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Understanding Seasonal and Spatial Variation of Water Quality Parameters in Mangrove Estuary of the Nyong River Using Multivariate Analysis (Cameroon Southern Atlantic Coast)

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Abstract

To evaluate the actual status of water quality and conclude on the mains source of pollution in the Nyong estuary River, seasonal and spatial variation of water quality parameters was interpreted by multivariate statistical techniques (Principal Component analysis). Nine (09) environmental variables were monitored at four surface stations in the estuary for two seasonal cycles. The fieldwork was conducted from 2018 to 2019 during high tide and low tide for each survey. In situ physical parameters were measured for a total of 64 samples (32 samples for each tide). The laboratory works consisted of some physicochemical analyses and processing of these data by descriptive and multidimensional statistical analyses. Temperature, suspended particle matter, nitrate, nitrite and phosphate change significantly in the estuary with season ($p < 0.05$), while salinity, dissolved oxygen, pH, and ammonium do not vary significantly with season ($p > 0.05$). Principal Component analysis found temperature, salinity, pH, ammonium to be the most important parameters contributing to the fluctuations of surface water quality in the Nyong estuary during the dry seasons whereas suspended particle matter, nitrate, and phosphate are the most important parameters contributing to the fluctuation of surface water quality in the Nyong estuary during the rainy seasons. Based on spatial variation, the Principal Component analysis found that, suspended particle matter, nitrate and phosphate contribute to the fluctuation of surface water quality parameters upstream of the estuary while downstream salinity, pH, and ammonium contribute the most to the fluctuation of surface water quality. This study shows us the usefulness of multivariate statistical techniques used in assessing water quality data sets that would help us in understanding seasonal and spatial variations of water quality parameters to manage estuarine systems.

Keywords

Water Quality Parameters, Nyong Estuary, Principal Component Analysis

1. Introduction

According to [1], estuaries is a semi-enclosed coastal body of water which has a free connection with the open sea, with extending upriver up to the tidal influence limit, and within which sea water is measurably diluted with fresh water derived from land drainage. In natural conditions, they are biologically more productive than the rivers and the adjacent ocean, due to their high nutrient concentration which stimulates primary production.

These are places where various fish, birds and animals congregate to feed, find refuge, grow to adulthood, and/or stage migration. They also play a major role in supplying domestic water, and supporting industrial, agricultural, and aquaculture activities [2].

Estuaries are unique places, strongly affected by tidal actions, where land, river and sea merge into a dynamic natural complex. These ecosystems receive large quantities of land—based nutrients and other pollutants from agriculture, industrial activities, human exploitation of water resources (domestic and industrial) and urban runoff which strongly affect water quality [3] [4] [5] [6]. Besides these anthropogenic activities, poor water quality could also be due to precipitation rate, weathering, and soil erosion. Aquatic life, biodiversity and water availability for human utilization are under the control of the quality of water in terms of nutrient enrichment, physical and chemical parameters. As it is established, environmental conditions such as salinity, oxygen, temperature, light, electrical conductivity, turbidity, and nutrients influence the composition, distribution and growth of organisms, therefore monitoring water quality in aquatic ecosystems and, especially in estuaries is essential for their sustainable management.

During water quality monitoring, it is very important to assess the physicochemical parameters of water in space and time. Biogeochemical variables and biotics data are usually gathered; several techniques have already been implemented to analyze water quality data, such as data reduction techniques [7] [8] [9] [10] [11], water quality index (WQI) [12] [13] [14] [15], univariate data analysis method, and estuary health index (EHI) [16]. Data reduction techniques usually used to simplify the process of interpreting large datasets. This technique has advantages and disadvantages, which are specific to each method. Many authors have adopted the use of water quality indices. The latter, highlights some specificities depending on the type of pollution and the geographical area; their universal application remains therefore limited. Univariate methods are also used for water quality analysis although they would not always bring out the similarities and differences for large data sets. The official method for determining ecological water requirements is an estuarine health index (EHI) for assessing the actual conditions of an estuary [16]. To evaluate estuary health conditions, this method need a large datasets [16] [17]. For an area with no historical data available, such as the Nyong estuary, multivariate statistics is the most appropriate method to provide an overview of temporal conditions as well as seasonal and geographical evolution of the ecosystem [18] [19].

The multivariate statistical approach have been mostly used recently for a better understanding of water quality and ecological status, due to its ability to treat large volumes of spatial and temporal data from a variety of monitoring sites. On the other hand in scientific literature, a different statistical technique was used for this kind of study which is that of the principal component analysis (PCA) because it is able to assess temporal and spatial variations in river water quality so as to identify potential sources of water contamination [20]-[28].

The Nyong river is the second most important river fully included in Cameroon's territory, it flows approximately 690 km into the Gulf of Guinea and due to its navigation possibilities and its hydroelectric potential has long attracted administrative authorities and technical ministerial departments [29]. Its lower course crosses the Douala—Edea Terrestrial and Marine Park, where active fishing is developed in mangrove area. Intensive agriculture is practiced on the banks of its middle course, while offshore oil and gas activities are developed in the vicinity [15].

These anthropogenic activities associated to mangrove and rainforest have increased nutrient input and as such excessive nutrient loading has accelerated primary production (eutrophication), accumulation of organic matter, increased turbidity, and excessive oxygen consumption. For the purpose of understanding the functioning of the Nyong river, several hydrological, geochemistry and biological studies have been performed upstream [30] [31] [32] [33] [34]. For the downstream section which is influenced by tidal dynamics research works are recent [15] [35]. Therefore, regular monitoring and evaluation of the quality of the river waters are required for the integrated management of this water resource.

The aim of the present study is to evaluate the actual status of water quality in the Nyong estuary and conclude on the main sources of pollution. This study will explore the seasonal changes of water quality and determine the contribution of river and marine influx on spatial distribution of environmental variables and consequently on estuarine water quality.

2. Material and Method

2.1. Study Area and Sampling Stations

The Nyong estuary is part of the Campo-Nyong hydrosystem of the Atlantic Meridional Coast of Cameroon. Unlike rivers located in the North coast and like all rivers located in Cameroon's South Atlantic the Nyong river like is less watered and subject to an equatorial climate with four seasons which are the long rainy season (LRS), short rainy season (SRS), the long dry season (LDS) and short dry season (SDS) [15] [29] [36]. Climate is influenced by Southwest monsoon, limited on average speed to 10km/h because of the highly developed rainforest [29].

The region is naturally covered by a large and very diverse humid forest characterized by several subsets such as: mangrove forest, coastal rain forest, medium Atlantic forest with dense foliage, rare herbaceous plants, and many vines. The geological substratum is Precambrian and the relief is formed by the coastal plain with altitudes below 350 m which is mostly constituted of weakly undulate sedimentary plains, with a coastal alluvial part [37] [38] [39] [40]. Geological formation is altered to produce more or less thick essentially ferrallitic yellow and red soils crossed in certain places by hydromorphic soils [41] [42].

Four stations were set up at different positions of the estuaries (**Figure 1**). The first marine station (station N1), was set 1 km off the mouth of the estuary, the second station N2 was set in the middle of the river, while the third and fourth station N3 and N4 were set at 1.5 km and 4 km upstream respectively from N2 station. So as to have global characteristics of the estuary. N1 was at marine station, while N2 was inside the mouth behind a sandbar giving the mouth a lagoon aspect. The N3 and N4 stations were positioned respectively in the mangrove creeks and at the entrance of the mangrove islands upstream.

