ASSESSMENT OF FECAL BACTERIA CONTAMINATION IN SEWAGE AND NON-SEWAGE IMPACTED MANGROVE ECOSYSTEMS ALONG THE COAST OF DAR ES SALAAM

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ABSTRACT
Microbiological quality of the intertidal pool water was evaluated in sewage impacted (Mtoni Kijichi) and non-sewage impacted (Rasi Dege) mangrove forest sites along the coast of Dar es Salaam, Tanzania. The Most Probable Number method was used for estimating the total coliform (TC), fecal coliform (FC) and fecal enterococci (ENT) levels. In addition, physico-chemical parameters (temperature, pH, salinity and nutrients) were measured. The results for microbial fecal indicators were compared to the World Health Organisation (WHO) and United States Environmental Protection Agency (USEPA) guidelines for marine recreational and shellfish harvesting waters. Fecal bacteria contamination was significantly higher at Mtoni Kijichi than at Rasi Dege mangroves Nutrient levels were also significantly higher at Mtoni Kijichi than Rasi Dege). No significant variation was noted on the values of temperature, pH and salinity. A significant correlation between the levels of fecal bacteria indicators and nutrient concentrations was observed at both sites. Regarding compliance to WHO and USEPA guidelines, only one station at Mtoni Kijichi was found to have levels exceeding the recommended thresholds for marine recreational waters. The high level of fecal bacteria contamination and nutrients was attributed to anthropogenic activities. Further studies and education of the users of these ecosystems is recommended.

INTRODUCTION

Most coastal cities in the tropics are growing at alarming rates and do not have the infrastructures to cope with the influx of people from rural areas. In many parts of Tanzania, Mozambique and Madagascar, sewage disposal systems are inadequate, poorly maintained and the volume of sewage frequently exceeds their capacity. Untreated municipal wastewater is sometimes discharged into the coastal waters and in some places directly onto coastal habitats such as mangroves, to the extent of threatening the health of several coastal communities (Richmond 2002).

Peri-urban mangroves of the cities in the tropics are the recipients of sewage-polluted rivers and flash-flood waters and are extensively used for sewage dumping. Examples are Tudor and Mtwapa creeks in Mombasa and Kunduchi in Dar es Salaam (UNEP 1998, Mohammed 2002). In Zanzibar, sewage effluents are poured directly in the mangrove stands at Bwawani hotel and Gulioni area, which receive direct raw sewage from Funguni outfall (UNEP 1998). There is much evidence to suggest that mangroves filter discharged wastewater and prevent coastal pollution, therefore buffering urban wastewater emission (Valiela *et al*. 2001, Marshal 1994). Mangrove forest's act as filtering systems by trapping sediments, litter, minerals and other materials and limiting their dispersal offshore (Duke 1992, Schrijvers *et al*. 1997).

Sewage discharge generates increasing loads of fecal wastes in natural waters. In many cases, the extent of pollution causes increases in numbers of fecal bacteria and may contain pathogenic microorganisms in high numbers beyond the assimilation capacity of the receiving water bodies (Mato 2002). The receiving water therefore becomes unfit for various purposes such as recreation in the case of seawater (Jagals *et al*. 2000). It is well known that enteric pathogens do not die quickly once exposed to the seawater as they tend to survive with survival rates varying from a few minutes to many days depending upon the marine environmental conditions e.g. nutrient availability, sedimentation, predation (by copepods and protozoa), parasitism, inactivation by sunlight, temperature, osmotic stress, or toxic chemicals and therefore pose several health risks to humans (Ashbolt 1995, Henrickson *et al*. 2001).

In Dar es Salaam, sources of fecal contamination in the marine environments include direct discharge of sewage into the ocean e.g. sewage is discharged directly into the Indian ocean at Ocean Road area via a 1 km sewer (Elmcret 2000), inflows from contaminated rivers and streams as for Mzinga and Kizinga creeks in Mtoni Kijichi Mangrove forests which receive substantial quantities of sewage wastes from the riparian households and municipal sewage dumping, underground seepage from the traditional pit latrines, septic tanks and soak away pits resulting from the use of on-site sanitation system by the surrounding coastal communities (Mgaya *et al*. 2004). Mangrove ecosystems are also used for different purposes such as small scale fishing mainly of edible crabs and shrimps, spiritual purposes, cutting of mangroves for fuel wood and building poles and this leads to the surrounding communities in using parts of the beach or mangrove forests as latrine areas and therefore becoming another source of fecal contamination other than direct sewage discharge (Richmond 2002).

