

Original Research Article
Analyzing Spatial-temporal Variation in Water Quality Parameters in South Coast Estuarine Ecosystem, Kenya

ABSTRACT

Estuarine ecosystems are classified as among the most productive systems on the planet earth supporting an array of biodiversity. However, due to the ever increasing human population, they experience environmental degradation originating from intensive anthropogenic activities hence the need for regular assessment and monitoring to inform its management. The purpose of this study, therefore, was to analyze the spatio-temporal variation in water quality parameters in South Coast estuarine ecosystem, Kenya. Twelve sampling stations were identified based on different hydrological regimes, anthropogenic activities, and accessibility factors. Sampling was done for 12 months taking into account different seasons of the year. Such parameters as temperature, dissolved oxygen, pH, conductivity, salinity and TDS were collected *in situ* using YSI Multiparameter meter (Professional plus) whereas nutrients (nitrates, phosphates and ammonia) were analyzed in the laboratory using established methods. Two-way analysis of variance (ANOVA) was applied to discriminate any significant differences among stations and between seasons, and where there was a difference, Tukey *post hoc* test was applied to show which site differed from each other. Principal Component Analysis (PCA) was performed to correlate the environmental factors with sampling sites, and months. There was significant difference in water quality parameters among the sampling stations ($P = .05$) that was attributed mainly to anthropogenic activities, and both the point and non-point sources of pollution. Conversely, there was no significant difference in most of the water quality attributes in terms of seasons due to unpredictable weather patterns associated with climate change. There is need for long term monitoring strategies in order to generate sufficient data for sound management of South Coast estuary in Kenya. The study further recommends for community sensitization and implementation of relevant policies on the protection and management of riparian land.

Keywords: Estuarine systems; Kenyan coast; environmental factors; anthropogenic activities; water quality

1. INTRODUCTION

Estuaries are highly productive compared to any other aquatic systems owing to the fact that they receive high levels of nutrients from the surface run-offs especially during spates which catalyze primary production. They are rich in biodiversity supporting fish, macroinvertebrates of different functional groups and other animals that seek a number of services and goods from them [1].

Estuaries are highly influenced by tidal actions and land-based anthropogenic activities such as urbanization, industrialization, agriculture, mining, tourism, and water abstraction [2-5]. This is compounded by the ever-increasing human population which is exerting intensive pressures and this situation is not likely to continue for centuries to come [6-8]. Estuaries are susceptible to pollution because they can be easily accessed by the surface run-offs thus receiving all forms of solid waste and effluent wastewater when compared to enclosed aquifers such as ground water [9].

Climate change has widely been documented as one of the drivers of water quality deterioration [10]. Increased temperatures, unpredicted precipitation and unprecedented permafrost thaw have been reported to be closely associated with general global warming ([10, 11]. Further, global warming has led to more freshwater discharge into estuarine systems coupled with terrestrial substances that is embroiled with marked soil erosion from the entire catchment [12-15]. Consequently, high water turbidity in coastal rivers and estuarine systems as well as increased primary productivity due to enhanced nutrient levels have been reported hence influencing the structural communities of aquatic biota [16]. Studies analyzed for Solid Particulate Matter (SPM) concentration in Canadian estuaries for a period of ten years displayed a mixed pattern [13]. Whereas [13] recorded a clear trend with a significant monthly increase in SPM at the river mouth to the estuary for a period of 10 years, [17] reported just one statistically negative significant SPM levels over a period of 17 years. Such kind of findings calls for a well-coordinated monitoring and sampling protocols.

Environmental water quality attributes such as temperature, conductivity, pH, DO, and nutrients are greatly impacted by rivers traversing urban landscapes which in the long run affect estuarine ecosystems that are at the receiving end [18, 19]. Wastewater originating from the urban storms carry with it dissolved particles that result into nutrient loads in adjacent rivers then to estuaries causing eutrophication [20, 21]. According to [22, 23] urban storm water charged with elevated levels of soil erosion and modern agriculture in the urban set-ups of coastal towns contribute to increased nutrient concentrations in the adjacent estuaries. In the same breadth, urban land use patterns including commercial, road networks and parking lots have been singled out as the main contributors to nutrient enrichments in urban rivers as well as estuarine systems [23]. All the above occurrences are highly influenced by both the point and non-point sources of pollution [24].

