Open Journal of Marine Science, 2022, 12, 185-199
https://www.scirp.org/journal/ojms
ISSN Online: 2161-7392
ISSN Print: 2161-7384

Effect of Tide on Temporal and Spatial Distribution of Some Physical and Chemicals Parameters in the Shallow Estuary of the Kienke River (Kribi Deep Sea Port Area, South Cameroon Coast)

Anselme Crépin Mama[1,2*], Willy Karol Bodo Abouga[1,2,3], Félix Besack[1], Firmin Landry Tadoum Bah[1,2], Stéphane Onla[1,2], Jennifer Cynthia Rachel Sissako Mongue[1,2], Frédéric Nkolo Mfoula[1,2], Fabius Kouegan[1], Durand Bernadin Djombe Kammen[1], Dorine Mara Ngo Nola[1,2], Ginette Thérèse Atoukoh Dingong[1,2], Laeticia Ingrig Ntangyong[1,2], Gervais Mani[1], Rose Eulalie Bekono Beyala[1], Josué Junior Manga Tchogom[1,2], Elcy Rhode Guiadem[2], Lawrence Mbeng Oben[1]

[1]Department of Oceanography, Institute of Fisheries and Aquatic Sciences, The University of Douala, Douala, Cameroon
[2]Association of Professionals in Coastal and Aquatics Management, Kribi, Cameroon
[3]Hydrography Service, Dredging Management Unit, Port Authority of Douala, Douala, Cameroon
Email: *mamacrepin@yahoo.fr

How to cite this paper: Mama, A.C., Bodo Abouga, W.K., Besack, F., Tadoum Bah, F.L., Onla, S., Sissako Mongue, J.C.R., Nkolo Mfoula, F., Kouegan, F., Djombe Kammen, D.B., Ngo Nola, D.M., Atoukoh Dingong, G.T., Ntangyong, L.I., Mani, G., Bekono Beyala, R.E., Manga Tchogom, J.J., Guiadem, E.R. and Mbeng Oben, L. (2022) Effect of Tide on Temporal and Spatial Distribution of Some Physical and Chemicals Parameters in the Shallow Estuary of the Kienke River (Kribi Deep Sea Port Area, South Cameroon Coast). *Open Journal of Marine Science*, **12**, 185-199.
https://doi.org/10.4236/ojms.2022.124011

Received: June 24, 2022
Accepted: October 25, 2022
Published: October 28, 2022

Abstract

The aim of this study was to highlight the effect of tide on the variation of the physicochemical parameter in the Kienké estuary. Six (06) environmental variables were monitored at nine (09) stations with the time step of one hour from 7 am to 7 pm on 4th August 2019. The hovmuller analysis showed that salinity, conductivity, total dissolved solids, and pH values increased during the flood phase and decreased during the ebb phase while oxygen concentration decreased during the flood and increased during the ebb phase. The stratification parameter has shown that the influx of seawater during high tide shifts the Kienké estuary from a well-mixed to a partially mixed environment.

Keywords

Kienké Estuary, Environmental Variables, Flood, Ebb, Stratification Parameter

1. Introduction

Approximately 60% of large cities around the world are located near estuarine regions, making these environments of great importance to the planet [1]. Estuaries are one of the most productive ecosystems on a per unit area basis and provide several important services to the coastal zone and society [2]. Estuarine ecosystems are highly productive, they are very complex and dynamic environments due to the simultaneous interaction of the river and marine forcing. Tide, wind, rainfall precipitation, surface heating, turbidity, marine and freshwater influxes are phenomena that induce important environmental change and cause estuary variability at various temporal scales. On a time scale of hours, ebb advection of fresh water and salt water intrusion during flood strongly determine strong fundamental changes in several parameters of the water column, such as salinity, nutrients and suspended particles [3] [4] [5] [6] [7]. An important aspect of the high variability and stratification of tidal estuaries is related to the short-time effects of a tidal cycle on physicochemical characteristics of the water, which can lead to various classifications. Classification is defined as a systematic arrangement of units into similar classes or groups that provide a logical approach to organizing and grouping information about ecological systems; it can be developed for coastal systems as a tool for 1) describing and inventorying near-coastal communities and habitat types, 2) increasing our understanding of differences and similarities among hundred semi-discrete units, 3) identifying and prioritizing conservation efforts, 4) managing ecosystem resources, and 5) guiding research [8] [9]. Estuaries can be classified base on water balance, geomorphology, vertical structure of salinity, and hydrodynamics criterions. Therefore, based on their salinity distribution, [10] distinguished three types: partially mixed, vertically homogeneous or well mixed, and highly stratified; and the types of estuary essentially depend on their river discharge and tidal regime, which have pronounced effects on the distribution of several physicals, chemical and biotic processes within the estuary ecosystem [11]. Permanently open estuaries are usually affected by the tidal regime but understanding the dynamic of these estuaries is particularly complex for the area with no historical data.

Cameroon is open to the Atlantic Ocean and approximately fourteen (14) major estuaries have been recorded. Despite their fluctuating nature and importance, they are poorly understood [12] [13]. The Kienké estuary is one of the estuarine system in Cameroon Southern Atlantic coast, on this system, salinity varies with seasons and governs the stratification. Sometimes, salinity values in the estuary are very close to ocean values. Although past studies have been contributed to understanding these ecosystems, tidal impact on some parameters as well as estuarine classification based on salinity gradient have received limited attention [14].

The main objective of this study was to evaluate the variation of physicochemical parameters in the Kienké estuary during a tidal cycle.

2. Data and Methods

2.1. Study Area and Sampling Stations

The Cameroon coastal rivers that are located in the south of the Nyong river are

Lokoundjé, Kienké, Lobé, and Ntem. They drain the entire Atlantic watershed in the south of the Nyong river while the eastern section is drained by tributaries rivers of the Congo river and few one by Ogoué river [15]. The watershed of Kienké is characterized by an equatorial climate with four seasons the major dry season (from November to March), the small rainy season (from April to Jun), the small dry season in July, and the large rainy season from August to October [16] [17] [18] [19] [20]. The Kienké estuary belongs to the downstream part of the Kienké watershed. It is located in the Ocean Division between 02˚934' - 02˚943' North and 09˚901' - 09˚909' East where it crosses a forest reserve. The lower course drains its waters through the city of Kribi and empties into the Atlantic Ocean through and estuary system that shelters a small port. Its watershed covers an area of 1435 km^2 dominated by a dense equatorial forest while the average flow is estimated at 49.2 m^3/s [15]. The tidal regime is semi-diurnal with two ebb and two flood phases (of approximately equal intensities each) per day (**Figure 1**). The vegetation found in the Kienké estuary indicates an area of traditional crops characterized by the presence of the *Ceiba pentadra*, *Munsanga smibii*, and palm trees [21]. The Kienké estuary is a shallow estuary due to its geological structure and measures approximately 1000 m whereas many anthropogenic activities are taking place; the Rapid Intervention Brigade (BIR) and the naval navy are situated on the right bank whereas the fisheries port and many hotels are located on the left bank.

