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Characterization of nutrients enrichment in the estuaries and related systems in Kenya coast

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Rivers Tana, Sabaki, Umba and Ramisi discharge their waters into the Indian Ocean along the Kenyan coastline. This study was carried out to examine the river nutrient input characteristics in terms of PO_4^{3-}-P, (NO_2^-+ NO_3^-)-N and NH_4^+-N concentration trends and their interactions with TSS, Chl a, DO and BOD_5, along the estuaries of these rivers, and the contiguous coastal systems. Standard methods were used for sample collection preparation and analysis. Sabaki and Tana estuaries PO_4^{3-}-P and (NO_2^-+ NO_3^-)-N levels (means± SD) were 0.145 ±0.075 mg/L and 5.133 ±3.39 mg/L respectively and were significantly higher compared to the other estuarine systems considered in this study. There were significant correlations between the nutrients and other variables suggesting the influence of nutrients on the overall water chemical and biological characteristics. In conclusion the study identified River Sabaki as the greatest contributor to marine pollution, by contributing the greatest quantities of nutrients and suspended matter. The study recommends measures aimed at counteracting this environmental problem at its very source, the catchment.

Key words: Nutrients, estuaries, eutrophication, pollutants.

INTRODUCTION

Good water quality is a desirable attribute for sound environmental health of surface waters (lakes, rivers, estuaries and the ocean) and by extension, all the spheres of the earth. The quality of surface waters is determined by the chemical, physical and biological characteristics. The chemical variables that influence water quality include dissolved gases, minerals, nutrients, metals, toxic substances, salinity and pH. Water quality is thus affected by the complex interactions between these chemical characteristics on one side, and the physical and biological factors on the other.

Nutrients, one of the water chemical parameters, provoke the greatest of environmental concerns. It is generally acknowledged that nutrient inputs into aquatic systems caused by natural events far exceed those generated by human activities. However, the anthropogenic nutrient inputs which include sewage discharges and agricultural fertiliser runoff can sometimes upset the natural self-cleansing processes of the marine environment, leading to eutrophication (Miller, 1985) which in turn poses problems to marine life and affects aquatic resources. Some of the negative manifestations of eutrophication are blooming of certain groups of algae that may eventually lead to depletion of dissolved oxygen (hypoxia). Some obloom forming types of algae are commonly referred to as Harmful Algal Blooms (HABs), due to their tendency to produce phycotoxins. There has been an apparent increase in the occurrence of HABS globally (Anderson, 1989; Hallegraeff, 1993; Smayda, 1990). The increasing linkages between nutrient loading and estuarine/ coastal marine HABs have more recently been recognized (Anderson et al., 2002; Burkholder, 2006; Gilbert and Heisler et al., 2008; Smayda, 1990, 1997).

Marine pollution like other environmental problems is attributable to anthropogenic impacts like population pressure, food production (intensive agriculture and industrialization), urbanization and coastal development (Looser et al., 2000; Seitzinger et al., 2005, Bhatnagar and Sangwan, 2009). The over enrichment of aquatic environments with nutrients is attributable to urbanization (Smith et al., 1999; de Jonge et al., 2002; Roman et al., 2000) and catchment agricultural activities. It has been observed that coastal ecosystems in the world serve as receptors for industrial and municipal effluents (Clark 1992; Palanisamy et al., 2007). Discharge of sewage effluent and dumping of sewage sludge has been implicated for loading of organic matter and eutrophication in coastal regions of the world (Subramanian, 1999).

Other important pathway of nutrients (PO_4^{3-}-P, (NO_2^-+ NO_3^-)-N and NH_4^+-N) to the ocean are rivers and streams through estuaries. Rivers usually contain high levels of dissolved and particulate-bound nutrients relative to the coastal and oceanic systems. Adsorbed phosphorus, and to a lesser extent nitrogen, may also be washed into the sea (Meybeck, 1982) or ocean (Milliman et al., 1984) through rivers or floods (McKee et al., 2000) and deposited or buried there as sediment (Stiller and Nissenbaum, 1999; Beusekom and Jonge, 1998; Noeel and Watanabe, 2000; Zhou, et al., 2000), and may later be released to the overlying water under different redox conditions (McAuliffe et al., 1998; Correll, 1998).

In the ocean, dissolved inorganic nutrient from river discharge and re-mineralization processes can both contribute significantly to the overall nutrients budget that can eventually be taken up by phytoplankton (Kuwae et al., 1998).

Chlorophyll (Chl a) concentration, which is a proven indicator of the biomass of microscopic plants such as unicellular algae and photosynthetic potential, is frequently used as an indicator of trophic status of marine waters (Painting et al., 2005) and as a measure of water quality (Boyer et al., 2008; Hakanson et al., 2007; Millie et al., 2006). Increases in the annual median concentrations of Chl a may be related to changes in nutrients and increasing eutrophication. High levels of Chl a concentrations often indicate poor water quality and vice versa.