Mgaya *et al*. (2004) in a study carried out at Mtoni mangrove ecosystem, which is one of the sites in this study, reported that mangroves from the densely populated area (western side of Mzinga creek) are enriched in ^{15}N relatively to other sides. Stable isotope compositions for mangrove parts showed high enrichment in ^{15}N for *Avicennia marina* relatively to other species, roots being the most enriched part of the plant. High enrichment in ^{15}N is attributed to utilization of nutrients rich in ^{15}N probably of anthropogenic origin such as sewage caused by proximity to the settlements. On the other hand, Rasi Dege mangrove ecosystem another site in this study, receives very little anthropogenic activities due to its relatively far location from the Dar es Salaam city centre. Therefore, this study is aimed at determining the levels of fecal bacteria contamination between the sewage-impacted (Mtoni Kijichi-Mzinga creek) as compared to non-impacted (Rasi Dege) mangrove forests. Furthermore, the study provides baseline information on microbial indicators, which will be used to access the feasibility of using mangrove forests as filters of domestic sewage, particularly on microbial filtration. The information on mangrove filtration will be useful in strategic mangrove conservation and reforestation in sewage discharge areas and therefore facilitating natural filtration may represent cheap and immediate implementable approaches to mitigating coastal sewage pollution.

MATERIALS AND METHODS

Study sites

The study was conducted in mangrove forests in the Dar es Salaam region (Fig. 1). Dar es Salaam coast stretches for about 100 km from the mouth of Mpiji River in the north to the mouth of Mbezi River in the south. In general, Dar es Salaam region has several mangrove stands including the Mbweni, Kunduchi, Salander Bridge, Mtoni Kijichi, Mji mwema and Rasi Dege mangroves (Akwilapo 2001). In this study, two mangrove forests i.e. Mtoni Kijichi and Rasi Dege were selected on the basis of sewage contamination, resulting from the influence of proximity to the settlements and incoming rivers.

Each site was subdivided into three stations designated A, B and C (for Mtoni Kijichi) and D, E and F (for Rasi Dege). The Mtoni Kijichi mangrove forest is surrounded by human settlements. The majority of the population in the area are squatters (un-surveyed) and dependent on on-site sanitation system comprising mainly of traditional pit latrines and to a smaller extent septic tanks and soakaway pits (Mgaya *et al*., 2004). Based on these facts, Mtoni Kijichi was considered as the sewage-impacted site. Rasi Dege mangrove forest was regarded as non sewage-impacted because it is very far from the human settlements with exception of only one structure, a small recreational hotel (Mbamba Bay Hotel) and therefore experiencing very little disturbances from various anthropogenic activities.

Physico-chemical Parameters

Sampling and field measurements were carried out at each site twice monthly from late September 2005 to early February 2006 during low tide. During each sampling event, measurements for pH, temperature and salinity of the intertidal pool waters were taken. Temperature and salinity were measured using a mult-meter (type YSI 85/10 FT, Yellow Springs, Ohio-USA) while pH was measured using Hydrus 100 pH meter (type FB 50101, UK) by dipping the probe into pool water to about 3-5 cm. Nutrients (Nitrate, Nitrite and Phosphate) concentrations of the collected water samples were determined as described by Parsons *et al.* (1989).

Microbial Analysis

Fecal bacteria concentrations i.e. total coliforms, fecal coliforms, and *Enterococcus* were determined according to the standard methods (APHA 1995) based on Most Probable Number (MPN) method (5 tube series). The MPN method comprised of three stages; presumptive, confirmation and completed test. In the presumptive test, dilutions of the water sample were added to the tubes containing MacConkey broth. The tubes were incubated for 24 to 48 hours at 35°C and 44.5°C for total and fecal coliforms respectively. Gas production (CO_2) as a result of Lactose fermentation was detected by small inverted vials (Durham tubes) present in test tubes and the colour change in the MacConkey broth medium from purple to yellow (resulting from acid production) indicated positive results. In the confirmation test, Eosin methylene blue (EMB) agar containing lactose was inoculated with samples from the highest positive dilutions followed by incubation for 48 hours at 35°C. Small colonies, dark, almost black at center, with greenish metallic sheen observed indicated a positive confirmation test (for the coliforms). In the completed test, the most typical colonies selected from EMB plate were inoculated in the lactose broth where production of gas indicated a positive test for the coliforms. By means of MPN tables, the number of the indicator bacteria in the water samples was determined. In the presumptive test for the *Enterococcus spp*, Azide dextrose broth was used whereby inoculated tubes were incubated for 24 to 48 hours at 35°C. Positive tubes were detected by observing turbidity in the tubes. In the confirmed test, Ethyl violet azide (EVA) broth was inoculated with inoculum from the highest positive dilutions. Growth in EVA, after 24 to 48 hours incubation at 35°C, was a confirmed evidence for the presence of *Enterococcus* spp. For the *Enterococcus* spp, the MPN was usually taken from the number of positive EVA tubes (Edberg *et al*. 1997).