The survey was carried out during the large rainy season *i.e.*, August 2019. It started at 7 am and ended at 7 pm on the 4th. We conducted our 13-h time series observation on a river transect (stations K9, K8 and K7), a midstream transect (stations K4, K5, and K6), a downstream transect (stations K1, K2, and K3) (**Figure 2**). The downstream transect was fixed in the estuary mouth whereas the midstream and the upstream transects were located at 0.5 km and 0.8 km from

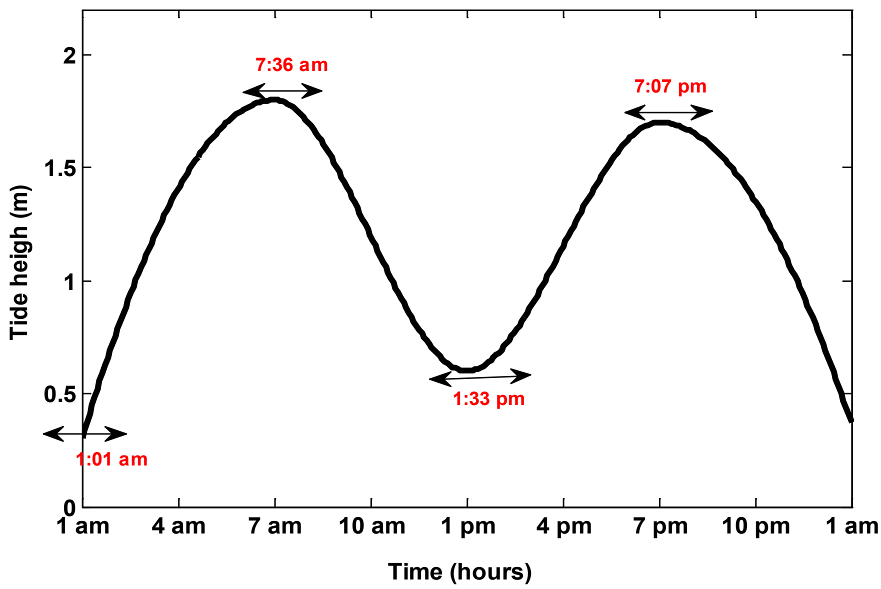

Figure 1. Tidal fluctuation in the Kienké estuary during the sampling period.

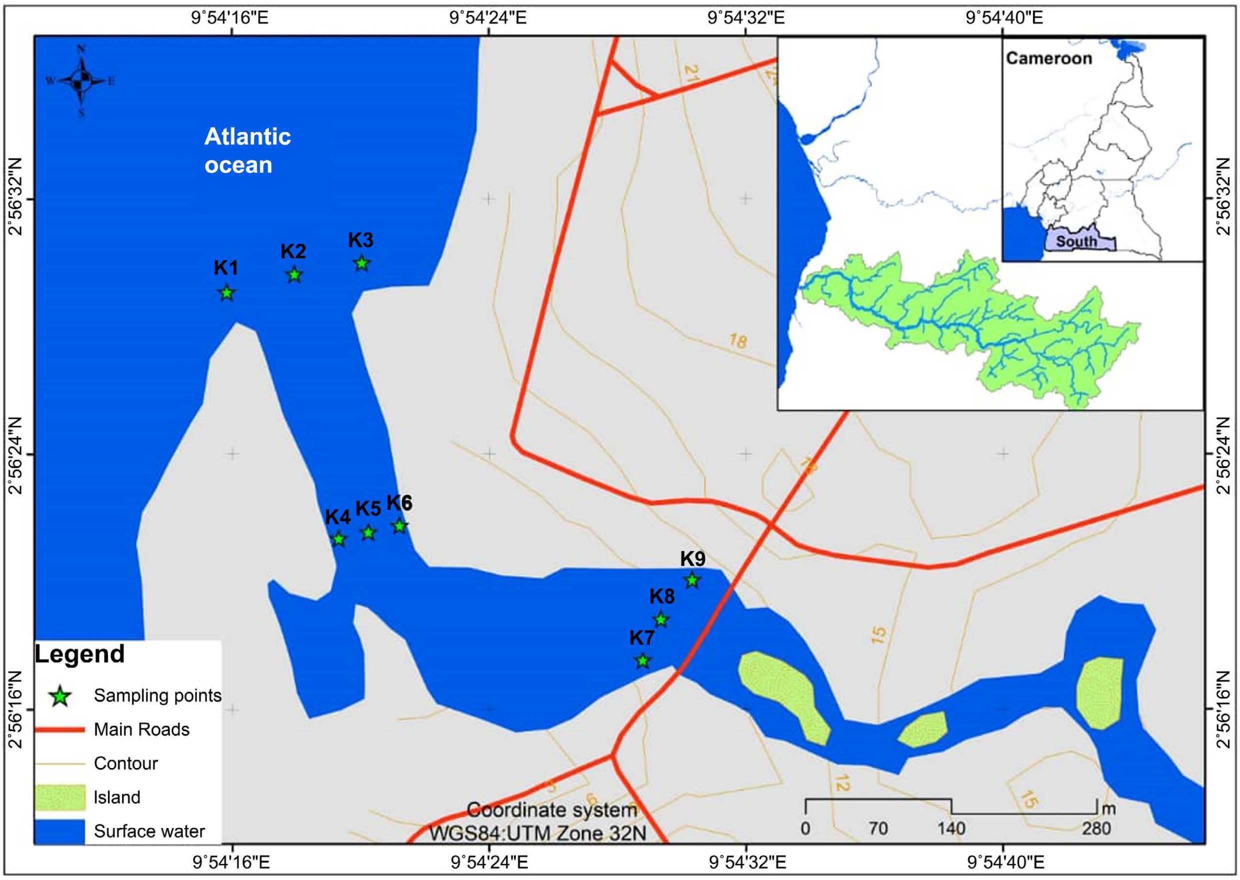

Figure 2. Map of the study area with sampling stations.

the mouth. In addition to this spatial sampling, vertical profiles were installed at 0 m, 1 m, 1.5 m, 2.5 m and 3 m depth of each transect. Temperature, salinity, conductivity, pH, dissolved oxygen, and Total Dissolved Solids (TDS) were measured using a HANNA multiparameter (HI 9829). These measurements were carried out with a sampling time step of one in every hour.

2.2. Data Analysis

The tidal effect on temporal variation of physicochemical parameters was highlighted by the hovmuller analysis. The latter is generally used to plot the temporal evolution of vertical profiles of scalar quantities of ocean constituents as a function of time. The longitudinal section of each physicochemical parameter was made to show the spatial distribution of physicochemical parameters in the estuary. Both analyses have been performed with Ocean Data View software. The stratification index η_s was calculated in each profile using [11] formula:

$$\eta s = \delta S / S'm$$

with: $\delta S = S_{\text{bott}} - S_{\text{surf}}$; $S'm = 1/2\left(S_{\text{bott}} + S_{\text{surf}}\right)$.

If $\eta_s < 0.1$, estuary is well mixed.

If $0.1 < \eta_s < 1$, estuary is partially mixed.

If $\eta_s > 1$, estuary is stratified.