Hydrodynamics and related transport processes help determine nutrient and biotic distributions in estuaries. The flushing time determines the sensitivity of nutrient concentrations in an estuary to loading from the watershed. It also determines export rates of plankton and nutrients from the estuary (Dettmann, 2001). Nutrient concentrations have been shown to vary with the ocean tides with (NO_2^- + NO_3^-)–N concentrations rising and falling with the rise and fall of the tide (Kitheka et al., 1999).

The dynamic nature of nutrients in estuarine and coastal systems motivated this study with the aim of identification and description of estuarine nutrient load characteristics as a function of river derived pollutants and its possible effects on marine environmental health, while pinpointing the possible sources, fate and the impacted areas. The study targeted estuaries of the major rivers draining to the Kenyan coastal areas. The merits of this work are to recommend, give impetus to and inform policy based mitigation actions, while forming part of the invaluable baseline information to augment and trend with other previous, on-going and future environmental risk assessment and pollution monitoring oriented studies.

MATERIALS AND METHODS

The study area included river estuaries and contiguous coastal systems located both in the North and South coast regions of the Kenyan coastal waters. The sampling stations were strategically selected to reflect a range of anticipated anthropogenic influence. The locations included those of anticipated influx of nutrients and suspended matter and those of relative low nutrient and organic matter perturbations to serve as reference sites.

In the North Coast, the sampling stations were located as follows; four stations along the Tana River estuary, at Tana Bridge (TANBR), Mulkani (MULK), Kipini Village (KIPVIL) and Kipini Mouth (KIPMOT) in succession upstream to the mouth; four sampling stations along the Sabaki river estuary, at Galana (GAL),) Sabaki 3 (SAB3), Sabaki 2, (SAB2) and Sabaki 1 (SAB1) in an advancing order upstream to river mouth; three sampling stations along the southern side of the estuary along Malindi Shoreline as Malindi Jetty (MAJET), Malindi Marine Park (MAPAK) and Malindi Navy (MANAV) and one station on the Nothern side of Sabaki estuary along the shoreline, known as Mambrui (MAMBR).

The relatively lowly impacted (with little urbanization, agricultural and industrial development) channels of the South coast were considered in this study for comparison due to their appeal as being pristine as the river inflow is from catchments of low agricultural perturbations. The sampling sites in South coast were Umba Mouth (UMMOT), Umba Village 1 (UMVIL1), Umba Village 2 (UMVIL2), Umba Bridge (UMBRG), Umba Boarder (UMBOD). In Ramisi River, the stations were Ramisi 1 (RAMS1), Ramisi 2 (RAMS2), Ramisi 3 (RAMS3), Ramisi Bridge (RAMBR). In Shimoni coastal system, the stations were located at Kibuyuni (KIBY) and Shimoni Jetty (SHIJET).

This study was carried out during 2009-2010 sampling campaigns. Sample collection for nutrients analysis was as follows; for nutrients analysis, two replicate surface water samples were collected in polyethylene bottles (prewashed in acid) and stored frozen until analysis. Three replicate water samples were taken in borosilicate bottles for BOD_5 and DO measurements. Chlorophyll a (Chl a) samples were collected by filtering one litre of surface water on GFF-filters under low suction.

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 the samples. Orthophosphate was determined using the ascorbic acid method and measured calorimetrically at a wavelength of 885 nm using UV-Vis spectrophotometer. Dissolved (nitrate and nitrite)-N was determined using the cadmium reduction method and determined calorimetrically at a wave-length of 543 nm. Ammonium-N was determined using the indophenol method and the absorbance read at 630 nm after at least six hours. DO and BOD_5 were determined by the modified Winkler method (APHA, 1992). Chl was extracted from seston retained on GF filter papers using acetone and measured spetrophotometrically. All chemicals used were of analytical grade and all the glassware pre-washed in acid before use. For nutrients analysis, procedural blanks and check standards were included for quality control.

RESULTS AND DISCUSSIONS

The results of this study showed that the mean (± SE) concentrations of PO_4^{3-}-P and (NO_2^-+ NO_3^-)-N for Sabaki estuary (0.145 ±0.075 mg/L and 5.133±3.39 mg/L respectively) were elevated (Table 2) as compared to the other systems studied. NH_4^+-N in Sabaki exhibited one of the lowest concentrations recorded in this study (0.007 ±0.004 mg/L (Table 2, Figure 2).