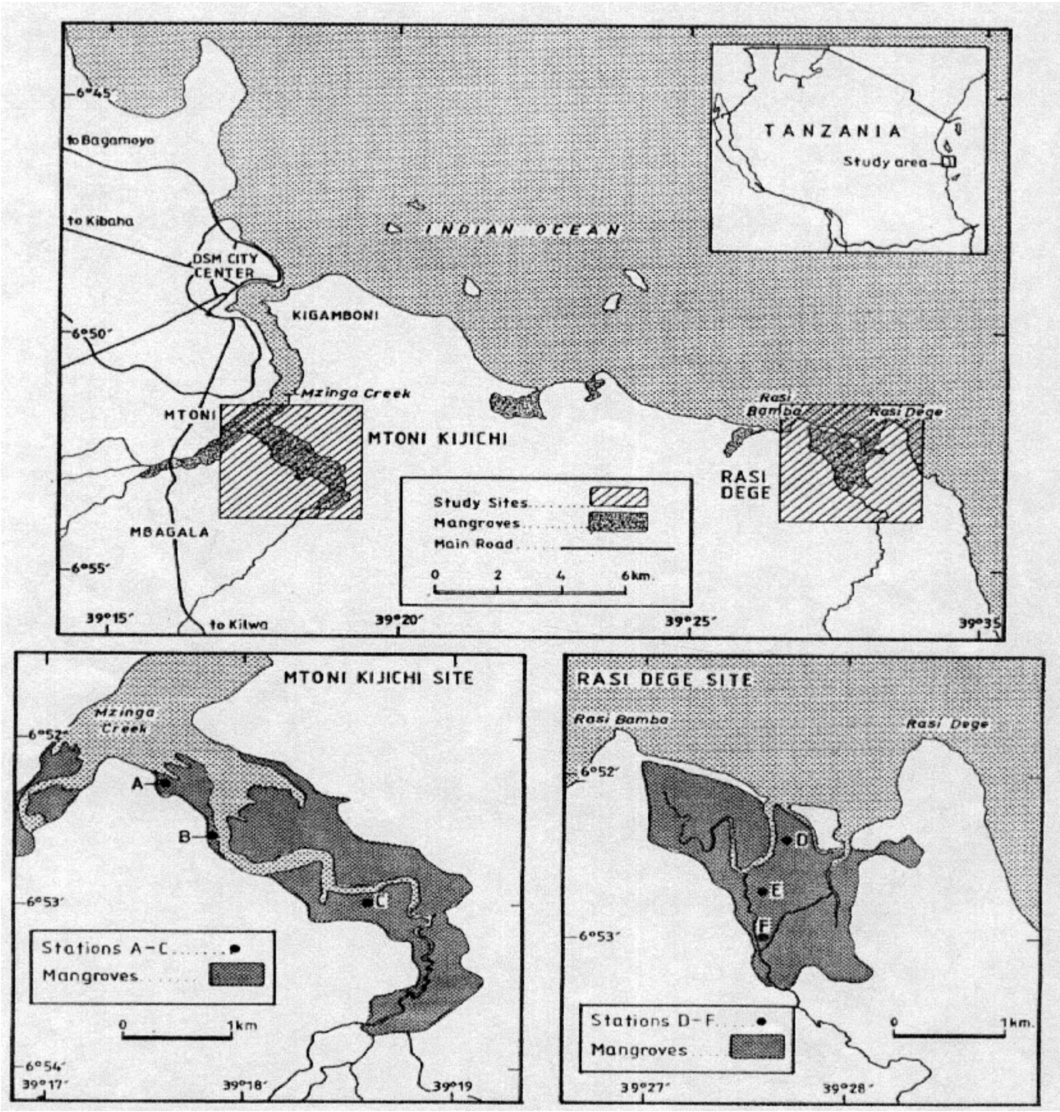


Figure 1: Map of Dar es Salaam Coast showing the study sites.

Statistical Analyses
The data collected were statistically analyzed as described by Zar (1999) using several tests done with the Statistical Package for Social Science (SPSS) for windows, version 11 (SPSS Inc., Chicago, Illinois). Since the data did not follow normal distribution, the significant difference in levels of fecal bacteria contamination in the sewage-impacted and non-impacted mangroves was tested using Mann-Whitney non-parametric tests. The determination of significant relationship between environmental parameters and levels of fecal bacteria was tested using Spearman Rank Correlation. Kruskal-Wallis test and Dunn's Multiple Comparison post-test was used for spatial variations in fecal bacteria contamination.

RESULTS

Chemical and physical characterization of the sampling Sites
The mean values of the physico-chemical parameters and nutrient concentration in the sampled sites are shown in Table 1. At Mtoni Kijichi, the pool seawater temperature, pH and salinity ranged from 28 - 32°C, 6.05 - 8.14 and 35 - 39‰, respectively. At Rasi Dege the seawater temperature, pH and salinity ranged from 27 - 32°C, 6.98 - 8.72 and 35 - 39‰ respectively. There was no significant difference in the pool water temperature, pH and salinity between the two sites (Mann-Whitney *U*-test: U = 266.5, p = 0.07; U = 170.5, p = 0.08; U = 303, p = 0.29 for temperature, pH and salinity respectively; n = 27). However, nutrient concentrations were higher in Mtoni Kijichi than in Rasi Dege stations (Fig. 2). Statistically, significant higher nutrient concentrations were observed at Mtoni than at Rasi Dege (Mann-Whitney test: U = 60, p = 0.0001 for Nitrate, U = 99, p = 0.0001 for Nitrites and U = 151, p = 0.0002 for Phosphates, n = 27).

