Trends in water quality in a tropical Kenyan river-estuary system: Responses to anthropogenic activities

ABSTRACT

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Aims: To determine the spatial variation in physico-chemical water quality attributes in estuarine ecosystems of South Coast Kenya to inform its management.
Study design: We employed diagnostic research design where such factors as anthropogenic activities, hydrology, and accessibility were considered in choosing 12 sampling stations. A mixed sampling design (probability and non-probability) was used to sample.
Place and Duration of Study: Four discharging rivers into estuarine system with a reference point were identified. 12 sampling points were earmarked and sampled for 12 months.
Methodology: Nine selected water quality parameters were collected in triplicates monthly for 12 months. Temperature, dissolved oxygen, pH, conductivity, salinity and TDS were collected *in situ* usingYSI Multiparameter meter (Professional plus) while nutrients were analyzed in the laboratory calorimetrically. Data was tested for normality and homogeneity of variances using Levene's and Shapiro-Wilk tests. Two-way analysis of variance(ANOVA), and Principal Component Analysis (PCA) were done using the 64-bit R Software version 4.3.0 to test for significant differences and correlate the parameters among the sampling sites respectively. Observed differences were considered statistically significant at $P < 0.05$.
Results: The measured environmental variables differed significantly among the sampling stations ($P < 0.05$).temperature and salinity exhibited moderate to strong effect on water quality, while pH and nutrients (phosphates, nitrates, and ammonia) exhibited mixed effects with both negative and positive loadings on the Principal Components. It isdemonstratedthatthesouthcoastestuary, Kenyaisaffectedbytwogradients: mineralization from the seaand the organic matter gradient at the upstream stations dominated by the fluvial inflows from the respective rivers.

Conclusion: The south coast of Kenya estuary is impacted by natural processes and anthropogenic activities.Werecommendforcontinuedregularwaterqualityassessmentandmonitoringtoacquiresufficientdatato shape policyframeworkstowardsitssustainablemanagement

Keywords: Pollution; water quality; Western Indian Ocean; estuarine systems; anthropogenic activities; south coast Kenya

1. INTRODUCTION

Globally, pollution of surface water is on the trajectory owing to rapid human population that is exerting enormous pressure on the environment. Anthropogenic activities have led to elevated physico-chemical water quality attributes of environmental concern because they have resulted into eutrophication and decreased biodiversity in aquatic ecosystems [1-10]. It has been confirmed that freshwater bodies although smallest in terms of surface area are the most important in sustaining human life and yet they are the most compromised in terms of integrity and their depletion is alarming [6-8, 11-15]. It is estimated that the demand for water may increase three-fold by the year 2050 [16]. The physico-chemical levels and sediment quality and quantity often indicate the integrity and health status of rivers and estuarine systems hence the need to assess the impacts of anthropogenic changes to underscore the implementation of management strategies to inform policy [17,18]. Having poorly documented data sets that runs for a longer extended time frames may not point out the real picture of quality changes in given ecosystems and in most cases may lead to misleading policy interventions [19]. To overcome these complex interactions, which may act synergistically or antagonistically [20,7] calls for regular and well-coordinated environmental monitoring and assessment that runs for a reasonable temporal and spatial scale especially in the current highly variable tropical climates that are defined by climate change.

For the last five decades, rivers and estuarine systems have witnessed spatial-temporal variations in terms of water quality parameters and sediment loads that have drastically impaired these ecosystems [1,20-25] Elevated agricultural activities, urbanization, industrialization, deforestation, river impoundments, and unregulated water abstractions have contributed to poor water quality downstream due to excessive nutrient and sediment loads [23, 24]. It is estimated that over 350,000 chemical substances and about 70,000 undocumented ones are in regular application globally [26] (Wang et al., 2020). Their effects are detrimental both to the environment and the organisms that reside in it and can access both compartments in form of solution, solid and/or gaseous [27]. Further, this situation (of environmental pollution) is compounded by the effects of climate change and variability, which are no longer predictable [28-30]. On the other hand, the construction of weirs for different reasons along the river continuum has altered the natural flow patterns, thus interfered with the downstream sediment matrix, physico-chemical water quality parameters and nutrient loads [12, 13, 26, 9]. In addition, constructed dams can act as pollution sinks whereby, they can hold sediments, and organic particulate matter rich in nutrients especially during their early stages of construction [31, 32]. Nutrient adsorption to inorganic particles and denitrification in a river longitudinally up to the estuary may vary depending on its morphology. Therefore, river impoundment and other anthropogenic effects may have serious impacts on downstream river flows and finally the adjacent estuaries thus affecting the water quality, and this may worsen due to erratic climatic variability that is being experienced of late as a result of global warming [33].

Flowing in a mixed complex terrain characterized by numerous anthropogenic activities, the rivers carry different forms/levels of pollution into smaller respective distinct estuaries which when put together make up the larger south coast estuary of Kenya in the Western Indian Ocean (WIO) region. Like any other coastal regions of the world, the south coast of Kenya is dominated by urbanization developments owing to the conducive climate for human settlements [21,34]. High population is being experienced day in day out and this is cause of concern owing to huge waste generated amidst poor urban planning that is resulting into unsustainable way of handling waste. Poor waste disposal remains an eye sore especially in third world countries [35, 36].