In addition, changes in water quality attributes may occur as a result of biogeochemical processes in discharging rivers into estuaries or may stem from within the estuarine ecosystems and its hydrological cycles. This may further be shaped by instant changes according to flow rate regimes, hydrological matrices and increased associated indirect factors in the basin [25, 26]. In order to underscore the real status of water quality in estuarine systems, therefore, it is imperative to measure such parameters in the respective rivers just before they discharge their waters into these systems.

The South Coast of Kenya estuary is one of the most critical habitats that is home to a number of fish species that support both artisanal and commercial fisheries which is the main economic activity of the communities living around there. This estuarine ecosystem is highly impacted by the human induced activities both intrinsically and extrinsically as a result of the ever-ballooning human population [12]. Extrinsic factors extend outward where it encompasses the entire landscape or basin from where different rivers and any form of surface run-off drain their waters during spates. There are five rivers that drain the larger South Coast basin and they include: Mkurumudzi, Ramisi, Umba, Mwena and Mapu. Despite intensified anthropogenic activities in the entire South Coast estuarine catchment, there exists data paucity in terms of environmental water quality of the estuarine ecosystem. There is need, therefore, to undertake studies on water quality in order to understand the environmental state and/or health of this system, its functional structure, and lay a basis for future monitoring protocols. This study will also act as baseline research

towards the formulation of sound strategies and policies in the control and management of pollution. The aim of this study, therefore, was to analyze the spatio-temporal variation in water quality parameters in South Coast estuarine ecosystem, Kenya to inform its management.

2. MATERIAL AND METHODS

2.1 Study Area

The Kenyan coast measures 600 km², extending from the northern side bordering Somalia at Kiunga (1°41'S) to the southern part bordering Tanzania near Vanga (4°40'S). The area has two seasons: the Southeast monsoon (SEM) that occurs between April and September, which is cooler, and the Northeast monsoon (NEM) which is dry weather, occurring between October and March [27, 28]. The two distinct seasons may not necessarily be applicable of late owing to the fact that long rains have been witnessed to start as early as March with a climax experienced in April and May before a tremendous decline beckons in as from August to September [12]. Short rains are encountered during the months of October and November [28]. This also is not predictable as weather patterns keep on shifting probably due to the effects of climate change [12].

Owing to the vast area of the Kenyan coast, this study was undertaken in the southern region (Figure 1). The area receives an annual rainfall of approximately 1,016 mm and a temperature range of 20 °C - 35 °C. It is characterized by a thick mangrove forest called the Vanga-Funzi system covering about 6,980 ha. The area is also rich in sea-grass beds and coral reefs.

The South Coast estuarine ecosystem is mainly found in Kwale County which has a human population of 866,820 people [29]. About ¼ of this population resides in the coast. This population is likely to grow by 10.6 % by the year 2027 hence high likelihood of intensified anthropogenic activities in the area [12]. Twelve (12) sampling stations were ear-marked for sampling along the five sub-estuaries as shaped by the 5 rivers discharging into the Indian Ocean namely: Mkurumudzi, Ramisi, Uмба, Mwena and Mapu (Figure 1).

The Mkurumudzi river basin covers an area of 230 km². The river's source is Shimba Hills National Reserve and it discharges at Gazi Bay, Indian Ocean, after traversing a distance of 40 km. The Base Titanium Limited Company and Kwale International Sugar Company (KISCOL) are the two major firms situated within its basin which extracts its water to run mining and irrigation activities respectively. The riparian communities also use its waters for home consumption and agricultural application [12].

The Ramisi sub-estuary is formed by the Ramisi river which flows down from the Chenze Ranges and is replenished by smaller tributaries. It supports an extensive mangrove ecosystem near Funzi Island. Underground infiltration of saline water takes place via geothermal from Mwananyamala hot springs. However, the salinity levels are not significant hence cannot affect the production of crops. The river is infested by crocodiles.

River Uмба flows from Usambara in Mkinga, Tanzania at an altitude of 2,000 m above sea level and discharge in the Indian Ocean near a small town of Vanga in Kenya. It flows down the slopes in a total distance of 200 km long carrying along tonnes of sediments into the estuary. It has a larger basin of about 8,000 km² covering both countries¹. A conservation area has been proposed to protect the Uмба transboundary ecosystem and will stretch from Diani, Kwale County in Kenya at an altitude of 39°00' E, 4°25' S to Tanga in Tanzania at an altitude of 39°40' E, 5°10' S [12]. Currently, the area is threatened by intense anthropogenic activities.

