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Variability of Chlorophyll-*a* in Relation to Physico-Chemical Variables in Zanzibar Coastal Waters

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Abstract: The relationships between chlorophyll-*a* (Chl-*a*), nutrients and other physico-chemical variables are important for marine water management strategies. In this study, monthly Chlorophyll-*a* (Chl-*a*) concentration, temperature, salinity, pH, dissolved oxygen and nutrients were measured at two sites (Bawe and Chwaka Bay) in Zanzibar coastal waters from May 2012 to May 2013. The mean Chl-*a* concentration ranged from 0.69 mg/m^3 to 1.86 mg/m^3, with insignificant variation between the sites, and significant differences among the stations being higher in near shore stations than in open seawater stations ($t = 5.296$, $P < 0.0001$). The results revealed significant higher Chl-*a* concentration during the southeast monsoon (SEM) than the northeast monsoon (NEM) ($t = 2.871$, $P < 0.0152$). In addition, the results showed that, the concentration was significantly correlated positively with salinity ($r = 0.640$; $p = 0.019$) and negatively with NO_3 ($r = -0.563$; $p = 0.044$). The results of this study suggest that high Chl-*a* concentration to the near shore station is due to sewage system which influence nutrients concentrations, hence result into high Chl-*a* concentration. Furthermore, the SEM experienced high Chl-*a* concentration due to strong winds which bring nutrients to the sea surface which favour growth of phytoplankton hence result into high concentration.

Key words: Chlorophyll-*a*, Zanzibar coastal waters, physico-chemical variables

1. Introduction

Assessments of the relationships between Chl-*a* and nutrients have provided insight into the relative importance of physico-chemical and biological constraints on phytoplankton biomass in water bodies. In the East African Indian Ocean the phytoplankton biomass are influenced by the monsoon trade winds (Levy *et al.*, 2007). The northeast monsoon (NEM) persists from December to April and the southeast monsoon (SEM)

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from June to October. The months of April/May and October/November may be considered as inter-monsoon periods (Lyimo, 2011). The NEM is characterized by higher temperature, lower wind speed and calmer sea (Lyimo, 2011). Kuo *et al.* (2007), state that the relationships between Chl-*a* and nutrients in water bodies are vigorous in most geographical regions. One of the well-known effects of anthropogenic nutrient enrichment of marine environment is the increase in phytoplankton biomass (Jones and Knowlton, 2005). Studies have shown that chlorophyll in oceans, seas and other water bodies can be limited by nitrogen, phosphorus or by physical factors such as temperature or light (Dzialowski, 2005). In most marine studies, nitrogen and phosphorus are generally described as driver variables of Chl-*a* (Kagalou *et al.*, 2008).

Normally, Chl-*a* is used as a stand-in for phytoplankton biomass in marine and lake waters research (Melack and Forsberg, 2001), and it is also one of the easiest measured. Although nutrients significantly influence the yield of chlorophyll in water bodies, studies suggest that other environmental factors such as the water temperature, salinity, light, dissolved oxygen and pH need also to be considered (Søballe and Kimmel, 1987). Coastal seas, estuaries and bays are ecosystems where the mixing of fresh and marine waters exerts considerable changes in physico-chemical properties and biological processes. Superimposed with these are the impacts of wastewater and other effluents from human and urban activities. All of which can exert a non-negligible impact on the structure and function of planktonic communities (Mathivanan *et al.*, 2007). The change in structure and function of phytoplankton could have an effect on Chl-*a* concentration due to eutrophication and other processes.

Eutrophication of coastal waters has been considered as one of the major threats to the health of marine ecosystems for several years (Elmgren and Larsson, 2001; Hamisi *et al.*, 2004; Bachmann *et al.*, 2005). The processes and effects of coastal eutrophication are well known and have been documented (Elmgren and Larsson, 2001; Hamisi *et al*., 2009). Coastal eutrophication has been and still remains an important issue for the scientific community. Despite many efforts to mitigate coastal eutrophication, the problems associated with eutrophication are still far from being solved (Cloern, 2001). Most recent scientific results in relation to specific eutrophication issues, has been focused on causes; nutrient loads, cycling and limitation; reference conditions, primary effects and secondary effects; trend reversal, as well as links to other pressures such as climate change and top/down control (Rönnberg and Bonsdorff, 2004). There have been also focusses on monitoring and modelling of coastal eutrophication, and adaptive and science-based nutrient management strategies around the world.

In Zanzibar coastal waters, however, some studies on phytoplankton diversity and Chl-*a* concentration have been done (Bryceson, 1977; Lyimo, 1995; Lugomela, 1996; Kyewalyanga, and Lugomela, 2001;

Kyewalyanga, 2002). This implies that there is still a need to understand the phytoplankton dynamic and the factors influencing their spatial and temporal variability, a knowledge that could be applied in the management of fisheries and other natural resources in the coastal waters off Zanzibar. This study was therefore an attempt to spatially and temporally determine the relationships between the dynamics of Chl-*a* and environmental factors (soluble reactive phosphorus, nitrate, ammonium, water temperature, salinity, dissolved oxygen and pH) in the Zanzibar near shore waters.