Table 1: Mean (± standard deviation) values for pool seawater physical chemical parameters Mtoni Kijichi (MK) Rasi Dege (RD).

SITE	Stations	Temp (^{0}C)	Salinity (‰)	pH	NO_3^- (μM)	NO_2^- (μM)	PO_4^{2-} (μM)
MK	A	30.0 ±1.00	37.6 ± 1.00	7.16 ±0.53	0.52 ± 0.17	0.23 ± 0.05	0.04 ± 0.01
	B	28.8 ±0.93	36.7 ± 0.71	7.45 ±0.61	0.25 ± 0.07	0.16 ± 0.06	0.02 ± 0.01
	C	30.1 ±1.26	36.0 ± 1.11	7.63 ±0.18	0.42 ± 0.10	0.18 ± 0.03	0.03 ± 0.01
RD	D	29.3 ±1.11	37.9 ± 0.78	8.23 ±0.29	022 ± 0.04	0.14 ± 0.03	0.03 ± 0.01
	E	28.6 ±1.22	36.8 ± 0.78	7.73 ±0.41	0.15 ± 0.03	0.07 ± 0.03	0.01 ± 0.001
	F	29.2 ±1.30	36.6 ± 1.01	7.70 ±0.50	0.16 ± 0.03	0.12 ± 0.01	0.02 ± 0.003

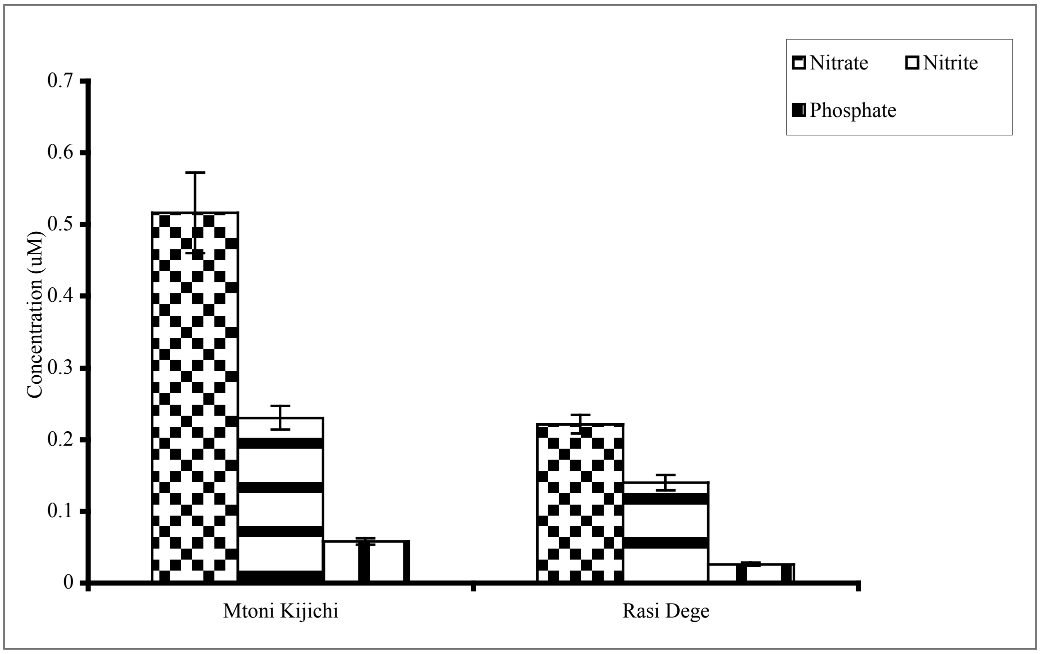


Figure 2: Mean of nutrient concentrations at Mtoni Kijichi and Rasi Dege sites (Bar shows standard deviation)

