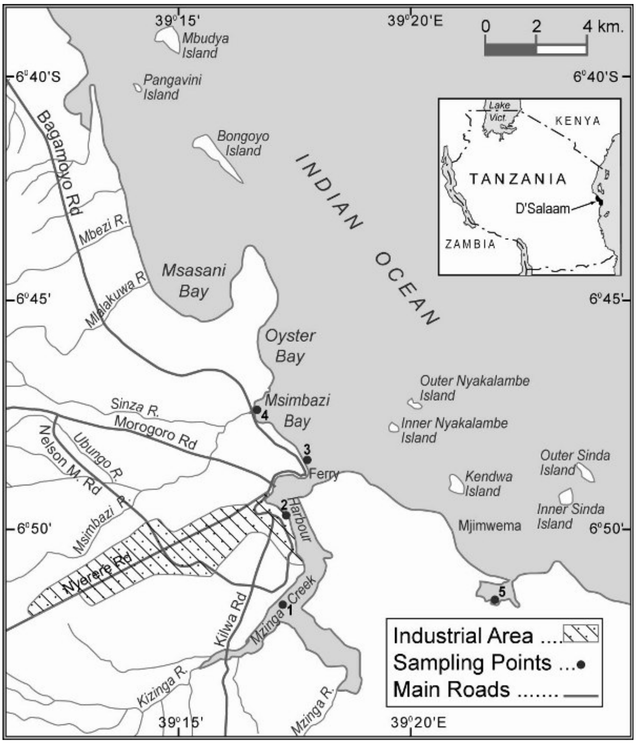

Fig. 1. Map of Dar es Salaam showing the sampling stations in the coastal marine areas (Station 1- Mtoni Creek; Station 2 – Port entrance channel; Station 3 – Ocean Road; Station 4 – Msimbazi Creek; Station 5 – Ras Dege Creek).

2000, DeWolf *et al.*, 2001, Mwevura *et al.*, 2002, Mremi & Machiwa, 2003; Mtanga & Machiwa, 2007). The coastline of Dar es Salaam from Msimbazi Creek to Mzinga Creek is considered to be a pollution hotspot (Mohammed *et al.*, 2006). The Msimbazi River drains a large proportion of the city's industrial and residential area, while the Mzinga and Msimbazi rivers receive domestic waste and effluents from industries located along Nyerere, Morogoro and Mandela Roads. Apart from these land-based sources of pollution, pollutants are also directly introduced to the coastal waters from shipping activities. The purpose of this paper was to present current data on pollution in the coastal marine environment of Dar es Salaam relative to the recommended environmental quality targets (EQTs) for the Western Indian Ocean (UNEP & CSIR, 2009).

MATERIALS AND METHODS

Study site

The coastline of Dar es Salaam is located between latitudes 6º27´and 7º15´S and longitudes 39º and 39º33´E, extending about 100 km from the Mpiji River in the north to the Mzinga River in the south (Fig. 1). The Dar es Salaam Region includes the Ilala, Kinondoni and Temeke municipal districts, with a total land area of about 1,350 km^2. Dar es Salaam has an estimated population of about three million people with an average annual growth rate of about 8%. About 70% of the urban population live in unplanned settlements (NBS, 2004, 2009). Ras Dege Creek (RDC), situated about 100 km from the city of Dar es Salaam, was sampled as an unpopulated reference location remote from the city.

Sample collection and analysis

Samples were collected in 2007 and 2008 at four sampling stations adjacent to wastewater or river discharges in Dar es Salaam and one station in RDC (Fig. 1). Station 1 was located at Mtoni (MTC) near the confluence of the Mzinga and Kizinga Creeks, Station 2 was located within the port entrance channel (PEC), Station 3 was located in the subtidal zone at Ocean Road (ORA), and Station 4 was located in the subtidal zone near Msimbazi Creek (MSC). Station 5 was the reference site located within RDC.