2. Methods and Materials

2.1. Study site and sampling design

The study was conducted at two sites in Bawe and Chwaka Bay located in the western and eastern sides of Unguja Island (Zanzibar), respectively (Fig. 1).

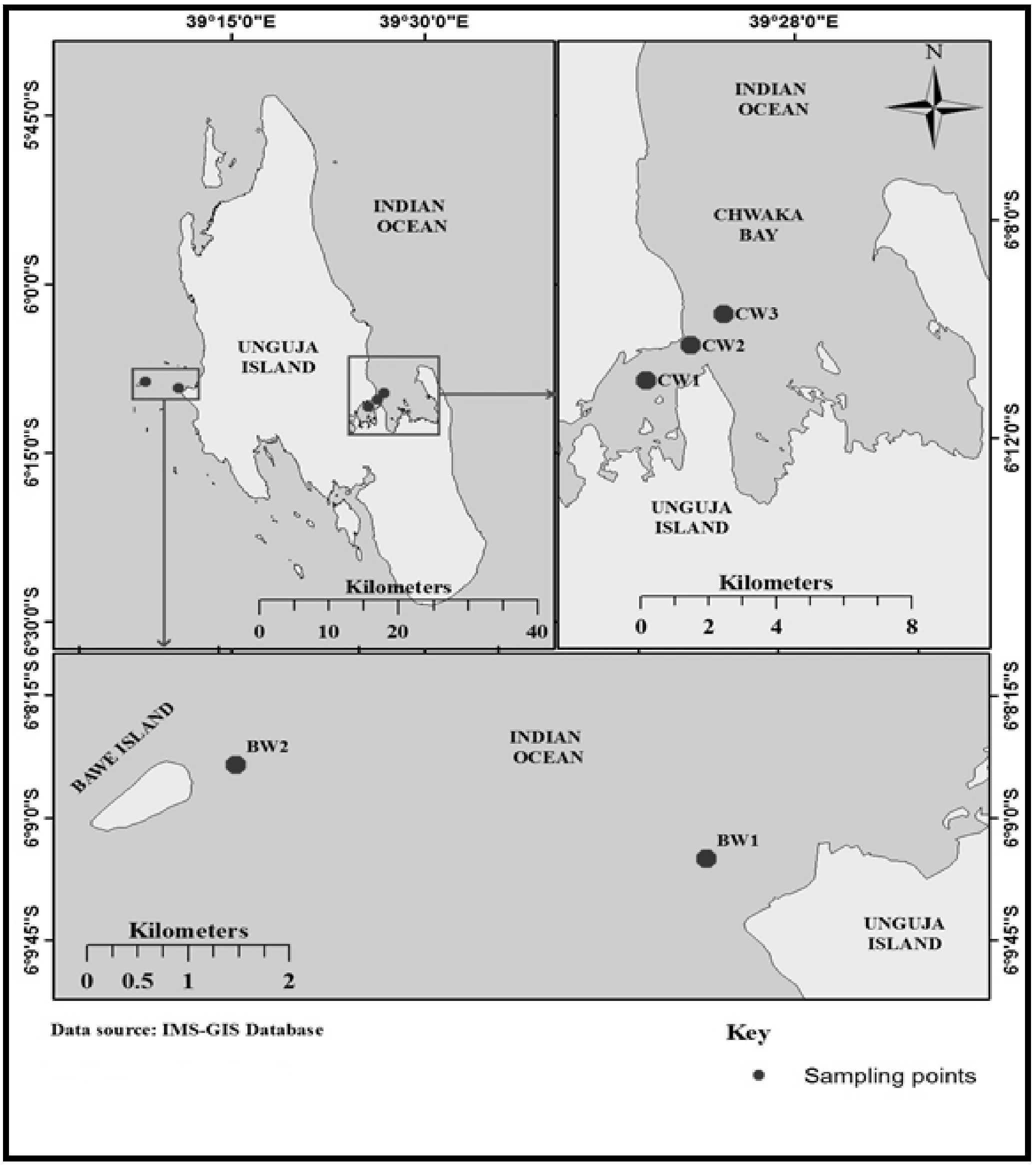

Fig. 1.Map showing the sampling points in Zanzibar coastal waters.

Chwaka Bay: Chwaka Bay is situated 22 km East of Zanzibar town in Unguja Island (Fig.1). The bay is characterized by shallow water body with an average of 3.2 m depth and an area of approximately 35 km^2 (Arthurton, 2003) and is fringed by a limestone reef, which is covered by a dense mangrove forest. Three sampling stations were set in this site, the first station (CW1) being within the creek with shallow water at approximately 06º10.490S and 039º26.000E, second station (CW2) being at the mouth of the creek at 06º10.257S and 039º26.354E and the third station (CW3) being in the open bay with oceanic characteristics located at 06º09.685S and 039º26.884E (Fig. 1).

Bawe Site: Bawe Island is a small island in Zanzibar archipelago located about 10 km from the shore of Stone Town. Two sampling stations were set at this study site; the first station (BW1) was located at approximately 06º09.443S and 039º11.451E near Zanzibar harbour and the Institute of Marine Sciences. This station was chosen as a representative of polluted area because it is close to the harbour and there is a waste pipe outlet from the city located very close to the station. The second sampling station (BW2) was near Bawe Island located at 06º09.654S and 039º11.022E (Fig. 1). This station is characterized by a relatively deep-water body of more than 10 m depth and is rich in coral reefs. Therefore, this area was taken as a representative of open sea, which has oceanic characteristics.