Microbial analysis

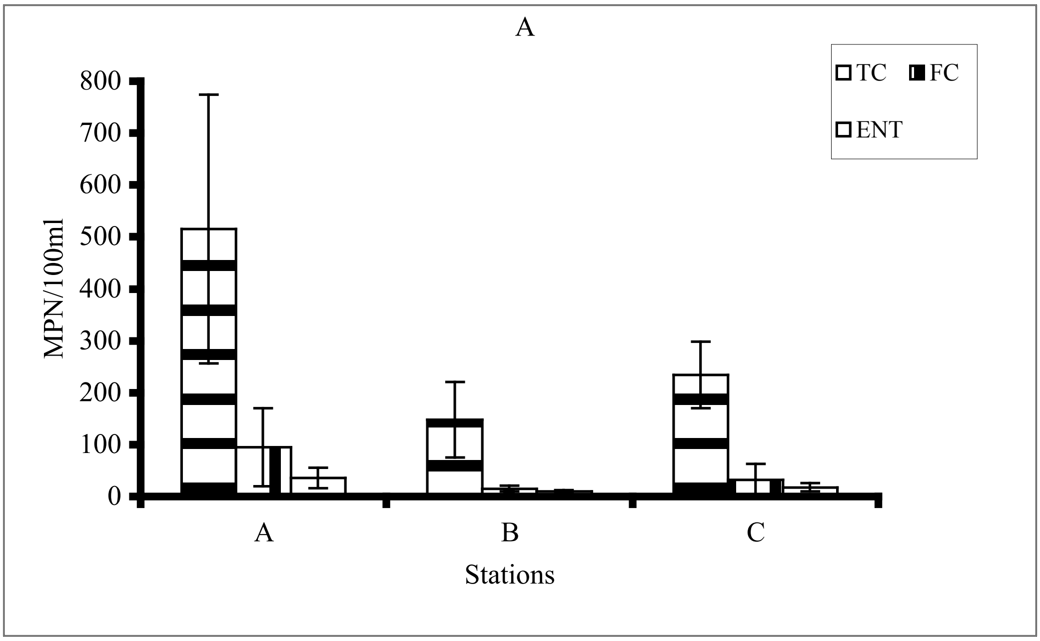
A total of 54 samples were analyzed for Total coliform (TC), Fecal coliform (FC) and *Enterococci* spp. (ENT). Table 2 shows the Most Probable Number (MPN) of fecal bacteria indicators in 100 ml of the water sample for the whole sampling period. The highest count, 920 MPN/100 ml for TC was recorded at station A at Mtoni Kijichi in samples taken on October 22 and November 15, 2005 while the lowest TC count was 9 MPN/100 ml recorded at station E at Rasi Dege. The highest count of FC was 220 MPN/100 ml in samples taken on November 1 and December 31, 2005 at station A while the lowest count was 5 MPN/100 ml recorded at station E and on Dec7 at station F. The ENT count ranged from 70 MPN/100 ml recorded in station A in the samples of September 19, 2005 to 2 MPN/100 ml recorded in the samples of October 18, 2005 at station E.

Table 2: The most probable number (MPN/100 ml) of fecal indicator bacteria in various stations at Mtoni and Rasi Dege sites. (Note, ET=ENT, sampling dates for Rasi Dege are in brackets)

Sites	**Mtoni**								
Stations	**A**			**B**			**C**		
Dates - 2005 to 2006	TC	FC	ET	TC	FC	ET	TC	FC	ET
Sept 19 (26)	540	79	70	110	17	12	240	27	33
Oct 09 (05)	350	110	33	240	21	9	280	46	26
Oct 22 (18)	920	49	17	280	11	5	350	17	14
Nov 01 (07)	540	220	22	170	9	7	220	13	11
Nov 15 (22)	920	31	18	79	17	9	130	110	12
Dec 15 (07)	540	43	49	110	22	13	280	27	22
Dec 31(20)	240	220	46	170	9	12	220	13	17
Jan 08 (22)	350	70	51	79	11	7	220	17	11
Jan 15, (Feb,09)	240	31	21	94	21	12	170	22	14
Average	515.6	94.8	36.33	148	15.3	9.6	234.4	32.4	17.8
SD	258.8	75.3	18.6	72.60	5.38	2.8	64.44	30.8	7.68
Sites	**Rasi Dege**								
Stations	**D**			**E**			**F**		
Dates - 2005 to 2006	TC	FC	ET	TC	FC	ET	TC	FC	ET
Sept 19 (26)	33	17	12	13	8	4	17	11	5
Oct 09 (05)	27	14	9	17	7	5	17	9	7
Oct 22 (18)	31	9	12	21	5	2	26	7	9
Nov 01 (07)	43	12	7	22	6	4	33	9	6
Nov 15 (22)	27	11	7	11	7	5	21	8	6
Dec 15 (07)	34	21	9	14	9	4	9	5	7
Dec 31(20)	27	22	9	22	6	6	21	14	8
Jan 08 (22)	33	14	8	12	7	6	22	12	7
Jan 15, (Feb,09)	27	17	11	14	5	4	21	8	9
Average	31.3	15.2	9.3	16.2	6.7	4.4	20.8	9.2	7.1
SD	5.3	4.4	1.9	4.4	1.3	1.2	6.6	2.7	1.4

Comparison of fecal bacteria counts at Mtoni Kijichi and Rasi Dege mangroves

The levels of fecal bacteria indicators varied considerably among the stations at Mtoni Kijichi (Fig. 3A). The highest fecal contamination was recorded at station A with an average of 515.6 ± 258.8, 94.8 ± 75.3 and 36.3 ± 18.6 MPN/100 ml of TC, FC and ENT respectively. The lowest counts of fecal indicators were found at station B with an average of 148 ± 72.6, 15.3 ± 5.38 and 9.6 ± 2.8 MPN/100 ml for TC, FC and ENT, respectively. Statistically, fecal bacteria indicators were significantly higher at station A compared to the other stations (K_w = 15.79, p = 0.0004 for TC, K_w = 16.14, p = 0.003 for FC and K_w =16.14, p = 0.003 for ENT).



