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

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Authors' contributions

This work was carried out in collaboration among all authors. Author KN designed the study, collected data, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors JO and FM managed the analyses of the study. Authors ZG, AG and JN managed the literature searches. All authors read and approved the final manuscript.

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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,

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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 at 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. MATERIALS AND METHODS

2.1 Study Area

The Kenyan coast measures 600 km^2, 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 earlier 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 (Fig. 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, Umba, Mwena and Mapu (Fig. 1).

The Mkurumudzi river basin covers an area of 230 km^2. 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

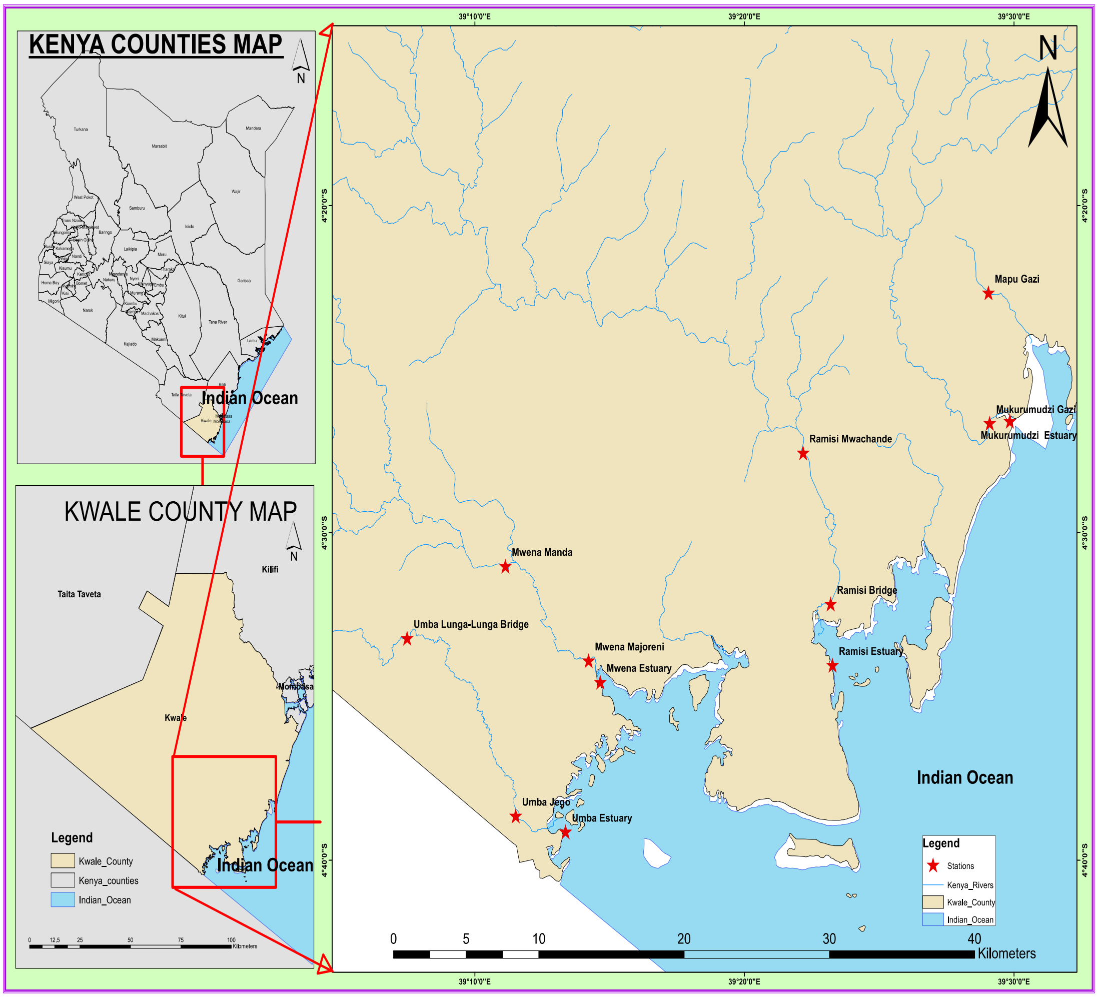

Fig. 1. Map of the study area [12]

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 Umba 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 km^2 covering both countries1. A conservation area has been proposed to protect the Umba 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.

