Int. J. Environ. Res., 5(4):865-874, Autumn 2011
ISSN: 1735-6865

Sewage pollution in the Coastal waters of Mombasa City, Kenya: A norm Rather than an Exception

Okuku, E. O.[1,2*], Ohowa, B.[1], Mwangi, S. N.[1,4], Munga, D.[3], Kiteresi, L. I.[1], Wanjeri, V. O.[1], Okumu, S.[1] and Kilonzo, J.[1]

[1] Kenya Marine and Fisheries Research Institute, P.O. Box 81651, Mombasa, Kenya

[2] Soil and Water Management Division, Faculty of Bioscience Engineering, Katholike Universiteit Leuven, Kasteelpark Arenberg 20, B-3001 Heverlee, Belgium

[3] Mombasa Polytechnic University, P.O. Box 90420- 80100, Mombasa, Kenya

[4] University of Nairobi, P.O. Box 30197, G.P.O, Nairobi, Kenya

Received 22 Nov. 2010; Revised 14 Feb. 2011; Accepted 3 March 2011

ABSTRACT: This study investigated the effects of sewage discharge on nutrient concentrations and BOD_5 levels in the coastal waters and sediments ofthe City of Mombasa. The results indicated that nutrient concentrations in Tudor, Mtwapa and Makupa Creeks were elevated as compared to concentrations in Gazi Creek (mean ranges of 0.022-0.039mg/L, 0.038-0.163mg/L and 0.034-0.118mg/Lphosphates, nitrates and ammonium respectively). Sediments were found to harbour relatively higher concentrations of nutrients than water compartment (mean ranges of 0.217-1.131mg/L, 0.199-0.603mg/L and 9.394-26.73mg/L for phosphates, nitrates and ammonium respectively) thus serving as a reservoir and potential source if sediments are re-suspended during heavy storms or dredging. Based on Chl-a levels, Makupa Creek could be classified as eutrophic whereas Mtwapa and Tudor Creeks could be placed at the upper limit of higher mesotrophy while Gazi Creekcould be considered as an oligotrophic system. Of the three impacted Creeks, Tudor was found to be the most polluted.

Key words: Pollution, Nutrients, Eutrophication,Chlorophyll a, Sewage

---

INTRODUCTION

The importance of marine resources is acknowledged worldwide. Coastal fisheries play a pivotal role in the livelihoods and cultures of many coastal communities. More than one third of the world's population live in the coastal zone which is just a narrow strip constitutingonly 4% of the total land surface (UNEP, 2006). Rapid increase in population, food production, urbanization and coastal development in most of the world's coastal regions are causing serious environmental concerns such as marine pollution (Looser *et al.*, 2000; Seitzinger *et al.*, 2005; Bhatnagar and Sangwan, 2009). Clark and Attrill, (2001) identified oil, sewage, garbage, chemicals, radioactive waste, and thermal pollution as some of the common types of pollution in marine ecosystems. Approximately 80% of marine pollution originates from land-based sources that reach estuaries and coastal waters via non-point runoff, direct deposit of waste and atmospheric fallout (GESAMP, 1990; Vijay *et al.*, 2008; Li and Daler, 2004). Despite this significant contribution of land-based activitiesto coastal pollution, it has not been given adequate attention (UNEP, 2006).

Most eutrophication and organic loading problems in coastal regions in the world are linked to discharge of sewage effluent and dumping of sewage sludge (Subramanian, 1999). Coastal ecosystems serve as receptors for industrial and municipal effluents (Clark, 1992; Palanisamy *et al.*, 2007).Sewage can simply be defined as a cocktail of waste from food preparation, dishwashing, garbage-grinding, toilets, baths, showers and sinks. It contains a wide variety of dissolved and suspended materialsas well asdisease-causing microorganisms. When small quantities of sewage are discharged into the ocean, a natural self-purification process occurs. However, densely populated

---

*Corresponding author E-mail: eokuku@kmfri.co.ke

communities generate such large quantities of sewage that dilution alone cannot avert pollution incidences. Sewage pollution has been identified as one of the most serious of all land-based threats to the marine environment and as an area where least progress has been achieved (UNEP, 2006). Between 80-90% of sewage is dischargedintothe coastal zones of many developing countries untreated(UNEP, 2006). With the current population level, man has the potential to pollute every single waterway, ocean and drinking water supply with raw sewage if no urgent measures are put in place.

Sewage-contaminated water introduces high levels of nutrients which cause eutrophication in receiving water bodies. Nitrates, phosphates and organic matter found in human waste serve as food for algae and bacteria. This makes these organisms to rapidly increase in number to the point that they use up most of the dissolved oxygen that is naturally found in water, making it difficult for other organisms in such aquatic environments to live. It is a scenario of bacteria basically "strangling" the other organisms. Moreover, biotic communities in sewage impacted environments are commonly exposed to a multitude of contaminants (Michael and Kennish, 1998) and disease-causing microorganisms. This situation puts human and wildlife health(Jenssen, 2003) as well as livelihoods (from fisheries to tourism) at risk through reduction of biodiversity and productivity (López-Gappa *et al.*, 1990;Hunter and Evans, 1995) and aesthetic and intrinsic value of the marine environmentespecially when sewage discharge occurs into relatively shallow and sheltered coastal areas (as is the case in Kenya). Sewage discharge is one of the main sources of coastal water pollution in Kenya. Mombasa city has only one sewage treatment facility which had previously stalled for several years and is currently only working at 50% capacity after renovation works. This 50% capacity can barely serve even 12% of the Mombasa City population leading to volumes of sewage being discharged either untreated or slightly treated.

The status of coastal water is an important indicator of environmental quality in terms of pollution load and related issues. The information on these aspects is important for highlighting the need for urgent planning and action in these areas. The objective of the present study was to assess the levels of sewage pollution and determine its effects and fate once it is discharged into the Kenyan coastal waters.