The Kruskal-Wallis test was applied to the dataset in order to examine the eventual difference between the physical and the chemical variables during high and low tide.

3. Results and Discussion

3.1. Temporal Variation of Physicochemical Parameters in the River Estuary

The temporal variation of temperature, salinity, conductivity, TDS, pH, and dissolved oxygen in the Kienké river estuary are shown below. The tidal variation was made possible by observing the behaviour of the investigated parameter under ebb and flood conditions. In this study, the flood tides occur around 07:30 (first flood) and 19:00 (second flood) while the main ebb phase having an interest in this work occurs at 13:30 (**Figure 2**).

3.1.1. Temperature and Salinity

During the thirteen (13) hours of measurements, temperature ranged between 24.5˚C - 27˚C. The maximum of temperature was observed during high tide with 27˚C and 26˚C respectively around 07:00-09:00 and from 17:00-18:30. A permanent thermocline of 25.25˚C is observed between 0 m to 0.75 m during the measurement times. The result in **Figure 3** shows the influence of tide on the temperature variation. However, the surface water above 1 m depth remains relatively fresher. This situation could be explained by the constant precipitations that freshen the surface water [22]. The temporal change in temperature below 2 m depth observed in this study could be explained from the fact that, during flood tide (high water) warmer water from the open ocean enter into the estuary and slightly warmed the estuarine water. In addition to the daily change in water temperature due to atmospheric forcing [23], the water temperature of the Kienké estuary is also influence by tidal fluctuations at depth lower than 2 m. During the thirteen (13) hours of measurements, the flood phase occurring at 8:30 am seem to have cause a vertical salinity stratification (difference between the surface and near-bottom salinities), with mean surface salinity showing minimum value of 2.5 PSU while the maximum mean salinity of 12.5 PSU was observed in the in the bottom (**Figure 3**). Oppositely, during ebb tide period (11:00 am to 04:00 pm), this vertical stratification nearly disappeared. The arrival of ebb phase decreased the salinity to a remarkably low value less than 2 PSU. This result could be explained by the domination of the estuary by fresh water from riverine end at low water. Similar observations have been obtained by [24] when studying salinity intrusion in a modified estuary system. The fluctuation of salinity in the Kienké estuary depends strongly on the river runoff and the tidal cycle.

3.1.2. Conductivity and TDS

The diurnal variation of electrical conductivity and total dissolved solids (TDS) showed a quasi-similar pattern (**Figure 4**). Conductivity and total dissolved

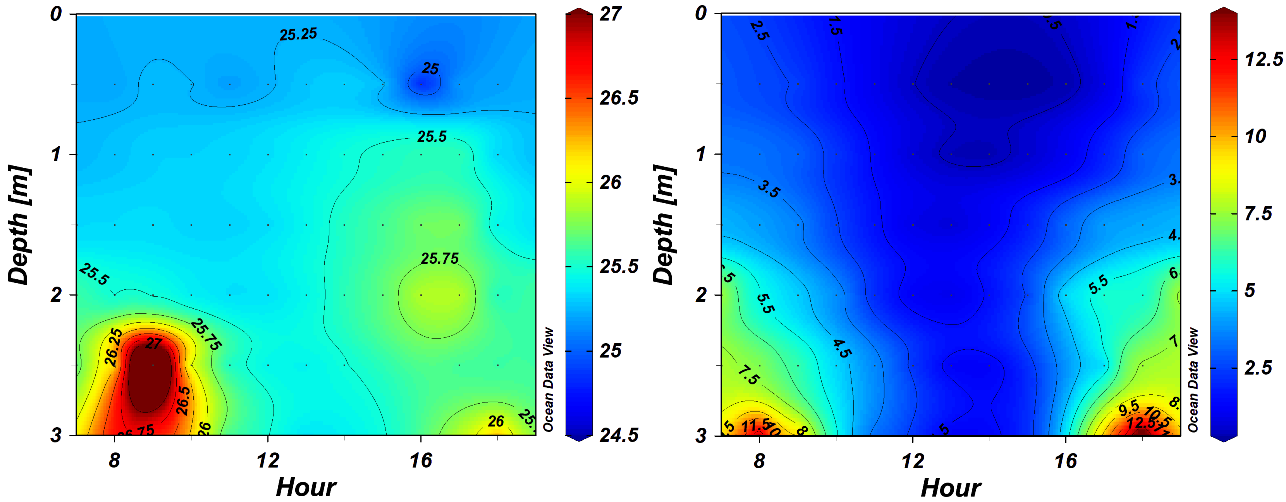

Figure 3. Temporal variation of temperature in ˚C (left) and salinity in PSU (right) in the Kienké estuary.

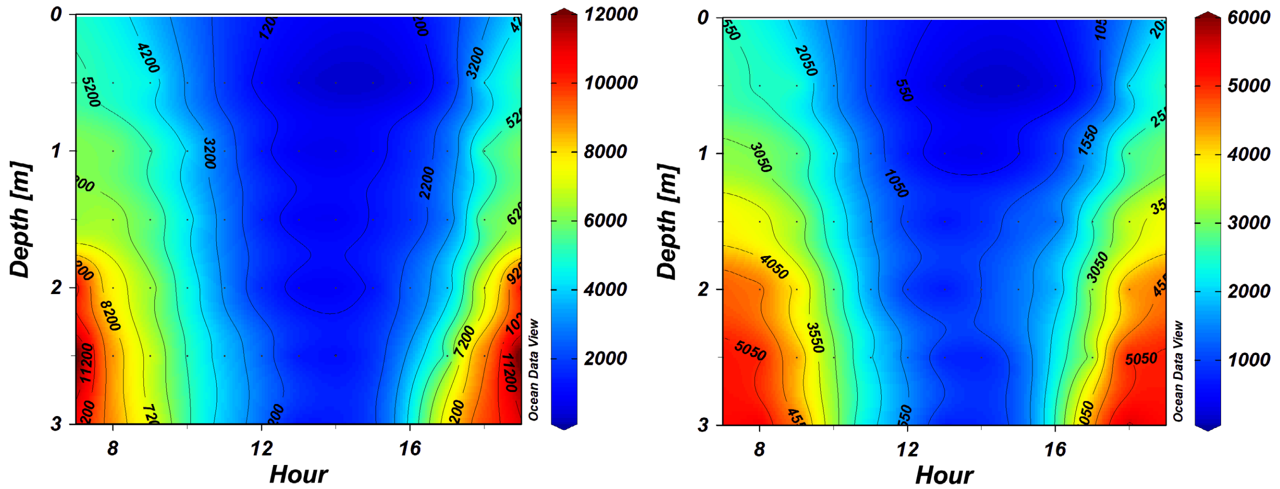

Figure 4. Temporal variation of conductivity in µS/cm (left) and total dissolved solid in mg/L (right) in the Kienké estuary.

solids increased in the river estuary during the flood phase and oppositely decreased during ebb tide period. These change are well noticeable at depth lower than 1 m. the vertical profile and the temporal gradient of conductivity ranged from 3200 µS/cm to 12,000 µS/cm with the lowest value registered during the ebb phase and at the surface. Similarly, the total dissolved solids ranged between 2550 mg/L - 5050 mg/L during the flood and between 550 mg/L - 2050 mg/L during the ebb phase. These results highlight that, at diurnal scale, conductivity and total dissolved solids significantly increase with depth during flood tide while during the ebb phase, the water column becomes homogenous. This situation is presented between the 12:00 am and 04: 00 pm. High values of electrical conductivity and total dissolved solids observed during high tide may be attributed to seawater intrusion [25].

