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Impact of nutrients on phytoplankton productivity on coastal marine waters of Mtwapa, Mida, and Kilifi Creeks, Kenya

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Abstract. *Pole TM, Tole MP, Otor SCJ. 2020. Impact of nutrients on phytoplankton productivity on coastal marine waters of Mtwapa, Mida, and Kilifi Creeks, Kenya. Ocean Life 4: 82-93.* Some of the major sources of coastal and marine pollution affecting coastal conditions vary worldwide. The objective of this study was to determine the levels of three nutrients (PO_{4-}, NO_{3-}, and NH_3) and whether they are within acceptable limits, their relationship with ongoing human activities, and marine primary productivity. Furthermore, to achieve these objectives, marine water samples were sampled and analyzed from identified point and area pollution sources in Mtwapa, Mida, and Kilifi Creeks, Kilifi County, Kenya. A quantitative one-way ANOVA was used to determine the variations between treatments. The Spearman correlation test was computed between nutrients and carbon and nutrients and rainfall. These studies revealed that the levels of nutrients fluctuated throughout the entire study period along the three creeks and the sampling stations. Moreover, the levels of nitrates were within the oligotrophic range in all three creeks. Mtwapa Creek recorded the highest levels of nitrates at $\alpha = 0.05$ from June to November 2011. The phosphate levels in the three creek waters were not significantly different throughout the sampling period. The ammonia levels in Mtwapa were in the higher mesotrophic levels of up to 0.009 mg/L, while Kilifi and Mida were within the oligotrophic levels. Alongside Mtwapa Creek, there was a positive correlation coefficient between phosphate and carbon fixation ($r = 0.869$) in the outer creek; on the other hand, the correlation coefficient for nitrates and ammonia was negative ($r = -0.624$ and -0.295). All the nutrients had a negative correlation coefficient with rainfall in outer Mtwapa Creek ($r = -0.76$, -0.37, and -0.336 for nitrates, phosphates, and ammonia, respectively. Kilifi was positively correlated with carbon fixation and all three nutrients in the inner creek. There was a positive correlation between nutrients and rainfall in all the sampling stations. At Mida, there were positive correlations between rainfall and phosphates in all six stations ($r = 0.78$, 0.3, 0.22, 0.78, 0.23, respectively). In Mtwapa, the high levels of nutrients in the outer creek stations and the negative correlation coefficient between the nutrients and rainfall suggests that runoff did not contribute to increased levels of nutrients but rather the waster roadside canal and sewage outfall from urban and tourist development contributed to increased levels. The higher levels of nutrients in the inner creek waters of Kilifi can be attributed to the destruction of vegetation close to the creek for farming upstream of the creek. Mida Creek had the lowest recorded nutrient levels apart from phosphates in all the sampling stations. These phosphate levels most likely were contributed by wastewater from some tourist establishments, especially at the Temple point hotel, which crept to the shore waters. Furthermore, to reduce the impacts of land-based human activities, it is recommended to analyze existing land-based activities that negatively impact coastal marine ecosystems and livelihoods to design mitigation measures.

Keywords: Coastal marine waters, Kilifi Creeks, Mida Creeks, Mtwapa Creek, nutrients, phytoplankton productivity, pollution

INTRODUCTION

The contamination of marine environments by urban developments, the tourism industry, and animal and crop farming is increasing worldwide. This water quality degradation affects various aquatic environments, including coastal waters, wetlands, estuaries, mangroves, rivers, and reefs, creating a serious health risk for aquatic life, humans, and wildlife (Webb and Gome-Gomez 2009; Bayan et al. 2016). Over 60 million people inhabit the WIO region's coastal areas, and most depend on exploiting the marine and coastal natural resources for their livelihoods (UNEP 2009). This region has had a rapidly growing population in recent years, which exerts pressure on the marine environment, causing degradation of critical coastal habitat, pollution, and changes in freshwater flow and sediment loads from rivers draining into the Western Indian Ocean. Many efforts have been made, and one initiative, such as the WIO-LAB project, addressed land-based activities in the West Indian Ocean (UNEP 2009). Formulating a Strategic Action Plan (SAP) to address the challenges of increased coastal water pollution was one of the outputs of the WIO-LAB project, among others

The algae often support the marine food web in the ocean. Their photosynthetic activity tends to be greatest near the coastline, where primary producers bring nitrogen, phosphorous carbon, and other nutrients from the land and fertilize. However, ocean currents transport nutrients and phytoplankton far from shore and contribute to the distribution of biological productivity (Hogarrth 1998). Apart from primary production, secondary productivity is a measure of zooplanktonic productivity. The marine zooplankton, useful in secondary productivity, belong to the mollusks, Arthropoda, phyla protozoa, and the crustaceans' largest group.

The marine pollution caused along shorelines with urban development includes discharges from sewage outfalls, which potentially cause environmental impacts on surrounding aquatic ecosystems. The testing with Direct Toxicity Assessment (DTA) or Whole Effluent Toxicity (WET) is an integral part of the regulatory framework in many countries to assess and manage leachates, effluents, and contaminated ambient waters in freshwater and marine environments. The DTA can serve as an early warning for implementing management actions and also provide a direct measure of the bioavailability and toxicity of mixtures whose chemical composition is unknown. Those common regulatory microbial indicators of fecal pollution include *Enterococcus* spp and *Escherichia coli*. The acceptable fecal indicator levels were determined during epidemiological studies (USEPA 2000).

Runoff from anthropogenic land use is a significant source of pollution impacting rivers, coastal streams, and marine waters. Agricultural production is a leading source of diffuse, non-point sources of pollution impacting waterways and coastal ecosystems. Agricultural management practices can result in depositing nutrients, sediments, pesticides, and microbial contaminants into waterways (Stuart 2010).

Due to their proximity to urban areas, Creeks are the most vulnerable marine ecosystem, and areas with agricultural practices have the potential to be polluted by agricultural fertilizers, sewerage effluents, and sediments. Those are among the most heavily polluted areas globally, with the world's population living along creeks and estuaries about 60%. In addition, 22 of the world's largest cities, including New York City, are located on an estuary (SCECAP 2010). The contamination problem of uncontrolled runoff from urban and agricultural areas, coastal and offshore environments and aquatic organisms by pathogenic bacteria manifests along the Kenyan coastal marine waters. Regardless of their vulnerability to the direct impacts of anthropogenic and natural disturbances, there have been few efforts to continuously monitor, determine, and understand the nature and extent of the impacts of land-based pollution sources. Studies on the impact of sewage discharge into coastal marine waters (Okuku et al. 2010) and the nutrient enrichment characterization in estuaries by the Kenya Marine and Research Institute (KEMFRI 2013) revealed that Mtwapa Creek was on higher mesotrophic levels than Tudor and Makupa creeks. As a result, there was an increased nutrient trend down the estuarine systems. However, there is no available information on similar nutrient studies along Kilifi and Mida Creeks. Therefore, this study evaluated whether the nutrient distribution and its impact on phytoplankton productivity have changed over time, forming the basis for suggesting further recommendations.

This study aims (i) to determine the levels of Nitrate (NO_{3-}), Ammonia (NH_3), and Phosphates (PO_{4-}) in the three creeks, i.e., Mtwapa, Mida, and Kilifi Creeks, Kilifi County, Kenya; (ii) to examine the spatial variations along the three creeks in the nutrient loads; (iii) to classify nutrient concentrations levels of the creek water following to standard water quality criteria; (iv) to determine the correlation between the net primary productivity levels and nutrient levels along the three creeks.

