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Cover image: A seagrass meadow (*Thalassia hemprichii*) at Inhaca Island, Mozambique (© José Paula, 2017)

Nutrient and Bacteria Concentrations in the Coastal Waters off Zanzibar Town

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Abstract

This study assessed the concentrations and distribution of nutrients (ammonium, nitrate, nitrite, soluble reactive phosphorous) and bacteria (total and faecal coliforms) in the waters off Zanzibar Town. The study covered both the SE and NE monsoon and the two transition periods for a total of one year. Nutrient concentrations near a sewage outlet in the Bwawani area and Port sites showed values that exceeded concentrations considered acceptable for healthy reef ecosystems. The mean concentrations of total coliforms were within the ranges reported previously in the area, but faecal coliform concentrations were comparatively higher. Stations close to a sewage outlet showed the highest mean concentrations of contaminants compared to those further from the pollution source. Stations located in the shallow waters off Bawe and Changuu Islets showed slightly higher mean values compared to those located in the deeper waters between Zanzibar Town, and Bawe and Changuu Islets, which showed lowest mean values. The study has shown that the surface coastal waters off Zanzibar Town are contaminated with nutrients and coliforms due to raw sewage effluents from the Zanzibar Municipality and the distribution of these contaminants are mainly determined by seasonal monsoon winds. Therefore, there is an urgent need to treat the waste before discharging it into the coastal waters.

Keywords: Water quality, nutrients, coliforms, sewage, contaminants.

Introduction

Zanzibar Town, in the Zanzibar Urban District, is the most densely populated district in Tanzania, with a population of 223,033 and a density of 13,940 people/km^2 (URT, 2013). Unfortunately, the domestic sewage infrastructure is poor, with only 25% of residences connected to the sewerage network. The remaining residences depend on soak pits, pit latrines and septic tanks, which discharge untreated sewage, storm water, solid waste and debris into marine waters off Zanzibar Town (Baur, 1993; UNEP 1998). This has a direct impact on recreational activities, natural resources and fisheries in waters off Zanzibar Town. Few pollution studies have been carried out in these waters. Bjork *et al.* (1995), Johnstone and Suleiman (1997), Mohammed (1997), and Moynihan *et al.* (2012) have indicated that sewage pollution is a major problem in Zanzibar Town. Unfortunately, the concentrations and distribution of contaminants in these waters is not well understood. There was thus a need to study the concentrations and distribution of contaminants in these waters to assist decision-makers in matters pertaining to coastal resource management and pollution control.

This study used nutrients and bacteria as indicators of pollution in waters off Zanzibar Town, and included an assessment of the distribution and seasonal variation in concentrations of these indicators.

Methods

Study Location and Climate

This study was carried out in waters off Zanzibar Town, Unguja Island, Zanzibar, Tanzania, which lies off the east coast of Africa in the West Indian Ocean between 39° 05' E and 39° 55' E, and 4° 45' S and 6° 30' S (Fig. 1). The climate is strongly influenced by monsoons. There are two peak rainfall seasons, the long rainfall season between March and May, and the short rainfall season between October and November. The sampling stations were located between the Zanzibar Town coastline and Bawe and Changuu Islets. Stations