The major nutrients, PO_4^{3-}-P and (NO_2^-+ NO_3^-)-N showed a general decreasing trend downstream in all the estuarine systems. There was a significant difference in (NO_2^-+NO_3^-)-N and PO_4^{3-}-P concentrations between stations along the Sabaki system (F=11.41, $p<0.05$; F= 124.4, $p<0.05$). Pos hoc analysis revealed significant differences between Galana station (which is the most upstream) and the other stations in Sabaki system.

Whereas the nutrient concentrations in Sabaki showed that the highest values of PO_4^{3-}-P and (NO_2^-+ NO_3^-)-N (Table 2, Figure 3) were recorded in the most downstream sampling station, the values of Chl a declined steadily down the stations. In Malindi coastal waters, Chl a showed uniform concentration across all the stations (Table 3).

It is noteworthy that nutrient levels in the adjacent coastal receiving system (Mambrui) were markedly relatively low for PO_4^{3-}-P and (NO_2^-+ NO_3^-)-N (0.024 ±0.003 mg/L and 0.052 ± 0.017 mg/L) respectively (Table 2), while the mean concentration of NH_4^+-N (0.0124 ±0.008 mg/L) surpassed the levels recorded in Sabaki estuary. (NO_2^-+ NO_3^-)-N levels remained relatively high in Sabaki stations compared to other nutrients.

It was also observed that the nutrient levels for Malindi Stations (Malindi Navy, Malindi Marine Park and Malindi Jetty), which were hypothetically thought to be receiving higher nutrient input, were strikingly low, (Table 3, Figures 2, 3 and 4).

There were significant differences in (NO_2^-+ NO_3^-)-N and PO_4^{3-}-P concentrations among the various estuarine systems (F=35.475; $p<0.05$ and F=175.45; $p<0.05$). Post hoc analysis for (NO_2^-+ NO_3^-)-N and PO_4^{3-}-P revealed significant differences between Sabaki river system and the other systems. Chlorophyll a also showed a significant difference (F=14.28; $p<0.05$) among the stations.

(NO_2^-+NO_3^-)-N, PO_4^{3-}-P (Figure 4, Table 3) and NH_4^+-N (Figure 2, Table 3) in Ramisi and Umba systems remained relatively low compared to the levels in Sabaki and Tana systems (Figure 2). In Ramisi, (NO_2^-+ NO_3^-)-N recorded the highest concentrations in all the stations, while NH_4^+-N concentrations exceeded those of PO_4^{3-}-P. Chl a levels showed a decreasing trend upstream and shooting up again at Ramisi Bridge.

In Umba channel, nutrients concentrations showed fluctuating patterns between stations (Figures 2, 3, and 4) whereby the highest concentrations for all nutrients were recorded at Umba river mouth. NH_4^+-N remained highest in all stations and lowest in Umba Border while (NO_2^-+ NO_3^-)-N and PO_4^{3-}-P showed a declining trend after Umba Bridge.

Higher N: P ratio were recorded in the Sabaki system (>40) compared to the rest of the systems including the other estuarine systems (Figure 5). The N: P ratio for the other rivers, although significantly lower than that of the Sabaki system (<20) were still higher than those recorded in the contiguous coastal systems. There was a general increasing pattern of N:P ratio downstream for all the estuarine systems. Upstream stations in Sabaki system had N:P ratio less than 10. This could be attributed to increasing sedimentation, subsequent remineralisation and ammonification processes as well as continuous uptake of PO_4^{3-}-P by algae.

Upstream stations in Sabaki system had N:P ratio less than 10 (Figure 5), implying a short-term N limitation. Upstream short term N limitation has been reported elsewhere by Furnas *et al*., (1990) and Charpy, (2001). This study showed that (NO_2^-+ NO_3^-)-N concentrations increased with reducing PO_4^{3-}-P concentrations downstream resulting into high N:P ratio at the river mouth implying that phosphorous was limiting at the river mouth. PO_4^{3-}-P usually becomes limiting downstream since nitrogen is replenished by nitrogen fixation whereas P is continuous consumed by phytoplankton or diluted by P-limited oceanic waters. The N: P ratio was highest in Sabaki River and lowest in Umba (Figure 5). A comparison of N: P ratio for all the systems showed a significant difference (F= 8.84, $p<0.05$). The differences in N: P ratios between the river systems alone were statistically

Table 1. Mean concentrations of water quality parameters BOD_5 (mg/L) and DO (mg/L) in the estuarine and associated systems under study.

System	**DO (mg/L)**			**BOD_5 (mg/L)**		
	Min	***Mean***	***Max***	***Min***	***Mean***	***Max***
Tana	4.40	5.60	6.7	4.70	5.60	6.60
Sabaki	5.70	8.50	10.4	2.60	4.70	5.80
Malindi	6.40	7.16	8.4	2.80	3.81	4.96
Mambrui	7.44	8.00	8.32	3.80	4.03	4.16
Ramisi	8.20	9.90	11.2	1.80	4.10	7.50
Shimoni	8.20	8.55	9.00	1.20	2.50	4.80
Umba	8.08	10.30	16.6	1.30	3.00	6.84

BOD_5= Biological Oxygen Demand measured after 5 day incubation, Dissolved Oxygen; mg/L= Milligrams per Litre.
Max= Maximum Value recorded, Min= Minimum Value recorded.