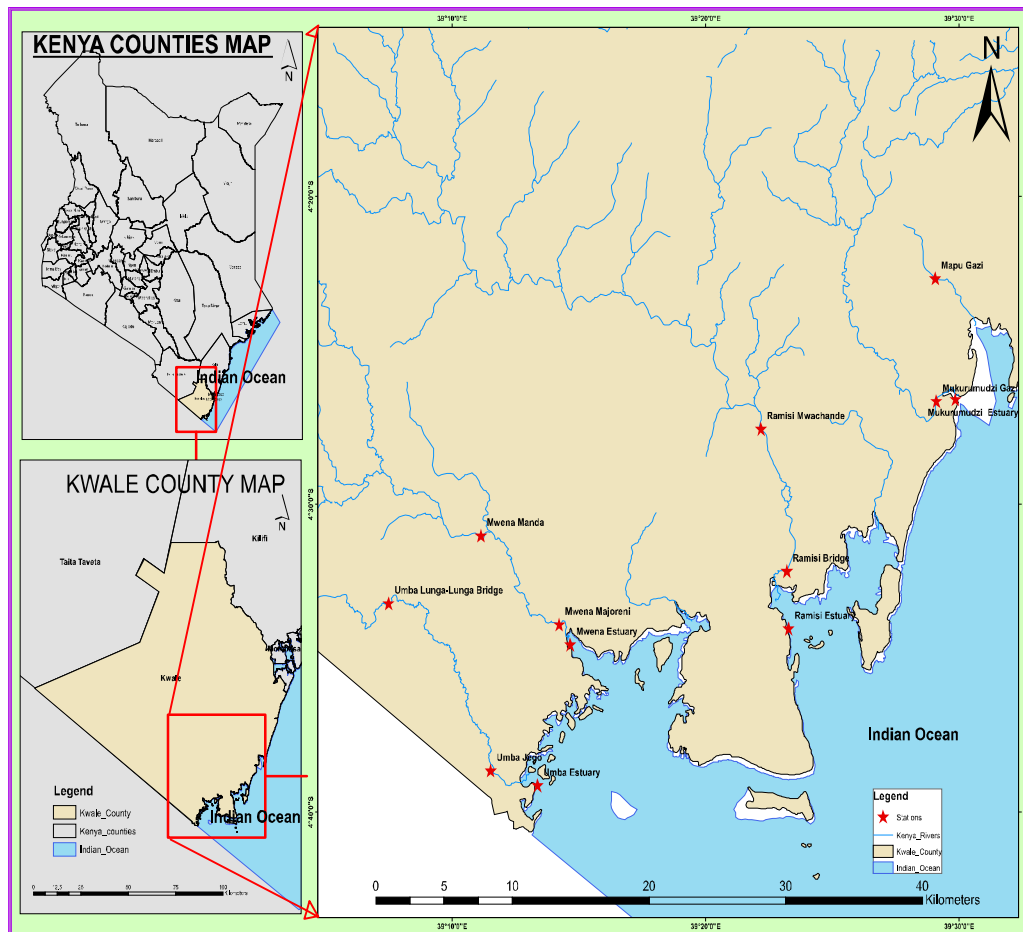


Figure 1. Map of the study area [12]

Mapu river which acted as the reference point is a small stream on the northern side of Gazi town that was considered unperturbed but it could receive sea water during the high tide.

2.2 Sampling sites selection

This study was carried out in 12 sampling stations spread out among four sub-estuaries each delineated with specific sampling sites depending on distinct ecological characteristics: Mwenja (3 stations), Mkuurumudzi (2), Ramisi (3), and Umba (3), with Mapu acting as a reference point. All the afore-mentioned sub-estuaries form the larger south coast estuarine ecosystem, Kenya, in the WIO region (Figure 1).

The sampling stations were selected based on hydrological and ecological factors. Anthropogenic activities along each river continuum were given priority owing to their effects on water quality and quantity. Accessibility was yet another factor that was considered. The latitudes and longitudes of each sampling station was measured using a Geographical Position System (GPS), Gemina (US made). Sampling was done for twelve months.

2.3 Physico-chemical measurements

Water sampled and analyzed were done using standard methods described in [30]. 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 nutrients (i.e. nitrate (NO_3^-), 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 [31].