MATERIALS & METHODS

Sampling was conducted during 2008-2010sampling campaigns and covered both dry and wet seasons.Sampling sites were chosen to cover a wide range of stations with different levels of sewage inputs. Three Mombasa Creeks (Tudor, Makupa and Mtwapa)were sampled as impacted areas whereas Gazi Creek(located more than 55 km from Mombasa City) was included in the study as a relatively pristine area to provide background concentrations (Fig. 1). According to this criteria, the sampling sites considered in this study were Fort Jesus (FOJE), Madumbini (MDB), Coast General Hospital (CGH) Nyali Bridge (NYBR), Kenya Meat Commission slaughter (KMC) and Mikindani (MIK) in Tudor Creek; Makupa Bridge (MKBR), Makupa Causeway (MKCW), Makupa mangroves (MKMA), Makupa Channel (MKCH)and Makupa Dumpsite (MKDS) in Makupa Creek; and Mtwapa Ferry (MTFE), Mtwapa Bridge (MTBR), Mtwapa Prisons (MTPR) and Mtwapa Mouth (MTMO) in Mtwapa Creeks. In Gazi Creek, samples were collected from old and new fish landing beaches.

From each sampling site, three replicate surface water samples for nutrients analysis were collected in polyethylene bottles (prewashed in acid) and stored frozen prior to analysis.Threereplicate water samples were taken in borosilicate bottles for 5 days Biological Oxygen Demand (BOD_5)and Dissolved Oxygen (DO)measurements. Chlorophyll a (Chl-a) samples were collected from each site by filtering one litre of surface water on Glass Fibre Filters (GFF filters) under low suction. Three random sediment samples for nutrients analysiswere collected to a depth of 16 cm from Makupa, Mtwapa and Gazi Creeks using plastic hand corers (Ø 8 cm) and extraneous material (such as debris and stones) removed.Sediments samples were sectioned at the resolutionsof 0-2, 2-4, 4-8, 8-12 and 12-16cm, placed in clean polythene zip bags and kept frozen prior to analysis. Makupa and Mtwapa Creeks were chosen for sediments sampling to give different degrees of sewage impacts whereasGazi Creekwas included as a reference site.

The methods described by Parsons *et al.*, (1984) and APHA, (1995) were used to analyse ammonium (NH_4^+-N), Nitrate + Nitrite {(NO_2^- + NO_3^-)-N}, and orthophosphate (PO_4^{3-}-P) in water samples and sediments.The extraction of nutrients from sediments samples was carried out following the procedure described by USDA, (2004)which involved treatment of samples with KCl, centrifugation and filtration using GFFfilter papers. Orthophosphate was determined using ascorbic acid method and measured calorimetrically at a wavelength of 885 nm using UV vis spectrophotometer. Ammonium-N was determined using indophenol method and absorbance read at 630 nm after at least six hours. Dissolved (nitrate and nitrite)-N was determined using cadmium reduction method and determined calorimetrically at a wave-

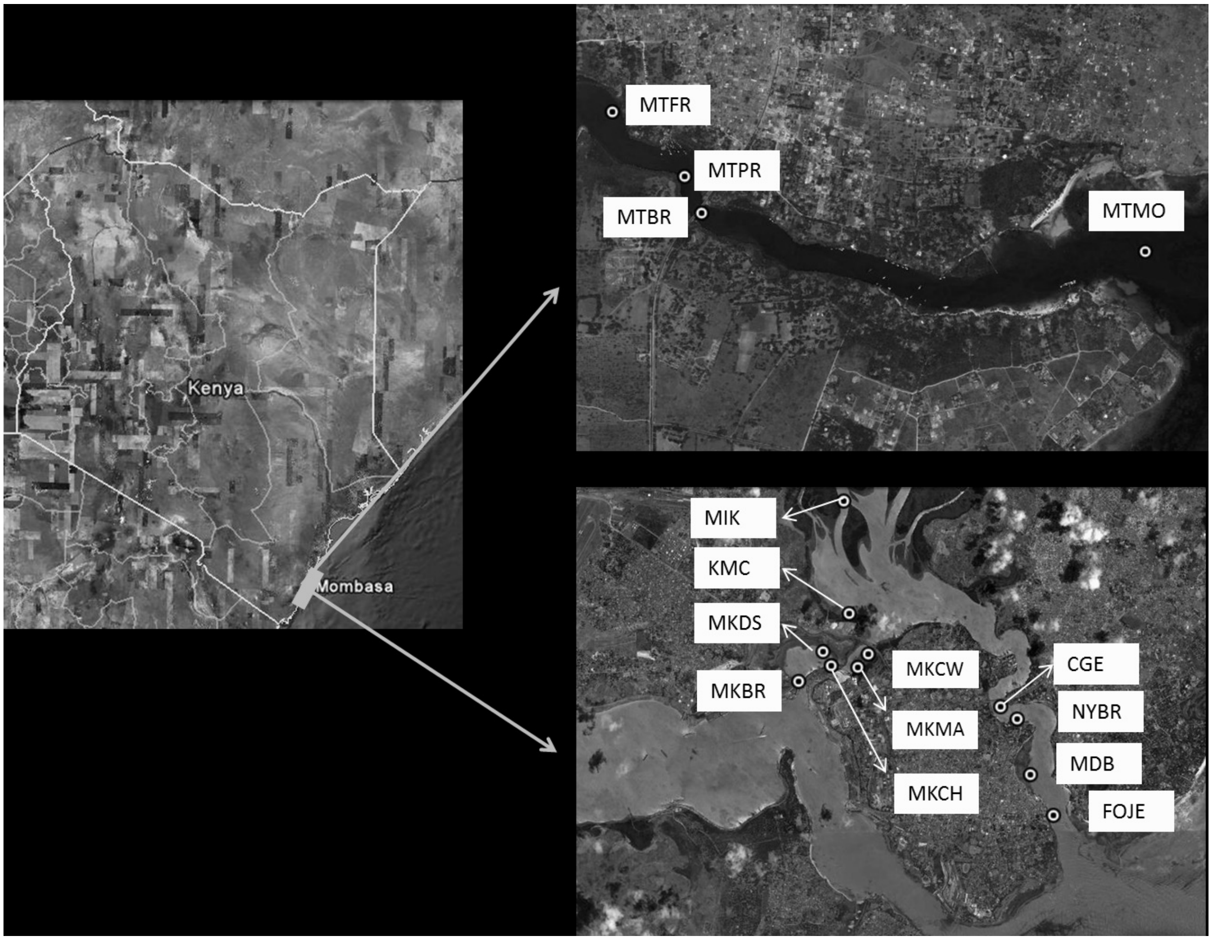

Fig. 1. Map of the study area showing sampling stations

length of 543 nm. DO and BOD_5 was determined by the modified Wrinkler method (APHA, 1992). Chl-a was measured spetrophotometrically using acetone extracts from seston retained on GFF filter papers. All chemicals used were of analytical grade and all the glassware were acid pre-washed before use. For all the analysis, procedural blanks were included. The accuracy and the consistency of the analytical procedure was determined by analysing check standards (which had an absorbance at the middle range of the calibration curve) analysed after every 20 samples.