Table 2. Mean concentrations of nutrients PO_4^{3-}-P, (NO_2^-+ NO_3^-) - N, (mg/L) and Chl a (mg/L) in the estuarine and associated systems under study.

System	**PO_4^{3-}-P (mg/L)**			**NO_2^-+ NO_3^-)-N (mg/L)**			**NH4+-N (mg/L)**		
	Min	***Mean***	***Max***	***Min***	***Mean***	***Max***	***Min***	***Mean***	***Max***
Tana	0.001	0.0022	0.003	0.0067	0.009	0.016	0.0024	0.006	0.010
Sabaki	0.002	0.1383	0.224	0.0333	5.133	10.83	0.0002	0.007	0.015
Malindi	0.011	0.016	0.028	0.0050	0.020	0.040	0.0002	0.006	0.014
Mambrui	0.019	0.024	0.026	0.0350	0.052	0.079	0.0043	0.014	0.022
Ramisi	0.001	0.016	0.040	0.0030	0.134	0.330	0.0098	0.079	0.213
Shimoni	0.004	0.011	0.032	0	0.063	0.020	0.02	0.020	0.030
Umba	0.004	0.023	0.068	0.0001	0.018	0.052	0.009	0.050	0.160

significant ($F= 12.4$, $p < 0.05$).

Chlorophyll a showed a distribution pattern which is almost completely in contrast with the major nutrients (Figure 1). Interestingly, the high concentrations observed for (NO_2^-+ NO_3^-)-N and PO_4^{3-}-P in the Sabaki and Tana systems did not influence the primary production (Chl a). Ramisi system had the highest mean concentration of Chl a followed by Umba system (Figure 1). This could be attributed to the high levels of ammonium (Figure 2) and reduced levels of turbidity (less TSS) (Table 3). The discriminate preference for ammonium to the other N forms by phytoplankton has been attributed to the fact that phytoplankton need to convert the other nitrogen forms (such as nitrate and nitrite) enzymatically into ammonium prior to assimilation (Eppley *et al.,* 1969), a process that is energy expensive.

These results revealed strong associations between physicochemical parameters and nutrients. Total suspended solids (TSS) and PO_4^{3-}-P showed a significant correlation of $r= 0.59$, $p<0.05$ in the Sabaki system (a relatively very turbid system). Dissolved oxygen and NH_4^+-N showed a significant correlation of $r= -0.61$, $p<0.05$. In Malindi coastal system, TSS correlated significantly with (NO_2^-+ NO_3^-)-N, PO_4^{3-}-P and $NH4^+$-N ($r= 0.83$, $p<0.05$, $r= 0.5$, $p<0.05$ and $r= 0.61$, $p<0.05$, respectively). In the Ramisi system, there were significant correlations between the nutrients and the other water quality parameters. There were significant associations between DO and (NO_2^-+ NO_3^-)-N, PO_4^{3-}-P, NH_4^+-N and Chl a ($r= 0.90$, $p<0.05$, $r= 0.77$, $p<0.05$ 0.80 and $r= 0.95$, $p<0.05$,). BOD_5 also portrayed similar significant associations with (NO_2^-+ NO_3^-)-N, PO_4^{3-}-P, $NH4^+$-N ($r= 0.7$, $p<0.05$, 0.64, $p<0.05$, 0.81, $p<0.05$ and 0.85, $p<0.05$). An interesting pattern in the BOD_5 trends was observed: for every estuarine system in which there were declining levels downstream (Table 3).

The major nutrients, PO_4^{3-}-P and (NO_2^-+ NO_3^-)-N showed a general decreasing trend downstream in all the estuarine systems. This observation agrees with the findings of Ohowa, (1996) that reported a general decrease in nutrient concentrations with increasing salinity during transportation through the estuarine zone. This trend could be attributed to adsorption and desorption of PO_4^{3-}-P from mineral surfaces forming a buffering mechanism that regulate PO_4^{3-}P concentration in rivers and estuaries (Froelich, 1988), a process which is dictated by salinity levels.

The generally high concentrations of nutrients [(NO_2^-+ NO_3^-)-N and PO_4^{3-} -P] observed in Sabaki system *vis a vis* the other systems is attributable to high input of

Table 3. Summary (Mean ±SE) of limnological parameters TSS (mg/L), BOD$_5$ (mg/L) and Chll a (mg/L) for the sampling stations.