Water samples for microbial analysis were taken from the surface using 250 ml sterile serum bottles rinsed with sea water from at the sampling sites. The bottles were immersed below the water surface and turned upright to collect the samples. Water samples were immediately transported to the laboratory in a cool box for analysis of total coliforms, faecal coliforms, *E. coli*, enterococci (faecal streptococci), *Salmonella* and *Staphylococcus aureas*. The analysis of faecal bacteria concentrations was based on most probable numbers

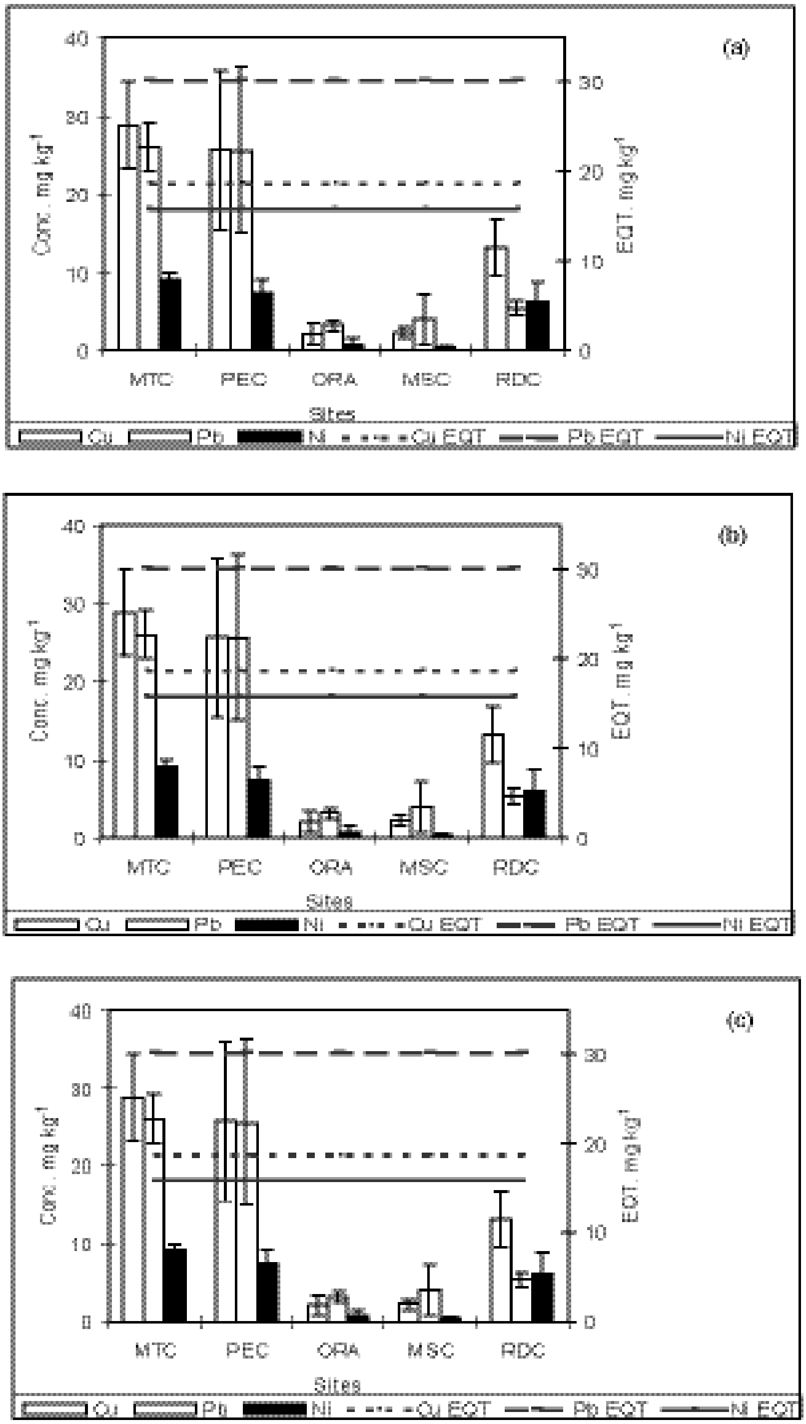

Fig. 2. Mean (± SD) concentration of (a) copper, lead and nickel (b) chromium and zinc, and (c) cadmium and total mercury in sediment samples with their Recommended Environmental Quality Targets (EQTs).

(MPNs) according to the standard methods (APHA, 2005).

Subtidal sediment samples were collected using a van Veen grab and placed in clean glass bottles for organic contaminants analysis and in polyethylene bags for metals analysis. The samples were kept frozen until they were analysed. Sediment samples were oven-dried at 60º C, sieved through 1 mm nylon sieve and thoroughly homogenized before analysis.