In addition, domestic and industrial effluents accompany ill-equipped waste disposal strategies in emitting unwarranted contaminants [4,37]. The landfills often operated within these catchments (the south coast of Kenya) lack basic leachate collection and treatment facilities. According to [38] landfills operated minus the appropriate treatment mechanisms result into environmental degradation and the magnitude of pollution is proportionate to the leachate's properties. Therefore, the rapid urbanization witnessed in the south coast catchments of Kenya is likely to have serious implications on the quality of rivers and adjacent estuaries with possible physico-chemical and biological water quality consequences [39]. Generally, the wastewater being generated from the leachate fills and general surface run-off from urban developments in the area may result into nutrient loadings in the receiving rivers. Surface run-off from urban leachate fills have got possible likelihood of causing eutrophication in the receiving estuaries [40]. It has been reported that domestic and industrial effluents coupled with soil erosion increase nutrient levels in aquatic ecosystems [3, 13, 41, 42] Therefore, the estuarine ecosystems along the south coast of Kenya, which are dotted with enormous levels of soil erosion fueled by loosely packed soils within their catchment areas are likely to suffer from nutrient enrichment and eventual eutrophication.

It is against the above backdrop that there is an urgent need to assess and monitor changes in environmental variables/factors in relation to anthropogenic impacts to rivers and estuaries along the south coast of Kenya in the WIO region to inform its management for sustainable utilization of its resources. Despite the fact that a number of studies have been concentrated in the north coast of Kenya [21, 23, 43], no comprehensive studies have been undertaken along the south coast rivers and estuaries of Kenya in the region to document the sources of pollution and their impacts. Physico-chemical water quality attributes measured monthly based on numerous sampling sites throughout the larger south coast estuary of Kenya in the WIO region, were used in this study to investigate river-estuarine water quality on a spatial scale. Therefore, the aims of this study were to (i) determine the selected physico-chemical water quality attributes in estuarine systems along the south coast of Kenya in the WIO region, (ii) identify the mechanisms driving the spatial variations in physico-chemical water quality parameters in estuaries along the south coast of Kenya in the WIO region, and (iii) evaluate the effects of anthropogenic activities on downstream river-estuarine water quality along the south coast of Kenya in the WIO region. We hypothesized that the anthropogenic activities did not have a negative impact on downstream rive-estuarine water quality along the south coast of Kenya in the WIO region.

2. MATERIAL AND METHODS

2.1 Study Area

The Kenya coast measures about 600 km2, bordering Somalia to the north at Kiunga (1°41'S) and Tanzania to the south in a town called Vanga (4°40'S). The region has a tropical climate whose weather patterns is influenced by the western Indian Ocean Monsoon winds [34]. There are two tropical monsoon seasons, the Southeast monsoon (SEM) prevailing from April to September, which is cooler compared to the Northeast monsoon (NEM) that is characterized by dry weather and sets from October to March [34]. The wet seasons are experienced between April and October, but long rains usually begin towards the end of March with the peak occurring in April or May in case of delays and then start declining through August and September when the dry period beckons. Short rains are then witnessed between October and November [44]. However, of late this is no longer the trend as rain of unpredictable heights can be experienced at any time of the year. Many studies have been concentrated in the north coast unlike the south coast hence the current study was undertaken in the southern region of the Kenyan coast (Figure 1). This region receives the highest mean annual rainfall of slightly above 1,016 mm. It experiences temperature range of between 20 °C and 35 °C. This study was carried out in 12 sampling stations spread out among four sub-estuaries with each delineated with specific sampling sites depending on distinct ecological characteristics: Mapu (reference), Mwena (3 stations), Mkurumudzi (2), Ramisi (3), and Umba (3) estuarine ecosystems in the south coast of Kenya, the WIO region (Figure 1).

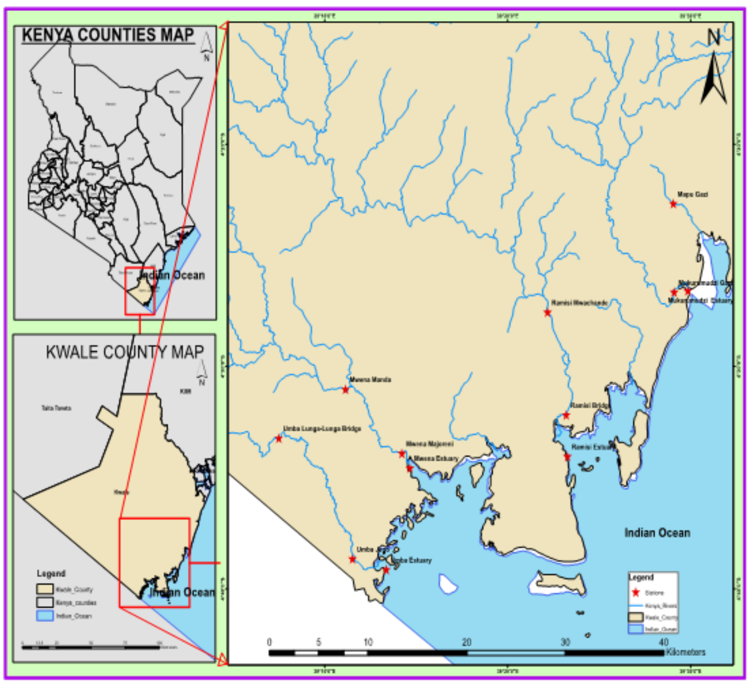

Fig. 1. Map of the study area

Generally, the area is characterized by one of the largest mangrove habitats (the Vanga-Funzi system covering 6,980 ha). Some of the common mangrove species found in this area include *Rhizophora mucronata* and *Avicenia marina*, plus other 7 more species, which supports a disarray of biodiversity. Other critical habitats include sea-grass meadows and coral reefs. These systems form an important ecological and socio-economic zone for the coastal people [45]. These systems' integrity definitely determines the productivity of the inshore waters and those of the continental shelf areas. According to the 2019 Census, Kwale County in which the study area is situated has a total population of 866,820 people with annual growth pegged at 3.1 % (Kenya National Bureau of Statistics [46]. Much of this population (17 %) is concentrated along the coastal parts bordering the Indian Ocean hence impacting the coastal ecosystems and marine habitats via different human induced activities to support their livelihoods. Further, it is projected that this population may increase to

969,442 (i.e. 10.6 %) by the year 2027, meaning much more degradation of both riverine and estuarine systems if sustainable management plans are not put into place.