All seasons were covered during eight (08) surveys: the long dry season (LDS) in December 2018 and December 2019, the short dry season (SDS) in June 2018 and July 2019, the Long rainy season (LRS) in September 2018 and September 2019 and the short rainy season (SRS) in March 2018 and April 2019. For each survey, two samplings were carried out at each station during low and high tide respectively. Surface water (50 cm) was sampled using a 1.7 L Niskin bottle. Water samples stored in 1.5 L double-capped polyethylene bottles were transported to the laboratory in an adiabatic enclosure at 4˚C for Physicochemical parameters analysis to be carried on [43]. Physicochemical parameters were determined according to [44] method coupled with the standard methods [43]. Temperature and pH were measured using a field pH-meter (Hanna model HI 98130, equipped with a SENTIX4 electrode) that of Conductivity and salinity were recorded using a WTW series 3310 set2 connected to a tetracon electrode. Dissolved oxygen was recorded using the EXTECH oxymeter model Exstik II DO 600 while that of Soluble reactive inorganic phosphorous (PO_4^{3-}), nitrites (NO_2^-), nitrate (NO_3^-), ammonium (NH_4^+) and suspended particle matter were determined using a spectrophotometer (HACH DR/2800), following the [43] method and standard methods of [45].

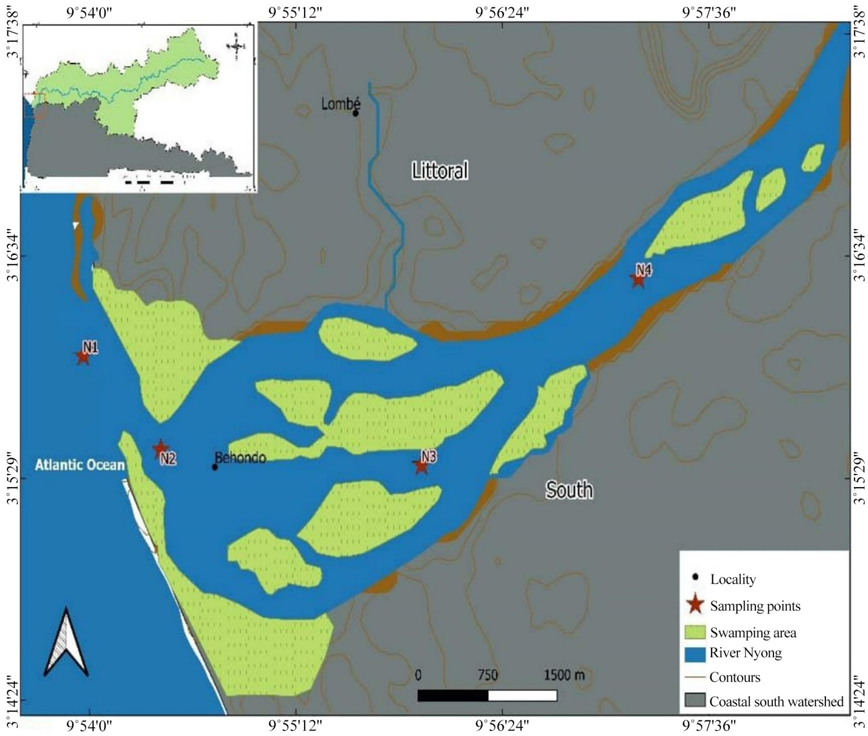

Figure 1. Map of the study area with sampling stations.

2.2. Data Analysis

Descriptive and multivariate statistics were used to analyze the multiple variables collected during various periods of the study at different sampling stations. The mean which is a central tendency indicator of a given data set was calculated so as to get a better idea of how all data were distributed around the calculated mean and standard deviation derived.

Seasonal variation of water quality parameters was evaluated through boxplot. As data were abnormally distributed, the nonparametric Kruskal-Wallis H test was used to determine the effect of the seasons and sampling stations on water quality parameters. The Kruskal-Wallis is a nonparametric version of the classical one-way ANOVA. It is often used to compare samples from two or more groups. The Kruskal-Wallis was used to compare medians of the sample and returned the p-values for the null hypothesis showing that all samples are drawn from the same population or equivalently from different populations with the same distribution. The Mann-Whitney test was performed to highlight the probable effect of tide on water quality parameters variation. For both tests, the significance level was fixed at 0.05.

The Pearson correlation matrix was performed in order to evaluate the relationship between water quality variables. PCA was used to reduce the size dimension of data set by explaining the correlation among many variables in terms of a smaller number of underlying factors (principal component), without losing much information [46] [47] [48].

Let considered p quantitative variables, observed on n individuals. The observation of the variable x_j on the individual i, is noted x_{ij} and the data are presented in a matrix (Equation (1)). The problem to be addressed is to find the relevant information contained in the data. Thus, it must be summarized by extracting the essentials of its structure in order to make graphical representations that are both faithful to the initial data and easy to interpret. These representations will have to be done in reduced dimension [49] [50]. The initial cloud, located in a space of dimension p (since we have, starting from p quantitative variables), will be summarized (reduced, projected) in dimension q (according to the q factors). The number of factors q selected will be between 1 and p.

$$X = \begin{matrix} u_1 \\ u_2 \\ \vdots \\ u_i \\ \vdots \\ u_{n-1} \\ u_n \\ \end{matrix} \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{1p} \\ x_{21} & x_{22} & \cdots & x_{2j} & \cdots & x_{2p} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} & \cdots & x_{ip} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{n-11} & x_{n-12} & \cdots & x_{n-1j} & \cdots & x_{n-1p} \\ x_{n1} & x_{n2} & \cdots & x_{nj} & \cdots & x_{np} \end{bmatrix} \tag{1}$$

$$\begin{matrix} v_1 & v_2 & \cdots & v_j & \cdots & v_p \end{matrix}$$

The q factors defined to summarize the information contained in the initial table must maximized the dispersion of the observations. It is interesting to remember that the dispersion of a quantitative variable is generally measured by its variance or by its standard deviation. The principle of PCA consists in finding, for a restricted dimension q, the q factors maximizing the inertia by these factors. Going from the p dimension to the q dimension, there is objectively a loss of dispersion and inertia. The idea is to lose as little as possible by choosing the right factors. Methodically, we must find linear combinations of variables called factors, or principal components, written in the following form:

$$\begin{aligned} C^1 &= a_1^1 x_1 + a_1^2 x_2 + \cdots + a_1^p x_p \\ C^2 &= a_2^1 x_1 + a_2^2 x_2 + \cdots + a_2^p x_p \\ &\vdots \\ C^q &= a_q^1 x_1 + a_q^2 x_2 + \cdots + a_q^p x_p \end{aligned} \tag{2}$$

The Combination C^1 should contain much information as possible. The criterion is that the Variance of C^1 must be maximum and it is necessary to take into account the constraint on the weighting coefficients assigned to each initial variable within the principal component C^1, it is question to verify that:

$$\sum_{j=1}^{p} \left(a_1^j\right)^2 = 1. \tag{3}$$

The same process is followed for C^2, by imposing that C^1 and C^2 are uncorrelated, that is to say that (C^1, C^2) = 0. The information provided by C^2 must be completely new with respect to C^1. And so on, up to the number of factors (2 or 3) to make graphs easy to read and interpret. As with any descriptive method, performing a PCA leads to the possible detection of suspicious values, and would help formulate hypotheses that should be studied using models and differential statistical studies. The PCA carried out in this study were applied to the reduced centered data since the initial variables are of various natures and expressed in different units. The great advantage of PCA resides in the fact that it takes into account all the variables simultaneously [48] [51]. It able to detect the existing links between the different variables; to reduce their number in subsequent similar studies and to visualize the distribution of the different readings considered. It can also provide information on certain links between the variables and the readings [48] [50].