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: Mwena (3 stations), Mkurumudzi (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 (Fig. 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 ($NO3^-$), 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 [31].

2.4 Statistical Analysis of Water Quality Parameters

Data were presented as means (± 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 ± 4.55 °C was recorded at station ME while the lowest level was registered at MAPU (27.2 ± 0.213 °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 ± 839.28 μScm^{-1}) whereas MAPU had the least (199.70 ± 4.38 μScm^{-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.

The PCA results on spatial variation in physico-chemical water quality variables are illustrated in Fig. 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.

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 (µg/L)	Ammonia (µg/L)	Phosphates (µg/L)	Salinity (mg/L)	DO (mg/L)	Temp (^{o}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}	389.06±49.01^{f}	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}	3498.09±1273.54^{cd}	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^{i}	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: Mkurumudzi Gazi; MKE: Mkurumudzi Estuary; MM: Mwena Manda; MMJ: Mwena Majoreni; RB: Ramisi Bridge; RE: Ramisi Estuary; RM: Ramisi Mwachande; UE: Umba Estuary; UL: Umba Lenjo; ULB: Umba Lunga-lunga Bridge

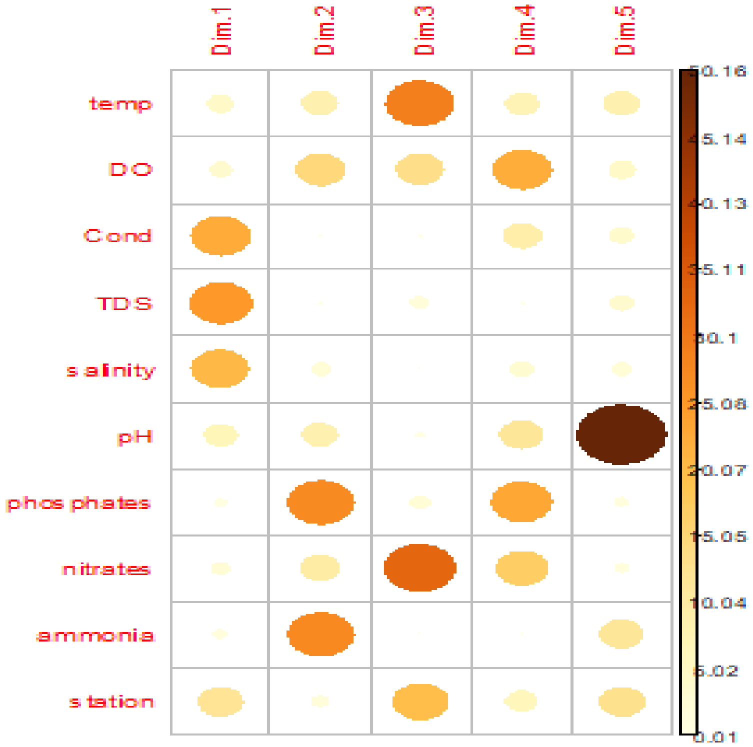

Fig. 2. Weighted effects on water quality derived from the original variables
DO = dissolved oxygen; temp = temperature; Cond = conductivity; TDS = total dissolved solids; Dim.1-5 = dimensions 1-5