Samplings were conducted on monthly basis from May 2012 to May 2013, and samples were collected between 7 am and 11 am from the 20th to the end of each month. Water temperature, pH, salinity and Dissolved Oxygen (DO) were measured *in situ* directly using a thermometer, portable pH meter (Hanna Instrument: HI 8014), hand refractrometer (ATAGO S/MILL, Japan) and DO meter (Hanna Instrument: HI 9146), respectively.

2. 2. Determination of Phytoplankton Biomass (Chl-a) and Nutrients

Water samples for analysis of phytoplankton biomass (Chl-*a*) were collected using plastic bottles (1.5 l). In the laboratory, 1.5 l of the collected water samples were filtered through 0.45 µm membrane filters using a vacuum pump. The filters were then transferred to glass test tubes containing 10 ml of 90% acetone and left refrigerated at 4^{o}C overnight to extract the pigment. After thorough shaking of the test tubes, they were centrifuged for ten minutes at 4000 rpm to settle the particles. The supernatant was then decanted into clean test tubes and measured for Chl-*a* concentration using an ultraviolet spectrophotometer (UV 1601-Shumadzu Cooperation, Tokyo, Japan) at different wavelengths as described by Parsons *et al*. (1989). A portion (300mls) of the filtered water was preserved at -20 C and later analysed for nutrients (NO_3, NH_4 and PO_4) concentration using standard methods as described by Parsons *et al*. (1989).

3. Data Analysis

Environmental parameters and Chl-*a* concentration were tested statistically for temporal and spatial variations; differences/variation was tested using parametric or nonparametric tests on the analysis of variance (ANOVA). In cases of significant differences, post comparison test (Tukey Krumer and Dunn’s multiple comparison tests) were applied to establish where a significant difference occurred among sampling stations. The quantitative relationships between the measured environmental variables and Chl-*a* concentrations were analyzed by calculating the Pearson correlation coefficients. Data were tested for normality and homogeneity of variances before running ANOVA using a Kolmogorov-Sminornov test and Levene`s test, respectively. The statistical analysis was performed using Origin Pro version 8.6 program. It was assumed that $p < 0.05$ signifies a difference.

4. Results

4.1. Chlorophyll-a concentration

The results of temporal Chl-*a* concentrations variation in Zanzibar waters are presented in fig. 2. The highest Chl-*a* concentrations value was 1.86 mg/m^3 recorded at BW1 in May, 2013 and the lowest value was 0.69 mg/m^3 recorded at CW2 in September, 2012. There was a significant difference in Chl-*a* concentration among sampling stations at Bawe and Chwaka Bay sites. Tukey-Kramer Multiple Comparisons Test showed that *p* value was < 0.0001, which considered to be extreme significant among sampling stations.

At Bawe site; generally, Chl -*a* ranged from 0.76 mg/m^3 to 1.86 mg/m^3 recorded in November, 2012 and May, 2013, respectively. At station BW1, the value ranged from the lowest value of 0.81 mg/m^3 recorded in November, 2012 to the highest value of 1.86 mg/m^3 recorded in May, 2013. At BW2, the minimum Chl-*a* value was 0.76 mg/m^3 recorded in November to the maximum value of 1.29 mg/m^3 recorded in May, 2012 (Fig.2A). Generally, when the two sampling stations between BW1 and BW2 were compared, it seemed Chl-*a* concentration tended to decrease as you move away from the onshore (BW1) towards open seawater body (BW2). Statistically, the Mann-Whitney test showed very significant difference in Chl-*a* concentration between BW1 and BW2, with BW1 having higher value ($p = 0.0004$, U’ = 154.00).