3.1.3. pH and Dissolved Oxygen

The diel variation of pH in the Kienké estuary is shown in Figure 5. In general,

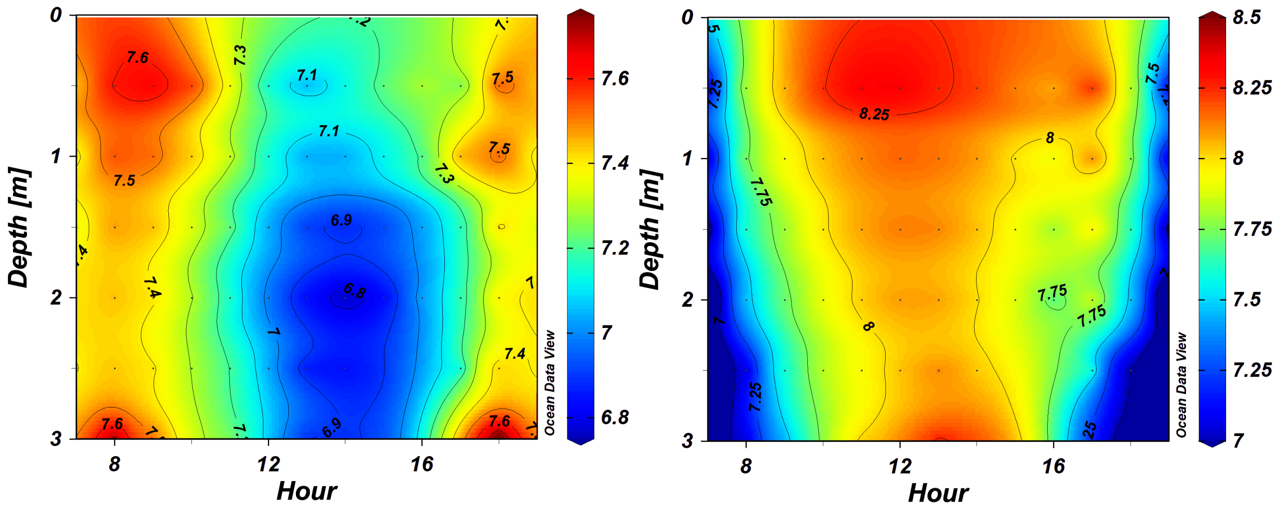

Figure 5. Temporal variation of pH (left) and dissolved oxygen in mg/L (right) in the Kienké estuary.

pH value fluctuated with tidal regime, its increased during flood periods and decreased during ebb phases. During flooding pH value ranged from 7.3 to 7.7 whereas during the ebb phase, the pH value ranged between 6.8 to 7.1. The Kienké river estuary is slightly basic during flood tide and acidic during ebb tide with is attributed to the basic character of marine water compare to the acidic fresh water of coastal rivers. Regarding the dissolved oxygen (DO) concentration varies inversely with tidal cycle in the Kienké estuary (**Figure 5**). During flood tide, oxygen concentration in the Kienké river estuary did not exceed 7.75 mg/L whereas it was between 7.75 mg/L to 8.5 mg/L during the Ebb phase (**Figure 5**). thus despite the fact that DO concentration does not vary significantly during these measurements a noticeable tidal cycle pattern is observed with slightly higher concentration during the ebb phase compare to flood phase. The inverse DO tidal pattern obtained in this result is similar to that observed in the Seto sea river estuary (Japan) by [26], indicating more oxygenated fresh water. However, the influence of diurnal tide on DO is found to be more pronounced in the Seto estuary where DO concentration double in value at diurnal scale in spring tide. This difference in gradient could be attributed to the degree of mixing and residence time of water masses in these two estuaries.

3.2. Vertical and Transversal Stratification of Physical and Chemical Parameters

The average values of vertical distribution of temperature, salinity, conductivity, total dissolved solids, pH and dissolved oxygen during high tide and low tide are showed in **Figures 6-11** respectively. During high tide, surface water temperature (0 - 1 m) is lower (24˚C - 25.5˚C) than bottom water (1 - 3 m) where temperature varies between 25.5˚C to 26.5˚C. A warm water mass is observed in the bottom closed the estuary mouth and it is expended around 200 m. During low tide water temperature seem homogenous for the whole estuary (**Figure 6**). The Kruskal-Wallis test ($p > 0.05$) revealed that water temperature does not vary

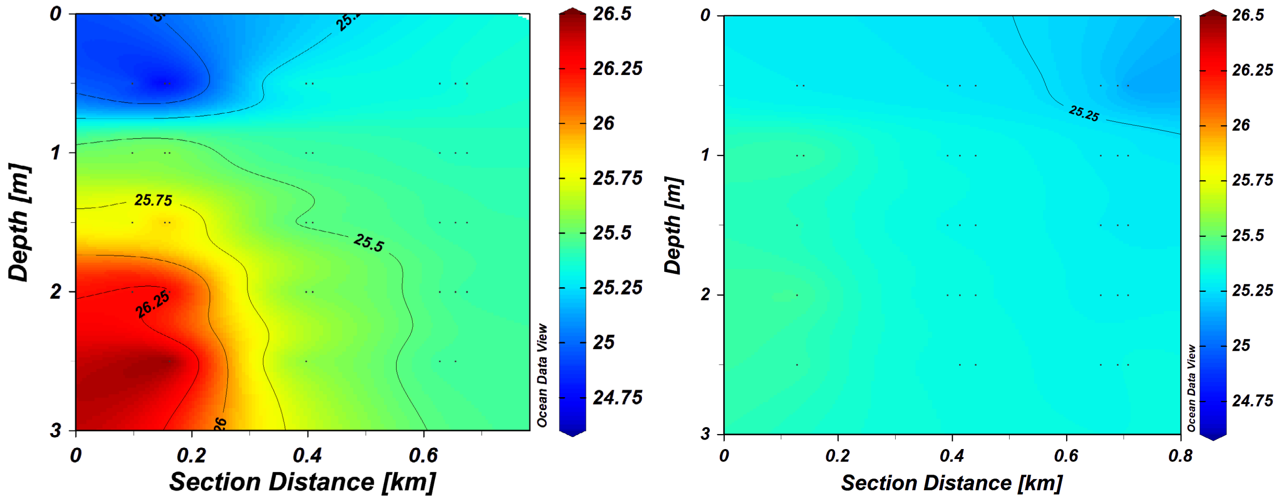

Figure 6. Vertical distribution of temperature (˚C) in the Kienké estuary during high (left) and low tide (right).