The Eigen value gave a measure of the significance of the factors: the factors with the highest Eigen values were the most significant [47]. Eigen values equal to or greater than 1.0 are considered significant [52]. For a better interpretation of associateships between environmental variables and factors and according to [53], the factors loading are classified as "strong", "moderate", and "weak" corresponding to absolute loading values of >0.75, 0.75 - 0.5, and 0.5 - 0.3 respectively.

3. Result

3.1. Seasonal Variation of Physicochemical Parameters

Seasonal variation of water quality variables is represented in **Figure 2**; and summarized in **Table 1**.

The seasonal average of water temperature in the Nyong estuary was 29.88˚C ± 0.55˚C, 26.71˚C ± 1.31˚C, 28.89˚C ± 0.86˚C, 23.96˚C ± 0.88˚C respectively during the major dry season, small rainy season, small dry season, and large rainy season. The maximum temperature of 31.2˚C was observed during the major dry season whereas the minimum of 22.9˚C was obtained during the large rainy season (**Figure 2(a)**). The Kruskal-Wallis test, $p < 0.01$ showed that temperature varied significantly from one season to another.

Salinity average in the Nyong estuary was 6.28 ± 8.69 PSU, 4.58 ± 6.87 PSU, 5.21 ± 7.47 PSU, 2.85 ± 4.98 PSU respectively during the major dry season, small rainy season, small dry season, and large rainy season. During the major dry season, salinity ranged between 0.01 - 24.5 PSU, and between 0.01 - 18.5 PSU, 0.01 - 20 PSU, 0.01 - 10.95 PSU, for the small rainy season, small dry season, and the large rainy season respectively. However, some extreme values are observed during the small dry season and the small rainy season (**Figure 2(b)**). Despite the large fluctuation of the salinity gradient, the Kruskal-Wallis test $p = 0.6678$, revealed that salinity does not vary significantly with season.

The seasonal average of pH varied from 7.59 ± 0.68 to 6.96 ± 0.21 with a maximum of 9.2 observed during the small dry season and a minimum of 5.89 during the large rainy season. The Kruskal-Wallis test $p = 0.2587$ showed that pH does not vary significantly with season.

During the study period, dissolved oxygen did not fluctuate significantly with season ($p = 0.231$). The average seasonal variation of dissolved oxygen in the Nyong estuary was 5.52 ± 0.19 mg/L, 5.24 ± 1.45 mg/L, 5.54 ± 0.34 mg/L, 4.68 ± 1.11 mg/L respectively during the major dry season, small rainy season, small dry season, and large rainy season. During the major dry season, dissolved oxygen was between 5.23 - 5.94 mg/L, and between 3.04 - 6.56 mg/L, 4.75 - 5.92 mg/L, 3.68 - 6.51 mg/L, during the small rainy season, small dry season, and the large rainy season respectively.

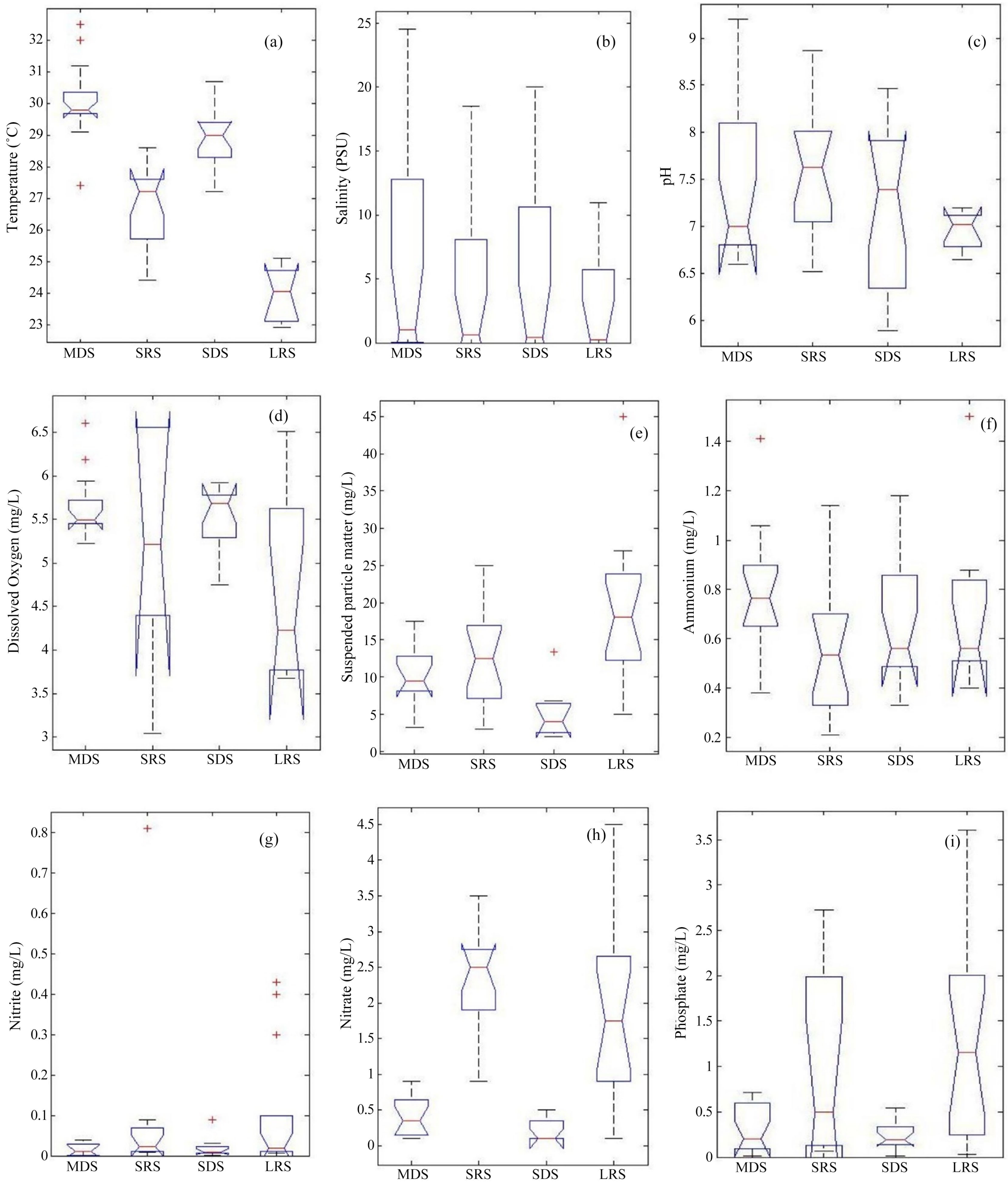

Figure 2. Seasonal variation of water quality parameters in the Nyong estuary.