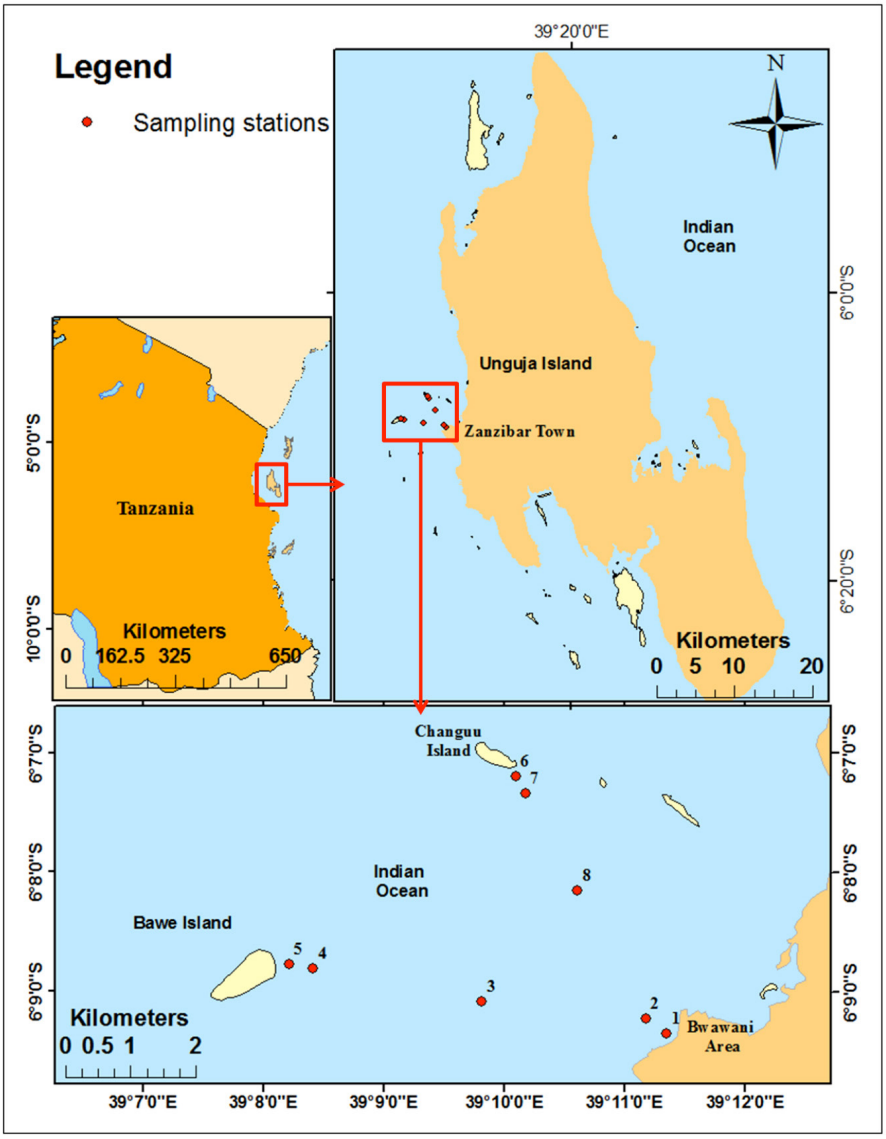

Figure 1. Map showing the study area and sampling stations.

1 and 2 were located close to a sewage outlet (Fig. 2) and the Port respectively. The stations were selected with an aim of assessing concentrations of contaminants near the discharge point. Stations 4, 5, 6 and 7 were located further offshore near Bawe and Changuu Islets, while Stations 3 and 8 were located between the islets and the main island. The stations thus form two transects, one from the coastline (source of contamination) to Bawe Islet and the other from the coastline to Changuu Islet. Sampling was carried out for one year between 2012 and 2013 and was designed to cover all seasons, including the Southeast (SE) and Northeast (NE) monsoons and transition periods.

Sampling and Analysis for Nutrients

Water samples were collected using a 1.5 L Nansen water sampler at depths of 0.5 m, 15 m and 20 m. Because Stations 1, 5 and 6 were located in very shallow waters (< 1 m depth), water samples were collected only at 0.5 m depth. At each depth three replicate water samples were collected. The samples were transported to the laboratory at the Institute of Marine Sciences, where the analysis was done.

Ammonium, nitrate/nitrite and soluble reactive phosphorus (PO4-P) concentrations were analysed according to methods described by Parsons *et al.* (1984).

Sampling and Analysis for Total and Faecal Coliforms

Three replicate water samples were collected at a depth of 0.5 m at all stations using 250 mL autoclaved sampling bottles. After collection the samples were stored in a sterilized cooler box filled with ice and transported

Figure 2. Sewage outlet in Bwawani area, from which waste discharges into coastal waters.

to the laboratory for analysis. Coliforms were analyzed within six hours of sample collection using the membrane filtration technique (USEPA, 1986).