Oyster samples (*Saccostrea cucullata*) were collected from Mtoni Creek and RDC mangrove stands. Samples for heavy metal analysis were stored in polyethylene bags and those for persistent organic pollutant analysis were kept in pre-cleaned aluminium foil. Samples were transported to the laboratory in a cool box where they were washed with distilled water, weighed and kept frozen at –20ºC until processed. The frozen oyster samples were thawed before they were opened, the soft tissues were removed and oven-dried at 50ºC. The dried oyster tissue was ground into fine powder using a mortar and pestle.

About 2 g sub-samples of finely powdered sediment samples and 1 g of well-homogenized oyster tissue were accurately weighed and placed in separate 100 ml flasks. The sediment and oyster samples were digested using aqua regia (HNO_3 : HCl, 1:3 v/v) and analyzed for copper (Cu), cadmium (Cd), lead (Pb), chromium (Cr), zinc (Zn) and nickel (Ni) using ICP-OES (model Vista MPX^{TM}) in accordance with Thomson and Wash (2003). The concentrations of these metals were recorded per unit dry weight.

Total mercury (Hg) was determined in the sediment and undried oyster flesh following the procedure of Akagi and Nishimura (1991). Mercury was analysed using a semi-automatic mercury analyser (Sanso Seisakusho Co. Ltd model HG 201).

Table 1. Microbial counts (MPN/100 ml) in coastal waters at various locations in Dar es Salaam and Ras Dege. The 95th percentile for Enterococcus/100 ml is in parentheses.

Site	Total coliforms	Faecal coliforms	*Escherichia coli*	*Enterococcus*
MTC	79 – 2 400	33 – 1 600	4 – 17	133 – 1 340 (1034)
PEC	49 – 240	23 – 49	4 – 9	17 – 33 (31)
ORA	3 500 – 24 000	1 800 – 3 500	7 – 70	110 – 920 (680)
MSC	9 200 – 24 000	2 400 – 9 200	9 – 17	33 – 220 (220)
RDC	13 – 30	6 – 14	0 – 7	5 – 10 (10)

Table 2. Recommended risk-based Environmental Quality Targets (EQTs) for application in coastal waters used for contact recreation in the WIO region based on estimated risk per exposure to gastrointestinal illness (GI) and acute febrile respiratory illness (AFRI).

Risk Category	95th Percentile of enterococci/100ml	Estimated risk per exposure
A (very good)	<40	<1% GI risk; <0.3% AFRI risk
B (good)	40 – 200	1 – 5% GI risk 0.3 – 1.9% AFRI risk
C (fair)	201 – 500	5 – 10% GI risk 1.9 – 3.9% AFRI risk
D (poor)	>500	>10% GI risk >3.9% AFRI risk

Quality control for metal analysis included procedural blanks, and measurement of the Certified Reference Materials (CRMs): DORM-2 (Dogfish muscle) DOLT-2 (Dogfish liver) PACS–2 (Marine sediment) from the National Research Council, Canada, and IAEA–436 from the International Atomic Energy Agency. The recovery values for the analysed metals were above 80%. Certified reference materials used for organic pollutants were IAEA–432 (mussel homogenate) and IAEA–417 (sediment). Recoveries ranged between 60 % and 110 %.

Persistent organic pollutants were extracted from sediment and oyster tissue samples in dichloromethane using Soxhlet apparatus. Samples for petroleum hydrocarbon determination were cleaned using pre-heated silica gel, alumina and activated copper. (Fig. 2b), the former value being above the recommended EQT (52.3 mg kg^{-1}). This may pose a threat to marine life in the area. Indeed, the

Table 3. Mean concentration (± SD) of total mercury (mg kg^{-1} ww) and other metals (mg kg^{-1} dw) in oysters from Mtoni and Ras Dege compared with FAO/WHO (2002) Codex alimentarius guideline levels for contaminants and toxins in food.

	Mtoni	Ras Dege	FAO/WHO
Cadmium	0.79 ± 0.21	0.04 ± 0.01	1.0
Chromium	24.3 ± 4.6	0.3 ± 0.1	-
Copper	38.8 ± 9.1	0.5 ± 0.2	-
Lead	1.2 ± 0.8	0.3 ± 0.2	1.0
Zinc	78.4 ± 16.3	21.9 ± 4.5	-
Mercury	0.536 ± 0.036	0.055 ± 0.026	0.5