Table 1. Average, standard deviation, and range of water quality parameters measure during the four seasons.

Variables/Seasons	MDS	SRS	SDS	LRS
Temperature (˚C)	29.88 ± 0.55^{a} (29.1 - 31.2)	26.71 ± 1.39^{b} (24.4 - 28.6)	28.89 ± 0.86^{ca} (27.2 - 30.7)	23.96 ± 0.88^{d} (22.9 - 25.1)
Salinity (PSU)	6.28 ± 8.69^{a} (0.01 - 24.5)	4.58 ± 6.87^{ba} (0.01 - 18.5)	5.21 ± 7.47^{cb} (0.01– 20)	2.85 ± 4.98^{d} (0.01 - 10.95)
pH	6.96 ± 0.21^{a} (6.6 - 7.2)	7.59 ± 0.68^{a} (6.52 - 8.87)	7.46 ± 0.86^{a} (6.6 - 9.2)	6.96 ± 0.21^{a} (5.89 - 8.47)
Dissolved oxygen (mg/L)	5.52 ± 0.19^{a} (5.23 - 5.94)	5.24 ± 1.45^{a} (3.04 - 6.56)	5.54 ± 0.34^{a} (4.75 - 5.92)	4.68 ± 1.11^{a} (3.68 - 6.51)
Suspended particle matter (mg/L)	9.81 ± 4.09^{a} (3.2 - 17.5)	12.46 ± 6.72^{b} (3 - 25)	3.97 ± 1.95^{c} (2 - 6.8)	16.73 ± 6.58^{d} (5 - 27)
NH_4^+ (mg/L)	0.75 ± 0.19^{a} (0.38 - 1.06)	0.57 ± 0.29^{b} (0.21 - 1.14)	0.67 ± 0.26^{b} (0.33 - 1.18)	0.6 ± 0.17^{b} (0.4 - 0.88)
NO_2^- (mg/L)	0.02 ± 0.01^{a} (0.001 - 0.04)	0.03 ± 0.02^{b} (0.01 - 0.09)	0.013 ± 0.008^{a} (0.001 - 0.03)	0.02 ± 0.03^{b} (0.007 - 0.1)
NO_3^- (mg/L)	0.41 ± 0.29^{a} (0.1 - 0.9)	2.34 ± 0.68^{b} (0.9 - 3.5)	0.21 ± 0.16^{c} (0.1 - 0.5)	1.78 ± 1.14^{d} (0.1 - 4.5)
PO_4^{3-} (mg/L)	0.33 ± 0.26^{a} (0.01 - 0.71)	1.01 ± 1.12^{b} (0.07 - 2.73)	0.23 ± 0.14^{c} (0.01 - 0.54)	1.24 ± 1.15^{da} (0.03 - 3.61)

The different superscript letters indicate statistical difference between seasons at $p < 0.05$.

Suspended particle matter varied significantly with season ($p < 0.001$) (Figure 2(e)). The mean concentration of suspended particle matter was 9.81 ± 4.09 mg/L, 12.46 ± 6.72 mg/L, 3.97 ± 1.95 mg/L, 16.73 ± 6.58 mg/L respectively during the major dry season, small rainy season, small dry season, and large rainy season. The maximum concentration of 27 mg/L was observed during the large rainy season and the minimum of 2 mg/L was obtained during the small dry season.

The ammonium mean seasonal concentration was 0.75 ± 0.19 mg/L, 0.57 ± 0.29 mg/L, 0.67 ± 0.26 mg/L, 0.6 ± 0.17 mg/L during the major dry season, small rainy season, small dry season, and the large rainy season respectively. The maximum of 1.18 mg/l was observed in the large rainy season while the minimum of 0.21 mg/l was obtained during the small rainy season. The Kruskal-Wallis test $p = 0.2309$ showed that ammonium concentration did not vary significantly with season (Figure 2(f)).

Mean nitrite concentration was 0.02 ± 0.01 mg/L, 0.03 ± 0.02 mg/L, 0.013 ± 0.008 mg/L, 0.02 ± 0.03 mg/L during the major dry season, small rainy season, small dry season, and the large rainy season respectively. The maximum of 0.1 mg/L was obtained during the large rainy season whereas the minimum of 0.001 mg/L was obtained during the major dry season, the small rainy season, and the small dry season. Nitrite concentration did not vary significantly with season (Kruskal-Wallis test $p > 0.05$).

Nitrate concentration was 0.41 ± 0.29 mg/L, 2.34 ± 0.68 mg/L, 0.21 ± 0.16

mg/L, 1.78 ± 1.14 mg/L during the major dry season, small rainy season, small dry season, and large rainy season respectively. Nitrate concentration was higher in the Nyong estuary during rainy season than in the dry season (**Figure 2(h)**). With $p < 0.001$, The Kruskal-Wallis test revealed that nitrate varied significantly with season.

Seasonal variation of phosphate is shown in **Figure 2(i)**. During seasonal investigations, phosphate concentration average was 0.33 ± 0.26 mg/L, 1.01 ± 1.12 mg/L, 0.23 ± 0.14 mg/L, 1.78 ± 1.14 mg/L during the major dry season, small rainy season, small dry season, and large rainy season respectively. The maximum of 4.5 mg/l was found during the large rainy season and the minimum of 0.01 mg/L was recorded during the major dry season and the small rainy season. The Kruskal-Wallis test ($p = 0.0347$) indicates that the variation of phosphate concentrations was significant with seasonal change.

3.2. Spatial Variation of Physicochemical Parameters

The spatial variation of physicochemical parameters with their average values and standards errors in different stations in the Nyong estuarine system are presented in Figures below.

The mean water temperature varied from 26.9˚C ± 2.54˚C (station N4) to 27.53˚C ± 2.63˚C (station N2) during the high tide and from 27.32˚C ± 2.11˚C (station N1) to 27.88˚C ± 3.14˚C during the low tide (**Figure 3**). The Kruskal-Wallis test $p > 0.05$ revealed that temperature did not vary significantly between stations and the Mann-Whitney U test $p > 0.05$ showed that temperature did not vary significantly between high tide and low tide.

Salinity average ranged from 0.04 ± 0.01 PSU (station N4) to 10.83 ± 2.07 PSU (station N1) during the high tide and from 0.01 ± 0.01 PSU (station N4) to 9.33 ± 2.37 PSU (station N4) during the low tide (**Figure 4**). The surface salinity of downstream stations (stations N1 and N2) was higher than salinity concentration of upstream stations (stations N3 and N4). The Kruskal-Wallis test $p < 0.01$ revealed that salinity vary significantly between sampling stations and the Mann-Whitney U test $p < 0.05$ showed that salinity changed significantly during both tidal cycles.

pH varied from 7.36 ± 0.98 (station N3) to 7.81 ± 0.56 (station. N1) during high tide and from 6.84 ± 0.35 (station N3) to 7.27 ± 0.7 mg/l (station N1) during low tide (**Figure 5**). The pH variations were not significant between stations (The Kruskal-Wallis H, test $p > 0.05$) as well as during high and low tide (Mann-Whitney U test $p > 0.05$).