MATERIALS AND METHODS

Description of the study sites

The study sites were three creeks along the coastal shoreline of Kilifi County, Coast Province of Kenya (Figure 1). Mtwapa Creek, which marks the boundary between Kilifi and Mombasa counties, lies between 3°45'0 S and 3°47'0 S to 39°42" 0 E and 39°48" 0 E. Mida Creek is situated at the border of Kilifi and Malindi counties at between 3°20'0" S and 3°25'0" S and 39°55'0" E and 39°58'0" E. Kilifi Creek in the middle of Kilifi town is located between 3°35'0" S and 3°38'0" S, and 39°43'0" E and 39°52'0" E. The region experiences an average rainfall of about 900 mm to 1,100 mm annually, with mean temperatures between 25°C to 30°C.

Seven sampling sites were selected along Mtwapa Creek: i.e., Moorings floating restaurant (S39), Shimo-La-Tewa waste water drainage outlet (S38), Drainage outlet from Kadongo landing site (S27), Maize farms opposite Kadongo (S24), Mtwapa town (S36), Shoreline near Kwetu Training Center (S29), and the Control site in the open ocean facing the mouth of the creek (SC). These sites constitute the creek point and diffuse sources of nutrient input.

Seven sampling sites along Kilifi Creek were also identified and marked using a GPS instrument. These sites were diffuse sources, i.e., Mnarani Club beach (K01), Boat Yard beach (K02), Maringoni valley shoreline (K05), Maya Mangrove conservation shorelines (K06), Sea Horse shoreline (K03), Maringoni farms shorelines (K04), and the control samples obtained from the open ocean facing the mouth of the creek.

Seven sampling stations along Mida Creek were also identified and marked with the GPS instrument. These also constitute diffuse nutrient sources entering the creek. They include the Temple point shoreline (md1), Mida Creek Mangrove project conservation shoreline (md3), Sudi Island picnic site (md4), Captain Andy and Hemmingway's Boatyard (md2), Shoreline opposite Captain Andy (md5), Safari Blue beach (md6) and the control at the open ocean facing the mouth of the creek.

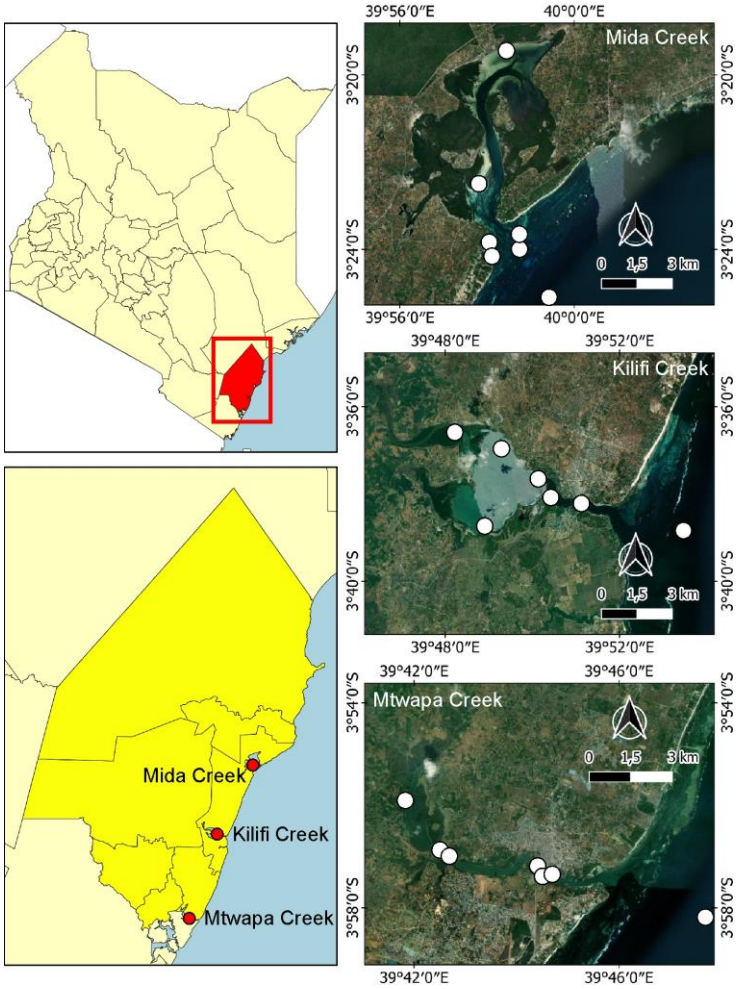

Figure 1. Sampling sites (solid dots) along Mtwapa, Kilifi, and Mida Creeks in Kenya

The sampling design was purposive, with sampling sites confined at identified locations with proximity to the identified sources of pollution within a 10 m distance from the shoreline. The sampling sites targeted areas close to urban developments, conservation areas, tourist hotel establishments, the Shimo La Tewa Maximum prison establishment, and the agricultural areas upstream of the creeks, representing both the sources area and point of effluents into the creeks. The sampling stations were marked using a GPS instrument, and grid references were saved for the entire study period. Sampling was done along the three creeks each month for six months, from June 2011 to November 2011. This period could allow a temporal comparison of the dry season from June to August 2011 and the short rain-wet seasons from October and November 2011. Furthermore, from the seven stations, triplicate surface water (0.5 m) samples were obtained, including the open water control in each creek. The water samples for determining nutrients were fixed on-site with Mercury Chloride (HgCl). Simultaneously, the water sample for instant carbon determination was fixed with a mixture of 0.4 mL of Manganese Sulphate ($MnSO_4$) and 0.4 mL of Potassium Iodide (KI).

Determination of nutrient levels in the creek waters

The water samples were collected in pre-cleaned polypropylene sample bottles that were autoclaved at 121°C 12 Lbs/sq In for 20 min. Nitrates, Phosphates, and Ammonia were determined using standard colorimetric procedures (Ascorbic Acid-Molybdate and Cadmium reduction methods),) at the Kenya Marine and Fisheries Research Institute (KEMFRI) laboratories in Mombasa, which produced colored complexes that were measured photometrically according to APHA (1995).

Determination of levels of nitrates (NO_3^-)

Concentrated ammonium chloride was prepared by dissolving 125 g of analytical reagent-grade ammonium chloride in 500 mL of distilled water and then stored in a glass or plastic bottle. Next, a dilute ammonium chloride solution was prepared by diluting 12.5 mL of conc. Ammonium chloride solution to 500 mL with distilled water, then stored in a glass or plastic bottle.

The sulfanilamide solution was prepared by dissolving 5 g of sulfanilamide in a mixture of 50 mL of hydrochloric acid concentrated (sp.Gr.1.18) and around 300 mL of distilled water and diluted with distilled water to 500 ml.

N-(-1-naphthyl)-ethylenediamine dihydrochloride solution was prepared by dissolving 0.5 g of dihydrochloride in 500 mL of distilled water. This solution was then stored in a dark bottle.

Cadmium-Copper fillings reactivation was done by removing fillings from the column, washing with 5% v/v hydrochloric acid, and next with distilled water until the pH of the decanted solution was >5. Next, the fillings were reactivated with 2% w/v copper sulphate until the blue color left the solution. Next, a small glass wool plµg was placed at the bottom of the reduction column, and then the column was filled with dilute ammonium chloride solution. Finally, a slurry of the cadmium–copper fillings was poured in, and the column was gently packed to a height of about 30 cm. The fillings were kept on not to be dried out during the procedure.

Stock standard A (400 µgat N/L) was prepared by dissolving 0.51 g of analytical grade potassium nitrate (KNO_3) in a 500 mL volumetric flask and made to volume using distilled water. Stock standard B (20 µgat N/L) was prepared by taking 4 mL of solution A and diluting it in a volumetric flask with distilled water to make 100 mL of solution.