Statistical Analysis

Data for nutrients were analyzed using one-way analysis of variance (ANOVA), while those for total and faecal coliforms were analyzed using Kruskal-Wallis ANOVA. In all cases significant differences were determined at the 95% confidence level.

Results

Concentration of Nutrients in the Water Column

The concentrations of nutrients in the water column are shown in Figures 3 - 5. The results are shown in spatial and temporal variations, including seasons and depth, with the exception of stations 2, 5 and 6 which were located in shallow waters where only samples at 0.5 m depth could be collected. The highest concentrations were usually recorded at 0.5 m depth in all four seasons. Only ammonium showed significant differences in mean concentrations of the vertical profiles (ANOVA, $p < 0.05$) (Fig. 3), while nitrate/nitrite and SRP were not significant (ANOVA, $p > 0.05$) (Fig. 4 and 5 respectively).

Differences in mean concentrations of nutrients between stations were significantly different (ANOVA, $p < 0.05$) (Figs. 3, 4 and 5). The highest mean concentrations were usually for Stations 1 and 2 in the Bwawani area and the Port, followed by Stations 4 – 7 near the islets and then Stations 3 and 8 between the shoreline and islets. Mean concentrations of nutrients in different seasons were significantly different (ANOVA, $p < 0.05$). Ammonium and PO_4-P concentrations were higher during the SE monsoon (Fig. 3 and 5 respectively), while the nitrate/nitrite concentration was highest in the NE monsoon (Fig. 4).

Concentrations of Total and Faecal Coliforms in Surface Waters

The mean concentrations of total (TC) and faecal coliforms (FC) in surface waters were significantly different between stations (Kruskal-Wallis ANOVA, $p < 0.05$) (Tables 1 and 2 respectively). The mean concentrations of TC bacteria at Stations 1 and 2 near the sewage outlet in the Bwawani area were higher than at other Stations in the shallow waters off Bawe (Stations 4 and 5) and Changuu Islets (Stations 6 and 7), and the intermediate waters between Zanzibar Town and the Islets (Stations 3 and 8). In spite of being furthest from the main sources of these bacteria, Stations 4, 5, 6 and 7 showed higher mean concentrations than Stations 3 and 8 located between the islets and main island. The mean concentration of TC bacteria in surface waters at Bawe Islet was slightly higher compared to Changuu Islet (Table 1).

FC bacteria were detected in the Bwawani area, and intermediate waters toward Bawe Islet (Table 2). The highest mean concentration of FC bacteria in surface waters was in the Bwawani area. At most stations, however, no FC bacteria were detected.

Seasonally, both TC and FC bacteria showed higher mean concentrations during the peak SE monsoon