concentration of Cr in oyster samples from Mtoni was an order of magnitude higher than samples from RDC (Table 3), suggesting that oysters at Mtoni accumulate Cr from the environment, affecting their quality as seafood. The concentration of Zn in sediment was highest (71.2 mg kg^{-1}) in samples from Mtoni (Fig. 2b) but was below the recommended EQT (124 mg kg^{-1}). Oyster samples from Mtoni similarly had higher concentrations (78.4 ± 16.3 mg kg^{-1}) of Zn, about four times higher than samples from RDC (Table 3). The nearby solid waste disposal site is a potential source of this element. Concentrations of Cd in sediment samples from Mtoni, the port entrance channel, Ocean Road and RDC were below the detection limit (<0.01 mg kg^{-1} dw), and detectable amounts of Cd in samples from Msimbazi were well below the recommended EQT (Fig. 2c). Cadmium in oyster samples from Mtoni was 0.79 ± 0.21 mg kg^{-1} dw, and 0.04 ± 0.01 mg kg^{-1} in samples from RDC. The relatively high concentration of Cd in oyster samples from Mtoni suggests contamination of the water. Concentrations of Hg were generally below the recommended EQT for sediment (0.13 mg kg^{-1}) except at Mtoni where the Hg concentration (0.093 ± 0.033 mg kg^{-1}) approached the recommended EQT (Fig. 2c). The concentration of Hg in oysters from Mtoni also approached the upper limit recommended in FAO/WHO guidelines (Table 3).

Apart from copper and lead, these results suggest that the current levels of heavy metals in the marine coastal waters off Dar es Salaam are not excessive relative to the recommended EQTs. It is unfortunate that land-based sources of heavy metal pollution cannot be pinpointed because of lack of data on the quality of industrial effluents. However, the nearby refuse dumpsite is a likely source of some of these heavy metal pollutants. Inappropriate industrial wastewater handling is the other major cause of the elevated levels of some heavy metals. The establishment and implementation of an industrial wastewater management framework would improve the quality of industrial wastewater, and hence the quality of the Dar es Salaam coastal marine environment.

Persistent organic pollutants in sediment and oysters

Organochlorine pesticide residues were generally higher in sediment and oyster samples from Dar es Salaam, compared with RDC (Table 4). The concentration of total dichloro-diphenyl trichloroethane (DDT), however, was lower in sediment and oysters compared with its metabolites DDD and DDE, for which concentrations were above the recommended EQTs in sediment. Apart from its previous use in the control of malaria, the insecticide DDT has also been used in vegetable gardens in the city (Mwevura *et* *al.,* 2002). Other organochlorine compounds like the polychlorinated biphenyls (PCBs) Samples for polycyclic aromatic hydrocarbons (PCBs) and organochlorine pesticides were analysed according to the methods described by Brownawell & Farrington (1986) and Åkerblom (1995). PCBs, pesticides and petroleum hydrocarbons were analysed by high resolution dual capillary column gas chromatography (Hewlett-Packard 5840) using ECD/FID and confirmed by GC/MS.

RESULTS AND DISCUSSION

Microbial contamination in seawater

The highest counts of faecal coliforms, enterococci and total coliforms were found in water samples from Mtoni, Ocean Road and Msimbazi (Table 1). Total and faecal coliform counts were highest in samples from Msimbazi followed by samples from the Ocean Road area. It was clear that the cause of high microbial pollution at the two locations was untreated wastewater discharge; there is a sewer discharge extending about 150 m into the water at Ocean Road beach and the outfall does not extend far enough for offshore transport to prevent pollution of the inshore water. High levels of contamination in Msimbazi Creek are also caused by a significant wastewater discharge.

The proposed EQTs recommend that faecal coliforms be the preferred microbial indicator to assess coastal water quality where shellfish are collected for direct human consumption (UNEP & CSIR, 2009). The median concentration of faecal coliforms should not exceed 14 MPN/100ml in a 5 tube, 3-dilutions method. In coastal waters that are used for contact recreation, risk-based EQTs have been recommended (UNEP & CSIR, 2009; WHO, 2003; Kay *et al.*, 2004). The risk levels and a range of target values are presented in Table 2. *Enterococci* (*faecal streptococci*) are proposed as the microbial indicator for recreational waters, and are considered to be the most suitable indicator for marine waters (although in the case where faecal pollution originates from a waste stabilisation pond, *E. coli* may be the more appropriate indicator).