The determination of nitrates in the sample was done by measuring 50 mL of water sample in a volumetric flask, adding 1.0 mL of concentrated ammonium chloride, and mixing. Next, 5 mL of this solution was poured on top of the column and allowed to drain off. Finally,15 mL of the residue was again poured into the column and allowed to drain off. The remaining 30 mL was poured into the column, and 25 mL was collected into the drain Erlenmeyer flask and put under the collection tube. The remaining solution was left to drain, and 100 mL of dilute ammonium chloride was added to rinse the column. The processes were repeated for each sample until all the samples were passed through the column.

To the 25 mL samples collected, 0.5 mL of sulfanilamide solution was added from an automatic pipette, mixed, and allowed to react for 2 minutes. Still, in less than 10 minutes, 0.5 L of the naphthalene-diamine solution was added and immediately mixed.

The absorbance was measured after 1 hour using a UV/Vis spectrophotometer at a 543 nm wavelength following APHA (1995).

Determination of levels of phosphates (PO_4^-)

The sulphuric acid solution was prepared with 100 mL of analytical-grade concentrated sulphuric acid (sp.gr = 1.82) added to 900 mL of distilled water, which was left to cool and stored in a glass bottle.

The ascorbic acid solution was prepared with 27 g of ascorbic acid dissolved in 50 mL of distilled deionized water and frozen-stored in a plastic bottle. Ammonium molybdate reagent was prepared with 15 g of analytical grade ammonium paramolybdate dissolved in 500 mL of distilled deionized water and stored in a glass bottle. A potassium antimony-tartrate solution was prepared by dissolving 0.34 g of potassium antimony tartrate in 250 mL of distilled deionized water. A mixed reagent was prepared by mixing 100 mL ammonium molybdate, 250 mL sulphuric acid solution, 100 mL ascorbic acid, and 50 mL Potassium antimony tartrate. This reagent was mixed as required and was not stored. This quantity prepared was approximately adequate for 100 samples.

Stock A (1000 µgat P/L) was prepared by dissolving 0.136 g of Anhydrous potassium dihydrogen phosphate in 900 mL of distilled deionized water in 1 mL of chloroform topped with 1 liter of distilled deionized water. Stock B (40 µgat P/L) was prepared by diluting 4 mL of stock standard A in a volumetric flask to 100 mL with deionized distilled water.

The following serial dilutions were prepared from the stock B as follows:

mL of stock B in 100 mL Volumetric flask	Concentration (µgat N/L)
0.2	0.1
2.0	1.0
4.0	2.0
6.0	3.0
8.0	4.0
10.0	5.0

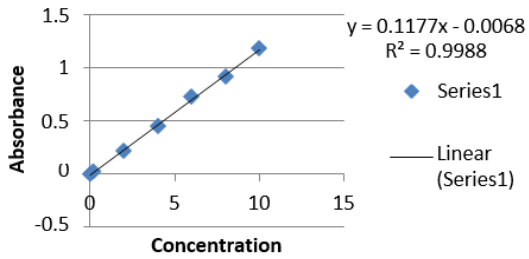

Figure 2. Calibration curve for NO_3^-

Working standards were prepared by using the following serial dilutions of stock B:

mL of stock B in 100 mL	Concentration (µgat P/L)
0.2	0.08
2.0	0.8
4.0	1.6
6.0	2.4
8.0	3.2
10.0	4.0

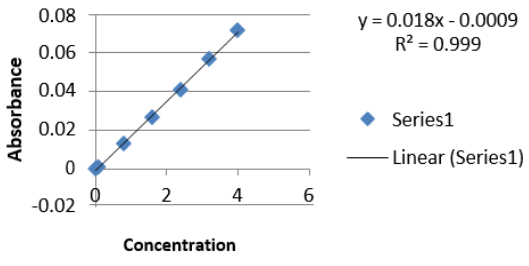

Figure 3. Calibration curve for PO_4^-

The procedure on samples to determining phosphates was by measuring 20 mL of water sample in a volumetric flask and adding 2 mL of mixed reagent using a micropipette. The samples were left to stand for between 30 minutes to two 2 hours, and then the absorbance reading was taken at a wavelength of 885 nm using a UV/Vis spectrophotometer

The model for the spectrophotometer (Beer-Lambert Law)

$\%T = (P/P_o) \times 100\%$
$A = -Log\ (\%T/100)$
$A = \mathcal{E}bc$

Where;
T : Transmittance
A : Absorbance
b : Solution path length
$\mathcal{E}$: Molar absorptivity
c : Molar concentration

Determination of levels of ammonia (NH_3)

Reagent 1 was prepared by dissolving 17.5 g of phenol and 0.2 g of sodium nitroprusside in 400 mL distilled deionized water and stored to 500 mL volumes in an amber bottle to prevent direct light in the refrigerator. Reagent II was prepared by dissolving 140 g sodium citrate and 11 g sodium hydroxide in 22 mL of sodium hypochlorite and 400 mL of distilled deionized water and added into 500 mL volumes with distilled deionized water.

Stock solution A (500 µgat NH_3/L) was prepared by dissolving 0.3310 g of ammonium sulphate in 900 mL distilled deionized water and 1 mL chloroform and added to a volume of 1 liter and stored in a refrigerator. Stock Solution B (100 µgat NH_3/L) was prepared by transferring 2 mL of stock solution A to a 100 mL volumetric flask and adding to the volume with distilled water

The working standards were prepared by making serial dilutions from stock solution B as follows:

mL of stock B in 100 mL	Concentration (µgatNH_3/L)
1.0	1.0
2.0	2.0
4.0	4.0
6.0	6.0
8.0	8.0
10.0	10.0

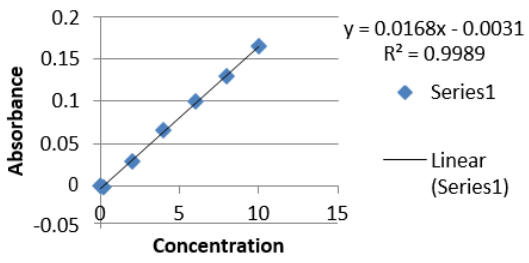

Figure 4. Calibration curve for NH_3

Ammonia was determined by measuring 35 mL of water sample in a volumetric flask, adding to reagent I, and shaking well, adding 1 mL of reagent II and then shaking well again. The reaction takes about 6 hours to complete. The absorbance reading is taken between 6 to 24 hours using a UV/vis double beam spectrophotometer at a wavelength of 630 nm. Next, 1 mL of reagents I and II were added to 35 mL of working standards and shaken well, and absorbance readings were taken at 630 nm wavelength to prepare the standard curve.

Calculation
Using the curve relationship
$Y = MX + C$
Where,
Y : the absorbance
M : the gradient of the curve
C : the Y-intercept
X : the concentration

On the making X the subject of the formula, absorbance readings were converted to concentration values
$X = Y - C/M$

Determination of carbon levels in the creek waters

Ex-situ primary productivity was measured using the Winkler method following APHA (1995) to determine the photosynthetic activity and the carbon assimilation per unit of time.

The Winkler method procedure

The creek water samples were to be analyzed (avoiding bubbles) by filling 50 ml of Winkler bottles and adding 0.4 mL $MnSO_4$ for every 50 mL sample. Then, 0.4 mL alkaline KI was added to every 50 mL water sample. The bottles were closed tight and shaken well. The precipitate formed was left to settle for half an hour. In this way, bottles could be preserved for 1-2 days. Finally, 0.2 mL of H_2SO_4 was added, bottles were shaken until all precipitate was dissolved, and titration was done within half an hour.