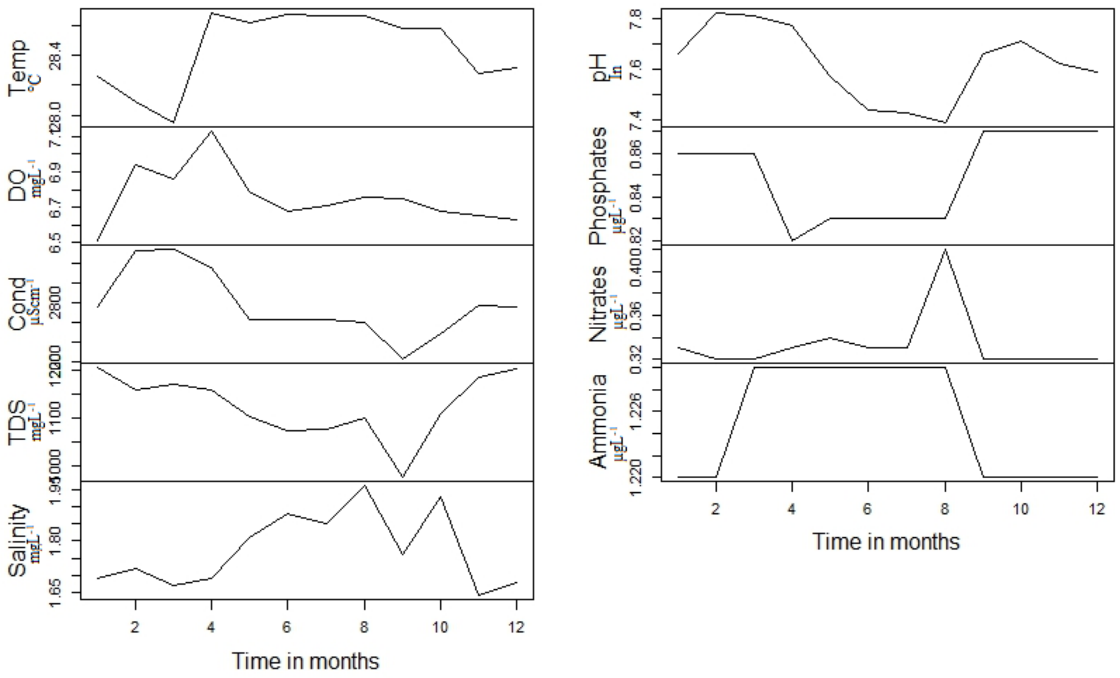

Fig. 3. Temporal variation of physico-chemical water quality attributes measured during the study period in estuarine ecosystems of the South Coast of Kenya, in the WIO region
TDS = total dissolved solids; Cond = Conductivity; DO = Dissolved oxygen; Temp = temperature

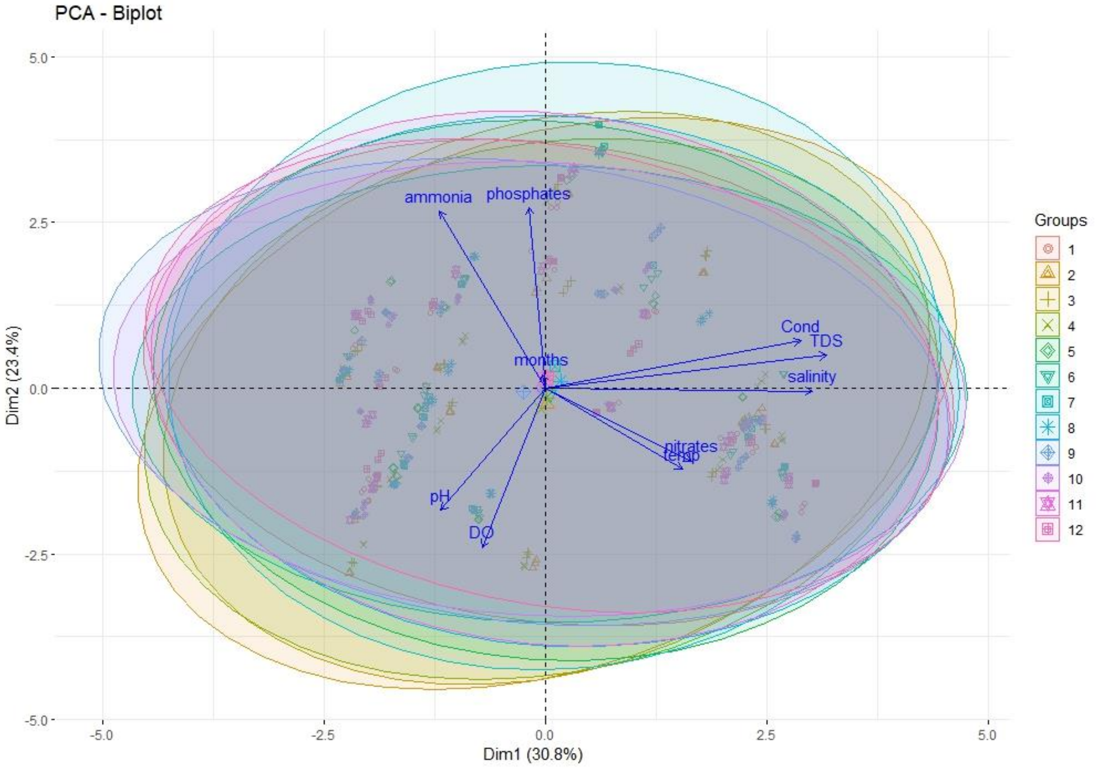

Fig. 4. The principal component analysis (PCA) shows the association between the physico-chemical water quality parameters (ammonia, phosphates, conductivity, TDS, salinity, nitrates, temperature, DO and pH) and the sampling months that were measured in surface water in estuarine ecosystems of South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