The Mkurumudzi River basin, covers an area of 230 km^2 and is located 50 km south of Mombasa city, Kenya. The river traverses about 40 km right from Shimba Hills National Reserve down to Gazi Bay in the Indian Ocean where it supports a vast forest of mangroves in the estuary. It is an important river in the region that support a number of commercial activities such as mining by the Base Titanium Limited Company and irrigation of sugar cane farms mainly run by Kwale International Sugar Company (KISCOL). It also provides water for domestic use, watering of livestock apart from irrigating small-scale farms in the area. Of significance also is that it regulates the micro-climate of this semi-arid region. The basin is characterized by a sub-humid climate, and experiences short rains of 800 mm between the months of October and December and long rains between March and May of about 1300 mm.

The river experiences a mean evaporation of 2,170 mm/year, with an aridity index of 0.55 [47] (Katuya, 2014). It enjoys warm temperatures during the months of November to April with mean temperature of 27.0 ^{o}C, whereas colder months record an average temperature of 25.0 ^{o}C. In the event of low rainfall, the river is recharged by groundwater making it a permanent river. Agriculture is the major economic activity that takes place whereby such crops as sugarcane, maize, beans, cowpeas, millet and sorghum, okra, cassava are grown. Livestock husbandry, commercial mining (Base titanium Ltd., Ukunda, Kenya), commercial farming of sugarcane, commercial mining, tourism activities associated with the sea and the Hills National Reserve, and fishing (in the river and mainly in the Indian Ocean) are other anthropogenic activities of importance. Ramisi River on the other hand, starts from Chenze Ranges with many first order ephemeral streams feeding it and traverses a mixed terrain before it flows to the Indian Ocean at Ramisi estuary. It supports an extensive mangrove ecosystem near Funzi Island. The river’s salinity levels are highly influenced through in-filtration by brackish geothermal originating from Mwananyamala hot springs. Consequently, it is saline, but its levels are not too high to significantly affect its utilization for irrigation of agricultural activities. The river offers a conducive refugia for crocodiles which are distributed in both upstream and downstream parts of the river depending on the period of the year.

The Umba River is yet another riverine system that plays an important role in the south coast estuarine ecosystem of Kenya. It is a transboundary river that flows through Tanzania and Kenya. Its source is in the tectonic type of mountain called Usambara in Mkinga, Tanzania, which stands at an altitude of 2,000 m above sea level. This river discharges its waters to the Indian Ocean on the Kenyan part at a fast-growing town known as Vanga, near the boundary of Kenya and Tanzania. It traverses a vast area of about 200 km long, transporting a rich allochthonous food materials and terrigenous sediments into the estuary. It has an approximated catchment of 8,000 km^2. There is a proposal that is at its advanced stage to have a Transboundary Conservation Area (TBCA) that will stretch from Diani, Kwale County in Kenya (39°00′ E, 4°25′ S) to Tanga in Tanzania (i.e. 39°40′ E, 5°10′ S) to protect its unique biodiversity that is currently threatened by anthropogenic activities. This conservancy shall include a narrow stretch of the coastline in the two countries, covering an estimated area of 2,500 km.^{2}

2.2 Sampling sites selection

The general features of the 12 sampling stations are provided in Table 1. The sampling stations were purposively selected taking into account different hydrological and ecological factors. Anthropogenic activities along the gradient of each river and urbanization, and at the estuaries where they (rivers) discharge their waters into the ocean were also considered.

Accessibility was also another factor that was considered and, therefore, stations at designated bridges were given priority. The latitudes and longitudes of each sampling station was measured using a Geographical Position System (GPS), Gemina (US made). The reference point was at MAPU, a small stream on the northern side of Gazi town that was considered unperturbed, but it could receive sea water during the high tide. Sampling was done for twelve months.

2.3 Physico-chemical measurements

Water sampled and analyzed were done using standard methods described in [48]. Temperature, conductivity, Dissolved oxygen (DO), total dissolved solutes (TDS), pH, salinity were measured in situ at each sampling sites, using a surveyor II model hydrolab. On the other hand, samples for nitrate ($NO3^-$), phosphate, and ammonia were filtered through 0.45 µm membrane filter papers (47 mm) and evaluated by the nutrient auto analyzer (SKALAR SAN plus ANALYZER) based on the approach of [48].