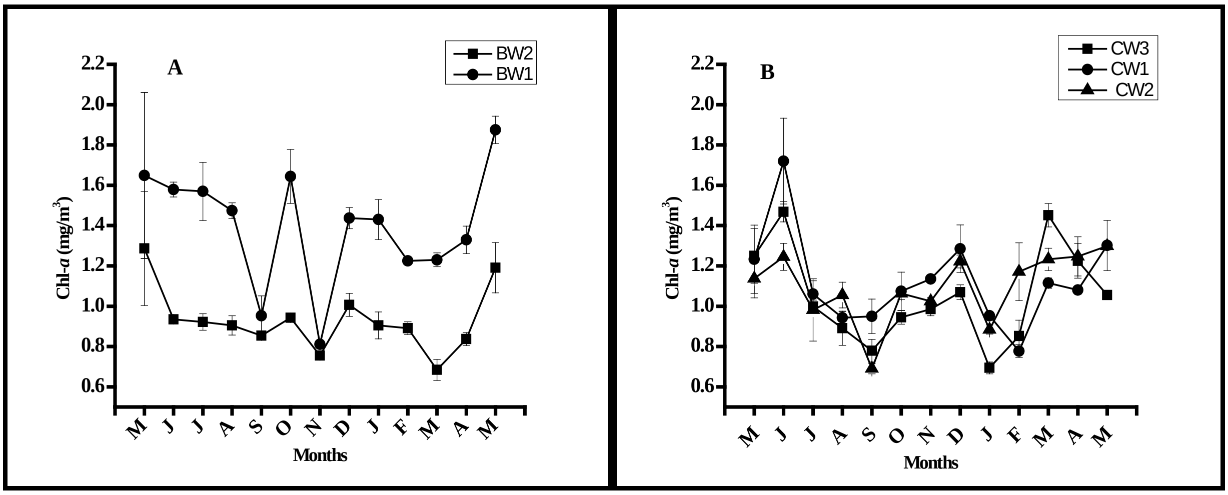

Fig. 2: Mean monthly Chl-*a* concentration in Zanzibar coastal waters. A: Bawe, B: Chwaka Bay. The error bars are the standard errors around the mean, n=3.

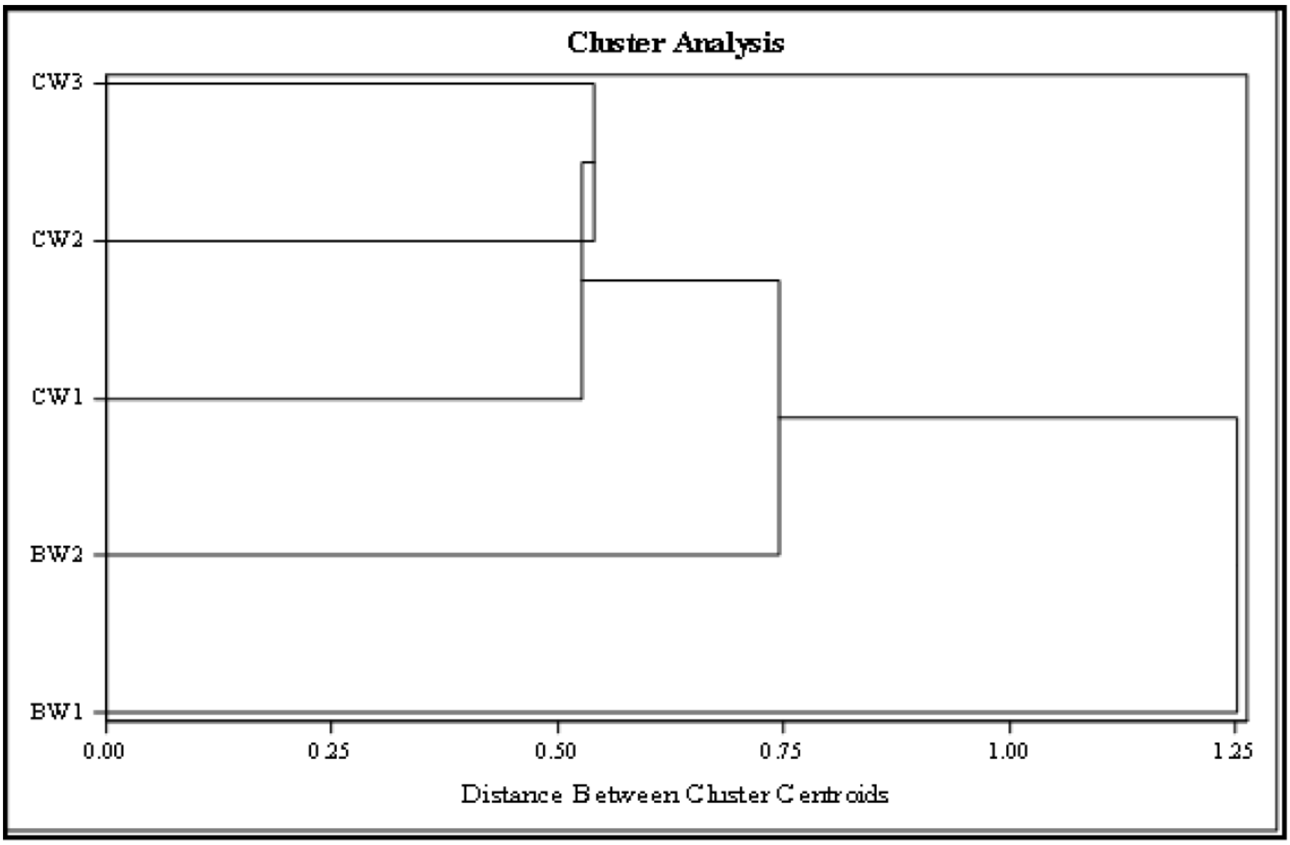

Fig. 3: Similarity of sampling stations in relation to concentration of Chl-*a*.

The Chl-*a* concentration at Chwaka Bay ranged from the minimum value of 0.69 mg/m^3 to the maximum value of 1.72 mg/m^3 (Fig. 2B). At CW1, Chl-*a* concentration ranged from a minimum value of 0.78 mg/m^3 recorded in February 2013 to a maximum value of 1.72 mg/m^3 recorded in June, 2012 (Fig. 2B). At CW2, Chl-*a* concentration ranged from a minimum value of 0.69 mg/m^3 recorded in September, 2012 to a maximum value of 1.30 mg/m^3 recorded in May, 2013 (Fig. 2B). At CW3, the values ranged from the a minimum value of 0.69 mg/m^3 recorded in January 2013 to a maximum value of 1.47 mg/m^3 recorded in June 2012 (Fig. 2B). Generally; at Chwaka Bay; the values of Chl-*a* concentration showed no variations between stations. The results of mean Chl-*a* concentration at Chwaka Bay stations showed that statistically there were no significant difference among the sampling stations ($p = 0.2053$).