Sampling Station	***D*.O(mg/L)**	***B.O.*D$_5$ (mg/L DO)**	***TSS* (mg/L)**	**Chl-a (mg/L)**
Tana Bridge	6.5±0.14	6.48±0.08	600±0.001	11.7985
Mulkani	6.1±0.08	5.84±0.20	920±0.001	2.2096
Kipini Village	5.35±0.06	5.2±0.12	170±0.001	4.335
Kipini Mouth	4.43±0.044	4.88±0.08	237.1428±0.001	1.6155
Galana	5.8±0.10	0.13±0.03	415±28	4.2486
Sabaki 1	9.973±0.25	4.933±0.13	166.887±56.66	3.410±1.81
Sabaki 2	9.093±0.41	3.867±0.64	542.222±172.23	2.786±0.35
Sabaki 3	9.013±0.11	4.160±0.08	623.175±196.24	2.569±0.55
Mambrui	8.000±0.28	4.027±0.10	35.3±3.06	0.588±0.07
Malindi Jetty	7.653±0.39	4.240±0.41	18.000±1.16	0.471±0.07
Malindi Marine Park	7.200±0.20	3.547±0.37	18.0±2.04	0.626±0.04
Malindi Navy	6.613±0.12	3.65±0.35	18.4±0.59	0.587±0.07
Ramisi 1	10.880±0.17	6.353±0.62	26.667±1.76	6.353±0.62
Ramisi 2	9.733±0.18	3.370±0.07	20.667±0.88	3.370±0.07
Ramisi 3	8.373±0.07	2.042±0.14	24.667±0.67	2.042±0.14
Ramisi Bridge	10.587±0.11	4.659±0.38	31.833±2.89	4.659±0.38
Kibuyuni	8.693±0.18	1.682±0.11	33.667±1.45	1.682±0.11
Shimoni Jetty	8.400±0.12	3.402±1.13	28.333±3.93	1.326±0.16
Umba Mouth	12.613±2.017	3.126±0.285	32.667±1.76	3.126±0.29
Umba Village 1	9.040±0.16	1.799±0.255	33.333±2.73	1.799±0.26
Umba Village 2	8.560±0.33	1.840±0.040	40.667±3.28	1.840±0.04
Umba Bridge	10.427±0.14	1.915±0.274	23.333±2.33	1.915±0.27
Umba Border	10.960±0.09	6.124±0.493	14.000±4.16	6.124±0.49

TSS= Total Suspended Solids, BOD$_5$= Biological Oxygen Demand measured after 5 day incubation, DO= Dissolved Oxygen, Chll a= Chlorophyll a; mg/L= Milligrams per Litre.

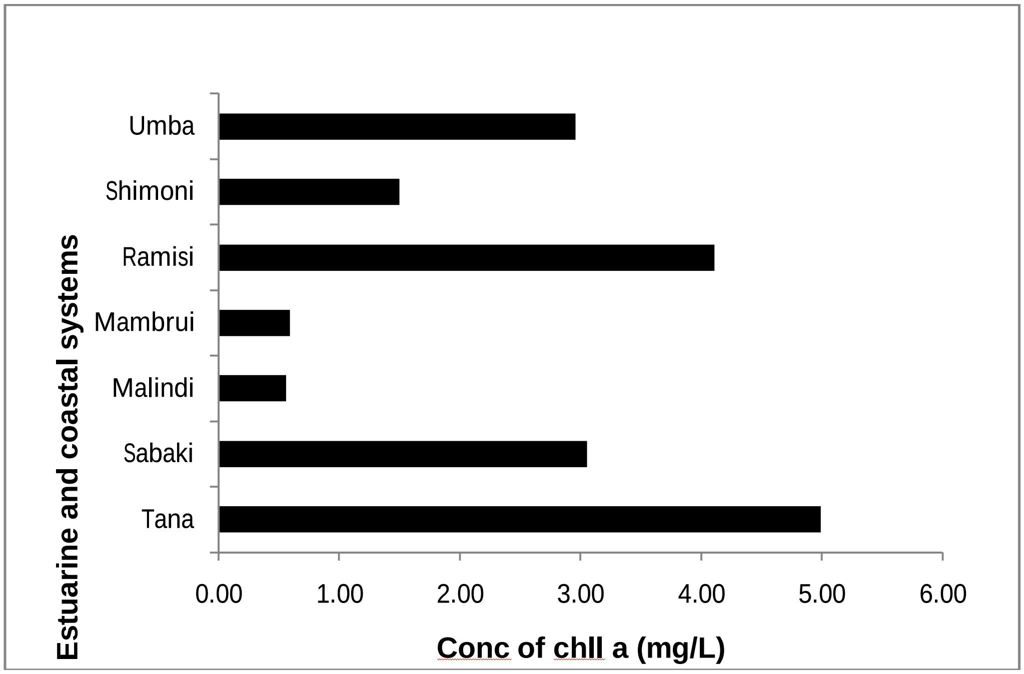

Figure 1. Comparison of mean Chl a (mg/L) concentrations among the systems.