Reactions

$2MnSO_4+4NaOH \rightarrow 2Na_2SO_4+2Mn(OH)_2\ Mn(OH)_2$
uses the free O_2 in the water to form $MnO(OH)_2$
$2Mn(OH)_2+O_2 \rightarrow 2MnO(OH)_2$
In the presence of KI, the addition of a strong acid (H2SO4) liberates I_2
$2MnO(OH)_2+4H_2SO_4+4KI \rightarrow 2MnSO_4+2K_2SO4+6H_2O+2I_2$

The amount of liberated I_2 is equal to the dissolved O_2 in the water: 2 molecules of I_2 are formed for each molecule of O_2.

Next, I_2 colored the solution brown, and I_2 was titrated with a standardized solution of $Na_2S_2O_3$
$I_2+2Na_2S_2O_3 \rightarrow 2NaI+Na_2S_4O_6$

Finally, the end of titration was made visible by adding a bit of starch which colored the I_2 blue.

Titration

50 mL was poured into Erlenmeyer flasks after shaking bottles. $Na_2S_2O_3$ (diluted 0.01 N solution) drop by drop till the color is light yellow. Next, with a spatula, a small amount of starch was added, which changed the color to dark blue. The drops of $Na_2S_2O_3$ were carefully added until the water became colorless.

Calculation of O_2 content

$O_2 mgL^{-1}$ is calculated as follows:

$$\frac{\text{Norm } Na_2S_2O_3 \times 0.25 \times 32 \times 1000 \times \text{Vol } Na_2S_2O_3 \text{ added}}{\text{Volume titrated}}$$

$$= \frac{0.1 \times 0.25 \times 32 \times 1000 \times \text{Vol. } Na_2S_2O_3 \text{ added (mL)}}{50 \text{ mL}}$$

$$= \text{Vol. } Na_2S_2O_3 \text{ added (mL)} \times 1.6$$

To express final results in mg $C.I^{-1}$ instead of $O_2.I^{-1}$:

$$\frac{mg\ O_2}{L} \times \frac{MWC}{MWO2} = \frac{mg\ O_2}{L} \times \frac{12}{32} = mg\ O_2 \times 0.375$$

To convert to mL L^{-1}: 1 mole of a gas has a volume of 22.4 L at 1 atm and 4°C temperature

$$\frac{mg\ O_2}{L} \times \frac{1}{32} \times \frac{22.4L}{L} = mgO_2 \times \frac{0.7}{L} = LO_2$$

Data analysis

After the data were tested for normality to determine the variations between treatments, the spatial water quality patterns resulting from the different parameters from the identified sampling sites among the three creeks were analyzed quantitatively using ANOVA. Dissolved Oxygen (converted into values of carbon, mgC/L), ammonia (µgat NH_3), Phosphates (µgat P/L), and nitrates (µgat N/L) were determined. ANOVA was computed using the Statistical Analysis System (SAS). The rainfall data were also recorded during the entire study period. Moreover, because rainfall data for the six months did not reveal a normal distribution pattern, a correlation analysis between nutrient loads and monthly mean rainfall was performed using Spearman's correlation test. Finally, a comparison with threshold levels for various parameters was made following the criteria of standard water quality variables by Siokou-Frangou and Pangou (2000).

RESULTS AND DISCUSSION

Levels and variations of nitrates

The levels of nitrates (NO_3^-) for Mtwapa, Kilifi, and Mida Creeks are presented in Tables 1, 2, and 3. These levels are for the period between June 2011 to November 2011 of the different sampling sites presented in the columns to the left of the table.

Along Kilifi Creek, station K02 (Kilifi Boatyard beach) had high levels of nitrates throughout the research period. In contrast, stations K05 and K06 recorded low levels in June but increased from August to November 2011. The NO_3^- concentration in the two stations also positively correlated with rainfall and was found further inland from the creek mouth. That indicated that runoff water from the adjacent farms could have contributed to the increase in the NO_3^- levels. The open water as the control samples (K0C) had low levels of nitrates throughout the sampling period, which also happened in the same situation as in Mtwapa Creek. However, the Mnarani Club beach area as Station K01 had a significantly high level of nitrates compared with the control in October 2011 when the monthly rainfall means was highest, suggesting that the increase in the levels of nitrates contributed by the runoff water composition (Barnes and Hughes 1988).

All sampling stations, except the open water control station (SC) along Mtwapa Creek between June 2011 and November 2011, had no significant difference in the monthly nitrate levels at $\alpha = 0.05$. The open waters as the control station (SC) had the lowest nitrates levels throughout the sampling period from June to August 2011. The results, however, reveal that in August 2011, there was an increase in nitrate levels in all the stations. This increase can be attributed to the waste discharged increase from urban development around the outer creek. All the sampling stations negatively correlated the mean rainfall amounts and nitrates. Therefore the increased levels in August cannot be attributed to runoff or stormwater from the neighborhood. These findings confirm that the amounts of runoff waters do not significantly influence the open ocean waters into the creek waters or human disturbances along the creeks (Kaiser et al. 2005). Those findings proved that agricultural and industrial pollutants and rivers or runoff water convey terrestrially derived materials loaded with sewage, while further offshore, the direct human influences are, so far, limited. Moreover, the decreased influence of human activities with distance from the coast is related to physical limitations inflicted by depth and wave height and the logistics of getting there (Kaiser et al. 2005).

Table 1. Levels of NO_3^- (µgat N/L), Mtwapa Creek, Kenya, June to November 2011

Site	Jun	Jul	Aug	Sep	Oct	Nov
S24	0.704^{b}	0.849^{b}	0.994^{b}	0.820^{b}	0.646^{b}	0.675^{b}
S27	0.749^{b}	0.845^{b}	0.940^{b}	0.856^{b}	0.772^{b}	0.760^{b}
S29	0.584^{b}	0.852^{b}	1.120^{b}	0.932^{b}	0.744^{b}	0.664^{b}
S36	0.615^{b}	0.885^{b}	1.154^{b}	0.882^{b}	0.610^{b}	0.612^{b}
S38	0.698^{b}	0.739^{b}	0.780^{ab}	0.699^{b}	0.618^{b}	0.658^{b}
S39	0.553^{b}	0.690^{b}	0.826^{b}	0.771^{b}	0.715^{b}	0.633^{b}
SC.	0.244^{a}	0.261^{a}	0.245^{a}	0.271^{a}	0.255^{a}	0.240^{a}

Note: The Mean values in each column with the same letter are not significantly different at $\alpha = 0.05$

Table 2. Levels of NO_3^- (µgat N/L), for Kilifi Creek, Kenya, June to November 2011

Site	Jun	Jul	Aug	Sep	Oct	Nov
K01	0.339^{ab}	0.322^{a}	0.304^{c}	0.517^{bc}	0.729^{a}	0.534^{ab}
K02	0.419^{a}	0.410^{ab}	0.402^{bc}	0.561^{bc}	$.720^{ab}$	0.570^{a}
K03	0.353^{ab}	0.444^{ab}	0.535^{b}	0.456^{cd}	0.376^{bc}	0.365^{bc}
K04	0.296^{bc}	0.331^{bc}	0.364^{bc}	0.530^{bc}	0.695^{ab}	0.496^{ab}
K05	0.287^{bc}	0.547^{a}	0.806^{a}	0.846^{a}	0.886^{a}	0.587^{a}
K06	0.233^{bc}	0.519^{a}	0.806^{a}	0.740^{ab}	0.880^{a}	0.557^{a}
K0C	0.233^{c}	0.265^{c}	0.265^{c}	0.265^{d}	0.265^{c}	0.265^{c}

Note: The Mean values in each column with the same letter are not significantly different at $\alpha = 0.05$

Table 3. Levels of NO_3^- (µgat N/L) for Mida Creek, Kenya, June to November 2011