2.4 Data analysis

Data were analyzed with various statistical techniques, such as descriptive statistics, two-way analysis of variance (ANOVA), and Principal Component Analysis (PCA) using the 64-bit R Software version 4.3.0 (R-core team, 2023). The data, consisting of 9 dependent variables collected from 12 sampling stations over 12 months, underwent thorough preprocessing. This involved organizing the data into a structured data frameand testing for assumptions, such as normality and homogeneity of variances, using Levene's and Shapiro-Wilk tests [49 -50]. To obtain descriptive statistics for key variables, R functions `summary () ` and `describe () ` were applied [51]. The ANOVA function `aov() ` was then utilized on the structured data frameto conduct two-way ANOVA, providing insights into the variability within the data [52] (Montgomery, 2017). All the observed differences were considered statistically significant at $p < 0.05$. For dimensionality reduction, Principal Component Analysis (PCA) was employed using the `prcomp()` function [53]. This technique allows for a concise representation of the data's variability through principal components. The results of descriptive statistics, two-way ANOVA, and PCA were presented either in Tables or Figures, and visualized using the ggplot2 package [54], for enhanced clarity and readability of complex data structures.

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3. RESULTS

3.1Spatial variation in water quality attributes

The mean spatial variation in water temperature, pH, ammonia, and dissolved oxygen measured in this study are as shown in Figure 2. Temperature ranged between 27.15±0.21 ^{o}C at the sampling station of Mapu and 32.21±4.55 ^{o}C at ME. There was significant difference observed between the sampling stations (F = 34.985; df = 11; *P* = <2e-16). Tukey's HSD pairwise mean comparisons showed no significant difference (*P*< 0.05) between station ME and MMJ, but they differed significantly with the rest of the stations. The lowest mean DO value of 5.55 ± 0.52 mg/L was recorded at station ME whereas the highest mean value was recorded at MM (7.74 ± 0.45 mg/L) (Table 2). DO concentrations differed significantly among the sampling stations during the study period (F=96.928; df=11; *P* =<2e-16) (Figure 2). There was an interaction between the station and season (F=2.773; df=11; *P*=0.00174). Tukey's HSD pairwise mean comparisons was significantly higher in MM (7.74 ± 0.45 mg/L) and lower in MKE (5.55 ± 0.52 mg/L). There was, however, slight similarity between station MM and UL, whereas MAPU, MKE and MG, were not statistically significantly different (Figure 2). Further, slight mean DO differences were witnessed among stations MMJ, RM and UE; and between ULB, UE and MMJ. In addition, the pH levels were significantly different among all stations (F = 21.275; df = 11; p = <2e-16). However, Tukey's HSD test was significantly higher at station RM (8.2 ± 0.61) and lower at MKE (7.21 ± 0.45) whereas MAPU, MM, UL and ULB did not differ significantly, but highly varied with the rest of the stations, and showed slight differences with RE and UE. Equally, MG and RB did not differ statistically. There were significant differences between stations for conductivity (F=125.929; df =11; *P*=<2e-16), but no significant interaction was observed on the station times season(Figure 2).

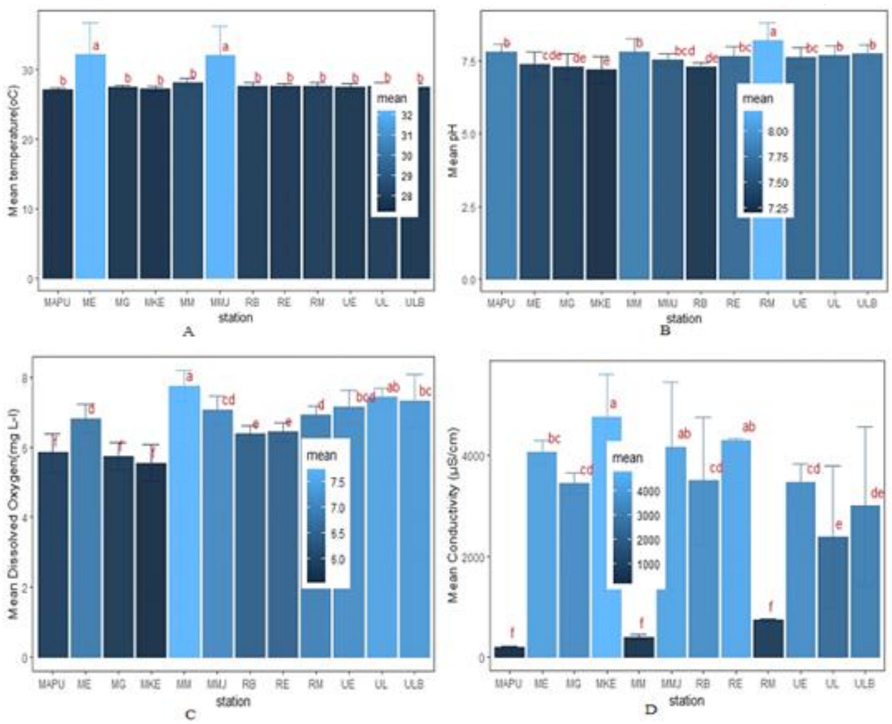

Fig. 2. Mean (±SD) spatial variation in temperature (A), pH (B), DO (C) and conductivity (D) measured in estuarine systems of South Coast of Kenya. The superscript letters alongside the standard deviation error bars represent mean differences among the sampling stations obtained by performing Tukey's HSD pairwise mean comparisons. The legend superimposed in each graph shows the changes in the mean of parameter levels among the sampling stations. MAPU: Mapu; ME: Mwena Estuary; MG: Mkurumudzi Gazi; MKE: Mkurumudzi Estuary; MM: Mwena Manda; MMJ: MwenaMajoreni; RB: Ramisi Bridge; RE: Ramisi Estuary; RM: RamisiMwachande; UE: Umba Estuary; UL: Umba Lenjo; ULB: Umba Lunga-lunga Bridge.