■ Levels of Chlorophyll a

Chll a= Chlorophyll a

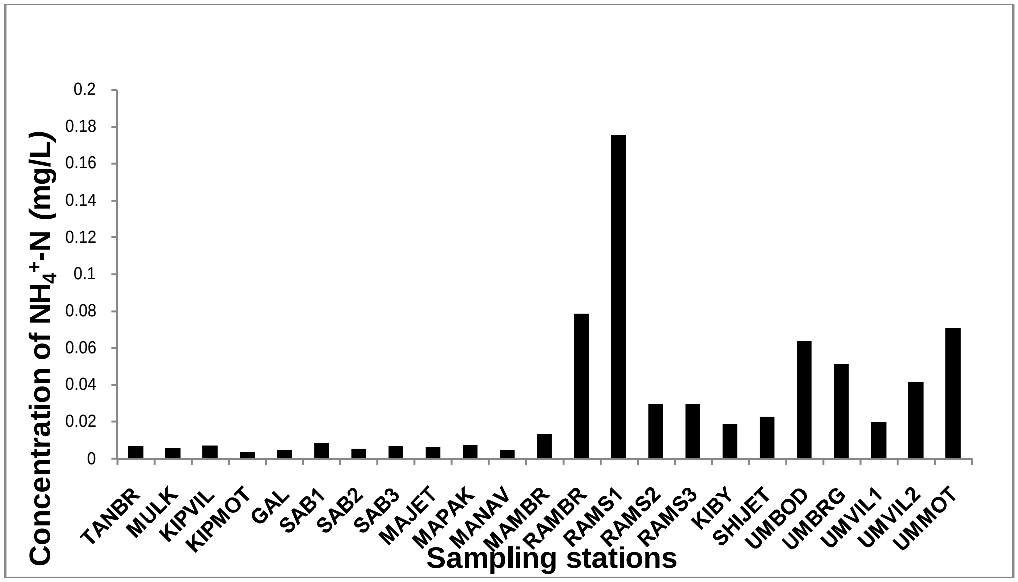

Figure 2. Mean NH_4^+-N (mg/L) concentrations among the stations.

■ Levels of NH_4^+-N

TANBR= Tana Bridge, MULK= Mulkani, KPVIL= Kipini Village, KIPMOT= Kipini Mouth, GAL= Galana, SAB1= Sabaki 1, SAB2= Sabaki2, SAB3= Sabaki 3, MAJET= Malindi Jetty, MAPAK= Malindi Marine Park, MANAV= Malindi Navy, MAMBR= Mambrui, RAMBR= Ramisi Bridge, RAMS1= Ramisi 1, RAMS2= Ramisi 2, RAMS3= Ramisi 3, KIBY= Kibuyuni, SHIJET= Shimoni Jetty, UMBOD= Umba Border, UMBRG= Umba Bridge, UMVIL1= Umba Village 1, UMVIL2= Umba Village 2, UMMOT= Umba Mouth.

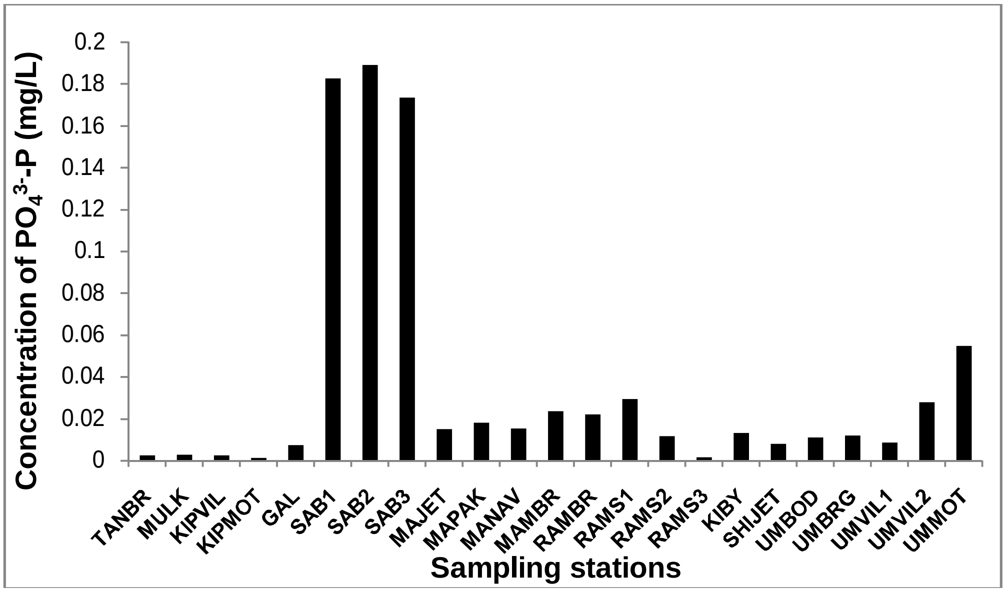

Figure 3. Mean PO_4^{3-}-P (mg/L) concentrations among the stations.