In relation to Chl-*a* concentration in different sampling stations, cluster analysis test revealed very close similarity between sampling stations CW1, CW2 and CW3 followed by BW2. The station BW1 had no close similarity with other stations with regard to Chl-*a* concentration (Fig.3).

Season variation in Chl-*a* concentration among sampling stations in Zanzibar coastal waters showed that there was a significant variation at Bawe between the NEM and SEM. The SEM season recorded higher Chl-*a* concentration than the NEM (t = 2.48, $p = 0.0348$). In Chwaka Bay there was no significant variation in Chl-*a* concentration between seasons ($p = 0.7728$). On computing Chl-*a* concentration between Chwaka and Bawe sites, result show that there was no significant difference in Chl-*a* concentration between sites ($p = 0.3025$, F = 1.054).

4.2. Physico Chemical Parameters

Temporal and spatial variation of physical parameters (temperature, salinity, pH, Dissolved Oxygen (DO)) recorded in this study are presented in Fig. 4. The values ranged from 7.67 to 8.36, 26 to 32°C, 30 to 39‰, and 4.9 to 9.46 mg/l for pH, temperature, salinity and dissolved oxygen, respectively. Statistically, using Kruskal Wallis test, pH, DO and temperature were not significantly different among the studied stations as well as with season ($p > 0.05$), while salinity showed significant difference among stations at Chwaka Bay (t = 3.713, $p = 0.0017$). Seasonal variation was observed at Chwaka Bay where salinity was low during NEM and increased during SEM (t = 3.49, $p = 0.0026$), while at Bawe it was uniform throughout.

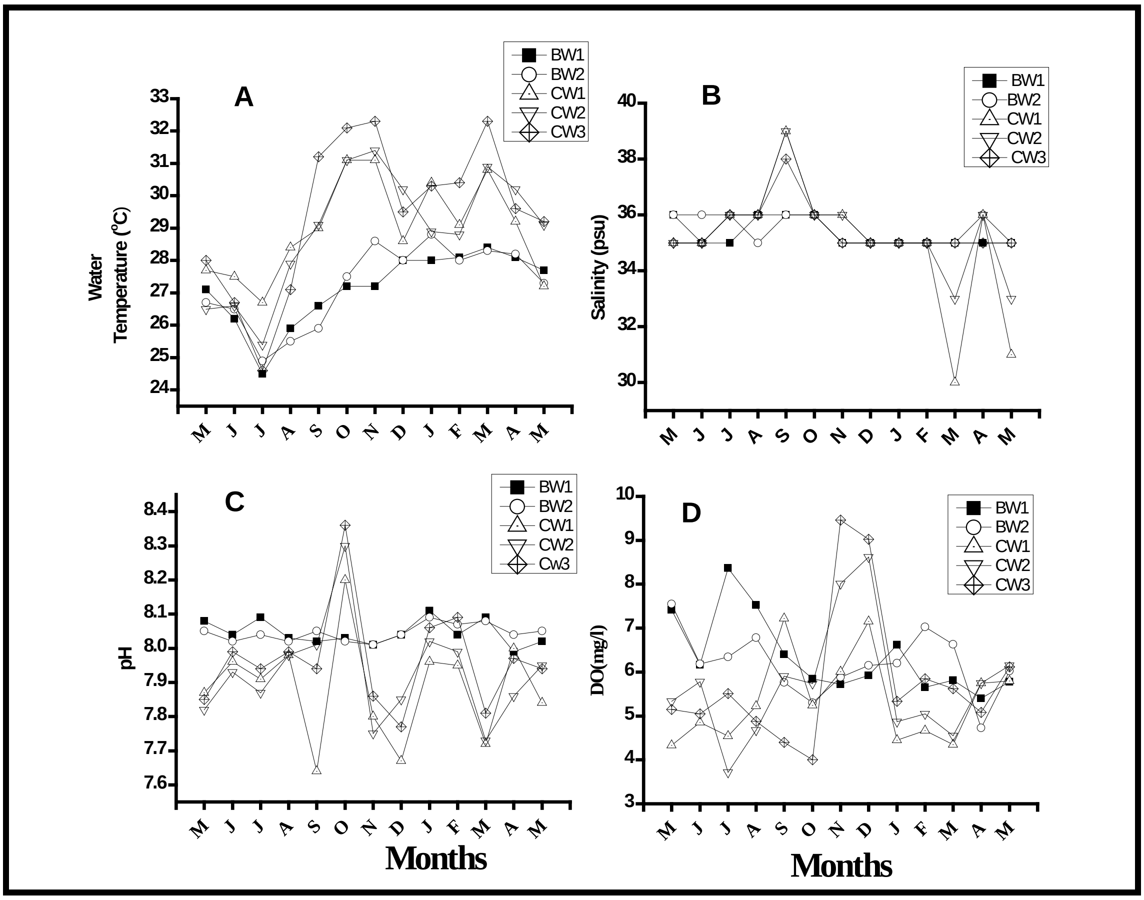

Fig. 4: Seasonal variation of Water temperature(°C) (A), Salinity(psu) (B), pH (C) and Dissolved Oxygen (mg/l) (D) in Zanzibar Coastal Waters.