2.4 Statistical analysis of water quality parameters

Data were presented as means (\pm SD) after testing for normality and homogeneity of variances, using Levene's and Shapiro-Wilk tests [32, 33] (Royston, 1982; Levene, 1960). Two-way analysis of variance (ANOVA) was used to test for significant differences between sampling stations and seasons. Tukey *Post hoc* Multiple Comparison test was applied to determine which sites and/or seasons differed significantly from each other. Principal Component Analysis (PCA) was done to denote the association between the water quality parameters and sampling sites; and seasons vis a vis stations. All the analysis was done using the 64-bit R Software version 4.3.0 (R-core team, 2023). All the observed differences were considered statistically significant at $p < 0.05$.

3. RESULTS

3.1 Spatial variation in physico-chemical water quality attributes

The spatial variation in physico-chemical water quality attributes is as shown in Table 1. All the measured parameters differed significantly between stations with a few showing similarities. However, temperature didn't indicate a remarkable difference in a majority of the stations with stations ME and MMJ displaying a significant difference ($P = .05$). The highest temperature level of $32.2 \pm 4.55^\circ\text{C}$ was recorded at station ME while the lowest level was registered at MAPU ($27.2 \pm 0.213^\circ\text{C}$). DO differed significantly among all the stations except stations MAPU, MKE and MG; with the highest mean concentration (7.44 ± 0.24 mg/L) being observed at station UL while MKE recorded the lowest (5.55 ± 0.52 mg/L). Similarly, the pH levels were significantly different among stations with two of the stations (MAPU and MM) showing no statistical differences.

Nutrients (ammonia, nitrates and phosphates) were statistically different across the sampling stations ($P = .05$) with the exception of the nitrates and phosphate levels which did not differ statistically in some stations. Stations RB and UE; UL and MG showed no significant differences in terms of nutrient levels. Similarly, stations MAPU and RM were statistically similar for phosphate concentrations. The highest salinity level on the other hand was registered at station ME (5.83 ± 1.19 mg/L) which differed significantly with the rest of the sampling stations. Stations MM, UE and MAPU, however, were statistically similar.

There existed significant differences in conductivity and TDS between the sampled stations ($P = .05$) (Table 1). As TDS concentration increased in each station, so does conductivity. The highest conductivity level was recorded at station MKE ($4771.63 \pm 839.28 \mu\text{Scm}^{-1}$) whereas MAPU had the least ($199.70 \pm 4.38 \mu\text{Scm}^{-1}$). Similarly, stations MKE and MAPU witnessed the highest and lowest TDS levels of 2249.31 ± 250.79 mg/L and 94.81 ± 4.11 mg/L respectively.

Table 1. Two-way Tukey *Post hoc* test for spatial variation in the physico-chemical water quality parameters, measured in South Coast estuary, Kenya. Superscript letters (a-k) denote significant differences ($p < 0.05$) down each column.