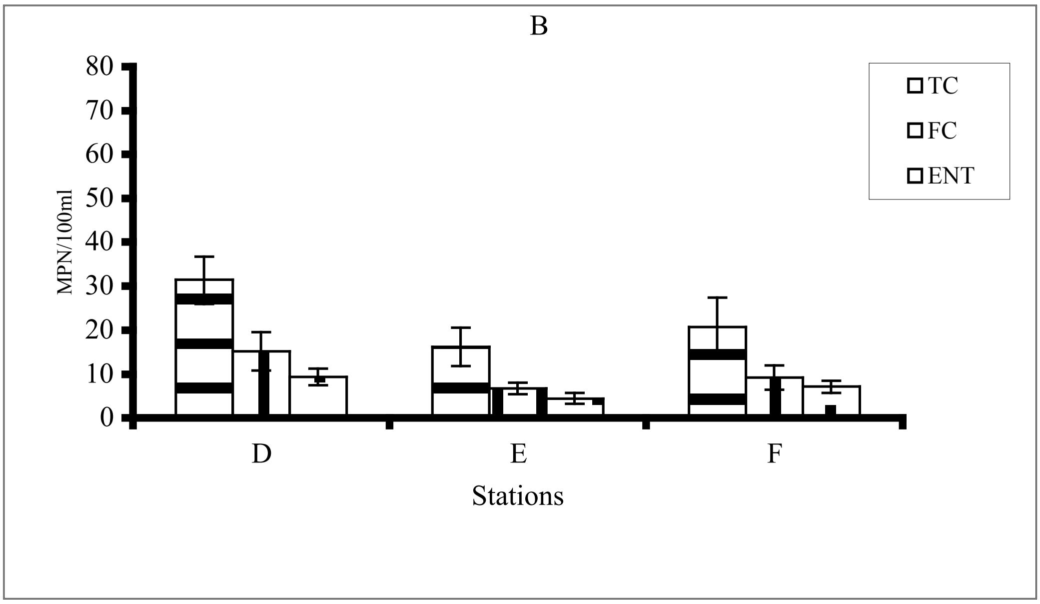


Figure 3: Mean levels of fecal bacteria at Mtoni Kijichi (A) and Rasi Dege (B) stations. (Bar is standard deviation)

Likewise, variations in fecal bacteria levels was observed at Rasi Dege stations (Fig. 3B), the highest fecal bacteria counts were recorded at station D with an average of 31.3 ± 5.3, 15.2 ± 4.4 and 9.3 ± 1.9 MPN/100 ml for TC, FC and ENT respectively. The lowest fecal bacteria counts were recorded at station E with an average of 16.2 ± 4.4, 6.7 ± 1.3 and 4.4 ± 1.2 MPN/100 ml for TC, FC and ENT respectively. Statistically, fecal bacteria indicators were significantly higher at station D compared to the other stations (K_w = 16.32, p = 0.0003 for TC, K_w = 16.73, p = 0.002 for FC and K_w = 18.52, p = 0.001 for ENT).

Combining all the data, it was clearly shown that Mtoni Kijichi mangroves are more polluted by fecal bacteria than Rasi Dege mangroves. The overall mean bacterial counts (for all the stations within a site) at Mtoni Kijichi were 299.3 ± 221.1, 48.3 ± 57.1 and 20.9 ± 16.1 MPN/100 ml for TC, FC and ENT, respectively. The overall mean bacterial counts for Rasi Dege, were 23.1 ± 8.3, 9.7 ± 4.7 and 6.7 ± 2.5 MPN/100 ml for TC, FC and ENT, respectively. In deed, statistical test showed significantly higher fecal bacteria contamination at Mtoni Kijichi than at Rasi Dege (Mann-Whitney U test: U = 16.60, p = 0.0001; U = 653, p = 0.0001; U = 65.5, p = 0.0001 for TC, FC and ENT respectively, n = 27).

Correlations between bacteriological and physico-chemical parameters

Spearman's rank correlation was determined to assess if a link exists between the levels of fecal bacterial contamination and the Physico-chemical parameters observed from Mtoni Kijichi and Rasi Dege sites are shown in Table 3 (a and b). No significant correlation was observed between the levels of fecal bacteria contamination and pool water temperature, pH and salinity over the study period. A significant correlation was observed between the levels of fecal bacteria and nutrient concentrations in both sampling sites.