Temporal and spatial variations of nutrients (nitrate, ammonia and phosphate) were analyzed and results are presented in fig. 5. The results showed that nitrate concentrations ranged from 0.05 mg/m^3 recorded at BW2 during August, 2012 to 2.16 mg/m^3 recorded at CW1 in May 2013 while ammonium concentrations ranged from 0.03 mg/m^3 as measured at CW1 during January 2013, to 3.42 mg/m^3 measured at BW1 in October, 2012. On the other hand, phosphate concentrations ranged from 0.09 mg/m^3 in July 2012 at CW3 to 0.47 mg/m^3 during January 2013 at CW1. Statistically, using the nonparametric ANOVA (Kruskal-Wallis Test) with Dunn's post-multiple comparison test showed significantly different for ammonia level among the sampling stations ($p < 0.0001$), being significantly higher at BW1 (close to discharge point at IMS) and low at BW2 (in open water). The post hoc test (Dunn's multiple comparison) also showed significant variation among the stations. However, there was no significant variation for PO_4 and NO_3 among stations as $p > 0.05$.

Furthermore, there was no significant monthly variation in dissolved inorganic nutrient measured (ANOVA, $p > 0.05$). Considering the monsoon seasonal changes, October to April which is Northeast Monsoon (NEM) and June to October (Southeast Monsoon (SEM)), results show that nitrate and phosphate levels do not have significant differences between NEM and SEM (Wilcoxon test, $p > 0.05$), while there were significantly higher ammonia levels during NEM than SEM ($p=0.0339$, t=2.211).

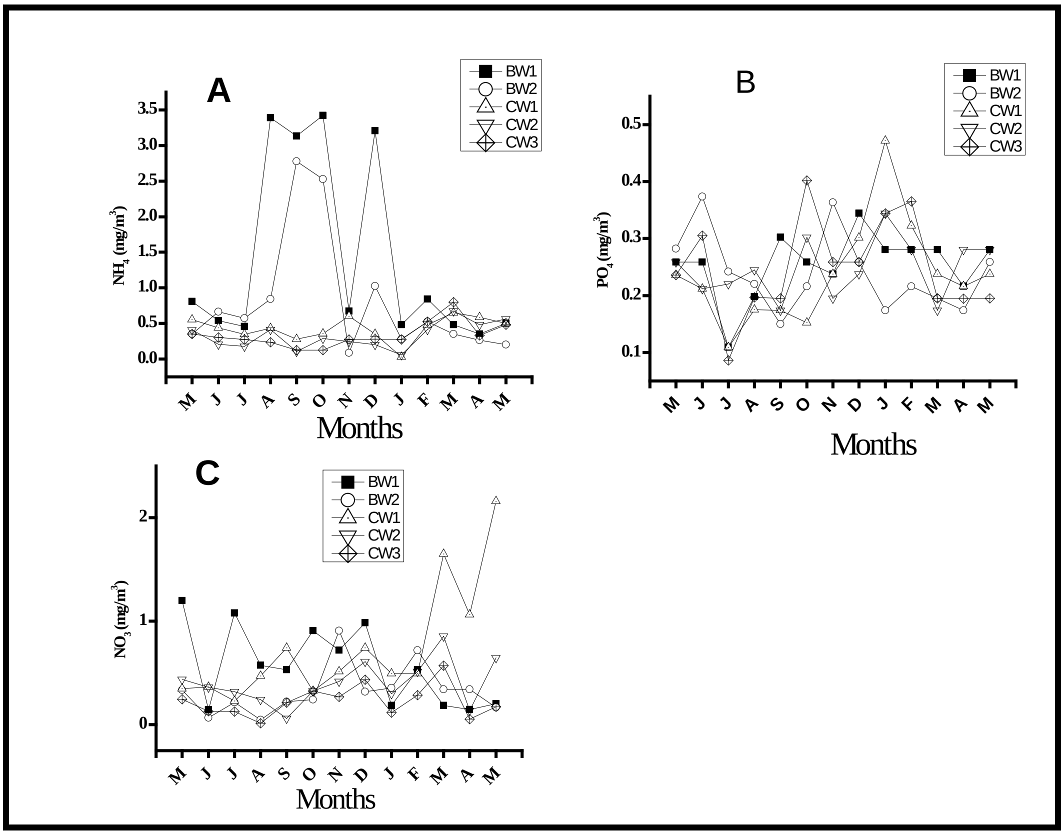

Fig. 5: The seasonal variation of Ammonium (A), Phosphate (B) and Nitrate (C) in Zanzibar Coastal Waters.