Site	Jun	Jul	Aug	Sep	Oct	Nov
md1	0.418^{b}	0.381^{b}	0.344^{a}	0.356^{a}	0.367^{a}	0.393^{b}
md2	2.395^{a}	1.329^{a}	0.262^{a}	0.329^{a}	0.396^{a}	1.396^{a}
md3	0.615^{b}	0.429^{b}	0.242^{a}	0.268^{a}	0.290^{a}	0.453^{b}
md4	1.344^{ab}	0.789^{ab}	0.233^{a}	0.258^{a}	0.282^{a}	0.813^{ab}
md5	0.823^{ab}	0.553^{ab}	0.282^{a}	0.348^{a}	0.413^{a}	0.618^{ab}
md6	0.720^{b}	0.484^{b}	0.248^{a}	0.245^{a}	0.242^{a}	0.481^{b}
mdC	0.256^{b}	0.256^{b}	0.256^{a}	0.256^{a}	0.256^{a}	0.256^{b}

Note: The Mean values in each column with the same letter are not significantly different at $\alpha = 0.05$

Along Mida Creek, the nitrates levels were significantly higher at station Md2 (Captain Andy and Hemmingway's boat yard), while Md3 and Md6 had low levels with nitrates significant difference in June and July 2011, but after that, with no significant difference in nitrate levels between August and October 2011. The nitrate levels in Mida Creek did not correlate with rainfall, suggesting that runoff water did not influence nitrate levels. In addition, being a conservation area, this creek's presence of mangrove bushes and their ability to stabilize nutrients and filter off nitrates may have minimized this effect (Hogarrth 1998).

Levels and variations in phosphates

The Phosphates (PO_{4-}) levels for Mtwapa, Kilifi, and Mida Creeks are presented in Tables 4, 5, and 6. These levels are for the period between June to November 2011 for the different sampling sites on the column to the left of the table. The measurement units are µgatoms of P per liter of the water samples.

The phosphates levels along Mtwapa Creek were highest at station S38, which shows significant differences from all the other stations, i.e., S24, S27, S29, S39, and SC, in June. Next, in July, stations S38 and S39 had significant differences in phosphate levels; finally, they were shown in station S38 in November 2011. There were no significant differences in the stations' levels between August and October. The highest phosphate levels were recorded in the outer creek stations (S38 and S39), with more urban and business developments compared to the inner creek. That confirms findings that wastewater and runoff from urban development contribute to inputs of phosphates and other pollutants into marine waters close to urban and tourist development (Bizsel and Uslu 2000). On the other hand, the inner creek stations' findings reflected the lack of major pollutant sources.

The phosphate levels also strongly correlate with mean monthly rainfall amounts for stations S27, S36, S29, and S39, which means that runoff water did not wash phosphates from land but rather human wastes near these stations. On the other hand, the open water control station did not correlate with PO_4^- and rainfall. Station S38 (discharge point of sewage and wastewater from Shimo-La-Tewa GK prison) had the highest amounts of phosphates (an important ingredient of detergents) in June, indicating that wastewater was being released into the creek from time to time from the prison. However, runoff water from rainfall does not seem to have affected the levels of phosphates for all stations except S24 which is further inland along the creek with no urban developments. That suggests that runoff water from the neighboring farms washed some phosphates into the creek.

Along Kilifi Creek, phosphate levels were generally higher at stations K04 and K05. Still, they were not significantly different from the control, in which all the other stations recorded low levels throughout the research period. These stations were also considered close and adjacent to maize farms in the Maringoni area (K04) and Maringoni valley (K05). These results suggest that phosphate levels may have been influenced by farming activities. That confirms the claim that agricultural practices contribute nutrients, sediments, and biological contaminants to waterways (Stuart 2010). In addition, the strong positive correlations between phosphates and rainfall for all stations except the open ocean water, as the control indicates that phosphates from land entered the creek by rainwater.

Table 4. Levels of PO_4^- (µgat P/L), for Mtwapa Creek, Kenya, June to November 2011

Site	Jun	Jul	Aug	Sep	Oct	Nov
S24	0.555^{a}	0.704^{a}	0.852^{a}	0.870^{a}	0.889^{a}	0.722^{a}
S27	1.019^{a}	1.009^{abc}	1.000^{a}	0.935^{a}	0.870^{a}	0.945^{a}
S29	1.444^{ab}	1.222^{abc}	1.000^{a}	0.843^{a}	0.685^{a}	1.065^{ab}
S36	0.908^{a}	0.917^{a}	0.926^{a}	0.889^{a}	0.851^{a}	0.880^{a}
S38	2.241^{b}	1.565^{c}	0.889^{a}	0.889^{a}	0.889^{a}	1.565^{b}
S39	1.611^{ab}	1.306^{c}	1.000^{a}	0.907^{a}	0.814^{a}	1.213^{ab}
SC.	0.770^{a}	0.960^{a}	0.871^{a}	0.895^{a}	$o.888^{a}$	0.876^{a}

Note: The Mean values in each column with the same letter are not significantly different at $\alpha = 0.05$

Table 5. Levels of PO_4^- (µgat P/L) for Kilifi Creek, Kenya, June to November 2011

Site	Jun	Jul	Aug	Sep	Oct	Nov
K01	0.629^{c}	0.602^{e}	0.574^{c}	0.815^{d}	1.055^{a}	0.842^{c}
K02	0.777^{bc}	0.685^{de}	0.592^{c}	0.843^{cd}	1.092^{a}	0.935^{c}
K03	0.555^{c}	0.602^{e}	0.648^{c}	0.815^{d}	0.981^{a}	0.785^{c}
K04	1.240^{a}	1.139^{b}	1.037^{b}	1.074^{bc}	1.111^{a}	1.176^{ab}
K05	1.111^{ab}	1.047^{bc}	0.981^{b}	1.111^{b}	1.240^{a}	1.176^{ab}
K06	0.796^{bc}	0.870^{cd}	0.944^{b}	1.157^{b}	1.370^{a}	1.083^{bc}
K0C	1.469^{a}	1.462^{a}	1.462^{a}	1.412^{a}	1.370^{a}	1.412^{a}

Note: The Mean values in each column with the same letter are not significantly different at $\alpha = 0.05$

Table 6. Levels of PO_4^- (µgat P/L), for Mida Creek, Kenya, June to November 2011

Site	Jun	Jul	Aug	Sep	Oct	Nov
md1	0.685^{b}	0.592^{d}	0.500^{e}	0.731^{c}	0.963^{b}	0.824^{b}
md2	0.852^{b}	0.722^{cd}	0.592^{de}	0.676^{c}	0.759^{b}	0.805^{b}
md3	1.648^{a}	1.296^{b}	0.944^{de}	1.130^{b}	1.314^{ab}	1.481^{a}
md4	0.778^{b}	0.796^{cd}	0.814^{bc}	0.926^{bc}	1.037^{ab}	0.908^{b}
md5	0.722^{b}	0.739^{cd}	0.722^{cd}	0.815^{bc}	0.907^{b}	0.815^{b}
md6	0.944^{b}	0.806^{c}	0.667^{cd}	0.741^{c}	0.815^{b}	0.880^{b}
mdC	1.648^{a}	1.648^{a}	1.648^{a}	1.648^{a}	1.648^{a}	1.648^{a}

Note: The Mean values in each column with the same letter are not significantly different at $\alpha = 0.05$

Station Md3, adjacent to the sandy beach and tourist entertainment area, generally had high but fluctuating phosphates levels. At the same time, the control station (MdC) showed high levels in the open water but was comparable with Md3 throughout the sampling period. The mangrove forest cover density was very low, and wave action was high, suggesting that land-based activities had influenced the phosphate levels.

Levels and variations in ammonia

The ammonia (NH3) levels for Mtwapa, Kilifi, and Mida Creeks are shown in Tables 7, 8, and 9. These levels are for the different sampling sites presented in the column to the left for the period from June to November 2011. The units of measurement are µgatoms of NH_3 per liter of the water samples.