Dissolved oxygen means ranged from 4.23 ± 0.75 mg/L (station N1) to 4.89 ± 0.8 mg/L(station N2) during the high tide and from 3.19 ± 0.94 mg/L (station N4) to 4.35 ± 0.95 mg/L (station N1) during the low tide (**Figure 6**). The Kruskal-Wallis test $p > 0.05$ revealed that dissolved oxygen did not vary significantly between stations and the Mann-Whitney U test $p > 0.05$ showed as well that dissolved oxygen did not vary significantly between high tide and low tide in the Nyong estuary.

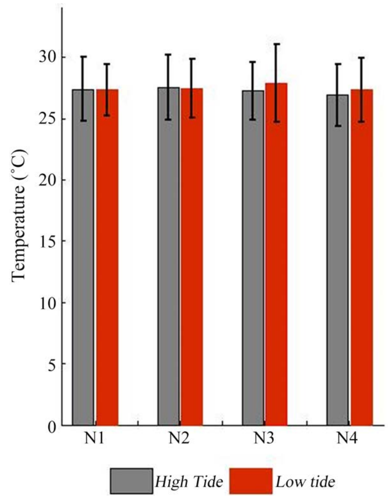

Figure 3. Spatial variation of water surface temperature during high and low tide.

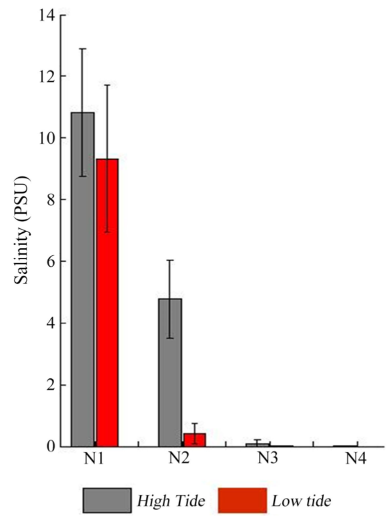

Figure 4. Spatial variation of water surface salinity during high and low tide.

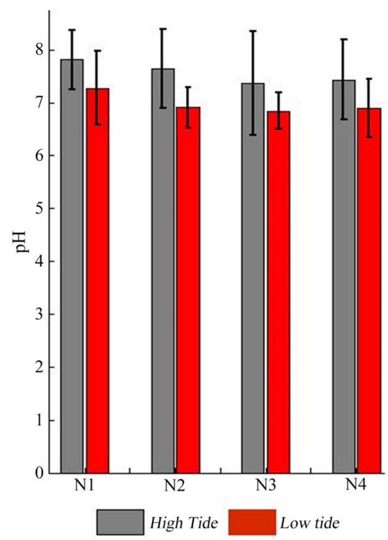

Figure 5. Spatial variation of potential hydrogen during high and low tide.

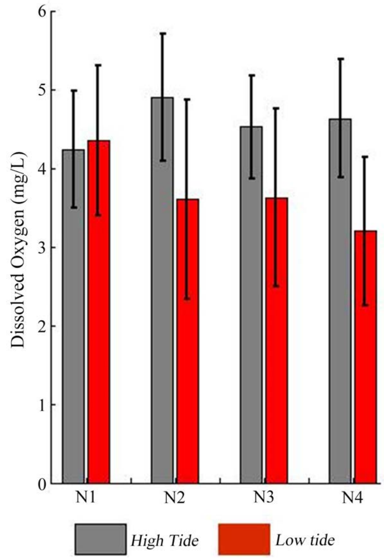

Figure 6. Spatial variation dissolved oxygen during high and low tide.

The average of suspended particles matters varied from 7.65 ± 1.01 mg/L (station N1) to 16.63 ± 1.77 mg/L (station N4) during high tide and from 9.31 ± 1.51 mg/L (station N1) to 14.12 ± 2.83 mg/L (station N3) during low tide (**Figure 7**). The Kruskal-Wallis test $p < 0.01$ revealed that suspended particle matter varied significantly among stations. Suspended particle matters decrease upstream to downstream and the Mann-Whitney U test $p < 0.05$ revealed that suspended particle matter varied significantly between high tide and low tide.

The mean surface concentration of nutrients (NH_4^+, NO_2^-, NO_3^-, PO_4^{3-}) are presented in **Figures 8-11** respectively. Nutrients concentrations are slightly high upstream of the estuary than downstream except for ammonium whose concentration decreased downstream to upstream. Ammonium concentration varied from 0.55 ± 0.16 mg/L (station N4) to 1.89 ± 0.41 mg/L (station N1) during the high tide and from 0.55 ± 0.19 mg/L (station N3) to 0.99 ± 0.28 mg/l (station N1) during the low tide. The Kruskal-Wallis test $p < 0.05$ revealed that ammonium concentrations varied significantly between stations and the Mann-Whitney U test $p > 0.05$ showed as well that ammonium concentration differences were not significant between high and low tide.

The mean surface water concentration of NO_2^- varied from 0.08 ± 0.03 mg/l (station N1) to 0.31 ± 0.1 mg/L (station N1) during high tide and from 0.07 ± 0.04 mg/l (station N2) to 0.2 ± 0.09 mg/L (station N3) during low tide. The Kruskal-Wallis test $p > 0.05$ revealed that nitrite did not vary significantly between stations and the Mann-Whitney U test $p > 0.05$ showed as well that nitrites did not vary significantly between both tides.

Nitrate average varied from 0.97 ± 0.23 mg/L (station N2) to 2.4 ± 0.75 mg/L (station N4) during high tide and from 1.11 ± 0.29 mg/L (station N1) to 1.5 ± 0.39 mg/L (station N2) during low tide. Phosphate ranged from 0.54 ± 0.06 mg/L (station N1) to 0.77 ± 0.26 mg/L (station N4) and from 0.41 ± 0.89 mg/L (station N1) to 0.77 ± 0.14 mg/L (station N3) respectively during high and low tide. The

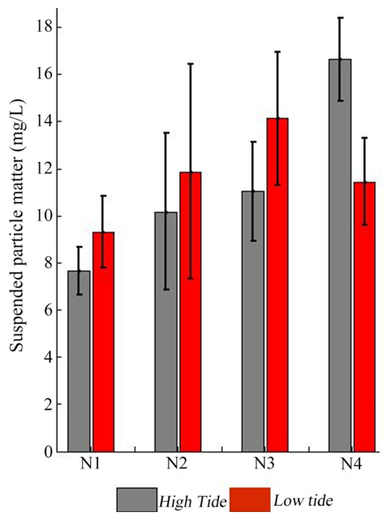

Figure 7. Spatial variation of suspended particle mater during high and low tide.

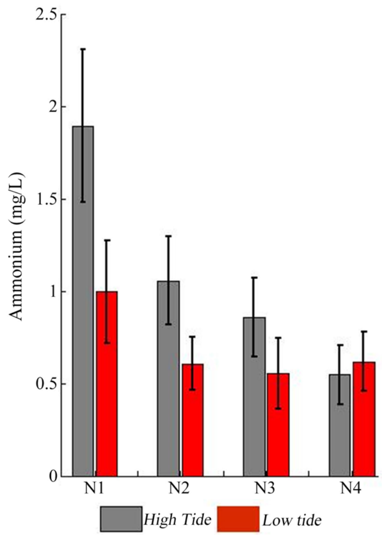

Figure 8. Spatial variation of ammonium during high and low tide.