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) (Fig. 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 µg/L) of ammonia before increasing steadily to 1.23 µg/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 mµ/l during the month of September and the same level was maintained through December (Fig. 3). The rest of the parameters did not differ significantly among the sampling seasons (*P* = .05).

The PCA results (Fig. 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.

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 live [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].

5. 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.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Saravanakumar A, Rajkumar M, Serebiah JS, Thivakaran GA. Seasonal variations in physico-chemical characteristics of water, sediment and soil texture in arid zone mangroves of kachchh-Gujarat. Journal of Environmental Biology. 2008;29:725- 732.
2. Lemley DA, Adams JB, Taljaard S. Comparative assessment of two agriculturally-influenced estuaries: Similar pressure, different response. Marine Pollution Bulletin. 2017;117:136-147. Available:https://doi.org/10.1016/j.marpolbul.2017.01.059
3. Davies OA, Ugwumba OA. Tidal influence on nutrients status and phytoplankton population of okpoka creek, upper bonny estuary, Nigeria. Journal of Marine Biology. 2013;2:1-17. Available:https://doi.org/10.1155/2013/684739
4. Steward JS, Lowe EF. General empirical models for estimating nutrient load limits for florida's estuaries and inland waters. Limnology and Oceanography. 2010;55: 433-445. Available:https://doi.org/10.4319/lo.2010.55.1.0433
5. Bricker SB, Longstaff B, Dennison W, Jones A, Boicourt K, Wicks C, Woerner J. Effects of nutrient enrichment in the nation's estuaries: A decade of change. Harmful Algae. 2008;8:21-32.
6. Nyakeya K, Gichana ZM, Nyamora JM, Boera P. Acute toxicity tests (LC_{50}) of the native *Chironomus* species (Diptera: Chironomidae) exposed to sugarcane and kraft pulp and paper mill effluents. Kenya Aquatica Journal. 2022;7(01):42-52.
7. Gajbhiye S, Sharma SK, Jha M. Application of principal component analysis in the assessment of water quality parameters. Science-Fronts: A Journal of Multiple Science. 2014;4:67-72.
8. Sharma SK, Gajbhiye S, Nema RK, Tignath S. Assessing vulnerability to soil erosion of a watershed of tons River basin in Madhya Pradesh using remote sensing and GIS". International Journal of Environmental Research and Development. 2014;4(2):153-164.
9. Samarghandi M, Nouri J, Mesdaghinia AR, Mahvi AH, Nasseri S, Vaezi F. Efficiency removal of phenol, lead and cadmium by means of UV/TiO2/H2O2 processes. International Journal of Environmental Science and Technology. 2007;4(1): 19-25.
10. Miner KR, Turetsky MR, Malina E, Bartsch A, Tamminen J, McGuire A, et al. Permafrost carbon emissions in a changing arctic. Nat. Rev. Earth Environ. 2022;3:55–67.
11. Po ̈rtner HO, Roberts DC, Adams H, Adler C, Aldunce P, Ali E, et al. Climate change 2022: Impacts, adaptation and vulnerability. IPCC Geneva, Switzerland; 2022.
12. Nyakeya K, Onchieku J, Masese FO, Gichana ZM, Getabu A, Nyamora JM. Trends in water quality in a tropical Kenyan river-estuary system: Responses to anthropogenic activities. Asian Journal of Biology. 2024;20(6):34-51.
13. Doxaran D, Devred E, Babin M. A 50% increase in the mass of terrestrial particles delivered by the Mackenzie River into the Beaufort Sea (Canadian arctic ocean) over the last 10 years. Biogeosciences. 2015; 12:3551–3565.
14. Matsuoka A, Babin M, Vonk JE. Decadal trends in the release of terrigenous organic carbon to the Mackenzie delta (Canadian arctic) using satellite ocean color data (1998–2019). Remote Sensing and the Environment. 2022;283:113322.
15. Juhls B, Matsuoka A, Lizotte M, B'ecu G, Overduin P, El Kassar J, et al. Seasonal dynamics of dissolved organic matter in the Mackenzie delta, Canadian arctic waters: Implications for ocean colour remote sensing. Remote Sensing and the Environment. 2022;283:113327.
16. Fatema K, Maznah WW, Isa MM. Spatial and temporal variation of physico-chemical parameters in the merbok estuary, kedah, Malaysia. Tropical Life Sciences Research. 2014;25: 1-19.