Along Mtwapa Creek, Station S38 (the discharge point for sewage and wastewater from Shimo-La-Tewa G.K prison) had extremely high ammonium levels in June, July, and November 2011, while the levels were not significantly different in August, September, and October 2011.

Table 7. Levels of NH_3 (µgat NH_3/L) for Mtwapa Creek, Kenya, water samples, June to November 2011

Site	Jun	Jul	Aug	Sep	Oct	Nov
S24	1.063^{a}	1.219^{ab}	1.375^{a}	1.802^{a}	2.229^{b}	1.646^{a}
S27	0.584^{a}	1.146^{ab}	1.709^{a}	2.615^{ab}	3.521^{b}	2.052^{a}
S29	0.688^{a}	1.000^{a}	1.313^{a}	1.844^{a}	2.375^{b}	1.532^{a}
S36	0.729^{a}	1.104^{ab}	1.479^{a}	1.938^{a}	2.396^{b}	1.563^{a}
S38	23.065^{b}	12.428^{c}	1.792^{a}	2.375^{ab}	2.959^{b}	13.012^{b}
S39	1.771^{a}	1.532^{ab}	1.292^{a}	1.761^{a}	2.229^{b}	2.000^{a}
SC	1.123^{a}	1.286^{b}	1.258^{a}	1.511^{a}	1.938^{a}	1.130^{a}

Note: The Mean values in each column with the same letter are not significantly different at $\alpha = 0.05$

Table 8. Levels of NH_3 (µgat NH_3/L) for Kilifi Creek, Kenya, water samples, June to November 2011

Site	Jun	Jul	Aug	Sep	Oct	Nov
K01	1.000^{b}	1.094^{c}	1.187^{c}	2.000^{a}	2.813^{a}	1.906^{b}
K02	1.250^{ab}	1.417^{abc}	1.583^{bc}	2.375^{a}	3.167^{a}	3.875^{a}
K03	0.979^{b}	1.146^{bc}	1.313^{bc}	1.729^{a}	2.146^{a}	1.563^{b}
K04	1.021^{b}	1.427^{abc}	1.833^{abc}	2.510^{a}	3.187^{a}	2.104^{ab}
K05	1.292^{ab}	1.990^{a}	2.687^{a}	2.250^{a}	1.813^{a}	1.552^{b}
K06	0.917^{b}	1.510^{abc}	2.104^{bc}	1.906^{a}	1.708^{a}	1.312^{b}
K0C	1.833^{a}	1.094^{c}	1.833^{abc}	1.833^{a}	1.833^{a}	1.833^{b}

Note: The Mean values in each column with the same letter are not significantly different at $\alpha = 0.05$

Table 9. Levels of NH_3 (µgat NH_3/L) for Mida Creek, Kenya, water samples, June to November 2011

Site	Jun	Jul	Aug	Sep	Oct	Nov
md1	1.000^{b}	2.209^{a}	2.208^{ab}	2.542^{a}	2.875^{a}	1.938^{a}
md2	1.500^{b}	1.521^{a}	1.542^{b}	1.386^{a}	1.229^{a}	1.365^{a}
md3	2.292^{ab}	2.135^{a}	1.979^{b}	1.844^{a}	1.709^{a}	2.000^{a}
md4	3.583^{a}	2.761^{a}	1.937^{b}	1.844^{a}	1.750^{a}	2.667^{a}
md5	1.021^{b}	2.156^{a}	3.291^{a}	2.594^{a}	1.896^{a}	1.458^{a}
md6	3.250^{a}	2.573^{a}	1.896^{b}	1.948^{a}	2.000^{a}	2.625^{a}
mdC	1.542^{b}	1.542^{a}	1.542^{b}	1.542^{a}	1.542^{a}	1.542^{a}

Note: The Mean values in each column with the same letter are not significantly different at $\alpha = 0.05$

The presence of high and sporadic ammonia levels are evident that untreated sewage and wastewater were discharged into the creek from time to time from the GK prison. Station S38's ammonia levels were comparable with the other stations in August and October. Furthermore, this suggests some form of wastewater treatment during certain times within the prison activity. A high tourist season still goes on in October, which can be associated with generating comparably high amounts of ammonia-containing wastes, which could have contributed to the observed high ammonia levels in all samples except S38. The open ocean water control (SC) had consistently moderate ammonia levels comparable with the other stations throughout the sampling period, indicating insignificant levels of biological contaminants offshore.

There were spatial and temporal variations in ammonia levels along Kilifi Creek. The levels were high at station K02 (Boatyard beach) from September to November, while station K05 (Maringoni valley) showed high ammonia levels between July and September 2011. The high ammonia levels in the stations could be attributed to agricultural sources and tourism. The other stations showed no significant difference in ammonia levels due to limited nitrification or less important pollutant sources (Bizsel and Uslu, 2000). The correlation values between ammonia and rainfall were strongly positive for stations K01, K3, K04, and K02. There was no correlation between rainfall and NH_3 for station K06 and a slightly positive correlation at the open water control station.

Stations Md3, Md4, and Md6 along Mida Creek had a significantly high ammonia level between the June and July sampling period. These stations are adjacent to the Mida beach, Sudi Island picnic site, and Safari Blue beach, respectively. Therefore, these high levels could be attributed to the tourist activities along these beaches, except for station Md1, all the other stations negatively correlated with rainfall. Moreover, the ammonia levels for station Md1 (Temple point shoreline) and Md5 (Shoreline opposite Captain Andy) were initially quite low. Then, from July, the levels arose and became comparable with stations Md3, Md4, Md6, and the control. That was a low season for tourist activities, suggesting insignificant levels of waste discharged into the creek.

Effect of nutrient loads on primary productivity

The primary productivity results for Mtwapa, Kilifi, and Mida Creeks calculated as a difference between photosynthesis and respiration using the Winkler method are shown in Tables 10, 11, and 12. The measurement units are milligrams of carbon per liter of water sample per hour. These results are for the period from June to November 2011.

The carbon assimilation levels along Mtwapa Creek were slightly high at stations S39, S38, and S36 around the sampling period, while lowest in the control sample. Station S29 also recorded low carbon values from June to November 2011. These results supposed more phytoplanktonic activities within the outer creek near Mtwapa town than the inner creek. In addition, these sites' levels of nutrients (phosphates) showed a strong positive

correlation with carbon. They were generally higher in all these three stations than in the inner stations, although the other nutrients showed a negative correlation with carbon. These findings reveal that the higher fertility levels of the outer creek waters influenced the rate of photosynthetic activity among the phytoplanktonic cells in addition to the decomposition and decay of these cells (Kaiser et al. 2005).

On the other hand, the open ocean waters revealed close to zero correlation between carbon and nutrients. That could be attributed to either dilution of the creek water or low biological activity as it mixes with the water from the open ocean. However, other chemical and physical properties of the water, including dissolved oxygen and turbidity, influence the photosynthesis rate.

Carbon assimilation levels for K01 and K02 stations were highly significant from June to August 2011, and there was no significant difference from September to November. The correlation coefficient at station K01 was positively strong with ammonia, whereas the correlation coefficient was almost zero at K02. These results confirm that higher rates of photosynthetic activity (Boat yard and Mnarani club beaches) are associated with higher nitrates and phosphates levels between the two months (Tew et al. 2006). However, the average does not show a clear relationship between nitrates and phosphates for the entire period. On the other hand, throughout the sampling period, ammonia maintained a clear positive correlation. The other stations did not record significantly different amounts. Moreover, throughout the research period, due to the lack of major pollutant sources and biological processes in the outer ocean, the control had consistently low carbon assimilation rates (Bizsel and Uslu 2000).