RESULTS & DISCUSSION

Nutrients concentrations were found to be higher in Tudor Creek with means of 0.039mg/L, 0.163mg/Land 0.118mg/Lfor orthophosphate (PO_4^{3-}-P), Nitrate + Nitrite $\{(NO_2^- + NO_3^-)\text{-N}\}$, and ammonium ($NH_4^+$-N) respectively (Table 1), whereasthe concentrations of nutrients were lowest in Mtwapa Creekamong the sewage impacted sites with means of 0.022 mg/L, 0.038mg/Land 0.034mg/L for phosphate,nitrate and ammonium respectively. Makupa Creek had intermediate concentrations. In Tudor Creek, Madubini (MDB) and Coast General Hospital (CGH) stations had the highest concentrations of all the nutrients studies, whereas in Makupa Creek, Makupa Causeway (MKW), Makupa Dumpsite (MKDS), and Makupa Mangroves (MKMA) stations had the highest concentration of nutrients, while in Mtwapa Creek, only Mtwapa Prison (MTPR) station had relatively higher concentration of nutrients (Fig. 2).

Gazi Creekwhich was included in this study as a reference site had very low concentration of nutrients (in comparison to the other sites) with means of 0.007mg/L, 0.019mg/L and 0.018mg/L for phosphates, nitrates and ammonium respectively (Table 1). The means of N:P ratios for the various Creeks were 17.14, 13.97 and 12.61 for Tudor, Makupa and Mtwapa Creeks respectively. Gazi Creek N:P ratio wasthe lowest in comparison to the other Creeks with a mean of 10.

TSS was more or less uniform in the impactedCreeks with average means of 36.0g/L, 36 g/ Land 40 g/Lfor Tudor, Makupa and Mtwapa Creeks respectively (Fig. 3). The BOD_5 levels were always above 4 mg/L for all the sampled stations in Tudor,

Table 1. Comparison of the mean concentrations of nutrients (mg/L) and Chl a (µg/L) in the four studied Creeks

Sampled Creek	PO_4^{3-}-P			$(NO_2^- + NO_3^-)$-N			NH_4^+-N			Chl a		
	Min	*Mean*	*Max*	*Min*	*Mean*	*Max*	*Min*	*Mean*	*Max*	*Min*	*Mean*	*Max*
Makupa	0.003	0.029	0.098	0.001	0.112	0.434	0.007	0.067	0.309	2.408	4.633	9.587
Mtwapa	0.002	0.022	0.599	0.003	0.038	0.143	0.001	0.034	0.171	0.654	2.176	4.585
Tudor	0.001	0.039	0.313	0.001	0.163	0.869	0.003	0.118	1.127	0.538	1.389	2.788
Gazi	0.006	0.007	0.010	0.012	0.019	0.031	0.013	0.018	0.019	0.820	0.950	1.120

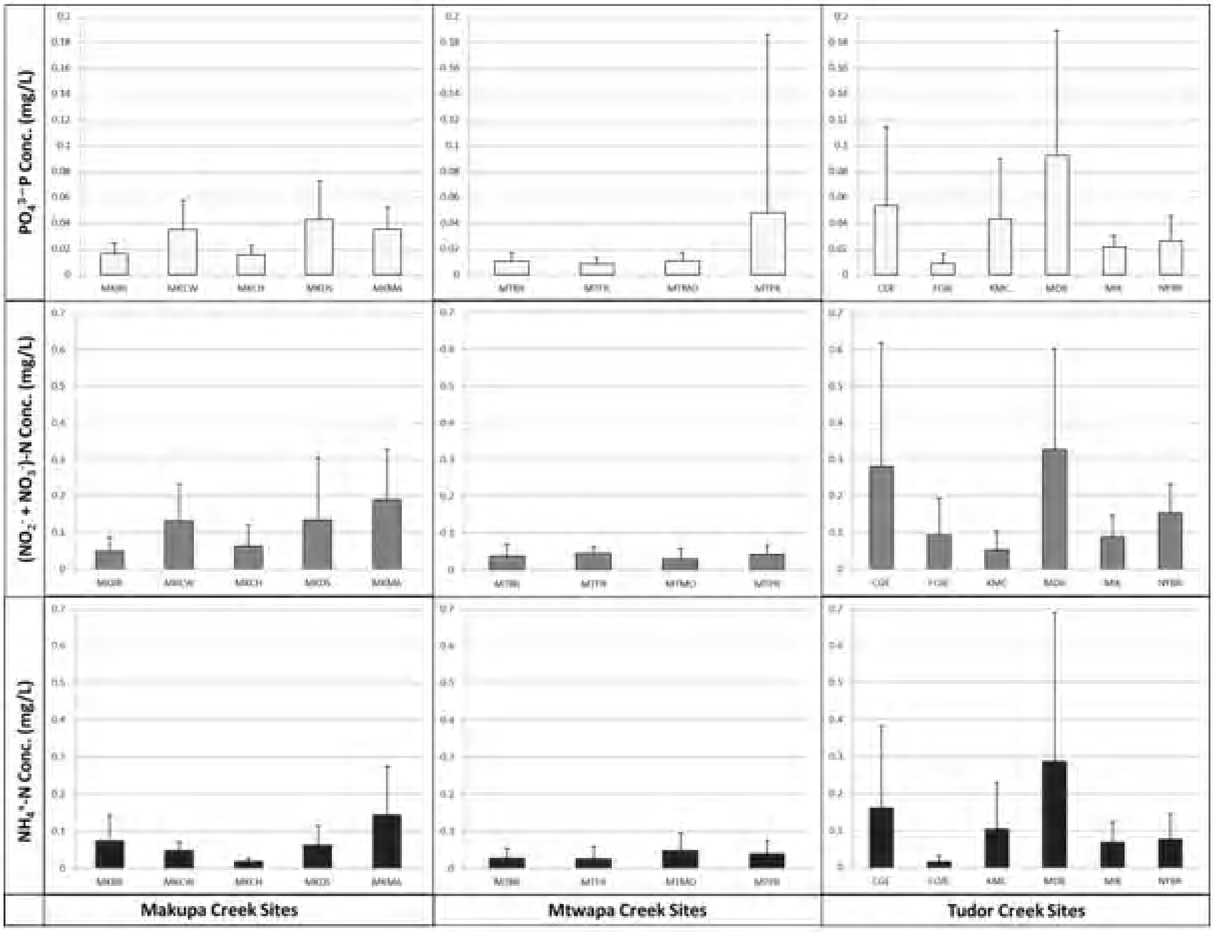

Fig. 2. Nutrients concentration (Mean+STDV) in water column of the sewage impacted Creeks