Station	Nitrates ($\mu\text{g/L}$)	Ammonia ($\mu\text{g/L}$)	Phosphates ($\mu\text{g/L}$)	Salinity (mg/L)	DO (mg/L)	Temp ($^{\circ}\text{C}$)	pH	Cond. (μScm^{-1})	TDS (mg/L)
ME	0.45±0.09 ^c	0.17±0.07 ^g	0.09±0.03 ^j	5.83±1.19 ^a	6.82±0.41 ^d	32.2±4.55 ^a	7.38±0.36 ^{cde}	4072.6±234.6 ^{bc}	1834.49±307.29 ^b
MMJ	0.07±0.02 ^{fg}	0.07±0.01 ^j	0.26±0.08 ^f	3.06±1.28 ^{bc}	7.06±0.40 ^{cd}	32.1±4.17 ^a	7.54±0.43 ^{bcd}	4167.34±1303.58 ^{ab}	2040.91±837.54 ^{ab}
MM	0.04±0.01 ^g	0.06±0.10 ^l	0.22±0.09 ^g	0.15±0.04 ^f	7.74±0.45 ^a	28.2±0.55 ^b	7.81±0.45 ^b	3498.09±1273.54 ^{cd}	172.66±18.13 ^e
RB	0.19±0.07 ^d	2.77±0.57 ^b	1.18±0.09 ^d	2.09±1.15 ^{de}	6.39±0.23 ^e	27.7±0.41 ^b	7.28±0.17 ^{de}		1442.85±784.92 ^{cd}
UL	0.17±0.05 ^{de}	2.64±0.48 ^c	0.21±0.11 ^h	0.19±0.05 ^f	7.44±0.24 ^{ab}	27.7±0.45 ^b	7.7±0.34 ^b	2374.53±1413.41 ^e	308.79±45.48 ^e
RM	0.03±0.01 ^g	0.12±0.08 ^h	0.31±0.09 ^e	0.17±0.06 ^f	6.93±0.26 ^d	27.7±0.48 ^b	8.2±0.61 ^a	726.80±26.24 ^f	283.60±15.12 ^e
RE	1.07±0.17 ^b	0.06±0.02 ^k	0.11±0.03 ⁱ	3.34±0.08 ^b	6.45±0.25 ^e	27.6±0.38 ^b	7.66±0.34 ^{bc}	4302.38±38.39 ^{ab}	2336.88±50.11 ^a
UE	0.18±0.08 ^d	2.13±0.98 ^e	2.82±0.20 ^b	0.24±0.06 ^f	7.14±0.50 ^{bcd}	27.5±0.568 ^b	7.62±0.22 ^{bc}	3472.31±358.49 ^{cd}	365.37±78.78 ^e
MG	0.15±0.04 ^{de}	2.83±0.94 ^a	3.49±0.97 ^a	2.37±1.97 ^{cd}	5.75±0.40 ^f	27.5±0.334 ^b	7.3±0.44 ^{de}	3450.0±219.14 ^{cd}	1774.84±136.55 ^{bc}
ULB	1.27±0.32 ^a	0.09±0.02 ^j	0.06±0.03 ^k	1.60±1.65 ^e	7.31±0.76 ^{bc}	27.5±0.49 ^b	7.74±0.30 ^b	2994.2±1581.99 ^{de}	1162±1035.85 ^d
MKE	0.21±0.03 ^d	1.08±0.22 ^f	1.33±0.19 ^c	2.29±0.26 ^{de}	5.55±0.52 ^f	27.3±0.37 ^b	7.21±0.45 ^e	4771.63±839.28 ^a	2249.31±250.79 ^a
MAPU	0.12±0.06 ^{ef}	2.63±0.65 ^d	0.31±0.06 ^e	0.13±0.05 ^f	5.84±0.56 ^f	27.2±0.213 ^b	7.81±0.26 ^b	199.70±4.38 ^f	94.81±4.11 ^e

ME: Mwena Estuary; MG: MkurumudziGazi; MKE: Mkurumudzi Estuary; MM: Mwena Manda; MMJ: MwenaMajoreni; RB: Ramisi Bridge; RE: Ramisi Estuary; RM: RamisiMwachande; UE: Uмба Estuary; UL: UмбаLenjo; ULB: UмбаLunga-lunga Bridge.

The PCA results on spatial variation in physico-chemical water quality variables are illustrated in Figure 2. Components 1 and 2 were responsible for 58.15% with 1 accounting for 34.02% and 2, 24.13% respectively. Generally, the data was grouped into five components which accounted for 98% variance hence very significant. Conductivity under component 1 showed a strong positive (0.4378) effect on water quality. However, the rest of the stations did not influence water quality significantly. Similarly, moderate effects in water quality were experienced for such parameters as temperature and salinity in components 3 (0.5434) and 1 (0.4285) respectively. The pH and nutrients had both negative and positive loadings on the main components. Salinity (0.4285), TDS (0.4947) and conductivity (0.4378) registered the highest variance under component 1.