In addition, the Pearson's correlations for the measured physico-chemical variables were analyzed. Results showed that, Chl-*a* had a significant negative correlation with NO_3 (r = -0.563) and a postive correlation with salinity (r = 0.640). For other parameters, DO showed a significant negative correlatin with pH (r = -0.649); salinity was significantly correlated negatively with NO_3 (r = -0.608), positively with NH_4 and pH (r = 0.534 and 0.969, respectively), and PO_4 showed a positive correlation with water temperature (r = 0.508).

5. Discussion

The present study examined the spatial and temporal variability of Chl-*a* concentration in Bawe and Chwaka Bay, Zanzibar coastal waters.

The observed higher variation of Chl- *a* concentration among sites and in particular close to the on shore where there is a sewage discharge and decrease towards open water might have been contributed by the sewage effluents discharged at Zanzibar Town (near IMS). However, location and distance from the discharge point have been seen as very important factors controlling the nutrient levels as well as the Chl-*a* concentration (Hamisi and Mamboya, 2014; Mlay *et al.*, 2001), the flow of nutrient rich water from the discharge point has been largely reduced, hence low nutrient levels and Chl-*a* concentration as compared to onshore station. For instance, BW2 being a station located away from the onshore, the flow of nutrient rich water from the discharge point has been largely reduced, hence low nutrient levels and Chl-*a* concentration as compared to BW1. Thus, high level of Chl-*a* concentration at near shore is due to the sewage system discharge contributing to high nutrients level to near shore of Stone Town. Also water mixing could be another factor contributing to high Chl-*a* concentration at near shore compare to open seawater. Water mixing tend to mix the surface water Chl-*a* with benthic community Chl-*a* (Wellman *et al.*, 2002), therefore, this result into an increase in Chl-*a* concentrations at near shore compare to open sea where water mixing is minimal. Hence from this study it has been proposed that the sewage effluents may have great contribution to the physicochemical and biological properties including phytoplankton composition and Chl-*a* concentration in this area.

In Chwaka Bay stations, the Chl-*a* concentration was almost similar in all sampling stations (from Creek to open bay). This could have been attributted by the presence of the mangrove ecosystem and associated ecology which supplies nutrients required for phytoplankton growth, hence result into high Chl-*a* concentration (Lugomela, 1996). Chl-*a* values recorded in this study in Zanzibar coastal waters were higher than those values recorded in earlier study by Lugomela (1996), in which the concentration of Chl-*a* ranged between 0.04 and 0.50 mg/m^3, but were low in comparison with results reported by Kyewalyanga (2001), in which the values ranged between 0.11 to 19.17 mg/m^3 (Table 1). This shows that, there has been a slight increase in Chl-*a* concentration in Zanzibar coastal waters over the decade, although the difference is not much significant. However the change is slight, but when you do projection, you will find that Zanzibar coastal waters is at risk of pollution, thus there is a need for proper/sustainable management of coastal waters for healthy ecosystem. The data reported by Kyewalyanga (2001) was exceptional high due to the influence of el-Niño, as the study was done during el-Niño period. The increase of Chl-*a* concentration in Zanzibar coastal waters might probably due to increase in nutrients concentration as it is indicated also in Table 1, anthropogenic activities and rainfall. Still the Chl-*a* and nutrients concentrations of Zanzibar coastal waters are low compare to Dar es Salaam coastal waters (Table 1). This implies that Zanzibar coastal waters is less polluted compare to Dar es Salaam coastal waters. Indeed, most part of the shores of Zanzibar are lined with a good cover of mangrove and coral community which support growth of phytoplankton particularly nanoplankton and picoplankton (Lugomela, 1996). A study by Mohammed *et al.,* (2001) on the role of mangrove on nutrient cycling and productivity at Chwaka Bay revealed that, there is high nutrient concentration in the creek and the concentration tends to decrease towards the open bay. This is due to high organic matter produced by mangrove and associated organisms with water soluble fulvo-humic acids which have been found to be stimulatory to the growth of some dinoflagellates (Prakash and Rashid,1968).

Table 1: Chlorophyll-*a* concentrations and Nutrients concentrations in different years in Zanzibar coastal waters

Locality (season)	**Chl-*a* conc (mg/m^3)**	**Nutrient conc (µg/ml)**			**Source**
		NO_3	**PO_4**	**NH_4**	
Zanzibar Coastal waters (Yearly)	0.04 – 0.50	0.03 – 0.81	0.04 – 0.38	0.5 – 1.1	Lugomela (1996)
Zanzibar Coastal waters (Yearly)	0.11 – 19.17*	1.05 – 4.01*	0.2 – 2.02*	Not measured	Kyewalyanga (2001)
Zanzibar Coastal waters (Yearly)	0.76 – 1.86	0.13 – 2.16	0.11– 0.47	0.12 – 3.42	Present study
Dar es Salaam coastal waters (Yearly)	Not measured	0.01 – 5.45	0.1 – 0.78	Not measured	Hamisi and Mamboya (2014)

* Sampling was done during el-Niño, hence extremely high nutrient level could be due to heavy rainfall.