Mtwapa and Makupa Creeks. The average BOD_5 values for the Creeks were 4.48 mg/L, 4.42 mg/Land 4.38 mg/Lfor Tudor, Makupa and Mtwapa Creeks respectively (Fig. 3). DOconcentrationswererelatively higher in Tudor Creek with a mean of 5.84 mg/L, whereas Mtwapa and Makupa had DO concentrations of 5.66 mg/Land 5.29 mg/Lrespectively.Chl-a concentrations were higher in Makupa Creek with a mean of 4.633 µg/Lwhereas Mtwapa and Tudor Creeks had Chl-a means of 2.176 µg/Land 1.389 µg/Lrespectively (Fig. 3, Table 1). Gazi Creek'sChl-a levels were the lowest in comparison to the impactedCreeks witha mean of 0.95µg/L (Table 1).

Nutrients concentrations were higher in sediment samples as compared to the water samples with ranges between0.217-1.131mg/L, 0.201-0.603mg/Land 9.394-26.73mg/Lfor phosphates, nitrates and ammonium respectively (Table 2). Makupa Creek had the highest concentration of nutrients in the sediment whereas Gazi Creek had the lowest concentrations. Makupa Creek

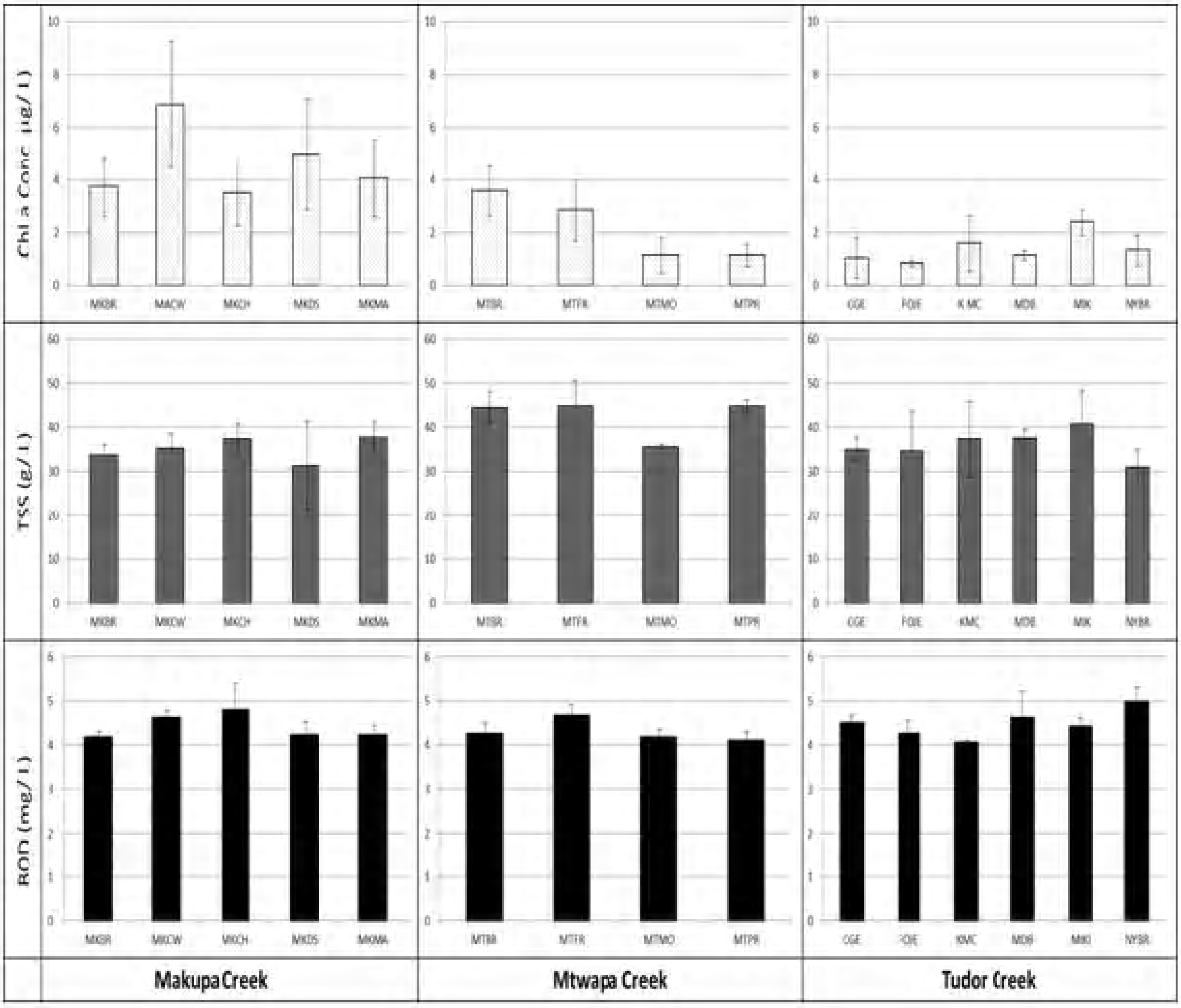

Fig. 3. Mean (±STDV) Chl a, BOD_5 and TSS levels in Tudor, Makupa and Mtwapa Creeks

sediment samples were relatively enriched in phosphates in comparison to Gazi and Mtwapa Creek sediment samples (Table 2). Ammonium was present in the highest concentration than the other nutrients in the sediments from Makupa, Mtwapa and Gazi Creeks. Ammonium was also relatively more abundant along the sediment depth profiles. In general, surface sediments were slightly depleted in nutrients as compared to the subsequent layers of sediments (Table 2).