The spatial variation for ammonia, phosphates, nitrates and TDS measured during this study are as indicated in Figure 3. Ammonia level differed significantly between stations during the study period (F=1.315e+06; *P*<0.05). Equally, the interaction between station and season did show a strong significant difference (F = 5.287e+00; df=11; *P*=7.9e-08). *Post hoc* Tukey test did indicate a clear discrimination in terms of ammonia mean differences in all the sampled stations. However, the mean ammonia level was highest in station MG (2.83±0.00

mg/L) and lowest in stations RE and MM with values of 0.06±0.01 mg/L each. Phosphates concentration in all the stations demonstrated significant differences (F=8.348e+05; df=11; *P*=<2e-16) (Figure 3) with *Post hoc* Tukey test displaying a distinct discrimination among the stations where station MG (3.49±0.01 mg/L) recorded the highest mean levels of phosphates and ULB the least (0.06±0.01 mg/L). The interaction between station x season differed significantly (F=5.791e+00; *P*<0.05). Nitrate levels also demonstrated a significant difference between the sampled stations (F=1061.980; df=11; *P*=<2e-16). *Post hoc* Tukey pairwise comparison showed that the mean nitrate levels was highest at station ULB (1.27±0.0 mg/L) and lowest at RM which recorded a value of 0.03±0.01 mg/L.

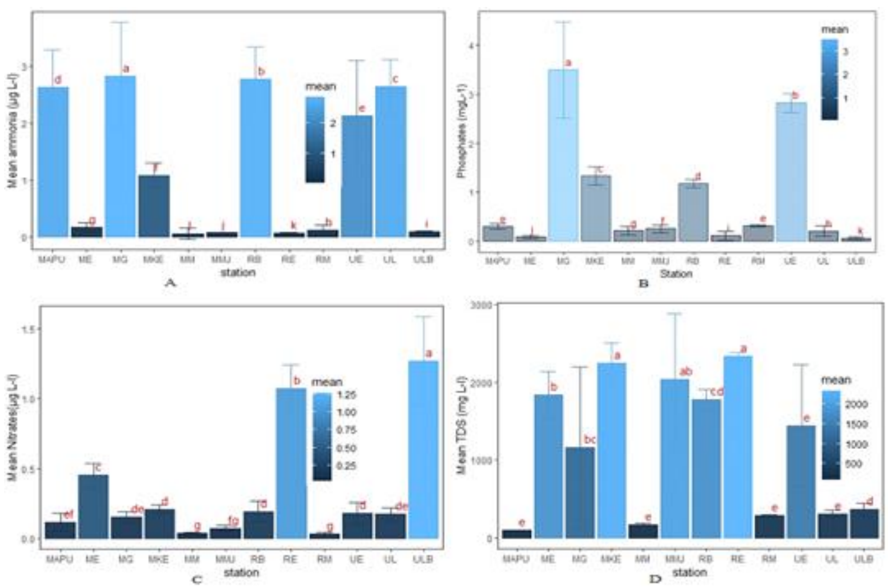

Fig. 3. Mean (±SD) spatial variation of ammonia (A), phosphates (B), nitrates (C) and TDS (D) measured in estuarine systems of South Coast of Kenya. The superscript letters alongside the standard deviation error bars represent mean differences among the sampling stations obtained by performing Tukey's HSD pairwise mean comparisons. The legend superimposed in each graph shows the changes in the mean of parameter levels among the sampling stations. ME: Mwena Estuary; MG: Mkurumudzi Gazi; MKE: Mkurumudzi Estuary; MM: Mwena Manda; MMJ: MwenaMajoreni; RB: Ramisi Bridge; RE: Ramisi Estuary; RM: RamisiMwachande; UE: Umba Estuary; UL: Umba Lejo; ULB: Umba Lunga-lunga Bridge.

There were significant differences observed in salinity between the sampling stations (F=120.060; df=11; *P*=<2e-16) (Figure 4). There was no interaction, however, observed on station times season (*P*=0.745). *Post hoc* Tukey pairwise comparison revealed that the mean salinity level was highest at station ME (5.83±1.19 mg/L) and lowest at MAPU (0.13±0.05 mg/L). Of interest, however, is that the mean salinity concentrations in stations MAPU, MM, RM, UE and UL were not significantly different (Figure 4).