Table 3(a): Spearman's rank correlation half matrix for Mtoni Kijichi water quality parameters (* = significant at α = 5 % level.)

	TC	FC	ENT	pH	TEMP	Salinity	NO_3^-	NO_2^-
TC	1							
FC	0.556*	1						
ENT	0.415	0.461	1					
pH	-0.022	-0.052	-0.253	1				
TEMP	0.183	0.318	0.314	0.265	1			
Salinity	0.393	0.184	0.006	0.264	0.166	1		
NO_3^-	0.609*	0.557*	0.694*	0.224	0.301	0.328	1	
NO_2^-	0.597*	0.344	0.402	0.111	0.166	0.249	0.558	1
PO_4^{3-}	0.644*	0.675*	0.650*	0.064	0.011	0.028	0.367	0.259

KEY: TC=Total coliform, FC=Fecal coliform, ENT=*Enterococci spp.*, TEMP=Pool water temperature, pH= Water pH, SAL= Salinity, NO_3^- = Nitrate, NO_2^- = Nitrite, PO_4^{3-} = Phosphate,

Table 3 (b): Spearman's rank correlation half matrix for Rasi Dege water quality parameters (* = significant at a = 5 % level.)

	TC	FC	ENT	pH	TEMP	Salinity	NO_3^-	NO_2^-
TC	1							
FC	0.643*	1						
ENT	0.314	0.454	1					
pH	0.477	0.362	0.276	1				
Temp.	0.425	0.127	0.114	0.022	1			
Salinity	0.445	0.227	0.230	0.499	0.870	1		
NO_3^-	0.586*	0.692*	0.676*	0.404	0.098	0.161	1	
NO_2^-	0.697*	0.594*	0.729*	0.493	0.062	0.341	0.782	1
PO_4^{3-}	0.743*	0.610*	0.733*	0.588	0.152	0.457	0.572	0.805

KEY: TC=Total coliform, FC=Fecal coliform, ENT=*Enterococci spp.*, TEMP=Pool water temperature, pH= Water pH, SAL= Salinity, NO_3^- = Nitrate, NO_2^- = Nitrite, PO_4^{3-} = Phosphate,

DISCUSSION

The physico-chemical parameters were within other finding in the region (e.g. Swilla *et al.* 2004, Mgaya *et al.* 2004, Lyimo and Lugomela 2006). The pH, temperature and salinity did not vary significantly between the sampling sites or among the stations within the sites, due to the fact that the entire sampling was done during low tide at day time and in dry season. However, higher levels of nutrients at Mtoni Kijichi mangroves were attributed to higher anthropogenic inputs (incoming contaminated freshwater streams/rivers, seepage from domestic wastewater) resulting from the influence of the surrounding human settlements. Lack of sewage treatment on the domestic water from settlements near the coastal environments can result in stormwater drains/seepage running into the adjacent nearshore areas and therefore resulting in increased nutrient concentrations in waters (Nixon 1990, 1995, Pan and Rao 1997, Freyman 2000).

The higher levels of fecal bacterial contamination in the Mtoni Kijichi mangroves compared to the Rasi Dege mangroves corresponds with the fact that Mtoni Kijichi mangroves are more exposed to anthropogenic influences, especially sewage from nearby settlements (Mgaya *et al.* 2004). Domestic sewage is one of the leading sources of marine pollution in the city of Dar es Salaam, as a result, hotspots of high fecal bacteria contamination occur in the coastal waters of the city (Mmochi and Francis 1998). High levels of fecal bacteria at Mtoni Kijichi mangrove corresponded with high nutrient levels. Sewage discharge in the marine environment is associated with an increase in levels of fecal bacteria contamination due to the fact that organic nutrients present within feces provide a favourable environment for growth or survival of fecal bacteria (Davies *et al.* 1995, Van Donsel *et al.* 1997).

Considering contamination levels at Mtoni Kijichi, there were higher levels of fecal bacteria in station A and C compared to station B, which shows that the fecal contamination is localized and does not spread throughout the mangrove ecosystem. In station A, higher levels may be due to possible contamination from incoming freshwater streams from nearby human settlements, also seepage from the use of pit latrines, septic tanks and soak away pits as high nutrient levels were found at this station compared to the other stations. The use of on-site sewage systems provides little treatment of domestic water and therefore contributes to high amounts of fecal bacteria and nutrient loads entering the mangrove forests (Lin and Dushoff 2001, Mohammed 2002). Another possible source of contamination which led to higher levels of fecal bacteria contamination in station A could be contamination from the use of mangrove parts as latrines. During this study, a lot of human feces was noted during every sampling event at station A, this was not observed in other stations, probably due to the fact that the mangrove stands were scattered (e.g. in station C) which does not provide privacy, also the location of the mangrove in station B (near the creek waterway), was much more difficult to reach. The surrounding communities in coastal areas have a tendency to use parts of the beach or mangrove forests as latrines (Richmond 2002). Significantly high levels of fecal bacteria were also noted by Mohammed (2002) in a study carried out at Chwaka bay in the east coast of Zanzibar, as a result of using the beach areas for toilet purposes.