In Makupa Creek, the surface sediments were depleted in all the three nutrients investigated as compared to the deeper sediments. The maximum concentrations of nutrients were observed in depth 8-12cm. A sudden drop in concentrations wasthereafter observed in depth 12-16cm (Table 2).In Mtwapa Creek, sediment depth 2-4cm had the lowest concentration of phosphates and nitrates whereas the ammonium concentration at this depth was the highest. Depth 4-16cm showed a more or less high concentrationof the three nutrients (Table 2).In Gazi Creek, sediment had more or less uniform concentrations of nitrates at all the depths apart from the drop observed at depths 2-4cm. Nitrates concentrations showed a marked increase from the depth 0-16 with a maximum at depths 12-16. Ammonia showed a decreasing trend from the surface to the depth of 16cm (Table 2).

In comparison, Makupa Creek sediments had the highest nutrientsconcentrations with means of 1.131mg/L, 0.603mg/L and 26.73mg/L for phosphates, nitrates and ammonium respectively (Table 2). Mtwapa Creek had the intermediate concentrations whereas, Gazi Creek (which was considered in this study as a reference site) had the lowest concentration with 0.271mg/L, 0.437mg/L, 17.318mg/L(Mtwapa)and 0.217 mg/L, 0.201 mg/L, 9.394 mg/L(Gazi) for phosphates, nitrates and ammonium respectively (Table 2). The concentrations of phosphates, nitrates and ammonium in all the three Creeks were statistically different (F= 14.04,pÂ 0.01; F= 16.728, pÂ 0.01and F= 5.744, pÂ 0.05 respectively).A comparison of the levels of

Table 2. Mean nutrients concentration (mg/L) in sediments samples from Makupa, Mtwapa and Gazi Creeks

Sampling Station	Sediment depth (cm)	Nutrients		
		PO_4^{3-}-P	$(NO_2^- + NO_3^-)$-N	NH_4^+-N
Makupa	0-4	0.564	0.275	15.774
	2-4	1.164	0.727	24.997
	4-8	1.266	0.608	32.205
	8-12	1.917	0.663	38.275
	12-16	0.744	0.742	22.399
	Mean Conc.	***1.131***	***0.603***	***26.730***
Mtwapa	0-2 cm	0.298	0.398	15.219
	2-4	0.188	0.365	18.562
	4-8	0.247	0.443	10.620
	8-12	0.306	0.509	16.482
	12-16	0.314	0.468	25.707
	Mean Conc.	***0.271***	***0.437***	***17.318***
Gazi	0-2	0.221	0.044	17.878
	2-4	0.144	0.096	12.170
	4-8	0.265	0.241	7.136
	8-12	0.228	0.193	5.478
	12-16	0.226	0.433	4.308
	Mean Conc.	***0.217***	***0.201***	***9.394***

phosphates, nitrates and ammoniumconcentrations at the different sediments depths for the three Creeks were not significant (F= 1.006, pÃ0.05; F= 3.138, pÃ 0.05 and F= 0.109, pÃ 0.05 respectively.

This study has confirmed that locations and sites with more intensive development and the associated effluent discharge points are a major source of sewage pollution expressed as high levels of nutrients and BOD_5. This confirms the finding of a previous study by Akpnan, (2004) that had attributed severe aquatic environment deterioration (due to nutrient enrichment) to the indiscriminate release of municipal sewage.The different levels of nutrients observed at different sampling stations in the three sewage impactedCreeks could be attributed to such factors as difference in sewage discharge volumes, distance from point sources and prevailing currents or tidal current direction.

The generally low concentrations of nutrients in the water column *vis a vis* the concentrations observed in the sediments could have probably been as a result of tidal dilution and phytoplankton uptake (Mallin, 2007) as well as the losses into the sediments since sediments have a higher affinity for nutrients as compared to water (Wetzel, 2001). Nutrients in the water column as well as those which are adsorbed on the suspended solids are usually trapped in the bottom sediment during the process of sedimentation. As such, sewage discharge may alter both the organic content and the biochemical composition of sediments (Cotano and Villate, 2006).

Nitrates-enriched water column in comparison to ammonium concentration observed in this study could be attributed to the preference of ammonium by phytoplankton, thus lowering its levels in the water column. The preference of ammonium in comparison to the other nitrogen forms is driven by the fact that phytoplankton can incorporate (assimilate) ammonium directly into amino acids whereas the other nitrogen forms such as nitrate and nitrite have to be converted enzymatically into ammonium in orderto be utilized, a process that requires energy expenditure (Eppley *et al.*, 1969). This general preference of ammonium over nitrate usually keeps ammonium concentrations lower than that of nitrates in the water column. The high concentrations of dissolved oxygen (which were always above 4mg/L for all the stations studied) reported in this study could have also favoured nitrification of ammonium to nitrates.Coastal waters are always regarded asN limited. The relatively high N:P ratio in the sewage impacted Creeksin comparison to the low values for Gazi Creek could have been as a result of sewage discharge. As reported by Emeis *et* *al.*, (2000), such an increase in N:P ratios could be indicative of increased anthropogenic input of nitrate and phosphate.

Naturally, phosphates are derived from decomposing organic matter and leaching of phosphorus rich bedrock. The levels of phosphates in the coastal waters are slowly rising due to increasing loading of human wastes, animal wastes, industrial wastes, and human disturbance of the land and its vegetation. Worth noting are the high levels of phosphates observed in the samples from sites adjacent to Madubini and Mtwapa Prison. These high levels could be attributed to the kinds and quantities of soaps used in Mombasa old town and Mtwapa prison that are densely populated. Goldman and Horne, (1983) observed that phosphate-containing detergents were the major sources of soluble phosphates, contributing approximately half the phosphates contained in domestic sewage.