■ Levels of $PO_4^{3—}$P

TANBR= Tana Bridge, MULK= Mulkani, KPVIL= Kipini Village, KIPMOT= Kipini Mouth, GAL= Galana, SAB1= Sabaki 1, SAB2= Sabaki2, SAB3= Sabaki 3, MAJET= Malindi Jetty, MAPAK= Malindi Marine Park, MANAV= Malindi Navy, MAMBR= Mambrui, RAMBR= Ramisi Bridge, RAMS1= Ramisi 1, RAMS2= Ramisi 2, RAMS3= Ramisi 3, KIBY= Kibuyuni, SHIJET= Shimoni Jetty, UMBOD= Umba Border, UMBRG= Umba Bridge, UMVIL1= Umba Village 1, UMVIL2= Umba Village 2, UMMOT= Umba Mouth.

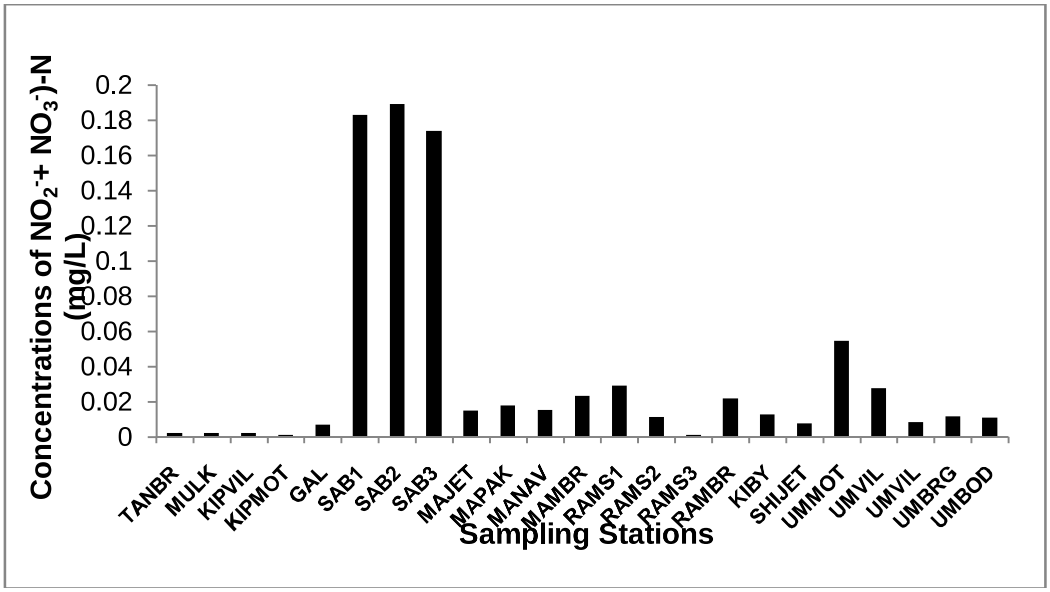

Figure 4. Comparison of $(NO_2^- + NO_3^-)$-N (mg/L) between stations.

■ $(NO_2^- + NO_3^-)$-N

TANBR= Tana Bridge, MULK= Mulkani, KPVIL= Kipini Village, KIPMOT= Kipini Mouth, GAL= Galana, SAB1= Sabaki 1, SAB2= Sabaki2, SAB3= Sabaki 3, MAJET= Malindi Jetty, MAPAK= Malindi Marine Park, MANAV= Malindi Navy, MAMBR= Mambrui, RAMBR= Ramisi Bridge, RAMS1= Ramisi 1, RAMS2= Ramisi 2, RAMS3= Ramisi 3, KIBY= Kibuyuni, SHIJET= Shimoni Jetty, UMBOD= Umba Border, UMBRG= Umba Bridge, UMVIL1= Umba Village 1, UMVIL2= Umba Village 2, UMMOT= Umba Mouth.