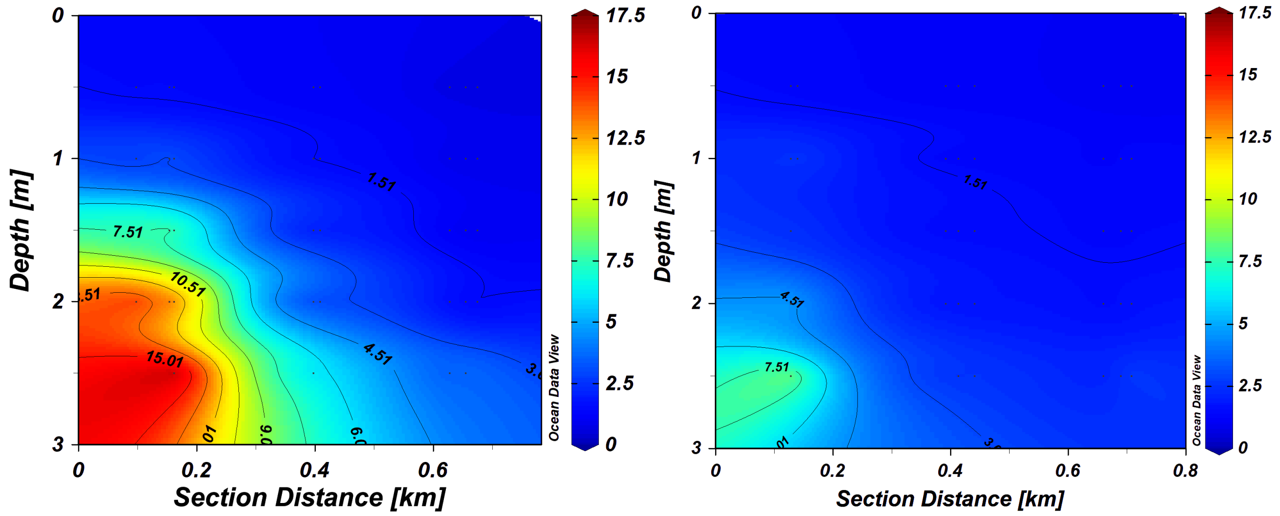

Figure 7. Vertical distribution of salinity (PSU) in the Kienké estuary during high (left) and low tide (right).

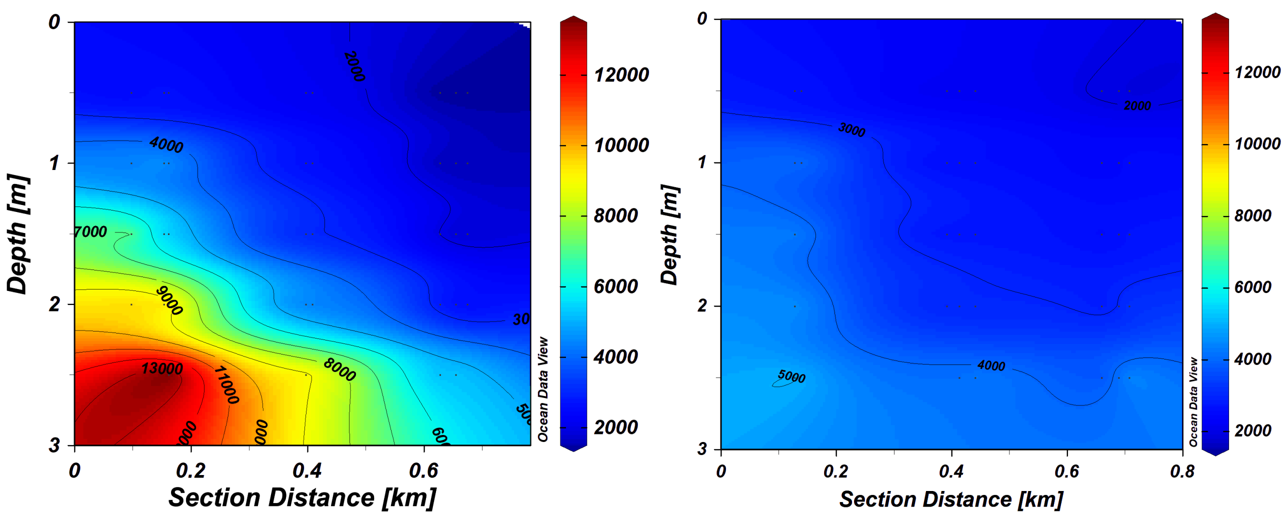

Figure 8. Vertical distribution of conductivity (µS/cm) during high (left) and low tide (right).

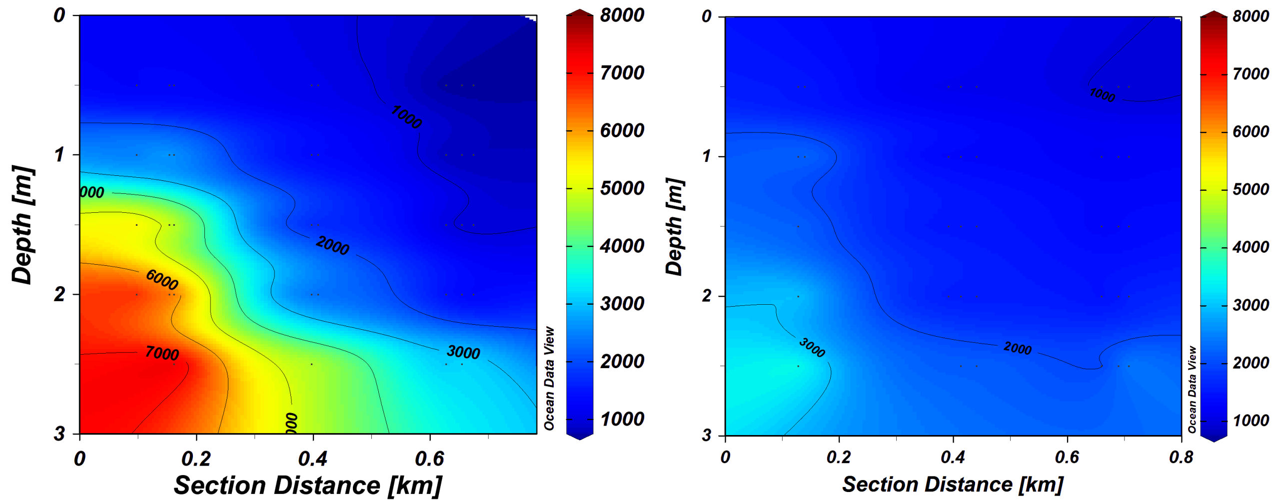

Figure 9. Vertical distribution of total dissolved solids (mg/L) during high (left) and low tide (right).