Higher levels of Chl-a observed in Tudor, Makupa and Mtwapa Creeks as compared to Gazi Creek could be attributed to the high nutrients levels in these systems. Donnelly *et al.*,(1998) singled out phosphorus as a nutrient that can encourage the growth of nuisance aquatic plants and can cause algal blooms. This is supported by this study that had mean phosphates concentration in the range of 0.022-0.039mg/L in the sewage impactedCreeks. The enhanced growth of microalgae (high Chl a levels) observed in sewage impacted Creeks furtherconfirm that Makupa, Tudor and Mtwapa Creeksareimpacted systems. This is supported by the work by Smith,(2006) which reported that nutrient control of eutrophication starts at the level of primary producers, and a strong statistical response of phytoplankton biomass to nutrient enrichment is evident in comparative analysis of worldwide coastal ecosystems.

From the high concentration of nutrients and the low TSS levels in TudorCreek as compared to Makupa and Mtwapa Creeks, it was expected that Tudor Creek would have relativelyhigh levels of Chl-a than the other two sewage impacted Creeks. However, it was noticed that TudorCreekinstead had the lowest Chl-a level. The possible explanation for this situation could be borrowed from the work by Li *et al.*,(2010)which noted that changing nutrient concentrations at local scales do not always cause a change in phytoplankton biomass and that such changes may depend on system-specific attributes (e.g. water residence time) and complexity of biotic responses. Indeed Makupa Creeks is a semi- enclosed Creek with relatively high water retention time as compared to Tudor and Mtwapa Creeks and this could have led to flourishing of phytoplankton communities in this Creek.

This study further identifiedsewage as the source of high nutrients concentrations by reporting elevated mean concentrations of dissolved nutrients in water and sediments from the sewage impacted sites in comparison to Gazi. Such high levels of nutrient levels have been reported elsewhere to cause multiple and detrimental effects on exposed organisms (Schlacher *et al.*, 2007; Larsen and Webb, 2009 and Reopanichkul *etal.*, 2009)) and can alter key structural and functional attributes of ecosystems that are affected by wastewater load (Reopanichkul*et.al*, 2010)as such sewage could already be affecting or there is a possible threat to the ecosystem health.

High levels of nutrients in the sediments in this study is not surprising given that nutrients often have a strong affinity for sedimentary particle surfaces and as such scavenging of nutrients by suspended particulate matter and subsequent sedimentation could have led to the high nutrients concentration with the resultantdeterioration in sediments' quality (Gerritse *et al.*, 1998). Even though sediment dating was not carried out in this study, the high ammonium concentrations along the sediments core profiles clearly indicate that the impact of sewage on the sediments was an on-going activity long after sedimentation. As reported elsewhere, the accumulated sediments contain a repository of valuable historical information on the temporal trend of pollutants input into aquatic ecosystems(Axelsson and El-Daoushy, 1989). Future studies could consider dating of sediments so that the temporal history of these systems (with regards to sewage pollution) could be discerned.

The depletion of the surface sediment nutrients concentrations (as compared to the deep layers) could be attributed to an upward concentration gradient created by nutrients concentration in the water column being below the equilibrium resulting into nutrients loss from sediments to the overlying water column (Carl, 1989). The increase of phosphates with depth could be attributed to the adsorption onto iron and manganese oxides/hydroxides.

High concentrations of ammonium as compared to nitrates in the sediments especially for Makupa and MtwapaCreeks is consistent with the findings of a study done elsewhere by Mallin, (2007)which reported that stations impacted by sewage are usually anaerobic and as such the principal inorganic nitrogen form is ammonium rather than nitrate. It was evident in this study that denitrification was not probably a major sink of N nutrients in the sewage impacted sediments since the bulk of the inorganic Nwasin the form of ammonium rather than nitrate (Wetzel, 2001).Ammonium concentrations remained relatively high with depth in the sediments from sewage impacted sediments (>15.219 mg/L), an indication of on-going organic matter remineralisation through the sediment profile. This clearly shows that the effects of sewage discharge at a particular time take a number of years to clear from the ecosystem.

Sediments were found in this study to be shielding Mombasacoastal waters from excessive nutrients pollution. However, it should be noted thatsedimentswill not continue to accumulate nutrients endlessly. When the loading is excessive (which is expected soon with the growing population), the sedimentscould easily become saturated. Beyond the point of saturation, the concentration gradient of nutrients in the overlying water and pore water is expected to occur and this could expose the organisms to elevated concentrations.

In general, phosphate enrichment was evident in Tudor, Makupa and Mtwapa Creeks (with means above 0.022 mg/L) as compared to Gazi Creek (with a mean of 0.007 mg/L). Following the argument of Girija *et al.*, (2007) that watercourses with phosphorus concentration exceeding 0.02 mg/L could be termed eutrophic, this study can confidently classify Tudor, Mtwapa and Makupa Creeks as eutrophic systems. This is further supported by trophic classification scheme based on nutrients (Table 3) that classifies the three sewage impacted Creeks as eutrophic whereas Gazi Creek could be classified to be at the lower limit of higher mesotrophy.However, according to Hinga *et al.*, (1995),Chl-a is probably a better 'instantaneous' indicator of trophic status than nutrient concentrations because nutrient concentrations are easily affected by biological uptake, which in turn is influenced by uptake capabilities, interaction with grazers, temperature, turbulence and turbidity levels.For this study, the classification scheme based on Chl a (Table 3) was therefore adopted.

Based on Chl-a levels, Makupa Creek could be classified as eutrophic, whereas Mtwapa and Tudor Creeks could be placed at the upperlimits of higher mesotrophy while Gazi Creekcould be classified as oligotrophic (Table 3). Further based on Chl-a data and a scheme provided by Simboura*et al.*,(2005), Makupa Creek could be classified as having bad ecological quality status (EQS), whereas Tudor and Mtwapa have poor EQS while Gazi has high EQS. Trophic status correspondingto higher mesotrophic eutrophication conditions (poor EQS) is indicative of sensitive ecosystems that could be eutrophic in the future if the increasing trend in eutrophication parameters continues (Pagou *et al.*, 2002). Higher mesotrophy therefore serves as a red flag for ecosystems that can potentially be threatened by future human impacts. Bad EQS status corresponds to eutrophic level characterizing sensitive eutrophic areas whereas oligotrophic systems (high EQS) are characterized by phytoplankton taxa composition and abundance that are consistent with undisturbed conditions (Simboura*et al.,* 2005).