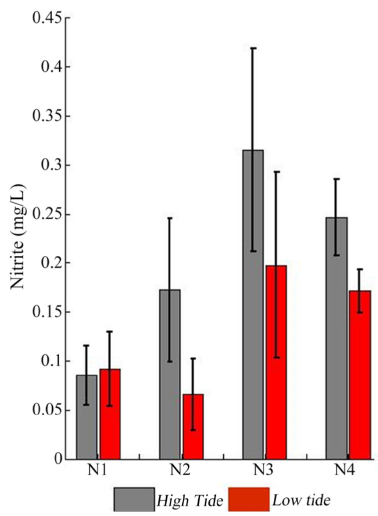

Figure 9. Spatial variation of nitrite during high and low tide.

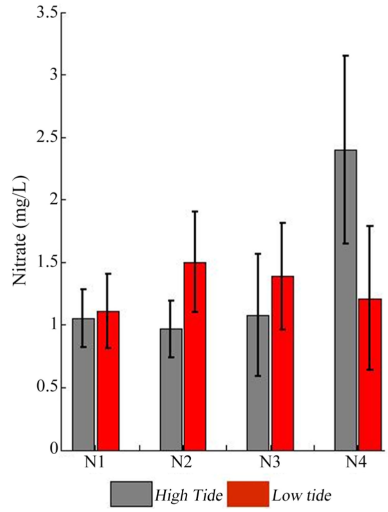

Figure 10. Spatial variation of nitrate during high and low tide.

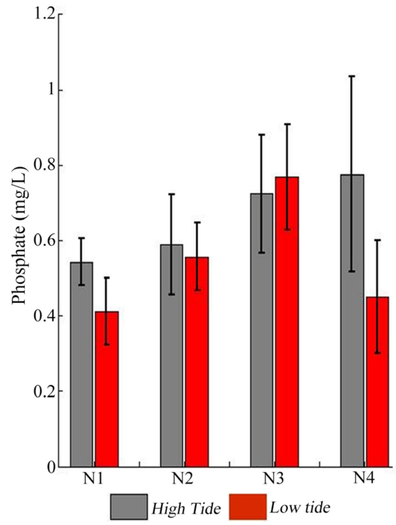

Figure 11. Spatial variation of phosphate during high and low tide.

Mann-Whitney *U* test results $p > 0.05$ and the Kruskal-Wallis test $p > 0.05$, showed that nitrate and phosphate did not vary significantly between high and low tide as well as between stations.

3.3. Multivariate Analysis Methods

3.3.1. Correlation Matrix of Physicochemical Parameters

Table 2 provides the correlation matrix of physicochemical parameters during high tide and low tide respectively.

Analysis of the matrix of correlations of variables during high tide reveals a strong positive correlation ($0.7 < r \leq 0.9$) between: salinity and pH, salinity and ammonium, pH and ammonium, suspended particle matter and nitrate, suspended particle matter and orthophosphates. A moderate positive correlation ($0.5 \leq r \leq 0.7$) is obtained between temperature and salinity, pH and ammonium; nitrite and orthophosphates, nitrates and orthophosphates. While a negative correlation is observed between temperature and suspended particle matter, nitrates and orthophosphates, salinity and suspended particle matter, nitrites and orthophosphates; ammonium and nitrites, nitrates and orthophosphates. However, in low tide a strong positive correlation ($0.7 < r \le 0.9$) is observed between: temperature and suspended particle matter, dissolved oxygen and salinity, pH and salinity, ammonium ions and salinity, pH and oxygen ammonium and pH, orthophosphate and suspended particle matter. In addition, moderate positive correlation ($0.5 \le r \le 0.7$) is observed between: temperature and nitrite, orthophosphate and nitrites, and orthophosphate and nitrates. On the other hand, a strong negative correlation ($r \ge -0.6$) is observed between: temperature and dissolved oxygen, temperature and salinity, temperature and pH, temperature and ammonium, pH and suspended particle matter, pH and nitrates, pH and orthophosphate, nitrite ions and orthophosphate ions.

Table 2. Correlation matrix of physicochemical parameters during high and low tide.

		Temperature (˚C)	Salinity (PSU)	pH	DO (mg/l)	SPM (mg/l)	NH_4^+ (mg/l)	NO_2^- (mg/l)	NO_3^- (mg/l)	PO_4^{3-} (mg/l)
High tide	Temperature (˚C)	1								
	Salinity (PSU)	0.59	1							
	pH	0.59	**0.97**	1						
	DO (mg/l)	0.12	−0.5	−0.32	1					
	SPM (mg/l)	−0.87	−0.79	−0.7	0.38	1				
	NH_4^+ (mg/l)	0.6	**0.96**	0.88	−0.64	−0.87	1			
	NO_2^- (mg/l)	−0.47	**−0.95**	**−0.98**	0.33	0.59	−0.84	1		
	NO_3^- (mg/l)	−0.94	−0.51	−0.45	0.09	0.92	−0.62	0.3	1	
	PO_4^{3-} (mg/l)	−0.84	−0.93	−0.93	0.22	0.89	−0.89	0.86	0.73	1
Low tide	Temperature (˚C)	1								
	Salinity (PSU)	−0.54	1							
	pH	−054	**0.99**	1						
	DO (mg/l)	−0.14	0.92	0.89	1					
	SPM (mg/l)	0.88	−0.81	−0.87	−0.57	1				
	NH_4^+ (mg/l)	−0.55	**0.99**	**0.99**	0.87	−0.87	1			
	NO_2^- (mg/l)	0.6	−0.46	−0.52	−0.49	0.63	−0.48	1		
	NO_3^- (mg/l)	0.5	−0.71	−0.72	−0.42	0.70	−0.75	−0.09	1	
	PO_4^{3-} (mg/l)	**0.98**	−0.57	−0.65	−0.25	0.93	−0.67	0.51	0.67	1

Values in bold are different from 0 with a significance level alpha = 0.05.

3.3.2. Principal Component Analysis

Table 3 shows the seasonality of the loading of experimental variables on principal component analysis. Factor F1 accounted for 60.6% of the total variance which had a strong positive loading for nitrate (0.89), suspended particle matter (0.9), and phosphate (0.98). Strong negative loading factor is observed for temperature (−0.93), nitrite (−0.95), whereas moderate negative factor loading is observed for salinity (−0.65), dissolved oxygen (−0.72) and weak negative loading factor for pH (−0.37). Factor F2 accounted for 26.6% of the total which had a strong positive loading for pH (0.85), moderate positive loading for salinity (0.74), ammonium (0.66), weak positive loading for temperature (0.36), nitrate (0.42), and weak negative loading factor for dissolved oxygen (−0.48) and nitrite (−0.3). The projection of the four seasons on the plan revealed that, rainy seasons are correlated positively with factor F1 and negatively with factor F1 (Figure 12). While, dry seasons are negatively correlated with factor F1.