Based on the recommended risk-based EQTs for microbial water quality assessment, it is clear that coastal waters off the city of Dar es Salaam, from Msimbazi Creek southward to Mtoni, are not safe for contact recreation or the collection of seafood for direct human consumption. RDC, an area which is remote from the city of Dar es Salaam, has low levels of microbial contamination. Based on the microbial indicator results, the water quality of RDC is good for contact recreation and the collection of shellfish for human consumption. Generally, the marine areas where microorganism densities were high are located close to point pollution sources. Proper management of municipal and industrial wastewater in urban Dar es

Salaam would improve the quality of its wastewater, thus reducing the level of the microbial pollutants in the receiving coastal waters.

Heavy metals in sediment and oysters

The concentrations of metals measured in sediment samples are presented in Figure 2a-c. The concentration of Cu in sediment samples from Mtoni (MTC) (28.8 ± 5.5 mg kg-1 dw) and the port entrance channel (PEC) (25.7 ± 10.2 mg kg^{-1} dw) was about twofold the concentration in samples from RDC. This is excessive relative to the recommended EQT for Cu (18.7 mg kg^{-1} dw) (Fig. 2a). The concentration of Cu was low in the sediment samples from Ocean Road and Msimbazi Creek, despite the high input of wastewater at these sites. The concentration of Cu in oyster samples from Mtoni was higher compared to oyster samples for the RDC (Table 3), suggesting the accumulation of this element in these filter-feeding marine organisms.

Previous studies also reported high Cu concentrations in sediment in the mangrove wetlands close to Dar es Salaam compared with mangrove stands in areas remote from the city (DeWolf *et al.,* 2001, Mremi and Machiwa, 2003). The potential sources of Cu to the coastal waters include the various industries in the city but it is unfortunate that the available data does not implicate any specific industry in view of the high levels of Cu in the sediment.

The concentration of Pb was similarly higher in sediment samples from Mtoni and the port entrance channel compared to the rest of the sites (Fig. 2a). A few stations in the port entrance channel had Pb levels higher than the EQT (30.2 mg kg^{-1}) for this element. Concentrations of Pb in oyster samples were 1.2 ± 0.8 mg kg^{-1} and 0.3 ± 0.2 mg kg^{-1} in samples from Mtoni and the RDC, respectively. The Pb level in oysters from Mtoni was slightly above the guideline recommended by the FAO/WHO (2002). The potential sources of Pb in the coastal waters off Dar es Salaam include contaminated storm water runoff from the city roads and garages as a result of previous usage of leaded petrol. Further contributions possibly come from runoff from paint shops and a nearby dumpsite.

Nickel concentrations in sediments were low relative to the recommended EQT (Fig. 2a). This is not uncommon since Ni is infrequently used in industrial manufacturing. Concentrations of Cr in sediment samples from Mtoni and the port entrance channel were 57.6 ± 8.2 and 35.6 ± 6.1 mg kg^{-1} respectively (Fig. 2b), the former value being above the recommended EQT (52.3 mg kg^{-1}). This may pose a threat to marine life in the area. Indeed, the concentration of Cr in oyster samples from Mtoni was an order of magnitude higher than samples from RDC (Table 3), suggesting that oysters at Mtoni accumulate Cr from the environment, affecting their quality as seafood. The concentration of Zn in sediment was highest (71.2 mg kg^{-1}) in samples from Mtoni (Fig. 2b) but was below the recommended EQT (124 mg kg^{-1}). Oyster samples from Mtoni similarly had higher concentrations (78.4 ± 16.3 mg kg^{-1}) of Zn, about four times higher than samples from RDC (Table 3). The nearby solid waste disposal site is a potential source of this element. Concentrations of Cd in sediment samples from Mtoni, the port entrance channel, Ocean Road and RDC were below the detection limit (<0.01 mg kg^{-1} dw), and detectable amounts of Cd in samples from Msimbazi were well below the recommended EQT (Fig. 2c). Cadmium in oyster samples from Mtoni was 0.79 ± 0.21 mg kg^{-1} dw, and 0.04 ± 0.01 mg kg^{-1} in samples from RDC. The relatively high concentration of Cd in oyster samples from Mtoni suggests contamination of the water. Concentrations of Hg were generally below the recommended EQT for sediment (0.13 mg kg^{-1}) except at Mtoni where the Hg concentration (0.093 ± 0.033 mg kg^{-1}) approached the recommended EQT (Fig. 2c). The concentration of Hg in oysters from Mtoni also approached the upper limit recommended in FAO/WHO guidelines (Table 3).

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Table 4. Concentration (µg kg^{-1} ± SD dw) of organic pollutants in sediment and oyster from Dar es Salaam and Ras Dege with the Recommended Environmental Quality Targets (EQTs) for sediment. Values that exceed the EQT are in bold.