The elevated concentrations of nutrients in sewage impactedCreeks in comparison to Gazi Creek typically means that people from the impacted Creeks could be swimming in (and swallowing) some amount of raw sewage. In the fight against water pollution, sewage seems to be one of the easiest pollutants to control in theory, but the hardest to deal with in practice. It is so absurd that human beings that pollute water are the very people that are affected by that pollution. Unless the perception that only "things that go up come down" changes and people become aware that even "those things that go down the drains" come back through bioaccumulated contaminants in seafood and swallowing during swimming, then we are far from winning the fight against sewage pollution.

If the current trends of sewage discharge are allowed to continue, then the swimmers will continue being at an increased risk of contracting illness due to bacteria and viruses present in sewage effluent (i.e. gastrointestinal disorders, giardiasis, amoebic dysentery and cholera) and seafood will continue to becontaminated thusincreasing consumers' risk of adverse health. Sewage contamination can also lead to high income lossesassociated with the closing of fishing grounds and beaches which could impact tourism and fishing industry negatively resulting into heavy economic loss for Kenya, a country that boasts of tourism as the second foreign exchange earner.

Even though the government clearlyunderstands the importance of treating raw sewage through a combination of physical, biological and chemical processes to remove some or most of the pollutants before discharge into the receiving body, the local authority that is mandated to carry out such activities are heavily incapacitated by lack of the necessary human, technical and financial capabilities to address the rising levels of sewage volumes.The role of controlling sewage pollution should therefore not be left to the local government alone for a simple reason that construction of sewage treatment facilities may not be able to catch up with the increasing human activities. It is therefore vital that everyone recognizes raw sewage as one of our nastiest but solvable water pollution issues. The cooperation of hotel owners, institutional and factory managers, local inhabitants and wastewater treatment facilities'managers could help reduce the threats of sewage pollution.

Table 3. Trophic classification scheme based on nutrients (phosphates, nitrates, ammonium) and chlorophyll a (modified from Siokou and Pagou, 2000; Pagou, 2000)

Parameter	Trophic class			
	Oligotrophic	**Lower mesotrophic**	**Higher mesotrophic**	**Eutrophic**
Phosphates (mg/L)	<0.002	0.002-0.004	0.004-0.021	>0.021
Nitrates (mg/L)	<0.0087	0.0087-0.0091	0.0091-0.018	>0.018
Ammonium (mg/L)	<0.008	0.008-0.015	0.015-0.031	>0.031
Chlorophyll a (µg/L)	<0.1	0.1-0.6	0.6-2.21	>2.21

CONCLUSION

It is evident from this study that TudorCreek is eutrophic whereas, Makupa and Mtwapa Creeks are at the upper limits of higher mesotrophic, conditions that arecaused by continuous discharge of sewage. Additional inflows of sewage to these systems compounded by occasional re-suspension of nutrient-enriched sediments will continue to reduce water quality significantly. Effective sewage management and long term water quality monitoring should be adopted to ensure that coastal systems continue to support marine life and the livelihood of the riparian coastal communities. In this regard, there is an immediate need to:

1. Fully repair and continuouslymaintainthe sewage treatment facility at Kipevu.
2. Encourage a national campaign that will encourage bagging of wastes instead of flushing them to the waterways. The more effort put into public education, the closer the move to solving the problems of water and sewage pollution.

The long term approaches to controlling sewage pollution would be to install new sewage treatment plantsalongsidethe repairs of the existing ones, adoption of the whole community approach to reducing waste and recycling wastes and exploration of newtechnologies to minimise the use of marine ecosystem as waste discharge basins.

ACKNOWLEDGEMENT

Funding for this work was provided by WioLab's Shimo La Tewa Constructed Wetland Project (through Coast Development Authority, CDA), SEED funds (Kenya Marine and Fisheries Research Institute, KMFRI) and RAF 7008 Project (International Atomic Energy Agency, IAEA). We are greatly indebted to the Directors of these Institutions for supporting this work. We also appreciate the efforts of KMFRI staff that assisted in field samples collection and analysis in one way or the other. We also acknowledge the efforts of the anonymous reviewer who tirelessly and promptly critiqued this work.

REFERENCES

Akpan, A. W. (2004). The water quality of some tropical freshwater bodies in Uyo (Nigeria) receiving municipal effluent, slaughter-house washings and agricultural land drainage. Environmentalist, **24,** 49-55.

APHA, (1992). American Public Health Association. Standard Methods for the Examination of Water and Waste Water, 18th ed. APHA, Washington, DC.

APHA, (1995). Standard Methods for the Examination of Water and Waste Water (19th Edition). American Public Health Association, Washington DC.

Bhatnagar, A. and Sangwan, P. (2009).Impact of Mass Bathing on Water Quality. Int. J. Environ. Res., **3 (2),** 247-252.

Carl, F. C. (1989). Measured and modelled effects of temperature, dissolved oxygen and nutrient concentration on sediment-water nutrient exchange. Hydrobiol., **174,** 185-194.

Clark, R.B, Frid, C. and Attrill, M. (2001). Marine pollution, 5th Edition. 1-145. Oxford University press oxford.

Cotano, U. and Villate, F. (2006). Anthropogenic influence on the organic fraction of sediments in two contrasting estuaries: a biochemical approach. Mar. Poll. Bull., **52,** 404-414.

Donnelly, T. H., Barnes, C. J., Wasson, R. J., Murray, A. S. and Short, D. L. (1998). Catchment phosphorus sources and algal blooms-An interpretative review. Technical Report 18/98-CSIRO Land and Water Canberra, ACT 2601.

Emmeis, K.C., Struck, U., Leipe, T., Pollehne, F., Kunzendorf, H. and Christiansen, C. (2000). Changes in the C, N, P burial rates in some Baltic Sea sediments over the last 150 years-relevance to P regeneration rates and the phosphorus cycle. Mar. Geol., **167,** 43-59.

Gerritse, R. G., Wallbrink, P. J. and Murria, A. S. (1998). Accumulation of phosphorus and heavy metals in the Swan-Canning Estuary, Western Australia. Estuarine, Coastal and Shelf Science, **47,** 165-170.

GESAMP, (1990). State of the marine environment, report and studies, No. 39 (p. 111). Nairobi: UNEP.

GESAMP, (1990). Joint Group of Experts on the Scientific Aspect of Marine Pollution: The State of the Marine Environment UNEP Regional Seas Report and Studies No. 115, UNEP.