The loading of experimental variables on principal component for high and low tides are shown in Table 4. For high tide, factor 1 accounted for 72.82% of total variance which had a strong positive loading for suspended particle matter (0.92), nitrite (0.85), and phosphate (0.98); positive moderate loading for nitrate (0.74); and positive weak loading for dissolved oxygen (0.4). Strong negative loading is observed for temperature (−0.78), salinity (−0.95), pH (−0.92), and ammonium (−0.95). Factor 2 accounted for 17.3% of total variance, it had a moderate positive loading for nitrate (0.6), moderate negative loading for temperature (−0.62), dissolved oxygen (−0.67), and weak negative loading for nitrite (−0.34). With 9.85% of the total variance, factor 3 had a moderate positive loading for dissolved oxygen (0.62), weak positive loading for pH (0.32), nitrate (0.31), and weak negative loading for nitrite (−0.39). The projection of the four (04) sampling stations on the factorial plan F1*F2 revealed that, factor F1 on its positive pole is represented by the upstream stations (stations N4 and N3) while on its negative pole, factor F1 is represented by the downstream stations (stations N1 and N2) (Figure 13(a)). However, for low tide, factor 1 accounted for 70.6% of total variance which had a strong positive loading for suspended particle matter (0.92), and phosphate (0.82), positive moderate loading for temperature (0.74), nitrite (0.59), and nitrates (0.73); while strong negative loading is observed for, salinity (−0.93), pH (−0.97), dissolved oxygen (−0.75), and ammonium (−0.97) (Figure 13(b)). Concerning the factor F2, it accounted for 16.8% of the total variance. Factor F2 had a moderate positive loading for temperature (0.67), dissolved oxygen (0.61), and phosphate (0.54). Weak positive loading is observed for salinity (0.36). Factor F3 had a strong positive loading for nitrite (0.76) and moderate negative loading for nitrate (−0.67). F1 on its positive pole is mainly represented by one upstream station (station N3) and on its negative pole, F1 is represented by a downstream station (station N3). Unlike factors F1 and F2, factor F3 highlights the nitrification process that occurs into the estuary.

Table 3. Loading factor of water quality parameters through different season.

Variables	Factor 1	Factor 2	Factor 3
Temperature	−0.9314519[b]	0.36022604[ac]	0.05132771
Salinity	−0.6556065[ba]	0.74531429[ab]	−0.12118890
pH	−0.3727169[bc]	0.85689739[a]	0.35610246[ac]
DO	−0.7242978[ba]	−0.48299073[bc]	−0.49204941[bc]
SPM	0.9007972[a]	0.08662833	−0.42551137[bc]
NH_4^+	−0.1258658	0.66348097[ab]	−0.73753021[ba]
NO_2^-	−0.9521744[b]	−0.30395310[bc]	0.03124656
NO_3^-	0.8861681[a]	0.42548985[ac]	0.18347864
PO_4^{3-}	0.9859329[a]	0.13461385	−0.09907263
Eigenvalue	5.452219e+00	2.392071e+00	1.155710e+00
Variance (%)	6.058022e+01	2.657856e+01	1.284122e+01
Cumulative (%)	60.58022	87.15878	100.00000

[a]variables with a strong positive factor loading; [b]variables with a strong negative factor loading; [ab]variables with a moderate positive factor loading; [ba]variables with a moderate negative factor loading; [ac]variables with a weak positive factor loading; [bc]variables with a weak negative factor loading.

Table 4. Loading of experimental variables (09) on principal components for the whole datasets for high and low tides.

Tide	Variables	Factor 1	Factor 2	Factor 3
High tide	Temperature	−0.7835975[a]	−0.6205467[ba]	0.02994514
	Salinity	−0.9580052[b]	0.2683396	0.10109305
	pH	−0.9211368[b]	0.2238657	0.31841973[ac]
	DO	0.3986291[ac]	−0.6717094[ba]	0.62442082[ab]
	SPM	0.9249118[a]	0.2461245	0.28976021
	NH_4^+	−0.9584619[b]	0.2372090	−0.15837508
	NO_2^-	0.8541921[a]	−0.3449656[bc]	−0.38904328[bc]
	NO_3^-	0.7386994[ab]	0.5961142[ab]	0.31459679[ac]
	PO_4^{3-}	0.9823081[a]	0.1005956	−0.15796008
	Eigenvalue	6.553558e+00	1.559712e+00	8.867298e−01
	Variance (%)	7.281731e+01	1.733013e+01	9.852554e+00
	Cumulative (%)	72.81731	90.14745	100.00000
Low tide	Temperature	0.7395420[ab]	0.67306889[ab]	−0.007480445
	Salinity	−0.9312366[b]	0.36440597[ac]	−0.002587593
	Ph	−0.9660537[b]	0.25782256	−0.016363939
	DO	−0.7511773[b]	0.60689364[ab]	−0.259639649
	SPM	0.9683200[a]	0.24943495	−0.011775080
	NH_4^+	−0.9672712[b]	0.25155927	0.033231181
	NO_2^-	0.5924011[ab]	0.25441296	0.764418093[a]
	NO_3^-	0.7345474[ab]	−0.07104398	−0.674827976[ba]
	PO_4^{3-}	0.8255534[a]	0.54485214[ab]	−0.146961702
	Eigenvalue	6.356946e+00	1.512743e+00	1.130312e+00
	Variance	7.063273e+01	1.680825e+01	1.255902e+01
	Cumulative (%)	70.63273	87.44098	100.00000

[a]variables with a strong positive factor loading; [b]variables with a strong negative factor loading; [ab]variables with a moderate positive factor loading; [ba]variables with a moderate negative factor loading; [ac]variables with a weak positive factor loading; [bc]variables with a weak negative factor loading.

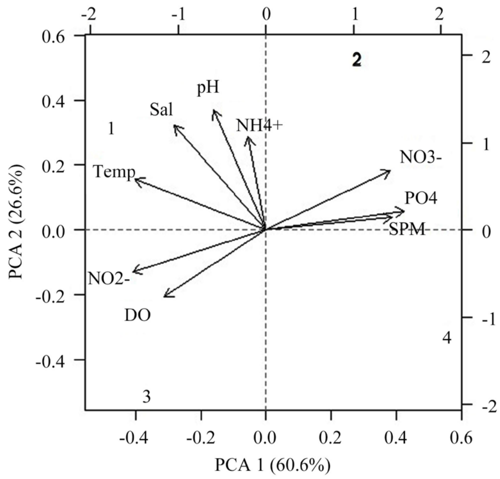

Figure 12. Principal component analysis biplot showing the seasonal variation of water quality parameters in the Nyong estuary ([1]Major Dry Season; [2]Small Rainy Season; [3]Small dry season; [4]Large rainy season).

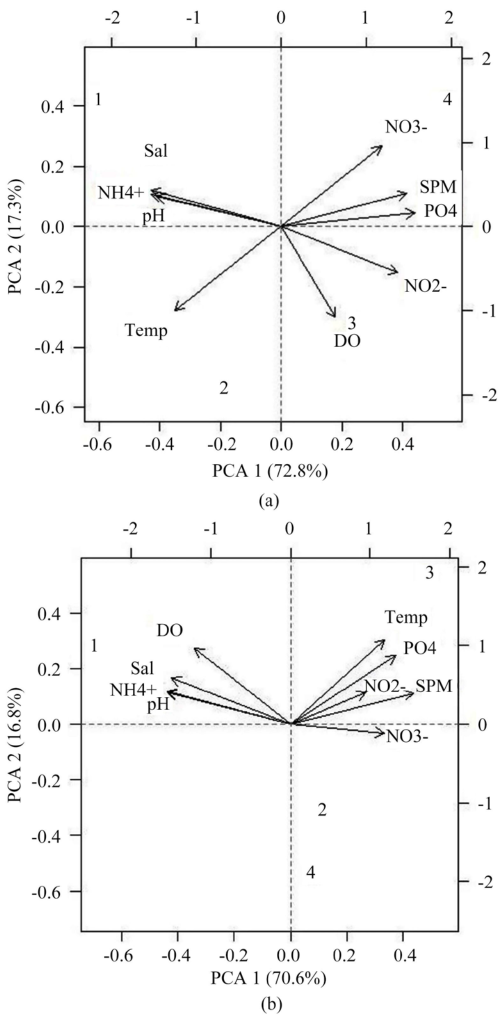

Figure 13. Principal component analysis biplot showing the spatial variation of water quality parameters in the Nyong estuary during high (a) and low tide (b). ([1]station N1; [2]station N2; [3]station N3; [4]station N4).