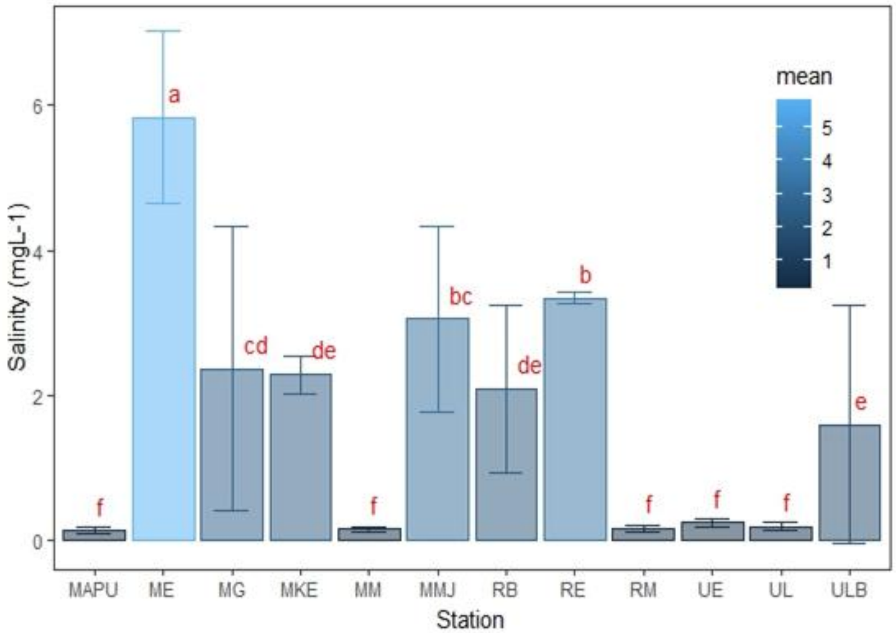

Fig. 4. Mean (±SD) spatial variation of salinity measured in estuarine systems of South Coast of Kenya. The superscript letters alongside the standard deviation error bars represent mean differences among the sampling stations obtained by performing Tukey's HSD pairwise mean comparisons. The legend superimposed in each graph shows the changes in the mean of parameter levels among the sampling stations. ME: Mwena Estuary; MG: Mkurumudzi Gazi; MKE: mkurumudzi Estuary; MM: Mwena Manda; MMJ: MwenaMajoreini; RB: Ramisi Bridge; RE: Ramisi Estuary; RM: RamisiMwachande; UE: Umba Estuary; UL: Umba Lenjo; ULB: Umba Lunga-lunga Bridge.

The results for PCA spatial loadings of physico-chemical water quality variables in south coast of Kenya estuarine systems are as shown in Table 2 below. Loadings are the weighted effects on water quality derived from the original variables. Original data was mapped into five principal components/dimensions. These components were considered to be highly significant because they explained 98% of the data variance. Components 1, 2, 3, 4 and 5 accounted for 34.02%, 24.13 %, 12.99%, 7.41% and 7.16% respectively.

Table 2. loading factor of water quality parameters through sampling stations during the study period between September 2018 and August 2019.

Parameter	Comp.1	Comp.2	Comp.3	Comp.4	Comp.5
Temp. (^{o}C)	0.1253^{d}	0.2910^{c}	0.5434^{a}	0.3929^{b}	0.3124^{c}
DO (mg/L)	-0.3014^{d}	0.3347^{a}	0.2994^{b}	-0.4544^{e}	0.2356^{c}
Cond.	0.4378^{a}	0.0180^{b}	-0.0755^{b}	-0.0333^{b}	-0.0614^{b}
TDS (mg/L)	0.4947^{a}	0.1006^{b}	-0.1087^{c}	0.1744^{b}	-0.1340^{c}

Salinity (ppm)	0.4285[a]	0.2052[b]	0.0002[d]	0.2357[b]	0.0195[c]
pH	-0.3616[d]	0.2315[b]	-0.0402[c]	0.3390[a]	-0.7178[e]
Phosphates (mg/L)	0.0966[a]	-0.5271[c]	0.0759[a]	-0.2045[b]	-0.2337[b]
Nitrates (mg/L)	0.1243[b]	0.3307[a]	-0.6053[d]	-0.3378[c]	0.1438[b]
Ammonia (mg/L)	-0.0874[b]	-0.5463[c]	-0.0966[b]	0.2754[a]	0.3625[a]

Temp = temperature; DO = dissolved oxygen; Cond = conductivity; TDS = total dissolved solids; and pH = potential of hydrogen

In most sampling stations, conductivity showed both negative and positive weak influence on water quality with loadings close to zero indicated on the principal components, except in principal component 1 where a moderately strong factor loading of 0.4378 was observed. Temperature and salinity exhibited very weak loadings to water quality in all the components except in component 3 (0.5434) and 1 (0.4285) respectively where moderate influence in water quality was experienced. On the other hand, pH and nutrients (phosphates, nitrates, and ammonia) exhibited mixed effects with both negative and positive loadings on the principal components.

In components 2, 3, 4 and 5, phosphates and ammonia, nitrates, DO and pH exhibited between moderate and strong effects on water quality. The moderate positive contribution of salinity (0.4285), TDS (0.4947) and conductivity (0.4378) to changes in water quality contributed to the highest variance (component 1), followed by the negative contribution of phosphates (-0.5271) and ammonia (-0.5463) both of component 2, and the negative and positive contributions of nitrates (-0.6053) and temperature (0.5434) respectively in component 3. In general, conductivity and TDS made minimal contributions to changes in water quality (Table 2).The PCA explained 56.1% of the variability in water quality for the first two components (Figure 5). Component one (PCA 1 = 34% of variance) reflected the effect of water quality on different stations separating the most influenced 5 sites from 3, 11, and 12 (Figure 5).