Organic	Dar es Salaam		Ras Dege		EQTs	
Pollutant	Sediment	Oyster	Sediment	Oyster	(sediment)	
Organochlorine pesticides						
Total DDTs	<1.0	2.1±1.1	<1.0	<1.0	3.89	
DDD	6.5±3.4	9.2±2.7	<1.0	<1.0	-	
DDE	7.1±1.6	31.3±11.4	<1.0	<1.0	2.2	
Dieldrin	1.0±1.0	3.0	<1.0	<1.0	0.72	
Polychlorinated biphenyls						
Total PCBs	11.2±2.1	-	-	-	21.6	
Polycyclic Aromatic Hydrocarbons (PAHs)	27.4±8.5	45.1±11.9	10.7±3.6	12.6	34.6	
Naphthalene Acenaphthylene		<1.0	<1.0	<1.0	<1.0	-
Acenaphthene	6.5±0.5	10.5±3.5	3.0±2.0	2.6	6.71	
Fluorene	21.0±3.8	13.5±4.5	10.0±6.4	3.0	21.2	
Phenanthrene	55.0±46.0	11.0±2.8	46.5±33.2	20.3	86.7	
Anthracene	39.2±28.7	1.0	30.0±14.1	1.5	46.9	
Chrysene	43.0±15.4	8.5±0.7	6.1±2.8	1.0	108	
Fluoranthene	59.2±47.4	4.5±2.1	42.5±19.5	6.4	113	
Pyrene	38.2±14.9	20.0±4.2	26.0±13.2	16.6	153	
Benzo[a]anthracene	53.6±17.2	2.5±0.7	5.0±2.8	1.0	74.8	
Benzo[b]fluoranthene	61.3±31.3	4.0	2.5±2.1	1.1	-	
Benzo[a]pyrene	24.2±9.7	<1.0	2.0±1.4	<1.0	88.8	
Indeno[c,d]pyrene	38.7±13.3	1.0	4.5±2.5	<1.0	-	
Dibenzo[a,h]anthracene	3.5±2.1	1.0	<1.0	<1.0	6.22	
Benzo[g,h,i]perylene	4.3±1.9	1.5±0.7	2.5±1.3	<1.0	-	

Polyaromatic hydrocarbons (PAHs), resulting mainly from petroleum spillage, were detected in sediment and oyster samples from Dar es Salaam and Ras Dege. Benzo[a] pyrene, a potent carcinogen and an indicator of petroleum hydrocarbon pollution, was detected in sediment samples from both Dar es Salaam and RDC. However, the levels were below the recommended EQT (Table 4). Oyster samples did not contain detectable concentrations of this compound. Concentrations of phenanthrene, anthracene and fluoranthene were higher in the subtidal sediments off Dar es Salaam than in samples from RDC but below the recommended EQTs.

The presence of petroleum hydrocarbons in the marine environment is presumed to result from shipping activities including accidental spillage, runoff containing oil from service stations and garages and municipal wastewater. Even though levels of most petroleum hydrocarbons were below the recommended EQTs, efforts should be made to control accidental spillages as well as reduce the levels of these compounds in wastewater and runoff from the city.

CONCLUSION

Based on a comparison with proposed EQTs for the WIO region, results from this study suggest that the level of microbial pollution in the coastal marine environment adjacent to urban areas of Dar es Salaam is excessive. In fact, the current status indicates that the waters within the port channel were not safe for contact recreation. Seafood from areas adjacent to Msimbazi Creek and the Ocean Road sewer outfall was unfit for human consumption due to high microbiological counts. The water quality in RDC, situated in a rural area, was excellent for contact recreation as well as the collection of seafood for human consumption. Concentrations of heavy metals at all sites were not significantly high relative to the recommended EQTs. Although some persistent organic pollutants in sediment and oysters along the coast of Dar es Salaam exceeded the recommended EQTs, concentrations of persistent organic pollutants in sediments and oyster were below the recommended EQTs in the rural area (Ras Dege).

It is obvious that insufficient wastewater treatment facilities are the main cause of the current elevated levels of some pollutants in Dar es Salaam. The establishment and implementation of industrial and municipal wastewater management would greatly enhance the quality of the coastal marine environment of the urban areas of the city. Furthermore, this study showed that the recommended EQTs for the WIO region, even though developed at a more generic level, are applicable to the coastal marine environment of Tanzania and would provide standards for wastewater disposal.

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