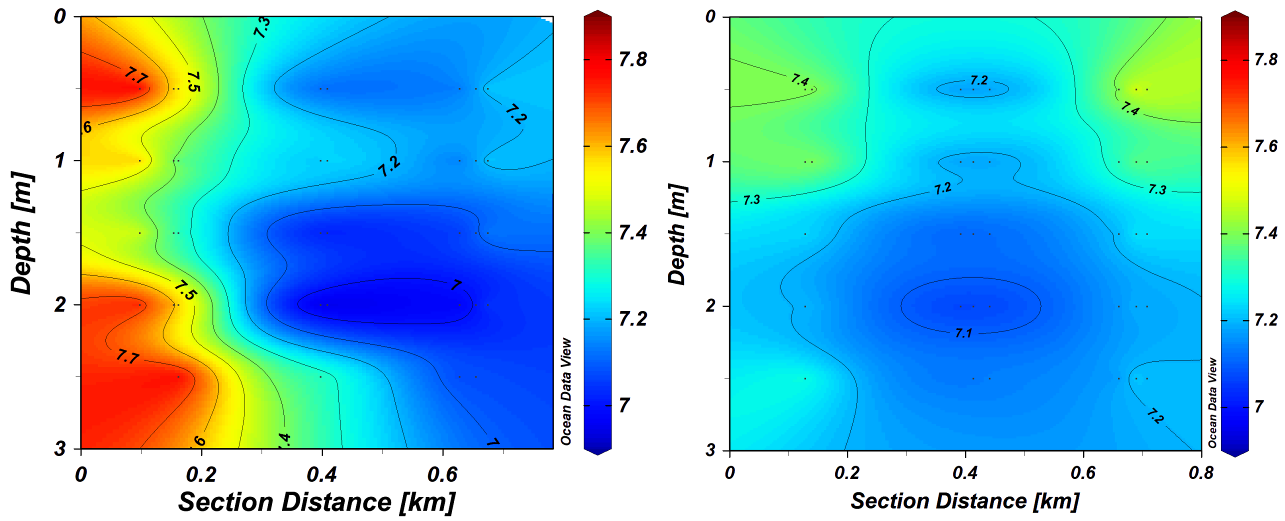

Figure 10. Vertical distribution of pH in the Kienké estuary during high (left) and low tide (right).

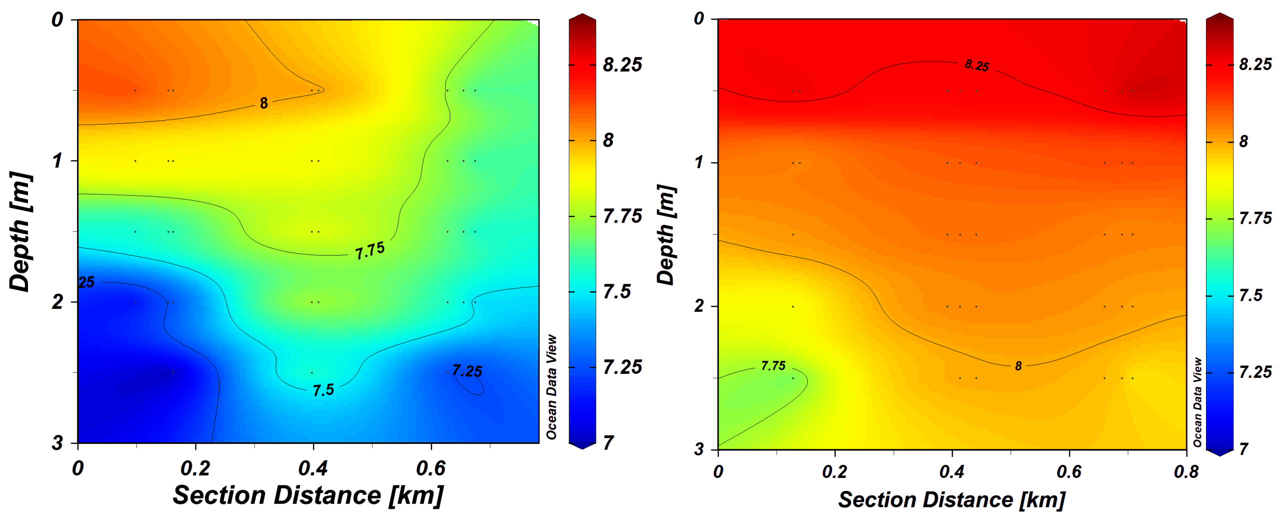

Figure 11. Vertical distribution of dissolved oxygen (mg/L) in the Kienké estuary during high (left) and low tide (right).

significantly. This result can be explained by the fact in shallow estuary, surface water temperature in shallow estuary is controlled by local condition of the atmospheric temperature [20] [27]. The vertical stratification observed during high tide could be explained by the penetration of marine water (low temperature at surface and high temperature in the bottom) into the estuary. Furthermore, the limit of this vertical stratification before 0.5 km could be explained by the limit of the sea water intrusion.

Like temperature, the vertical stratification of the estuarine salinity revealed highest values at the bottom (**Figure 7**). A minimum of 0.01 PSU was measured in the upper river estuary during both tides. The highest salinity was recorded close to the estuary mouth between 2 m to 3 m depth indicating the limit of high influence of marine water. The Kruskal-Wallis test ($p < 0.01$) revealed that the longitudinal variation of salinity varies significantly from high to low tide. Salinity increased from the surface to the bottom and the horizontal gradient showed that salinity increased upstream to downstream. The halocline (1.51 PSU) observed respectively during high tide and low tide marked the barrier between freshwater from the Kienké river and salt water from the Atlantic Ocean. These results also showed that, salt water penetrates further upstream during flood tide (0.5 km) compare to ebb tide (0.2 km). A similar trend has been noticed by [27] in the Wouri-Nkam estuary indicating the positive nature of the horizontal salinity gradient of these estuaries.

The stratification index calculated based on the salinity profile are shown in **Table 1**. During high tide the stratification index varied from 0.04 to 0.42 obtained respectively at the stations K1 and K9. While during low tide, the stratification index is comprised between −0.25 to 0.49 (**Table 1**). Except for the stations K1, K5 where the stratification parameter is less than 0.1 during high tide and for stationS K7, K8 where it was greater than 0.1, the stratification parameter was in general greather than 0.1 in the Kienké river estuary during the flood and less than 0.1 during the ebb phase. The result showed that, throughout the tidal variation, the Kienké estuary fluctuated from a partially mixed estuary during high tide to well mixed estuary during low tide. When the vertical stratification is important, the estuary behaves approximately as two layered systems, comprised of a low salinity surface layer and high salinity lower layer. When water column is completely mixed, salinity increases toward the sea but varies little with depth and the two layers can no longer be differentiated [28]. This situation commonly occurs when the dynamics of the estuary is mainly controlled by one of the two mains hydrodynamics forces (freshwater flow and tidal exchange). Thus the Kienké river estuary hydrodynamic is mainly controlled by river discharge during the ebb phase but during the flood phase estuary dynamic is govern by river and tidal forces.

Conductivity and total dissolved solids (TDS) are higher in the Kienké estuary during high tide than the low tide. For conductivity, its average ranged between 2000 - 13,000 μS/cm and 2000 - 5000 μS/cm (**Figure 8**) during high and low tide respectively. Total Dissolved Solids ranged between 1000 - 7000 mg/L and between 1000 - 3500 mg/L during high and low tide respectively (**Figure 9**). The Kruskal-Wallis test with $p < 0.05$ has revealed that conductivity varies significantly from high to low tide.