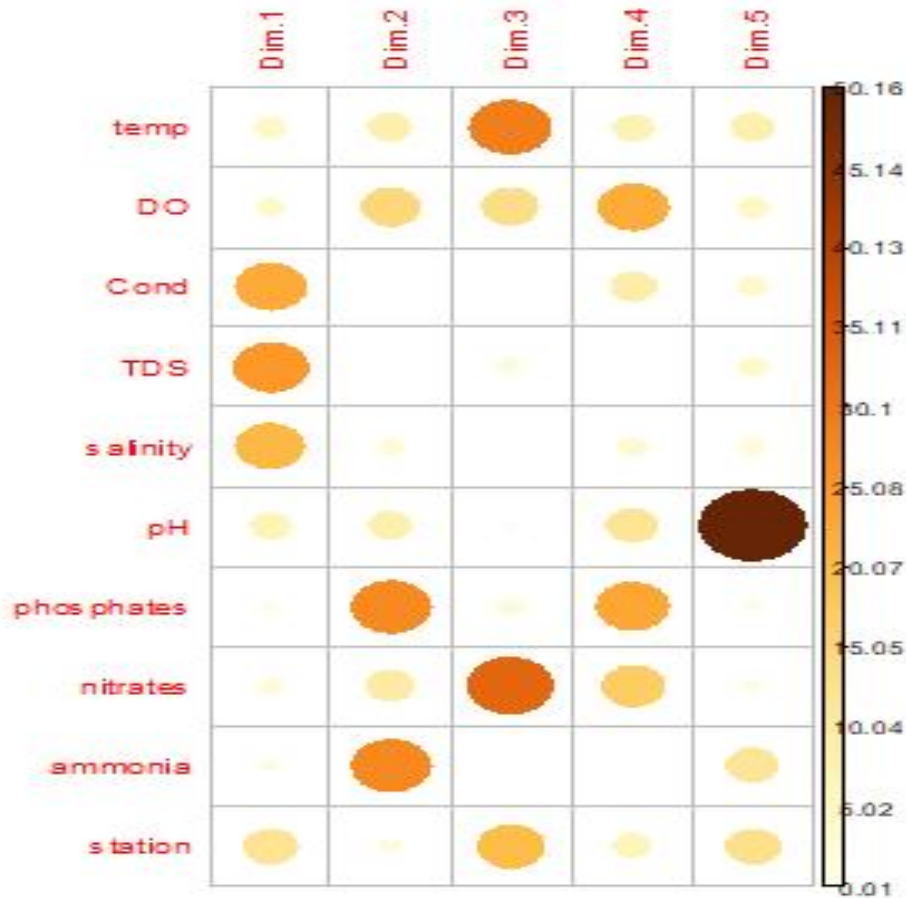


Figure 2. Weighted effects on water quality derived from the original variables. DO = dissolved oxygen; temp = temperature; Cond = conductivity; TDS = total dissolved solids; Dim.1-5 = dimensions 1-5.

3.2 Seasonal variations in physico-chemical water quality attributes

Among the sampling months or seasons, only ammonia exhibited significant differences ($F=6.532e+0.00$; $df=1$; $P=0.011$) (Figure 3). There were significant interactions between sampling stations x seasons in nitrates ($F=3.353$; $P=0.00019$), ammonia ($F=5.287e+00$; $P=7.9e-08$), phosphates ($F=5.791e+00$; $P=9.94e-09$), pH ($F=4.125$; $P=8.91e-06$) and DO ($F=2.773$; $P=0.00174$). The months of January and February recorded the lowest levels (1.22 $\mu\text{g/L}$) of ammonia before increasing steadily to 1.23 $\mu\text{g/L}$ for the month of March, which was

the highest level to be witnessed. This trend was kept constant up to the month of August when it declined steadily to 1.22 m μ /l during the month of September and the same level was maintained through December (Figure 3). The rest of the parameters did not differ significantly among the sampling seasons ($P = .05$).