4. Discussion and Conclusion

Studies of water quality parameter variation in estuary represent important tools to understand estuarine functioning and diagnose natural and anthropogenic impacts as well as the change of the ecosystem overtime. Average temperature average value was 27.14˚C, similarly of those obtained in other tropical and subtropical estuaries [54]. The significant seasonal variation of temperature in the Nyong estuary may be due to the fact that surface water temperature in a shallow estuary is controlled by local conditions of the atmospheric temperature. Temperature is the most important factor to maintain the growth, reproduction, survival, and distribution of organisms in the physical environment [55].

pH is also an important variable in water quality assessment as it influences many biological and chemical processes. pH higher than 7 indicates increasing salinity and basicity while values lower than 7 tend towards acidity. Although pH average values in the Nyong estuary are around 7, they can reach a basic state with values around 9 due the influx of salt water. However, it can also be a very acidic environment with the pH below 6. pH higher than 7 but lower than 8.5 is ideal for biological productivity, while pH lower than 4 is detrimental to aquatic life [56]. According to [57], pH values vary from acidic to alkaline when colloidal particles mix with seawater and become coagulated. Changes in pH will depend on factors which govern the removal of CO_2 caused by photosynthesis through bicarbonate degradation, fresh water influx leads to a reduction in salinity and degradation of organic matter [58].

In estuarine zones, salinity is a key factor, because it depends on tide amplitude as well as river flow. Increased salinity indicates increased halide ions (Cl^-, Fl^-, Br^-, I^-), which may be due to increase in positive ions at downstream [55]. An Increase in halide ions downstream, imply a decreasing salt gradient downstream to upstream in the estuary. The decrease of horizontal salinity gradient downstream to upstream in the Nyong estuary favors the development of mangrove species. *Avicennia sp* occupies the downstream front and the *Rizophora sp* follow backward. Such structure of mangrove was also observed in Bamosso, in the Rio Ntem and also in the Cameroon estuary [59] [60] [61]. According to [62] and [63] classification, the level of salinity variation in this study, classifies the Nyong estuary as oligohaline but sometimes it can shift to mesohaline during the large dry season.

In order to survive, fish, crabs, shrimps, and other aquatic animals must have sufficient levels of dissolved oxygen in the water. The amount of dissolved oxygen in estuarine systems is a major factor that determines the type and abundance of organisms in the ecosystem. Oxygen concentration in water is the result of two natural processes: diffusion from the atmosphere and photosynthesis by aquatic plants. The mixing of surface waters by winds and waves increases the rate at which oxygen from the air get dissolved or absorbed into water. Low levels of dissolved oxygen in water could be due to high temperature, salinity and biological activities, while high concentration of dissolved oxygen is attributed to high fresh water input and the presence of phytoplankton species.

Suspended particle matter showed a significant seasonal variation ($p < 0.01$). High terrestrial runoff, along with heavy suspended solid loads brought from ground soils during small and large rainy season could be responsible for the increase of suspended particle matter in the estuary. This observation is according to [64], also showed that high terrestrial runoff during the monsoon period in the Bengal bay increases the total suspended solids concentration. Suspended particle matter is influenced by salt intrusion in the estuary. Suspended particle matter concentration increases downstream to upstream and is slightly higher during low tide. Indeed, solid suspended particles in contact with salty water will aggregate and depending on their gravity, quickly settle at the bottom, thus limiting horizontal transport by currents [64].

Parameters such as nitrate, nitrite and phosphate in coastal environment exhibit substantial seasonal variations depending on the rainfall, freshwater input, tidal ingress and consumption of nutrients by autotrophs [65]. NO_3^-, PO_4^{3-} and NO_2^- concentration decrease upstream to downstream, indicating the effect of anthropogenic activities. These nutrient concentration patterns may be attributed to the point and nonpoint sources of pollution and erosion effects [55] [66]. In general, nutrient concentration is highest during rainy seasons while the lowest concentration was found during the dry seasons. The highest concentration observed during rainy season may be due firstly to soil leaching during which particles are leached out as well as dissolved nutrients associated with these sediments. NH_4^+ concentration decreases downstream to upstream in the Nyong estuary. The highest amount of ammonium found in the downstream section of the estuary may be due to the excretion and decomposition of aquatic organisms. Nutrient concentrations in the Nyong estuary are low compared to those observed in the Douala estuary [67]. The high concentration of nutrient in the Douala estuary may be due to industrial discharge as its watershed has the highest concentration of industries in Cameroon.

The strong correlation observed between salinity, conductivity, pH and ammonium during low and high tide proves that the evolution of these variables is controlled by salt water intrusion in the river. This result is observed in most tropical estuaries. During high tide orthophosphate and dissolved oxygen are negatively correlated. This could be explained by the precipitation of phosphorus in water sufficiently oxygenated by adsorption of oxides, iron hydroxides and clay particles [68].

On a seasonal view, dray seasons and the mineralization variables contribute moderately to the first factor on its negative pole. This would express the fact that, during these seasons the estuary is more enriched by the mineralized water of the sea. On the positive pole of the first factor, the strong contribution of the organic parameters rather reflects the inflow of fluvial water, the leaching of soils during the rainy seasons [23]. During high tide, PCA shows that, salinity, pH, and ammonium are negatively correlated with factor F1, and they describe a dissolved salt gradient. These variables are opposed to nitrate, phosphate, suspended particle matter, and nitrite which describe an organic matter enrichment gradient. This result is similar with those obtained in the Lokkos estuary in Morocco and in the right bank of the Senegal River [69] [70]. During low tide, a similar contrast is observed. Two gradients are highlighted, the mineralization gradient downstream dominated by the marine stations and the organic matter gradient upstream dominated by the fluvial stations. These PCA analyses revealed that water quality in the Nyong estuary is affected by natural processes and anthropogenic activities.

In the present investigation, the principal component analysis method established by the physico-chemical typology in the estuary is governed by the combination of both the gradient of mineralization and the gradient of organic matter enrichment. Hence, the environmental factors that control the quality of estuary water are mainly influenced by oceanic and fluvial dynamics and human activities. As the marine environment is changing rapidly, this study provides a starting point in understanding biogeochemical processes as a prelude to the long-term monitoring program which will lead to modeling the hydro-biogeochemical dynamics of the Nyong estuary and may thus help authorities in elaborating strategies for integrated estuarine management to maintain a sustainable ecosystem.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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