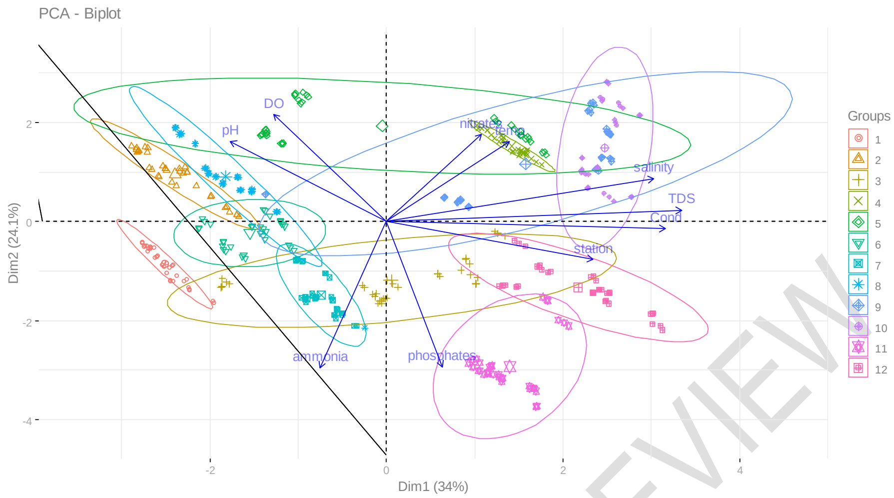

Fig. 5. PCA biplot showing loadings for sampled stations for water quality physico-chemical attributes in the estuarine ecosystems of south coast, Kenya. 1=Mapu; 2=RM: RamisiMwachande; 3= RB: Ramisi Bridge; 4= RE: Ramisi Estuary; 5= ULB: Umba Lunga-lunga Bridge; 6= UL: Umba Lenjo; 7= UE: Umba Estuary; 8= MM: Mwena Manda; 9= MMJ: Mwena Majoreini;10= ME: Mwena Estuary 11= MG: Mkurumudzi Gazi and 12= MKE: mkurumudzi Estuary.

4.0 DISCUSSION

4.1 Water quality parameters in estuarine ecosystems

Water quality monitoring in estuarine environment using physico-chemical parameters is one of the most important tools used by researchers to underpin its function and scrutinize both natural and anthropogenic factors influencing changes over time. Temperature plays a key role in terms of growth maintenance, reproduction and the community structure of resident biota [12, 55,56]. Temperature in a water body also enhances nitrification process and catalyzes ion exchange, sorption and weathering processes [57]. Temperature did not vary so much among all the sampling stations except stations ME and MMJ which registered the highest probably due to low depth hence light attenuation gets into the bottom hence warming up the water. The two stations may have received warm waters from the cooling plants situated just a few meters upstream. Generally, temperature levels were above the room temperature with an average of 28.36 ± 1.79 oC. This could be as a result of climate change where in the recent past warm temperatures are being experienced in most of the tropical coasts. This scenario is exacerbated by unprecedent clearing of native riparian vegetation thus light heating directly on the surface of the water. In addition, anthropogenic activities such as agricultural production could probably increase the rate of soil erosion causing an increase in particulate organic matter and total suspended solids which absorbed more heat thus increasing temperature levels. This study's findings are in contrast with other similar studies that have been reported in the tropical and subtropical estuaries [58]. The significant seasonal variation of temperature in the Kenyan coast estuaries may be due to the fact that surface water temperature in a shallow estuary is controlled by local conditions of the atmospheric temperature.

A small change in pH can trigger a serious effect on both chemical and biological attributes of an aquatic ecosystem and as a result impact on community structure. It is therefore, one of the most key environmental variables that shape the ecology of any given ecosystem. The pH levels in south coast estuarine environment of Kenya varied between 8.2±0.61 and 7.21±0.45 but the mean was about 7.5 which is not badly off in terms of neutrality. This means that many of the sampled stations tended to be alkaline most probably due to underground saltwater intrusion. The High pH values witnessed could imply alkali prevalence that can be explained by the fact that huge human population is concentrated along the coastline hence intensified socio-economic activities affecting the pH of the estuarine systems [42, 59, 60]. High PH values could also be as a result of surface run offs originating from mature landfills. According to [61) old landfills can attain pH levels ranging from 7.5 to 8.6 unlike young ones that have reported values between 5.0 to 6.5.

These results also do imply that the south coast estuarine systems are not acidic because there was no single station where a pH value less than 7 was observed. pH showing a neutral value but can range to a maximum of approximately 9 is conducive enough to support any biological activity but below 4 is an indication of acidity hence toxic to a majority of aquatic flora and fauna [62]. Further, pH levels can change from acidic to alkaline and vice versa depending on coagulation and mixing of colloid particles with water [63]. During the bicarbonate process the pH values can also change especially when photosynthesis occur where CO2 is removed from the system. The incoming rivers that flow a mixture of catchments dilute the seawater thus reducing the salinity levels [64]. The high DO concentrations noted during the elevated levels in temperature could be attributed to oxygenic denitrification by microbes where NO is disproportionated directly into N2 and O2 [65]. The produced O2 could support life in anoxic environments thus giving microbes an added advantage to thrive [66]. Reduced concentrations of DO for the most part of the year corresponds well with the increased levels in temperature whereby there could have been decomposition processes in organic matter thus high consumption of DO. Ammonium concentrations rose considerably during the dry season most probably due to low surface water dilution hence effluents from point and non-point sources enter the river-estuarine systems undiluted.

There are two types of tides in marine ecosystems (i.e. high or low) and they highly influence the level of salinity in estuarine systems. The high levels of salinity that were experienced in some stations (i.e. ME, MKE, MMJ, RB, RE, and ULB) were as a result of high tide bringing in mainly salt water. High salinity levels could also be an indication of the presence of such ions as chloride, fluoride, bromine, and iodine. According to [56] increased levels of salinity show the presence of halide ions. The downstream-upstream decrease in salinity in many of the sampled stations during the present study can be explained by the dilution effect of the respective discharging rivers. The high level of salinity that was recorded in one of the upstream stations of Ramisi (RB) could be as a result of seepage of hot springs from the underground (riverbed). Generally, the decreased downstream-upstream salinity gradient in the South Coast estuary supports large biodiversity as is evidenced by the growth and development of thick mangrove forest with a distinct zonation of different species. Avicennia species for example, is tolerant of high concentrations of salinity hence is found in the downstream front with Rizophoramucrunata growing at the backward. Such an occurrence of mangrove zonation has been reported in Bamosso, the Rio Ntem and the Cameroon estuary [67]. Going by the salinity levels recorded in this study, the Kenyan south coast estuary can be classified as oligohaline.