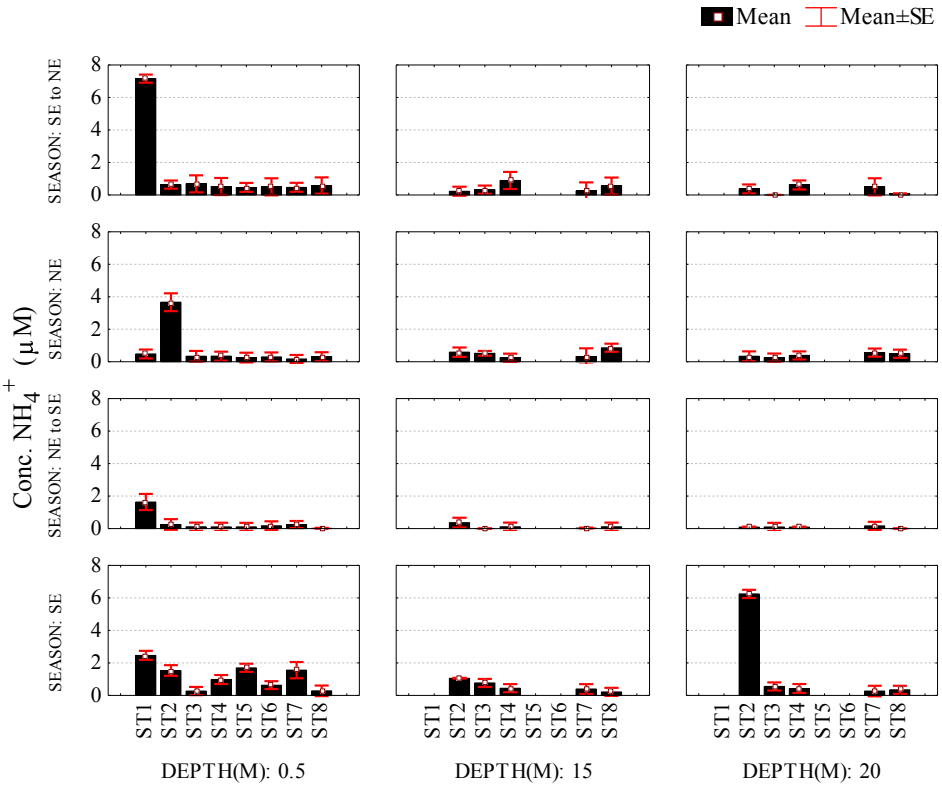

Figure 3. Mean concentration of ammonium by depth and season.

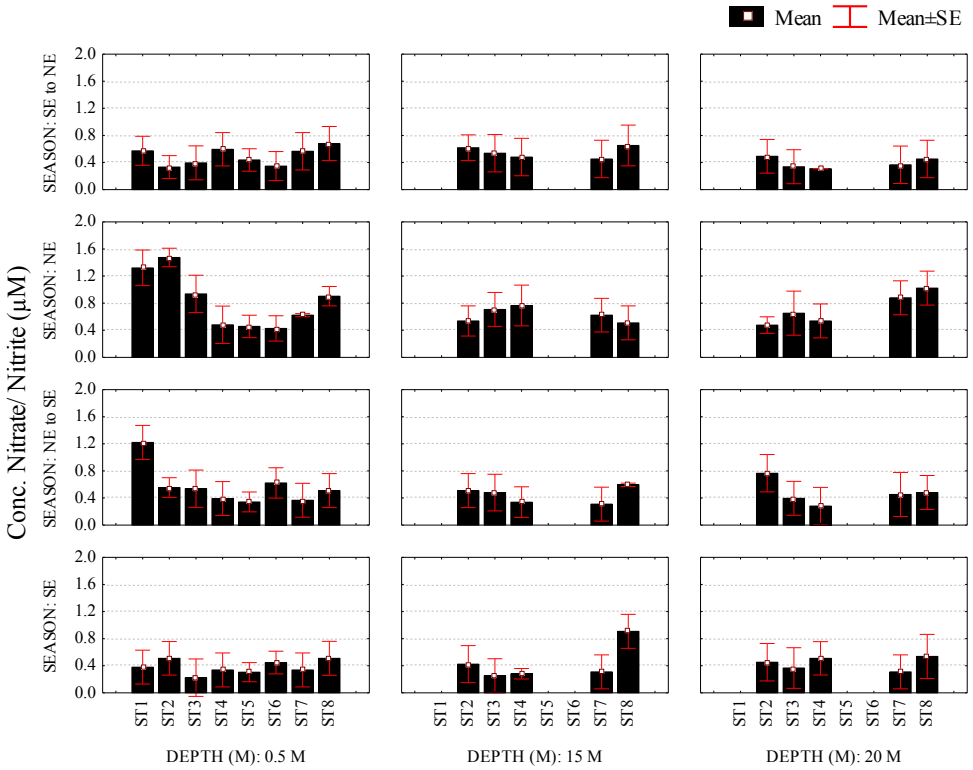

Figure 4. Mean concentration of nitrate/nitrite by depth and season.