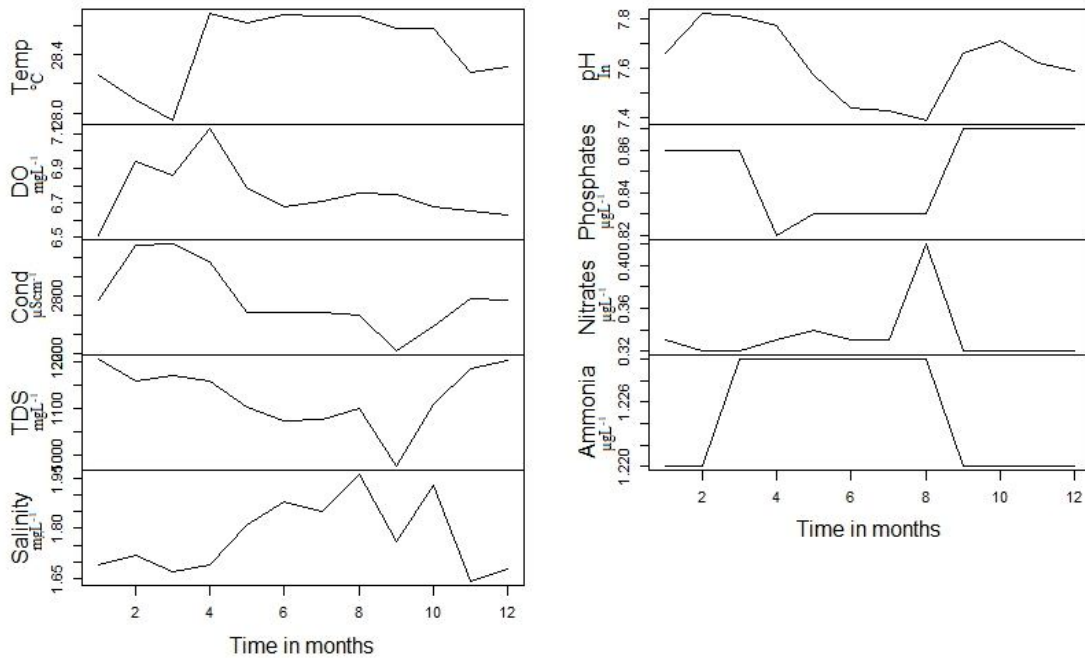


Figure 3. Temporal variation of physico-chemical water quality attributes measured during the study period in estuarine ecosystems of the South Coast of Kenya, in the WIO region. TDS = total dissolved solids; Cond = Conductivity; DO = Dissolved oxygen; Temp = temperature.

The PCA results (Figure 4) showed that the first PCA component (PCA1) and the second (PCA2) accounted for meaningful amounts of the total variance (54.2%). PCA1 explained 30.8% of the total variance and was positively correlated with conductivity, TDS, and salinity and negatively correlated with pH and DO. PCA2 explained 23.4% of the total variance and was positively correlated with ammonia and the phosphates, and negatively correlated with nitrates and temperature.

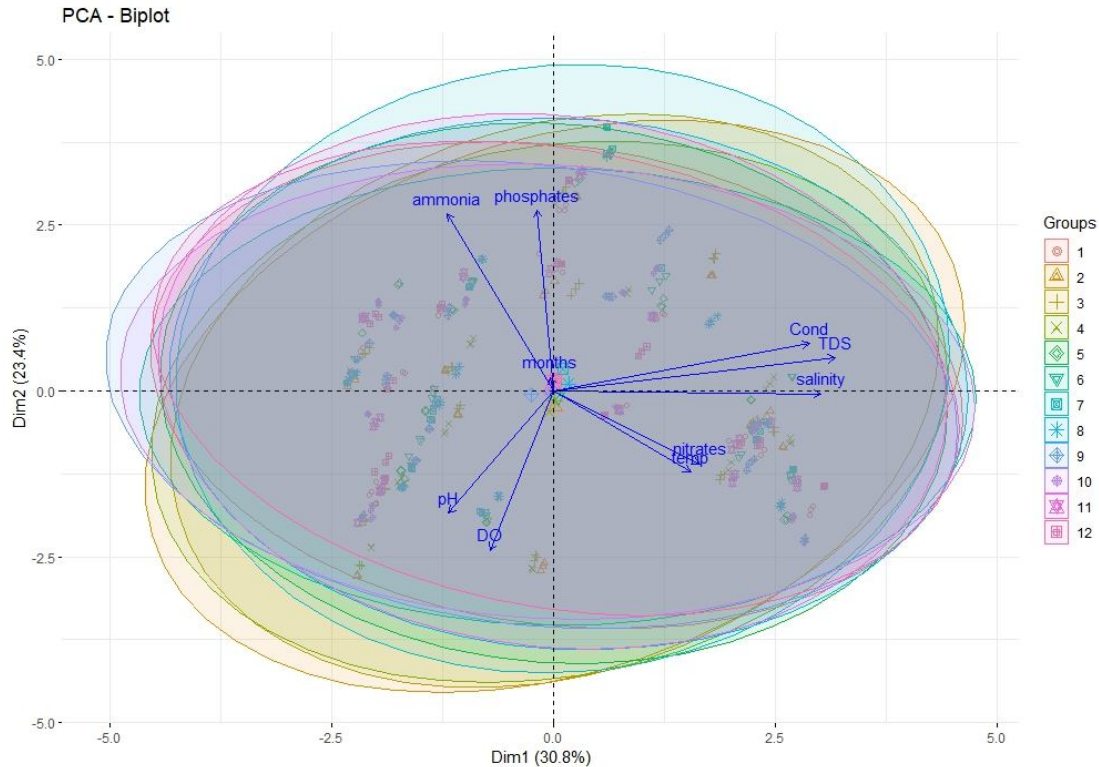


Figure 4. The principal component analysis (PCA) shows the association between the physico-chemical water quality parameters (ammonia, phosphates, conductivity, TDS, salinity, nitrates, temperature, DO and pH) and the sampling months that were measured in surface water in estuarine ecosystems of South Coast, Kenya. Numbers 1-12 represents the months of the year (January – December); sampled months are denoted by color and a symbol.