The vertical gradient of both variables increased from surface to bottom and the longitudinal variation, revealed a decreased from the estuary mouth to upstream riverine end. The vertical and axial trend in TDS and conductivity could be due by the salt gradient produce during the intrusion of marine water [27]. Depending on the ionic properties of water, excessive total dissolved solids can produce toxic effect on fish eggs. When total dissolved solids range above 2200 - 3600 mg/L salmonids, perch and pike all showed reduced hatching and egg survival rates. Dissolved solids are also important to aquatic life by keeping cell density balanced. In water with a very high total dissolved solids concentration, cells will shrink while in distilled or deionized water cell will swell. These changes can affect an organism's ability to move in water column, causing it to float or sink beyond its normal range.

pH is not a conservative parameter as salinity. Many redox reactions such as biodegradation, nitrification, denitrification, sulfide oxidation, sulfate reduction, etc., involve H+ as a reactant or product [29]. **Figure 10** illustrated the vertical distribution of the average pH in the Kienké estuary during high and low tide. pH concentration ranged from 7 to 7.7 during high tide while during low tide it ranged from 7 to 7.7. Despite the fact that the higher values of pH were obtained during high tide in the estuary mouth (distance lower than 0.2 km upstream) due to the seawater influence, the two sample t_test with a *p*_value greater than 0.05 revealed that pH variation is not significant between both tide. However, the axial pH gradient observed during flood tide disappeared during ebb phase. Despite the non-conservative nature of pH, its axial gradient of flood period highlighted a domination of a basic character (marine water) near the estuary's mouth and a les basic or neutral property at the riverine upstream. The disappearance of the axial trend (flood phase) lead to the establishment of a vertical stratification with higher pH values at the surface. The high pH values observed in the surface layer during ebb tide could be explained from surface photosynthesis that may have led to the uptake of huge amount of CO_2 thereby reducing the hydrogen potential of surface water.

Dissolved oxygen is vital for microorganism activities and impacts numerous reactions. The dissolved oxygen content ranged between 7 mg/l to 8.25 mg/l during the high tide and between 7.7 mg/l to 8.3 mg/l during the low tide (**Figure 11**). The maximum DO was recorded at the surface during low tide and

Table 1. Estuary stratification index (η_s).

Stations		K_1	K_2	K_3	K_4	K_5	K_6	K_7	K_8	K_9
High Tide	η_s	0.04	0.24	0.28	0.19	0.08	0.19	0.35	0.17	0.42
Low Tide	η_s	0.1	0	0.1	0	0	0	0.49	0.49	−0.25

the minimum of was observed at the bottom. As it recognized that DO concentration pattern can be explained by air-sea interaction and photosynthetic process, Figure 11 also revealed that tidal action has an influence on oxygen distribution indeed, during low tide the distribution of dissolved oxygen concentration was almost homogeneous but during high tide a gradient is observed with an oxycline of 7.75 mg/L. The Kruskal-Wallis test revealed that dissolved oxygen concentration variation was not significant ($p > 0.05$) from high tide to low tide indicating that they are no significant variations of the external factors influencing oxygen concentration such as atmospheric pressure, air temperature, wind speed, circulation and tides. However, the permanent vertical stratification with higher DO at the surface could be attributed to the domination of photosynthesis process in the surface and respiration at the bottom (oxygen consumption).

4. Conclusion

The present study investigated the tidal variation of physicochemical in the shallow estuary. Studying the redox dynamics under the effect of tidal fluctuation is essential to comprehensively understand the biogeochemical processes in estuarine system. Through continuous sampling and in situ measuring, the temporal and spatial variations of physicochemical parameters such as salinity, temperature, conductivity, total dissolved solids, pH, and dissolved oxygen are presented in this study. The results demonstrated that the tidal fluctuation could largely impact the distribution of physicochemical parameter in estuarine system. Specifically, salinity, conductivity, total dissolved solids, pH could be easily modified by seawater influx at flooding tide. The mixing process between the seawater and fresh water is the key contributor for salinity dynamic. This study is part of a large monitoring program of the estuarine system of Cameroon South Atlantic Coast by APCAM in order to understand their functioning.

Acknowledgements

The authors thank Pr. MOACYR ARAUJO and his team from the University of Pernambuco in Brazil for their collaboration during this project.

Conflicts of Interest

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

References

[1] da Silva, A.S.X., Noriega, C., Koening, M.L., Montes, M.F. and Araujo, M. (2017) Distribution of Nutrients and Changes in Phytoplankton Composition in a Tropical Mesotidal Estuary, Northeastern Brazil. *Open Journal of Ecology*, **7**, 460-494. https://doi.org/10.4236/oje.2017.77032

[2] Ortega-Cisneros, K., Scharler, U.M. and Whitfield, A.K. (2014) Inlet Mouth Phase Influences Density, Variability and Standing Stocks of Plankton Assemblages in Temporarily Open/Closed Estuaries. *Estuarine, Coastal and Shelf Science*, **136**,

139-148. https://doi.org/10.1016/j.ecss.2013.11.021

[3] Hernández-Ayón, J.M., Galindo-Bect, M.S., Flores-Báez, B.P. and Alvarez-Borrego, S. (1993) Nutrient Concentrations Are High in the Turbid Waters of the Colorado River Delta. *Estuarine*, *Coastal and Shelf Science*, **37**, 593-602. https://doi.org/10.1006/ecss.1993.1075

[4] Balls, P.W. (1994) Nutrient Inputs to Estuaries from Nine Scottish East Coast Rivers; Influence of Estuarine Processes on Inputs to the North Sea. *Estuarine*, *Coastal and Shelf Science*, **39**, 329-352. https://doi.org/10.1006/ecss.1994.1068

[5] Constanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P. and Van Den Belt, M. (1998) The Value of the World's Ecosystem Services and Natural Capital. *Ecological Economics*, **25**, 67-72. https://doi.org/10.1016/S0921-8009(98)00019-6

[6] Renshun, Z. (1992) Suspended Sediment Transport Processes on Tidal Mud Flat in Jiangsu Province, China. *Estuarine*, *Coastal and Shelf Science*, **35**, 225-233. https://doi.org/10.1016/S0272-7714(05)80045-9

[7] Das, S., Giri, S., Das, I., Chanda, A., Akhand, A., Mukhopadhyay, A., Maity, S., and Hazra, S. (2016) Tide Induced Annual Variability of Selected Physico-Chemical Characteristics in the Northern Bay of Bengal (nBoB) with a Special Emphasis on Tropical Cyclone-Phailin, 2013. *Indian Journal of Geo-Marine Science*, **45**, 952-959.

[8] Engle, V.D., Kurtz, J.C., Smith, L.M., Chancy, C. and Bourgeois, P. (2007) A Classification of US Estuaries Based on Physical and Hydrologic Attributes. *Environmental Monitoring and Assessment*, **129**, 397-412. https://doi.org/10.1007/s10661-006-9372-9

[9] De Miranda, L.B., Andulta, F.P., Kierfve, B., and De Castro Filho, B.M. (2017) Fundamentals of Estuarine Physical Oceanography. Vol. 8, Springer, Singapore.