On the other hand, high levels of pollution at station C may be due to proximity to the river channel and therefore it is possible the contamination comes from incoming contaminated freshwater. It is very well recognized that the major cause of bacterial pollution in coastal waters is urban runoff entering rivers and storm drains that discharge their contents into the marine environments (Lin and Dushoff, 2001; Dwight *et al*. 2002, Reeves *et al*. 2004). Low levels of fecal bacteria contamination in station B could be as a result of the location of the sampling point i.e. near the creek waterway. Station B was much closer to the water channel which might have resulted in dilution of the fecal bacterial levels. It is well known that dilution is a major factor that reduces the concentration and distribution of fecal bacteria (Rubindamayugi 1996, Henrickson *et al.* 2001). Along with the dilution effect on the concentration of the fecal bacteria, there is a probable role of the landward mangroves decreasing the fecal bacteria since mangroves can act as effective buffers of anthropogenic effluents in the ocean environment. Thus, there is much evidence to suggest that mangroves filter discharged wastewater and prevent coastal pollution (Marshal 1994, Lin and Dushoff 2001, Valiela *et al*. 2001).
Even though Rasi Dege site was selected as a non-sewage impacted site, the findings from this study showed that the area is not 100% pristine since a certain level of contamination was revealed. Higher levels of bacterial contamination were found at stations D and F compared to station E. The higher levels in station D could be attributed to possible contamination from the nearby hotel (Mbamba bay hotel). At station F, the river Mbalaganje may have caused the observed high fecal contamination. Low levels of contamination in station E could be due to dilution effects since this station is located in a creek water way (Henrickson *et al.* 2001).

Correlation was found between the MPN of fecal coliform and total coliforms ($p>0.05$), a result which was expected since the former is a subgroup of the latter (Prescott *et al.* 1996, Silva *et al.* 2003, WHO 2003a). Another correlation was found between the levels of fecal bacteria contamination and nutrient levels, this can be explained by the fact that organic nutrients found in incoming contaminated freshwater streams is due to seepage from domestic wastewater containing nutrients (Davies *et al*. 1995, Van Donsel *et al*. 1997).

Mangrove ecosystems are known to be potential breeding grounds and refuge sites for various marine organisms (Talbot and Wilkinson 2001). The presence of fecal bacteria may indicate possible presence of pathogens which pose significant threats to human health. Pathogen contamination in the mangroves can result in contamination in sea foods e.g. shellfish and oysters. Shellfish and oysters have the ability to accumulate pathogens in their tissue and this can result in adverse effects to the health of seafood consumers (Freyman 2000, Silva *et* *al*. 2003). Also with pathogen contamination in the mangroves, there is a high possibility of the contamination to extend into the open waters due to the splashing effect of the waves and therefore result in infecting the people who utilize the water such as bathers. It is well known that the most frequent adverse health effect associated with exposure to pathogen contaminated recreational waters is enteric illness, with children being the most affected as in most cases they bath in shallow waters (WHO 2003a).

The mean levels of fecal bacterial contamination exceeding WHO and USEPA thresholds for marine recreational and shellfish harvesting waters (the standards are based on the geometric mean of multiple samples) was measured in both sites. However, for marine recreational, station A at Mtoni Kijichi was the only station found with mean levels exceeding WHO and USEPA thresholds (for *Enterococci* spp.) (USEPA 2001, WHO 2003b). Thus, bathing near station A may be a risk because the water was contaminated with fecal material and possibly pathogens are present that may lead to a disease outbreak (Kelly *et al.* 2003, WHO 2003a). On the other hand, all stations in Mtoni Kijichi and one station at Rasi Dege (Station D), were found to have fecal contamination exceeding the thresholds for shellfish harvesting (for TC and/or FC) (USEPA 2001). This also presents a threat of disease outbreaks to the users of shellfish from these particular stations in the case of consuming pathogen contaminated shellfish (Ashbolt 1995, Henrickson *et al*. 2001, Daby *et al*. 2002).

In conclusion, detection of fecal bacteria contamination in the sampling sites with levels exceeding WHO and USEPA thresholds is a definite sign of elevated microbial pollution at Mtoni Kijichi mangroves. This poses the danger of enteric illnesses where the water is used for recreational purposes or through the consumption of contaminated seafood such as shellfish. However, the detected levels of fecal bacteria in the study sites are not enough to make decisions such as closure of bathing waters or shellfish harvest restrictions by responsible authorities as further more extensive research and monitoring is required before such suggestion's could be made.

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