Table 10. Rate of carbon assimilation (mgC/L), levels for Mtwapa Creek, Kenya, water samples, June to November 2011

Site	Jun	Jul	Aug	Sep	Oct	Nov
S24	0.367^{ab}	0.243^{abc}	0.120^{ab}	0.860^{d}	1.600^{c}	0.983^{c}
S27	0.360^{ab}	0.230^{a}	0.103^{a}	0.230^{b}	0.360^{b}	0.360^{b}
S29	0.136^{a}	0.140^{a}	0.150^{b}	0.150^{a}	0.150^{a}	0.140^{a}
S36	0.330^{ab}	0.330^{bc}	0.330^{c}	0.323^{c}	0.320^{b}	0.323^{b}
S38	0.340^{ab}	0.353^{bc}	0.370^{c}	0.383^{c}	0.400^{b}	0.370^{b}
S39	0.450^{b}	0.393^{c}	0.343^{c}	0.343^{c}	0.343^{b}	0.393^{b}
SC.	0.137^{ab}	0.130^{a}	0.170^{a}	0.132^{a}	0.140^{a}	0.141^{a}

Note: The Mean values in each column with the same letter are not significantly different at $\alpha = 0.05$

Table 11. Rate of carbon assimilation (mg C/L), levels for Kilifi Creek, Kenya, water samples

Site	Jun	Jul	Aug	Sep	Oct	Nov
K01	0.340^{b}	0.286^{a}	0.240^{a}	0.203^{a}	0.170^{b}	0.253^{b}
K02	0.550^{a}	0.326^{a}	0.110^{cd}	0.123^{b}	0.140^{bc}	0.340^{a}
K03	0.083^{c}	0.110^{c}	0.140^{bc}	0.190^{a}	0.240^{a}	0.160^{c}
K04	0.270^{b}	0.190^{b}	0.110^{cd}	0.180^{a}	0.260^{a}	0.260^{b}
K05	0.100^{c}	0.123^{c}	0.150^{b}	0.150^{b}	0.150^{bc}	0.123^{c}
K06	0.130^{c}	0.110^{c}	0.100^{d}	0.130^{b}	0.160^{bc}	0.140^{c}
K0C	0.130^{c}	0.123^{c}	0.130^{bcd}	0.126^{b}	0.136^{c}	0.126^{c}

Note: The Mean values in each column with the same letter are not significantly different at $\alpha = 0.05$

Table 12. Rate of carbon assimilation (mg C/L), levels for Mida Creek, Kenya, water samples, June to November 2011

Site	Jun	Jul	Aug	Sep	Oct	Nov
md1	0.026^{c}	0.120^{c}	0.220^{c}	0.320^{a}	0.420^{a}	0.220^{a}
md2	0.016^{c}	0.086^{d}	0.160^{d}	0.196^{c}	0.240^{c}	0.126^{de}
md3	0.080^{c}	0.080^{d}	0.080^{e}	0.100^{d}	0.120^{d}	0.100^{e}
md4	0.026^{c}	0.156^{b}	0.290^{b}	0.276^{b}	0.273^{bc}	0.146^{cd}
md5	0.050^{bc}	0.196^{a}	0.350^{a}	0.323^{a}	0.300^{b}	0.170^{bc}
md6	0.090^{a}	0.203^{a}	0.320^{ab}	0.306^{ab}	0.300^{b}	0.193^{ab}
mdC	0.033^{c}	0.032^{e}	0.033^{f}	0.032^{e}	0.033^{e}	0.033^{f}

Note: The Mean values in each column with the same letter are not significantly different at $\alpha = 0.05$

Along Mida Creek, station Md1 (Temple point) had highly significant levels of carbon assimilation from August to November 2011. Station Md5 recorded highly relative levels of carbon fixation between July and September, which relates to the higher levels of ammonia and phosphate, which also showed a positive correlation coefficient during the same period. These results can be attributed to high input rates of nitrogenous organic wastes from anthropogenic sources. The control station recorded low levels of carbon assimilation throughout the research period. The correlation coefficient between carbon and ammonia and carbon and nitrates was negative, while between carbon and phosphates, there was a slightly positive correlation.

Correlation between mean nutrient levels and carbon assimilation

The correlation coefficients were calculated using Spearman's correlation analysis, and the correlation relationships for the three creek creeks are shown in Tables 13, 14, and 15.

Along Mtwapa Creek, the element which mostly limits primary production in the ocean, Nitrate nitrogen, showed a negative correlation in all stations except S29 and S36. Although Nitrites and Ammonium ions can be taken up, nitrates are algae's primary source of nitrogen utilized (Kaiser et al. 2005).

Phosphates along Mtwapa Creek showed unclear trends concerning productivity and nutrient levels. The correlations varied from negative at stations S29 and S38 to positive at S39 and S36. Phosphorous is the second limiting nutrient in marine systems and happens in several forms. It is also present in various organic compounds, which can be broken down by enzymes located in many algal species' membranes. Within the outer stations, including S36, S38, and S39, ammonia negatively correlated with carbon assimilation. In the oligotrophic deep ocean sites, the values are normally very low, below 0.1 $\mu molL^{-1}$, due to be little input of fresh nitrates into the upper mixed layer from below. However, coastal upwelling in coastal sites can result in high input of nitrates.

Spearman's correlation analysis was used to manage the correlation between nutrients and carbon. Nitrate nitrogen showed a negatively strong correlation within the outer creek station of Mnarani Club beach (K01) and a negatively moderate correlation along the Boat Yard beach

(K02). However, the inner creek stations showed positive correlations, particularly strong near the agricultural area of Maringoni valley. The outer ocean control station revealed a near-zero correlation.

The correlation between phosphates and carbon along Kilifi Creek was closely related to nitrates, with a negatively strong relationship within the outer creek stations and a positively strong relationship within the inner creeks. The correlation results for nitrates and phosphorous indicate that land-based activities within the inner creek could have contributed to the high levels of carbon fixation coupled with the other inner creek waters' physical and chemical characteristics. In addition, other characteristics, such as turbidity and dissolved oxygen, affect photosynthetic activity.

The correlation between carbon and ammonia showed a strongly positive trend in both the outer and inner creek waters. Only two stations where the correlations were slightly negative, at K02 and K06. That reveals if other factors were to be assumed constant, that ammonia nitrogen in all stations played a role in the photosynthetic activities of phytoplanktons.

Table 13. Correlation r values between mean levels of nutrients and carbon assimilation for Mtwapa Creek, Kenya, June to November 2011

Station	NO_3^-	PO_4^-	NH_3
S24	-0.742*	0.451	0.914*
S27	-0.994*	-0.393	0.1337
S29	0.7105*	-0.886*	0.761*
S36	0.495	0.947*	-0.831*
S38	-0.506	-0.857*	-0.831*
S39	-0.624	0.869*	-0.295
SC	-0.517	-0.186	-0.141

Note: R values with * are significant

Table 14. Correlation r values between mean levels of nutrients and carbon assimilation, Kilifi Creek, Kenya, June to November 2011

Station	NO_3^-	PO_4^-	NH_3
K01	-0.763*	-0.743*	0.86*
K02	-0.4033	-0.088	-0.269
K03	-0.0367	0.983*	0.996*
K04	0.2915	0.817*	0.0759
K05	0.9912*	0.0028	0.783*
K06	0.143	0.736*	-0.289
K0C	-0.161	-0.477	0.586

Note: R values with * are significant

Table 15. Correlation r values between mean levels of nutrients and carbon assimilation, Mida Creek, Kenya, June to November 2011

Station	NO_3^-	PO_4^-	NH_3
Md1	-0.665	0.601	0.897*
Md2	-0.913*	-0.498	-0.689
Md3	-0.393	0.0298	-0.844*
Md4	-0.999*	0.558	-0.988*
Md5	-0.996*	0.356	0.878*
Md6	-0.995*	-0.885*	-0.999*
MdC	-0.433	0.305	-0.542

Note: R values with * are significant

Along Mida Creek, Nitrates correlation analysis revealed a completely different trend using the same analysis model. There was a negatively strong correlation between nitrate nitrogen and carbon in all sampling stations except the outer ocean control and Md3, which had a positively slight correlation throughout the sampling period. These results indicate that the carbon assimilation rate was influenced by other marine water chemicals, nutrient amounts, and biological and physical factors along Mida Creek, which might have had a strong influence.