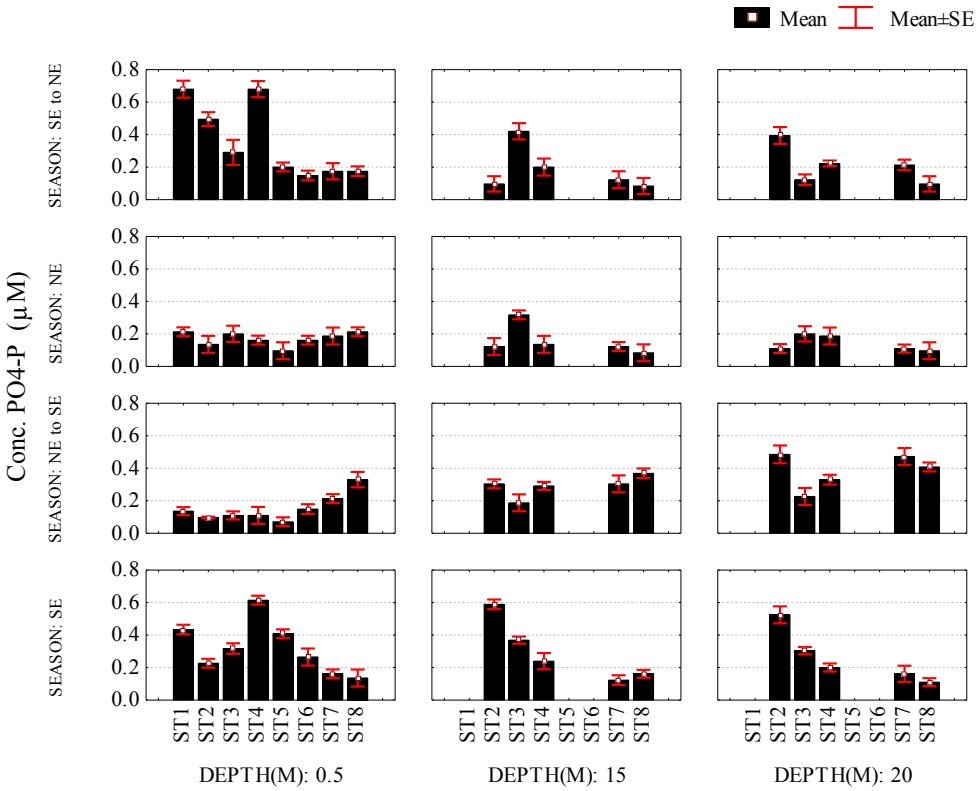

Figure 5. Mean concentration of SRP (PO_4-P) by depth and season.

months and inter-monsoonal period between the NE and SE monsoon seasons. At the peak of the SE monsoon, FC bacteria were detected only in the Bwawani area (Station 1). During the peak of the NE monsoon and inter-monsoonal period between the SE and NE monsoon seasons, FC bacteria were detected at the three stations closest to the coastline of the main island, although the concentrations were lower compared to the concentrations recorded at the peak of SE monsoon and inter-monsoonal period between the NE and SE monsoon seasons (Table 2). The mean concentrations of TC bacteria in surface waters were significantly different (Kruskal-Wallis, $p < 0.05$) in the different seasons.

Discussion

Concentration of Nutrients in the Water Column

Nutrient concentrations in the waters off Zanzibar Town in this study were higher than concentrations reported previously (Mohammed, 2000). This could be attributed to an increase in the population of Zanzibar Town, as population increase is linked directly to an increase in waste water generation. As reported previously, the study area is mainly affected by sewage pollution (Bjork *et al.,* 1995; Mohammed and Johnstone, 1995; Johnstone and Suleiman, 1997; Mohammed, 1997; Moynihan *et al.,* 2012). The high nutrient concentrations in surface waters in all seasons is probably a result of nutrient enrichment by sewage from Zanzibar Town, as sewage tends to disperse in surface waters after it has been discharged into the receiving seawater body (Alloway and Ayres, 1997; Chow *et al.,* 2004). The lower concentrations at the mid depth (15 m) suggest that there is poor vertical water mixing, retaining the nutrients at the surface. The concentrations of nutrients in the water column correspond with the results reported by Sierra *et al.* (2007), who observed highest nutrient concentrations near the surface followed by bottom waters, and the lowest concentration at mid depths. However, only ammonium showed significant differences in mean concentrations in the vertical profiles (Fig. 3). This is in agreement with Mohammed's (2000) results, which showed significant differences in ammonium concentration in the water column while those of nitrate/nitrite and PO_4-P were not significant.