Girija, T. R., Mahanta, C. and V. Chandramouli. (2007). Water Quality Assessment of an Untreated Effluent Impacted

Urban Stream, The Bharalu Tributary of the Brahmaputra River, India. Environ. Monit. Assess., **130,** 221-236.

Goldman, R. C. and Horne, J. A. (1983). Limnology. New York: McGraw-Hill Book.

Hinga, K.R., Jeon, H. and Lewis, N. F. (1995). Marine eutrophication review I: Quantifying the effects of nitrogen enrichment on phytoplankton in coastal ecosystems. NOAA Coastal Ocean Office, Silver Spring, MD. 36p.

Hunter, C. and Evans, C. W. (1995). Coral reefs in Kaneoche Bay, Hawaii: two centuries of western influence and two decades of data. Bulletin of Marine Science, **57,** 501-515.

Jenssen, B. J. (2003). Marine pollution: the future challenge is to link human and wildlife studies - Guest Editorial. Environmental Health Perspectives, **111,** A198.

Karou, J. (1992). The control of land-based sources of marine pollution: Recent international initiatives and prospects. Mar. Poll. Bull., **25,** 80-81.

Larsen, M. C. and Webb, R. M. T. (2009). Potential effects of runoff, fluvial sediment, and nutrient discharges on the coral reefs of Puerto Rico. Journal of Coastal Research, **25 (1),** 189-208.

Li, D. and Dag D. (2004). Ocean Pollution from Land-based Sources: East China Sea, China. Ambio, **33,** 107-113.

Li, W. K. W., Lewis, R. M. and Harrison, W. G. (2010). Multiscalarity of the Nutrient-Chlorophyll Relationship in Coastal Phytoplankton. Estuaries and Coasts, **33,** 440-447.

Looser, R., Froescheis, O., Cailliet, G. M., Jarman, W. M. and Ballschmitter, K. (2000). The deep-sea as a final global sink of semi volatile persistent organic pollutants? Part II: organochlorine pesticides in surface and deep-sea dwelling fish of the North Atlantic and South Atlantic and the Monterey Bay Canyon (California). Chemosphere, **40,** 661-670.

López-Gappa, J. J., Toblado, A. and Magaldi, N. H. (1990). Influence of sewage pollution on a rocky intertidal community dominated by the mytilid *Brachidontes rodriguezi*. Mar. Ecol. Progress Series, **63,** 163-175.

Mallin, M. A., Cahoon, L. B., Toothman, B. R., Parsons, D. C., McIver, M. R., Ortwine, M. L. and Harrington, R.N. (2007). Impacts of a raw sewage spill on water and sediment quality in an urbanized estuary. Mar. Poll. Bull., **54,** 81-88.

Michael, J. and Kennish, T. (1998). Pollution impacts on marine biotic communities. Boca Raton, FL: CRC.

Nellemann, C. and Corcoran, E. (2006). Our precious coasts: marine pollution, climate change and the resilience of coastal ecosystems. Arendal, Norway, UNEP/GRID-Arendal.

PAGOU, K. (2000). Assessment of the trophic conditions in the Inner Thermaikos Gulf. Technical Report for the Ministry of Environment, Planning and Public Works, NCMR, Athens. 11pp.

Palanisamy, S., Neelamani, S., Yu-Hwan, A., Ligy, P. and Gi-Hoon, H. (2007). Assessment of the levels of coastal marine pollution of Chennai City, Southern India. Water Resources Management, **21,** 1187-1206.

Parsons, T. R., Maita, Y. and Lalli, C. M. (1984). A manual of chemical and biological methods for seawater analysis. Pergamon Press. 173 pp.

Reopanichkul, P., Carter, R. W., Worachananant, S. and Crossland, C. J. (2010). Wastewater discharge degrades coastal waters and reef communities in southern Thailand. Marine Environmental Research, **69 (5),** 287-296.

Reopanichkul, P., Schlacher, T., Carter, R. W. and Worachananant, S. (2009). Sewage impacts coral reefs at multiple levels of ecological organization. Mar. Poll. Bull., **58,** 1356-1362.

Schlacher, T. A., Stark, J. and Fischer, A. B. P. (2007). Evaluation of artificial light regimes and substrate types for aquaria propagation of the staghorn coral *Acropora* solitaryensis. Aquaculture, **269,** 278-289.

Seitzinger, S. P., Harrison, J. A., Dumont, E., Beusen, A. H. W. and Bouman, A. F. (2005). Sources and delivery of carbon, nitrogen, and phosphorus to the coastal zone: an overview of Global Nutrient Export from Watersheds (NEWS) models and their application. Global Biogeochem. Cycles, **19,** 1-2.

Simboura, N., Panayotidis, P. and Papathanassiou, E. (2005). A synthesis of the biological quality elements for the implementation of the European Water Framework Directive in the Mediterranean Ecoregion: The case of Saronikos Gulf. Ecological Indicators, **5,** 253-266.

Siokou-Frangou, I. and Pagou, K. (2000). Assessment of the trophic conditions and ecological status in the Inner Saronikos Gulf. Technical Report for the Ministry of Environment, Planning and Public Works, NCMR, Athens. 43pp.

Smith, V. H. (2006). Responses of estuarine and coastal marine phytoplankton to nitrogen and phosphorus enrichment. Limnology and Oceanography, **511 (2),** 377-384.

Subramanian, B. R. (1999). Status of marine pollution of India. In Proceeding of Indo-British integrated coastal zone management training short-course conducted by Institute for Ocean Management, Anna University.

UNEP, (2006). The state of the marine environment-trends and processes. United Nations Environment Programme and the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA) of the United Nations Environment Programme (UNEP), The Hague. 52 p.

USSD, (2004). Soil survey laboratory methods manual. Rebecca Burt, Eds. Soil Survey Investigations Report, **42**, 735.

Vijay, R., Sardar, V. K., Dhage, S. S., Kelkar, P. S. and Gupta, A. (2010). Hydrodynamic assessment of sewage impact on water quality of Malad Creek, Mumbai, India.Environ. Monit. Assess., **165,** 559-571.

Wetzel, R. G. (2001). Limnology, Lake and River Ecosystems. Academic Press, San Diego, 1006 pp., third ed.

Williams, C. (1996). Combating marine pollution from land-based activities: Australian initiatives. Ocean and Coastal management, **33,** 87-112.