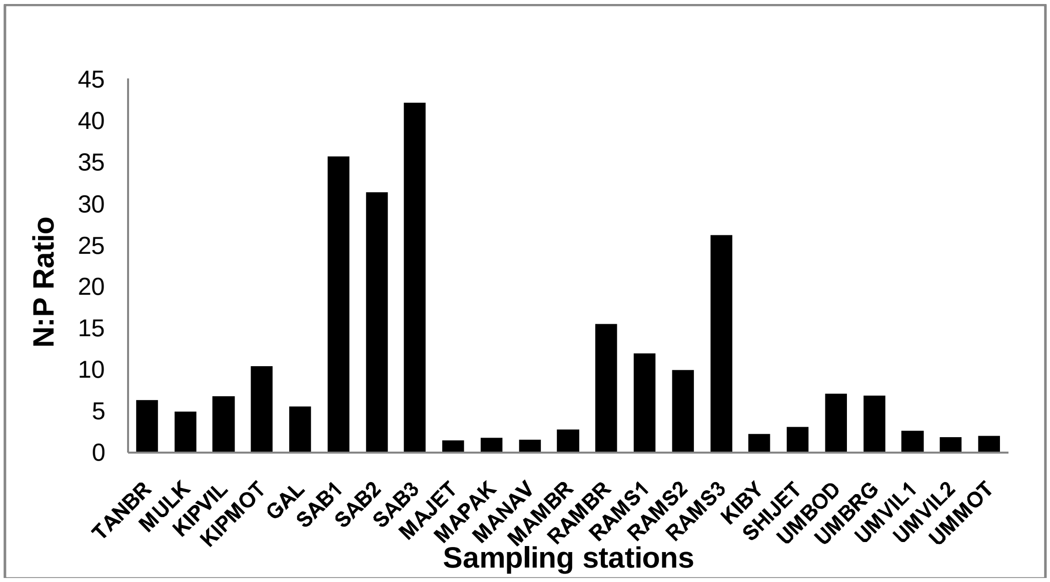

Figure 5. Comparison of N: P Ratio between stations.

■ N:P Ratio

TANBR= Tana Bridge, MULK= Mulkani, KPVIL= Kipini Village, KIPMOT= Kipini Mouth, GAL= Galana, SAB1= Sabaki 1, SAB2= Sabaki2, SAB3= Sabaki 3, MAJET= Malindi Jetty, MAPAK= Malindi Marine Park, MANAV= Malindi Navy, MAMBR= Mambrui, RAMBR= Ramisi Bridge, RAMS1= Ramisi 1, RAMS2= Ramisi 2, RAMS3= Ramisi 3, KIBY= Kibuyuni, SHIJET= Shimoni Jetty, UMBOD= Umba Border, UMBRG= Umba Bridge, UMVIL1= Umba Village 1, UMVIL2= Umba Village 2, UMMOT= Umba Mouth.

nutrients from the agriculturally active catchment of the Sabaki system and sewage input in Athi River that joins Sabaki river. Even though Sabaki and Tana systems could be assumed to be having catchments of almost similar attributes in terms of agricultural perturbations, the results of this study suggest that the two rivers could be having distinct catchments and therefore different levels or types of disturbances or possibly different responses to pollutants. This observation is explainable by the fact that unlike the Sabaki system that does not have reservoirs on its course, in the Tana system, there are a number of dams which form the Seven Folks Dams Scheme. Dams are known to facilitate the settling of suspended matter with the adsorbed nutrients (Rosenburg *et.al.,* 2000) thus reducing sediments and nutrients transport downstream.

The N:P ratio of less than 10 recorded at the upstream of Sabaki system implies a short-term N limitation. The observed general increasing pattern of N:P ratio downstream for all the estuarine systems could be attributed to increasing sedimentation and subsequent remineralisation and ammonification processes as well as continuous uptake of PO_4^{3-}-P by algae.

The declining pattern of nutrient levels down the estuary could probably be as a result of tidal dilution and phytoplankton uptake as observed elsewhere by Mallin, (2007). Sedimentation of the suspended matter with the adsorbed nutrients could have partly been responsible for reduction of nutrients down the estuaries given that sediments have a higher affinity for nutrients as compared to the water compartment (Wetzel, 2001). The settling down of suspended matter continues as the river water travels down the estuary and eventually into the sea. The conditions of reduced turbidity in lower estuarine stations promote primary productivity depicted with increased Chl a concentrations downstream.

Conclusion

The study has shown that the Sabaki and Tana systems transport significantly high amounts of sediments and nutrients compared to the other Kenyan rivers draining into the Indian Ocean. This study therefore recommends that measures be taken to reduce erosion and transport of sediments (with adsorbed nutrients) and any other sources of nutrients (i.e sewage inputs).

The increasing trend of nutrients down the estuarine systems of R. Umba and R. Ramisi as compared to R. Tana and R. Sabaki systems could be attributed to nutrients cycling in the adjacent mangrove ecosystems. Further studies should be carried out to investigate in-depth mechanisms of nutrients cycling in these systems.

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