Nutrient concentrations at stations close to the sewage outlet in the Bwawani area and the Port had predictably higher mean concentrations of nutrients which often exceeded the concentration of 1.0 µM that is considered acceptable for healthy reef ecosystems (Bell, 1992), compared to stations situated further from the sewage outlet. On the other hand, stations located in shallow waters off Bawe and Changuu Islets

Table 1. Mean concentration (MPN/100 mL ± SE) of TC in surface waters.

	Seasons	SE to NE	NE	NE to SE	SE
Stations	ST1	4000 ± 11	2800 ± 12	10000 ± 14	11270 ± 16
	ST2	1240 ± 13	2400 ± 13	4760 ± 9	8230 ± 11
	ST3	500 ± 6	640 ± 10	302 + 7	3530 ± 13
	ST4	120 ± 4	520 ± 9	310 ± 8	480 ± 5
	ST5	240 ± 9	282 ± 6	540 ± 5	192 ± 7
	ST6	290 ± 7	320 ± 9	740 ± 10	250 ± 5
	ST7	102 ± 5	170 ± 7	260 ± 6	100 ± 11
	ST8	104 ± 8	350 ± 9	120 ± 9	97 ± 4

showed slightly higher concentrations than stations between the these islets and the main island, suggesting a source of nutrients from the islets. This might reflect inputs from tourist hotels on the islets. The low mean concentrations of nutrients at stations between the main island and the islets probably reflect dilution of the nutrients from these source areas.

There were significant seasonal differences in nutrient concentrations. This implies that seasonal monsoon rainfall has a significant influence on the concentration of nutrients in the study area. The highest mean concentrations of ammonium and PO_4-P in the water column for all stations were observed during the SE to NE transition, followed by the SE monsoons, possibly due to increased rainfall at these times. This could facilitate the entry of nutrients and bacteria into the sea, while the south easterly winds trap the contaminants at the source (McClanahan, 1988). The highest mean concentrations of nitrate/nitrite in the water column observed during the peak of the NE monsoon are possibly associated with nitrogen fixation processes. Several studies (Bryceson, 1977; McClanahan, 1988; Lugomela *et al*., 2002) indicate higher nitrate concentrations in the water column during the NE monsoon period linked to nitrogen fixation by the planktonic cyanobacteria *Trichodesmium*, which appears in high abundance during this period in the study area. During the peak SE monsoon, mean concentrations of nutrients at stations near the main island (particularly ammonium and PO_4-P) increase while during the NE monsoon they are flushed away. It is evident that changes in monsoon winds in the study area affects dispersion of nutrients in the waters off Zanzibar Town. This is in agreement with the findings of Nyandwi (2013), who stated that current direction affects surface flows in the Zanzibar Channel and are controlled by prevailing monsoon winds throughout the year, while mean current at the bottom remains relatively constant. Therefore, the increased mean concentrations of nutrients (particularly ammonium and PO_4-P) in the water column at the stations located further from nutrient sources during the peak of the NE monsoon suggests the contaminants were trapped during the SE monsoon, but dispersed throughout the study area during the NE monsoon.

Concentrations of TC in Surface Waters

Concentrations of TC measured in surface waters for this study are within the ranges reported by Lyimo (2007) at Ocean Road near Dar es Salaam City, and Mohammed (1997) in seawaters off Zanzibar Town. The concentrations were, however, higher than those reported by Abbu and Lyimo (2007) and Namkinga *et al.* (2013) for Mtoni Kijichi and Mzinga Creek (Dar es Salaam), Pangani estuary (Tanga), and the Ruvu estuary (Pwani), all located on the Tanzanian Mainland coast. This implies that waters off Zanzibar Town receive higher bacteria loads from anthropogenic sources than Mtoni Kijichi, Pangani estuary, Ruvu estuary and Mzinga Creek areas. Stations located close to the sewage outlet showed higher mean concentrations compared to stations further from the sewage outlet (Table 1). The results correspond with the work of Shiaris *et al.* (1987), who reported that sewage-borne bacteria (and nutrients) decline significantly with distance from sewage outfalls. The shallow waters off Bawe and Changuu Islets showed slightly higher mean concentrations of TC compared to stations located between the main island and islets. This is possibly due to discharges from hotels on the islets. It has been shown that microbiological contamination of coastal

Table 2. Mean concentration (MPN/100 mL ± SE) of FC in surface.