Available:https://doi.org/10.3329/bjz.v41i1.23294

17. Hilborn A, Devred E. Delineation of eastern Beaufort Sea subregions using self-organizing maps applied to 17 years of modisaqua data. Frontiers in Marine Science. 2022;1061.
18. Lu W, Wu J, Li Z, Cui N, Cheng S. Water quality assessment of an urban river receiving tail water using the single-factor index and principal component analysis. Water Supply. 2019; 19(2):603-609.
19. Lyu SD, Chen WP, Zhang WL, Fan YP, Jiao WT. Wastewater reclamation and reuse in China: Opportunities and challenges. Journal of Environmental Science. 2016;39:86–96.
20. Akhigbe S, Udoh GJ, Nwankwoala HO. Impact of domestic and industrial waste on surface and ground water quality within slaughter area, transamadi industrial layout, Port Harcourt, Nigeria. International Journal of Waste Resources. 2018;8: 327.
    Available:https://doi.org/10.4172/2252-5211.1000327.
21. Ternes T, Joss A, Oehlmann J. Occurrence, fate, removal and assessment of emerging contaminants in water in the water cycle (from wastewater to drinking water). Water Research. 2015;72: 1–2.
22. Bisimwa MA, Mwanuzi F, Nobert J. Water quality management in Lake Kivu basin, DR Congo: Estimation of nutrient and sediment loading into Lake Kivu from Bukavu sub-basin. Lambert Academic Publishing, Germany. 2014;128.
23. Lina AA, Buregea H, Mindele U, Bouezmarni M, Vasel JL. Parasitological loads of rivers crossing the city of Bukavu, Democratic Republic of Congo. International Journal of Innovative Science and Research. 2015;19(2):412-422.
24. Ding J, Jiang Y, Fu L, Liu Q, Peng Q, Kang M. Impacts of land use on surface water quality in a subtropical river basin: A case study of the Dongjiang river basin, Southeastern China. Water. 2015;7: 4427–4445.
25. Beck SM, McHale MR, Hess GR. Beyond impervious: Urban land-cover pattern variation and implications for watershed management. Environmental Management. 2016;58:15–30.
26. Mockler EM, O'Loughlin FE, Bruen M. Understanding hydrological flow paths in conceptual catchment models using uncertainty and sensitivity analysis. Computer and Geosciences. 2016;90:66–77.
27. Nyamora JM, Njiru JN, Getabu A, Nyakeya K, Muthumbi A. An overview of heavy metal pollution in the Western Indian Ocean (WIO) region of Kenya: A review. Journal of Aquatic and Terrestrial Ecosystems. 2023; 1(1): 35-41.
    Available:https://blueprintacademicpublishers.com/index.php/JATEMS/
28. Nyamora JM, Nyakeya K, Wairimu E, Mwihaki G, Muya J. Long line seaweed farming as an alternative to other commonly used methods in Kenyan Coast. Kenya Aquatica Journal. 2018; 4(01):23 38.
29. KNBS. Kenya population and housing census. Volume I: Population by county and sub-county. 2019;39.
30. APHA. Standard methods for the examination of water and wastewater. American Public Health Association, Washington, DC; 2005.
31. Grasshoff K, Kremling K, Ehrhardt M. Methods of seawater analysis-third edition. Wiley-VCH Verlag GmbH, Weinheim. 1999; 203-223.
    Available:https://doi.org/10.1002/9783527613984
32. Royston JP. An extension of Shapiro and Wilk's W Test for Normality to Large Samples. Applied Statistics. 1982;31(2): 115-124.
33. Levene H. Robust Tests for Equality of Variances. In: Olkin, I., Ed., Contributions to Probability and Statistics, Stanford University Press, Palo Alto. 1960; 278-292.
34. Nyakeya K, Kipkorir KGK, Nyamora JM, Odoli CO, Kerich E. Dynamics of hydrology on the physico-chemical water quality parameters and trophic State of Lake Baringo, Kenya. Africa Environmental Review Journal. 2018;3(1):94-107.
35. Ngabirano H, Byamugisha D, Ntambi E. Effects of seasonal variations in physical parameters on quality of gravity flow water in Kyanamira sub-county, Kabale district, Uganda. Journal Water Resource Protection. 2016;8:1297–1309.
36. Nyakeya K, Raburu PO, Masese FO, Gichuki J. Assessment of pollution impacts on ecological Integrity of the Kisian and Kisat Rivers in Lake Victoria Drainage Basin, Kenya. African Journal of Science and Technology. 2009;3(4): 97- 107.