On comparing Chl-*a* concentration between Bawe and Chwaka Bay sites, there was a slight high in Chl-*a* concentration at Bawe compare to Chwaka Bay. This could have been contributed by the turbidity of water flowing into Chwaka Bay and decreased salinity which limit the growth and survival of some phytoplankton and hence result into low Chl-*a* (Barron *et al.,* 2002). Also discharges of waste through the sewage system located at near shore of Stone Town into the sea caused an increase in nutrients, suspended sediments and other components that may affect the dynamics of coastal phytoplankton and hence affect Chl-*a* concentration at Bawe (Mohammed and Mgaya, 2001). Chl- *a* concentrations are generally low in estuaries and tidal creeks due to the strong tidal flushing rates which dilutes nutrients, and tidal resuspension gives rise to high turbidity levels (Scanes *et al.,* 2007).

The seasonal variation results from the *in situ* physical and biogeochemical measurements in the Zanzibar coastal waters showed that high Chl-*a* biomass occurred during the SEM (June - October). This result is in line with the observation by with the findings by Lyimo, (1995), but in contrast with Bryceson (1977) and Lugomela (1996). During the SEM, the water and air temperatures were low. The surface waters of the Southern Indian Ocean are generally warmer in the summer and the southern equatorial currents thus bring cool waters to the East African Coast (Piton and Magnier, 1975). Also, the presence of planktonic cyanobacteria *Trichodesmium spp* during the SEM season enhances overall phytoplankton Chl-*a* concentration by increasing the availability of assimilable new nitrogen in the surface of oceans. Thus, the ability of *Trichodesmium spp* to fix nitrogen may influence production of Chl-*a* during the SEM (Lyimo, 2011). On the other hand, rainfall may also be stimulating an increase in phytoplankton Chl-*a* biomass by contributing micronutrients through surface run-off to the sea.

Generally, although the tropical waters of Zanzibar are subjected to relatively high temperature and light levels throughout the year, but overall Chl-*a* concentration in the Zanzibar coastal waters remain moderately low. Presumably, nutrients are inadequate and are rapidly consumed by phytoplankton, which explains the generally low levels of nitrogen, ammonium and phosphorus measured. There is also seasonal variation in nutrients and Chl-*a* due to the different monsoon periods. In common, slightly higher values were recorded during the SEM compared with the NEM. This is partly due to the changes in flow pattern and direction between the two seasons, as flows enter the Zanzibar coastal waters during the SEM but are reversed during the NEM. Therefore, this study revealed that, Chl-*a* concentration varies with time and space in Zanzibar coastal waters. This result is in contrast with other studies in the Indian Ocean waters (Wallberg *et al.*, 1999; Bryceson, 1981), but it correlates with the finding by Lyimo, (1995).

Correlation of physco-chemical variables

The investigated physico-chemical variables showed spatial and temporal variations. Inorganic nutrient level is one of the most variable components of coastal waters (Gilbes *et al.*, 1996). High surface nutrient concentrations with clear fluctuations were observed at Bawe site. Chl-*a* variations mainly depend on nutrient abundance, temperature changes and light availability (Lakkis *et al.*, 2003), although in tropics light is not limited. Chl-*a* was positively correlated with salinity and negatively with NO_3.

In the present investigation, dissolved oxygen was negatively correlated with pH. The DO was relatively high throughout the study at all the stations, which might be due to the cumulative effect of higher wind velocity coupled with rainfall and the resultant freshwater mixing or it may be also due to photosynthesis. It is well known that the temperature and salinity also affect the dissolution of oxygen (Vijayakumar *et al.*, 2000). In this study, DO showed a weak negative correlation with water temperature, meaning that an increase in water temperature results into a decrease of DO, which in turn has an effect on Chl-*a* concentration.

For nutrients, the most distinctive patterns in nutrient dynamics were observed in ammonium (NH_4) concentrations. NH_4 peaked in August, October and December in the year 2012. This pattern of recurrence coincided with the high water temperature and salinity. High temperature must have triggered the accumulation of NH_4 produced by bacterial activity and domestic waste discharge from Zanzibar town.

Nitrate levels showed a negative correlation with salinity. This might imply that the terrestrial input of nitrate mainly due to land runoff was enhanced by rains during the NEM, which at the same time lowered salinity. As opposed to nitrate, phosphate was positively correlated with temperature and salinity. Temperature is the most important factor controlling the phosphate content in the water column (Herrera-Silveira, 1996). Temperature increases phosphate concentrations through mineralization and excretion. This finding corresponds with the finding by Herrera-Silveira (1996), who carried out a study in the Gulf of Mexico. According to this author, phosphate is recycled in the water column by the activity of aquatic organisms including microorganisms and fish, which prevent phosphate from returning to the sediment.

6. Conclusion

The present study revealed that, onshore coastal waters of Zanzibar have higher levels of Chl-*a* concentration which is due to high nutrient discharged into the sea through the sewage discharge which drains the Zanzibar city and presence of mangrove ecosystem which contribute to high nutrients into the sea. High Chl-*a* concentration near the shore indicates that there is water pollution which may pose risk to other living organisms including humans. Furthermore, change in Chl-*a* concentration over the decade indicates that, Zanzibar coastal waters are at risk of pollution. Therefore, a proper management and monitoring is required for healthy ecosystem. The sewage system shall be extended inward the sea for quick dilution of the discharge. In addition, more periodic studies are needed in order to access and monitor the trend of Chl-*a* concentration and nutrients concentrations variation.

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