	Seasons	SE to NE	NE	NE to SE	SE
Stations	ST1	1540 ± 12	2350 ± 10	5240 ± 17	8050 ± 21
	ST2	320 ± 9	1050 ± 8	1020 ± 13	0
	ST3	80 ± 3	150 ± 5	0	0
	ST4	0	0	0	0
	ST5	0	0	0	0
	ST6	0	0	0	0
	ST7	0	0	0	0
	ST8	0	0	0	0

waters is a result of the combined effects of environmental factors and human activities (Hennani *et al.,* 2012). Bawe Islet showed slightly higher mean values both of TC in surface waters compared to Changuu Islet. This may be due to its closer proximity to the Maruhubi sludge dumping site, but could also be due to the higher population of tourists on Changuu Islet. The mean concentrations of TC at the Bwawani area and the Port were higher than those recommended for marine recreation, shellfish harvesting and aquaculture in other countries (WHO, 1999), but were below the guidelines at other stations.

Concentrations of FC in Surface Waters

Concentrations of FC measured in surface waters for this study were higher than mean concentrations reported by Mohammed (1997) in the same area. It is reasonable to assume the increase in FC concentrations is related to an increase of the residential population on the study area. Unlike TC, FC was only detected at three stations; probably because of dilution effects (Davenport *et al.,* 1976; Ji, 2008). The decrease and absence of FC further from the origin is due to transformation processes such as dilution, dispersion and decay that affect spatial distribution (Shiaris *et al.,* 1987; Alloway and Ayres, 1997; Sierra *et al.,* 2007). The FC results showed that water quality in the Bwawani area and the Port was poor, and unsuitable for recreation and aquaculture (WHO, 1999). Unlike TC, the presence of FC bacteria in the surface waters indicates faecal contamination and the presence of enteric pathogens from warm-blooded animals, including humans (Byamukama *et al.,* 2000; Karafistan and Arik-Colakoglu, 2005). This causes enteric illness when water is used for recreational purposes or through the consumption of contaminated seafood.

Distribution of Nutrients and Bacteria in the Study Area

The distribution of nutrients and bacteria in waters off Zanzibar Town were mainly determined by monsoon rainfall and wind variations. However, biogeochemical processes and station location were also shown to influence distribution. The nutrient and bacteria concentrations were generally highest during the SE and NE monsoon periods. During peak SE monsoon, nutrients and bacteria accumulated near the Bwawani area. FC was only detected at Bwawani area during this period and the mean concentration was much higher (8050 ± 21 MPN/100 ml) compared to other seasons. This implies that winds trap FC in the Bwawani and Port areas. However, the situation was reversed during peak NE monsoon when contaminants were flushed out toward offshore waters. For example, during this period station 3 and 8 located in deeper waters between Zanzibar Town and the Islets showed relative higher mean concentration values of contaminants compared to other seasons. This indicates that monsoon winds under this period facilitate transport and distribution of contaminants from point of discharge toward offshore waters.

Conclusion and recommendations

Coastal water quality off Zanzibar Town is affected by nutrients and coliforms derived from sewage generated in Zanzibar Town. The distribution of contaminants in waters off Zanzibar Town is determined by seasonal monsoon variation, location of a particular area relative to anthropogenic sources of nutrients and bacteria, and biogeochemical processes. There is an urgent need to treat waste before discharging it into the coastal waters, to eliminate the negative impacts of contaminants in the waste. It is recommended that further studies on

the extent of degradation among the adjacent aquatic communities (mangroves, sea grass, coral reefs, fish etc.) due to raw sewage effluents discharged in the study area be performed, and to isolate the pathogenic species in order to understand the associated risk.

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