37. Capodaglio AG, Hlavínek P, Raboni M. Physico-chemical technologies for nitrogen removal from wastewaters: A review. Revista Ambiente and Água. 2015;10(3):481–498.
38. Mahadevan H, Krishnan KA, Pillai RR, Sudhakaran S. Assessment of urban river water quality and developing strategies for phosphate removal from water and wastewaters: Integrated monitoring and mitigation studies. SN Applied Science. 2020; 2: 772. Available:https://doi.org/10.1007/s42452 020-2571-0
39. Fouad D, Khadija H, Issam H, Abdelouahad El H, Kaouthar A. Impact des facteurs de pollution sur la qualité des eaux de la zone aval de la vallée de l'Oued Nekor (Al-Hoceima, Maroc). European Science Journal. 2017;13(3):43–60.
40. Nyakeya K. Sensitivity of *Chironomus* species in monitoring of riverine ecosystems in the catchments of Lake Victoria Drainage Basin, Kenya. MSc. Thesis, University of Eldoret, Kenya; 2017.
41. Hossain MF, Jahan E, Parveen Z, Ahmed M, Uddin MJ. Solid waste disposal and its impact on surrounding environment of Matuail landfill site, Dhaka, Bangladesh. American Journal of Environmental Science. 2018;14:234–245.
42. Ivanovsky A, Criquet J, Dumoulin D, Alary C, Prygiel J, Duponchel L, et al. Water quality assessment of a small peri-urban river using low and high frequency monitoring. Environmental Science: Processes and Impacts. 2016;18:624–637.
43. Nyakeya K, Gichana Z, Nyamora JM, Masese FO, Getabu A, Onchieku J, et al. Cage farming in the environmental mix of Lake Victoria: An analysis of its status, potential environmental and ecological effects and a call for sustainability. Aquatic Environmental Health and Management. 2023;25(4):37-52.
44. WHO. The WHO recommended classification of pesticides by hazard and guidelines to classification. World Health Organization, Geneva; 2012.
45. Balakrishnan P, Saleem A, Mallikarjun ND. Groundwater quality mapping using geographic information systems (GIS); A case study of Gulbarga City, Karnataka, India. African Journal of Environmental Science and Technology. 2011;5(12):1069 – 1084.
46. Bagalwa M, Majaliwa M, Mushagalusa N, Karume K. Estimation of transported pollutant load from small urban Kahuwa river micro-catchment in Lake Kivu, Democratic Republic of Congo. Journal of Environmental Science and Engineering. 2013;B2:460–476.
47. Zakaria SNF, Aziz HA. Characteristic of leachate at Alor Pongsu landfill site, Perak, Malaysia: A comparative study. IOP Conf. Ser. Earth Environmental Science. 2018;140:012013.
48. Rodier J, Legube B, Merlet N. L'analyse de l'eau. 9th´edition. Dunod, Paris. 2009;1526.
49. Nyakeya K, Chemoiwa JE, Nyamora JM, Kerich E, Gichana Z. Zooplankton communities of Lake Victoria and its effects on the fishery. Africa Environmental Review Journal. 2020;3(2): 45-57.
50. Ra K, Kim J-K, Hong SH, Yim UH, Shim WJ, Lee S-Y, et al. Assessment of pollution and ecological risk of heavy metals in the surface sediments of Ulsan Bay, Korea. Ocean Science Journal. 2014;49:279–289.
51. Jiang X, Wang W, Wang S, Zhang B, Hu J. Initial identification of heavy metals contamination in Taihu Lake, a eutrophic lake in China. Journal of Environmental Sciences. 2012;24(9): 1539–1548.

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