[10] Mofjeld, H. (1973) Dyer, K. R. 1973. Estuaries: A Physical Introduction. Wiley-Interscience, New York and London. xv + I40 p. £3.00. *Lymnology and Oceanography*, **18**, 1012. https://doi.org/10.4319/lo.1973.18.6.1012

[11] Shivaprasad, A., Vinita, J., Revichandran, C., Reny, P.D., Deepak, M.P., Muraleedharan, K.R. and Naveen Kumar, K.R. (2013) Seasonal Stratification and Property Distributions in a Tropical Estuary (Cochin Estuary, West Coast, India). *Hydrology and Earth System Sciences*, **17**, 187-199. https://doi.org/10.5194/hess-17-187-2013

[12] Folack, J., Mbome, I.L., Bokwe, A. and Tangang, A. (1991) Cameroon Coastal Profile. Ministry of the Environment, Large Marine Ecosystem Project for the Gulf of Guinea. MINEF-Cmr/United Nations Industrial Development/UNDP-GEP Meaning United Nations Development Programme—Global Environment Facility, 102 p.

[13] GWP-Cmr (2011) Plan d'Action National de Gestion Integree des Ressources En Eau (PANGIRE), Rapport sur l'état des lieux du secteur eau et environnement au Cameroun, Tome 2, 35-180.

[14] Mama, A.C. (2019) Structure et dynamique hydrobiogéochimique des estuaires du Cameroun: Cas du Nyong et de la Kienké sur la Côte Atlantique méridionale au sud de la Sanaga, Thèse de doctorat, Université de Douala, Douala, 196 p.

[15] Olivry, J.C. (1986) Fleuves et rivières du Cameroun. Monographies hydrologiques ORSTOM, No. 9.

[16] Lienou, G. (2007) Impacts de la variabilité climatique sur les ressources en eau et les transports de matières en suspension de quelques bassins versants représentatifs au Cameroun. Thèse de doctorat, Université de Yaoundé 1, Yaoundé, 486 p.

[17] Sighomnou, D. (2004) Analyse et redéfinition des régimes climatiques et hydrologiques

du Cameroun: Perspectives d'évolution des ressources en eau. Thèse de doctorat d'état ès-sciences. Université de Yaoundé I, Yaoundé, 290 p.

[18] SOGREAH-GWP-Cmr (2012) Rapport d'établissement du Projet de Port en Eau Profonde de Kribi, 1712740—Rapport no.1 d'Etablissement, 20 p.

[19] Mama, A.C., Ghepdeu, G.F.Y., Ndam, J.R.E.N., Bonga, M.D., Onana, F.M. and Onguene, R. (2018) Assessment of Water Quality in the Lower Nyong Estuary (Cameroon, Atlantic Coast) from Environmental Variables and Phytoplankton Communities Composition. *African Journal of Environmental Science and Technology*, **12**, 198-208. https://doi.org/10.5897/AJEST2017.2454

[20] Mama, A.C., Bodo, W.K.A., Ghepdeu, G.F.Y., Ajonina, G.N. and Ndam, J.R.N. (2021) Understanding Seasonal and Spatial Variation of Water Quality Parameters in Mangrove Estuary of the Nyong River Using Multivariate Analysis (Cameroon Southern Atlantic Coast). *Open Journal of Marine Science*, **11**, 103-128. https://doi.org/10.4236/ojms.2021.113008

[21] Nyeck B., Braun J.J., Ndam J.R., Viers J., Dupré B., Bedimo Bedimo J.P., Boeglin J.L., Sigha Nkamdjou L., Freydier R., Robain H., Rouiller, J. and Muller J.P. (2004) Present Weathering Rates in a Humid Tropical Watershed: Nsimi, South Cameroun. *Geochimica et Cosmochimica Acta*, **69**, 357-387. https://doi.org/10.1016/j.gca.2004.06.022

[22] Boutin, J., Martin, N., Reverdin, G., Yin, X. and Gaillard, F. (2013) Sea Surface Freshening Inferred from SMOS and ARGO Salinity: Impact of Rain. *Ocean Science*, **9**, 183-192. https://doi.org/10.5194/os-9-183-2013

[23] Davies, O.A. and Ugwumba, O.A. (2013) Tidal Influence on Nutrients Status and Phytoplankton Population of Okpoka Creek, Upper Bonny Estuary, Nigeria. *Journal of Marine Biology*, **2013**, Article ID: 684739. https://doi.org/10.1155/2013/684739

[24] Hoagland, P., Beet, A., Ralston, D., Parsons, G., Shirazi, Y. and Carr, E. (2020) Salinity Intrusion in a Modified River-Estuary System: An Integrated Modeling Framework for Source-to-Sea Management. *Frontiers in Marine Science*, **7**, Article No. 425. https://doi.org/10.3389/fmars.2020.00425

[25] Magni, P., Montani, S. and Tada, K. (2002) Semidiurnal Dynamics of Salinity, Nutrients and Suspended Particulate Matter in an Estuary in the Seto Inland Sea, Japan, during a Spring Tide Cycle. *Journal of Oceanography*, **58**, 389-402. https://doi.org/10.1023/A:1015826212267

[26] Gisen, J.I.A., Savenije, H.H., Nijzink, R.C. and Abd. Wahab, A.K. (2015) Testing a 1-D Analytical Salt Intrusion Model and Its Predictive Equations in Malaysian Estuaries. *Hydrological Sciences Journal*, **60**, 156-172. https://doi.org/10.1080/02626667.2014.889832

[27] Besack, F., Rodrigue, E.S., Nwutih, A.G., Dieudonné, E.R., Willy, S.E., Brice, N., *et al.* (2021) Spatial and Temporal Variation of the Hydrological Parameters in the Wouri-Nkam Section of the Cameroon Estuary, Central African Atlantic Coast. *Open Journal of Marine Science*, **11**, 129-156. https://doi.org/10.4236/ojms.2021.114009

[28] Charette M.A., Lam, P.J., Lohan, M.C., Kwon, E.Y., Hatje, V., Jeandel, C., Shiller, A.M., Cutter, G.A., Thomas, A., Boyd, P.W., Homoky, W.B., Milne, A., Thomas, H., Andersson, P.S., Porcelli, D., Tanaka, T., Geibert, W., Dehairs, F. and Garcia-Orellana, J. (2016) Coastal Ocean and Shelf-Sea Biogeochemical Cycling of Trace Elements and Isotopes: Lessons Learned from GEOTRACES. *Philosophical Transactions of the Royal Society A*, **374**, Article ID: 20160076.

https://doi.org/10.1098/rsta.2016.0076

[29] Liu, Y., Jiao, J.J. and Liang, W. (2018) Tidal Fluctuation Influenced Physicochemical Parameter Dynamics in Coastal Groundwater Mixing Zone. *Estuaries and Coasts*, **41**, 988-1001. https://doi.org/10.1007/s12237-017-0335-x