TDS varied significantly across the sampling stations ($p < 0.05$). High levels of rainfall coupled with surface run-off as a result of intensive anthropogenic activities within the given aquatic ecosystems has a net effect on the level of suspended particle matter. Therefore, the

TDS concentrations recorded in the south coast of Kenya can be attributed to unpredictable weather patterns that are reminiscent in the area. As a result, irregular rainfall has been experienced causing high level soil erosion across the basin that is fueled by such activities as agriculture and infrastructural developments. These findings corroborate well with [68] associated enhanced surface runoff with unprecedented increase in soil erosion to the main cause of TDS. Equally, the TDS concentration levels observed in the south coast estuary of Kenya can also be linked to suspended matter as a result of salt intrusion in the estuary. Such an observation is witnessed increasing downstream to upstream and in most instances is likely to be higher during low tide. TDS intimate with salty water and depending on their rate of settling to the substrate can limit horizontal transport by the action of waves [69].

Nutrients such as nitrates and phosphates vary greatly in coastal estuarine environments depending on anthropogenic activities and this may vary from one point to another. Other factors that impact on them include the dilution effect of the freshwater river discharge, precipitation, tidal changes and the ingestion by both macro and micro plants (autotrophs). Surface runoff changes the chemical composition of rivers and thus the receiving lotic systems because a lot of organic matter rich in nitrates and phosphates that may have gathered on roads and car parks during the dry spell are likely to be swept downstream during spates [70, 71]. Generally, the low levels for nitrates and phosphates that were observed in the present study could be as a result of high rate of absorption by the mangroves that are common and intensively distributed in the south coast estuarine ecosystem of Kenya. Mangroves are regarded as the best plants when it comes to carbon sequestration. Equally, the rich deposits of sediments usually trapped by the mangrove roots make them excellent sinks for nutrients hence low levels could be witnessed on the surface waters. According to [72,73] and [34], sediments in aquatic systems play a key role in the storage of pollutants.

Nonetheless, changes in nutrient concentrationsare shaped by both point and non-point sources of pollution [1, 3, 6-9]. During spates, there is a lot of surface water run-off that carries much of the dissolved nutrients that are linked with sediments and also it is in such a season that leaching do occur from farmlands. Ammonia levels decreased downstream of the respective river (Figure 3) due to probably farming activities, urbanization, and industrialization which over time are again likely to double. It is, however, expected that the highest amount of ammonia ought to be in the upstream downstream of the estuarine system owing to the fact of elevated amount of sediments burying organic matter in form of leaves, defecation andgeneral debris of wood as well as the decaying of dead animals. Another reason for low ammonia levels could be due to conversion of all organic matter into nitrates by bacterial microbes [68-70].

In stations ULB, UL, MMJ and ME, PCA showed that nitrates, salinity, TDS, conductivity and temperature were positively correlated with factor Comp.1, thus describing an organic matter enrichment from the inflow fluvial water discharged by each respective river. DO and pH are negatively correlated with factor Comp.1 hence they describe a dissolved salt gradient. Therefore, two gradients are evident in the South Coast estuarine system of Kenya namely; downstream marine stations characterized by mineralization from the sea, and the organic matter gradient upstream dominated by the fluvial stations. Authoritatively, it can be deduced that that water quality in the South Coast of Kenya estuary is impacted by natural processes and anthropogenic activities.

5. CONCLUSION

Estuarineecosystemsarethemostproductiveaquaticecosystemsintheworldwhichsupportarichbiodiversity. Waterqualityinthesesystemsthenremainscrucialin sustainingresidentbiotainthesesystems. However, they are highly impacted by human drivers for socio-economic gain. Theaimofthisstudy was to investigate river-estuarine water quality on a spatial scale. All the sampled water quality attributes differed significantly among the sampled stations showing clearly that different sites in the South Coast estuary of Kenya were impacted by different anthropogenic activities. The study did also indicate that all the 12 sampling stations were impacted by both point and non-point sources of pollution. The PCA demonstrated that theKenyan South Coast estuary is mainly affected by two gradients: mineralization from the sea that had an impact on the downstream marine stations, and the organic matter gradient at the upstream stations dominated by the fluvial inflows from the respective rivers.Consequently, water quality in the south coast of Kenya estuary is impacted by natural processes and anthropogenic activities. Moreover, the Kenyan south coast estuary can be classified as an oligohaline systems. There is need to protect the shorelines of each respective river draining a complex catchment in order to minimize surface run-off and therefore, there is reason for restoring riparian land by planting trees. Sound agricultural practices in the entire river basins is encouraged in order to reduce downstream water quality impacts. Lastly, we recommend for continued regular water quality assessment and monitoring to acquire sufficient data to be used in coming up with sound policy frameworks towards sustainable management of South Coast estuarine system of Kenya.

ETHICAL APPROVAL (WHEREEVER APPLICABLE)

The authors complied with the provisions of Kenya marine and fisheries research institute (KMFRI) research policy that spells out the code of conduct for researchers.KMFRI is a state corporation establishedin 1979 by the science and technology act, cap 250 of the laws of Kenya. The act was repealed in 2013 by the science, technology and innovation act no. 28, which recognizes KMFRI as a national research institution under section 56, fourth schedule.

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