Ammonia and phosphates showed a positively strong correlation at the Temple Point shoreline (Md1) and the sampling station opposite captain Andy (Md5). The rest of the stations revealed a negative correlation between ammonia and phosphates. However, Sudi Island (Md4) positively correlated with phosphates and carbon.

Correlation between mean monthly rainfall amounts and nutrient loads

Correlation between mean monthly rainfall amounts and nutrient loads are shown in Tables 16, 17, and 18 for the three creek creeks. The tables show a negative correlation between rainfall and nitrate levels for stations S24, S27, S29, S36, and S38. There is almost no correlation between rainfall and nitrates in the open water control station and station S39.

The phosphate levels also have a strong correlation with mean monthly rainfall amounts for stations S27, S36, S29, and S39. Station S24, however, phosphate still shows some positive correlation with rainfall. On the other hand, the open water control station does not correlate with PO_4^- and rainfall. Moreover, for all stations except S38, the ammonia level has a strong correlation with the monthly mean rainfall amounts. Only station S38 had a negative correlation between NH_3 and rainfall.

Along Kilifi Creek, there was a positively strong correlation between NO_3^- and rainfall for stations K01, K02, and K04. Correlation values were low for stations K05 and K06. K0C had almost zero correlation, and station K03 recorded a negative correlation value. There was a positively strong correlation between rainfall and PO_4^- for stations K01, K02, K03, K05, and K06. Conversely, the open water station control had a negatively strong correlation between rainfall and PO_4^- while station K04 had almost no correlation.

Correlation values between rainfall and ammonia were positively strong for stations K01, K3, K04, and K02. Conversely, there was a slight positive correlation at the open water control station and no correlation between rainfall and NH_3 for station K06. Moreover, for all the stations, the correlation values between nitrates and rainfall were all close to zero to slightly positive.

There was a positively strong correlation between rainfall and PO_4^- at stations Md1, Md4 and Md5. There was a slightly positive correlation between the rainfall and PO_4^- for stations Md2, Md3, and Md6. A weak negative correlation showed on the open water station control, implying that runoff water contributed to increased phosphates in the creek water.

Table 16. Correlation r values between rainfall and NO_3^-, PO_4^- and NH_3, Mtwapa Creek, Kenya, June to November 2011

Station	NO_3^-	PO_4^-	NH_3
S24	-0.585	0.45	0.81*
S27	-0.399	-0.843*	0.768*
S29	-0.273	-0.66	0.773*
S36	-0.486	-0.85*	0.736*
S38	-0.768*	-0.374	-0.336
S39	0.032	-0.537	0.766*
SC	0.0743	0.004	0.877*

Note: R values with * are significant

Table 17. Correlation r values between rainfall and NO_3^-, PO_4^- and NH_3, Kilifi Creek, Kenya, June to November 2011

Station	NO_3^-	PO_4^-	NH_3
K01	0.863*	0.865*	0.83*
K02	0.86*	0.85*	0.549
K03	-0.48	0.79*	0.778*
K04	0.818*	0.018	0.736*
K05	0.392	0.814*	-0.27
K06	0.44	0.789*	0.01
K0C	0.152	-0.813*	0.268

Note: R values with * are significant

Table 18. Correlation r values between rainfall and NO_3^-, PO_4^- and NH_3, Mida Creek, Kenya, June to November 2011

Station	NO_3^-	PO_4^-	NH_3
Md1	0.0315	0.784*	-0.474
Md2	0.167	0.32	-0.787*
Md3	-0.12	0.22	-0.54
Md4	-0.18	0.735*	-0.28
Md5	-0.027	0.789*	-0.299
Md6	-0.219	0.23	-0.157
MdC	0.069	-0.33	0.14

Note: R values with * are significant

The study found that primary productivity along Mtwapa Creek was higher within the outer creek, and the levels exposed a positive correlation (S39 and S36 had 0.869 and 0.947, respectively) with phosphates. However, there was a negative correlation between these rainfall amounts and nutrient levels. Therefore, this suggests that this fertility level resulted from land-based human developments, including businesses and tourist hotels close to the outer creek stations. The roadside drainage channels from the neighboring Mtwapa town could be the most likely source of these phosphates due to wastewater collected from business establishments. The null hypothesis is therefore rejected. The inland station positively correlated with rainfall, suggesting that runoff water from the neighboring cleared farm fields was the most likely source of the nutrients. The control station, which was marine water samples from the open ocean, had a very close to zero correlation coefficient between nutrients and rainfall, implying there was very little influence on its water fertility from land-based anthropogenic activities. The null hypothesis is therefore rejected.

Along Kilifi Creek, at the Sea Horse shoreline (0.983), Maringoni valley (0.817), and Maringoni area (0.736), the correlation coefficient results were positive between carbon and the three nutrients. The correlation coefficient between the nutrients and rainfall was also positive among all the creek stations, indicating the most likely source of these nutrients in the creek could be runoff water from the surrounding area. The most important human activity, allowing the nutrients from land to enter the creek directly, maybe the opening up of vegetation, including mangrove destruction within areas close to the creek.

In Mida Creek, in five sampling stations, the analysis results show a positive relationship between rainfall and nutrient levels and slightly close to zero at the outer ocean control station. However, only phosphates showed a positive correlation (0.601, 0.498, 0.0296, 0.558, 0.356, 0.885, and 0.305) with carbon assimilation. Phosphates and ammonia had a positive relation (0.601 and 0.897, respectively) with carbon at the Temple point shoreline. These results suggest that some level of land-based nutrients are washed into the creek, although Mida Creek is a conservation area under the strict rules of Kenya Wildlife Service (KWS) and the presence of the Marine Park. The highest nutrient levels, especially phosphates, recorded at the Temple Point Hotel suggest that some contaminated wastewater from this establishment could have contributed to the increased levels. The monthly averages in nutrient levels in all three creeks fluctuated throughout the study period.

Mtwapa Creek consistently recorded higher levels of nitrates within the oligotrophic level throughout the period, even within acceptable levels (Siokou-Frangou and Pangou 2000). The nutrient level along Kilifi and Mida Creeks kept fluctuating and did not give a clear, consistent trend throughout the study period. The outer ocean control for nitrate in Mtwapa, Kilifi, and Mida were 0.00024, 0.000256, and 0.00023 mg/L, respectively. The Kilifi, Mida Creeks, and the controls nitrate levels were all less than 0.00067, which is within the oligotrophic levels of less than 0.0087 mg/L. Therefore, in all three creeks, the phosphate levels were between the higher oligotrophic ranges of 0.002 mg/L. According to the trophic classification scheme, these levels are within acceptable limits.

The higher mesotrophic level sampling was station S38 (Shimo-La-Tewa GK Prison), while all the other stations were in the oligotrophic levels below 0.008 mg/L; those levels are above acceptable limits according to the trophic classification (Siokou-Frangou and Pangou. 2000). However, the ammonia levels along Kilifi and Mida Creeks were within the oligotrophic range of less than 0.008 mg/L. Furthermore, for the entire study period, the distance of the sampling sites from the identified sources of nutrients was fixed at 10 meters from the shoreline along the creek. Changing the distance of the sampling sites from the potential sources of nutrients would have allowed a proximity analysis, making the results more valid.

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