4. DISCUSSION

High levels in temperature, conductivity and TDS witnessed in all the sampled stations can be attributed to a number of anthropogenic activities. Due to increased human population, a lot of pressure is exerted on land for food production. This results into forest/vegetation clearing, thus soil erosion takes place especially during the rainy season which end up into the aquatic systems. This occurrence enriches the water systems with the all manners of debris and organic matter. Due to increased organic matter in the water column, heat is readily attracted hence an enhanced rise in temperature. Low depth levels especially during the low tide can highly impact on increased temperatures because heat irradiance can heat the entire column [12]. The lack of clear differences in terms of seasons on temperature, conductivity and TDS can be attributed to the effects of climate change whereby unpredictable weather patterns have been observed in the recent past where the usually known rainy seasons are no longer definite [12, 34]. As much as high temperatures are regarded to be detrimental to aquatic system processes, sometimes they play a significant role in aiding certain processes such as bacterial nitrification [35].

Conductivity can further be influenced by suspended particulate matter, ionization capacity and temperature fluctuations [12, 34, 36-37]. In addition, high level conductivity is indicative of inorganic contaminant loads [38-39]. According to [40-41] increased conductivity

concentrations means that the level of nutrients especially the nitrates as a result of man-induced activities such as urban surface runoffs and wastewater is evident [42].

Elevated organic matter results into increased temperature levels, which further has a cascading effect of reduced dissolved oxygen concentrations. This is because much of the DO is consumed during decomposition processes. The different levels of DO observed across the stations may be attributed to different sources of pollution as a result of different human activities [43]. Generally, the DO levels recorded during this study was above 5 mg/L, which is sufficient enough to support aquatic life [12, 34, 44].

A small change in the water pH has a remarkable impact on the aquatic community structure [22, 45-46]. Heaping of urban garbage in form of landfills increases the pH levels more so during the rainy season [47] and this makes aquatic systems to be alkaline. pH levels of about 7 is regarded to be neutral hence favourable for most of the aquatic life, and from this study, the spatio-temporal variation did exceed the normal neutral value, an indication of good water quality [48].

High concentration of nutrients in any given aquatic ecosystem enhances eutrophication whereby huge amount of DO is consumed during the dying off of the biota [43]. Moreover, increased nutrient levels result into the total disappearance of certain communities of organisms such as the diatoms while favouring the proliferation of cyanobacteria as it has happened in Lake Victoria [49]. The differences in nutrient levels both spatially and temporally was due to different sources of pollution and seasons respectively.

From the CPA biplots, the close association of some of the environmental parameters was a clear pointer to similar sources of pollution. However, the varying degree of high to moderate loadings of either positive or negative could be attributed to different sources of anthropogenically influenced enrichment and differences in seasons, which influenced the level of loadings in some materials into the system thus affecting water quality parameters differently [50-51].

4. CONCLUSION

Water quality assessment and monitoring is key in determining the state of environment of the aquatic ecosystems for informed management. The use of physico-chemical attributes offers an added advantage for it provides a snapshot of state of a given water body for further action. This study aimed at analyzing the spatio-temporal variation in water quality parameters in South Coast estuarine ecosystem of Kenya to inform its management. This study's findings showed that water quality parameters differed significantly across the sampled stations mainly due to different anthropogenic activities originating from both point and non-point sources of pollution. On the other hand, there was no remarkable statistical differences in temporal variations of the measured water quality attributes. This occurrence was attributed to unclear weather patterns observed throughout the year due to the effects of climate change. In order to provide a clear picture on the state of the environment in the South Coast estuarine ecosystem of Kenya, there is need for long term monitoring strategies. However, there is urgent need to manage point and non-point sources of pollution. The study further recommends for community sensitization and implementation of relevant policies on the protection and management of riparian land.

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