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Ecological Role Of Water And Soil Physicochemical Properties In Mangrove Environment Of Cameroon And Ghana Within The West And Central African Ecoregion

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Abstract

Mangrove water and soil properties are crucial parameters in understanding the importance and role of mangrove forests and their impact on the adjacent aquatic systems. The actual study was conducted within the period of two years for both countries (One year in each country), two major sites were chosen in Ghana (Songor Ramsar site) and Cameroon (Douala Edea Reserve). In each site, three mangrove stands: 1) *Avicennia*, 2) *Rhizophora* and mixed (*Rhizophora* and *Avicennia*) were selected and marked out, and water and soil properties were assessed.

The objective of this study was to compare and characterize selected water and soil properties of the two countries. This research on mangrove ecosystem addressed three specific objectives: 1) Determine physicochemical and climatic factors affecting mangrove environment; 2) Assess the spatio- temporal variations in water and soil quality parameters of the mangrove of Cameroon and Ghana; 3) Show the interrelationships between mangrove water and soil properties in both countries within the West -Central African Ecoregion.

It was appeared that as the season changes there was a fluctuation in the physicochemical characters of the water, this will be due to ebb and flow, flushing of rain water, change in the temperature and salinity as season changes. All physicochemical parameters, except for DO, meet the requirements for marine protected waters' standard water quality as specified by DAO 2016- 08. The Effective Cation Exchange capacity (ECEC) values ranged from 4.57 to 6.62 cmolkg-1 in Ghana and 6.88 to 25.53 cmolkg-1 in

Cameroon. The mangrove soils of Cameroon were more fertile compared to those of Ghana. The present information of the physico-chemical characteristics of water would form a useful tool for further ecological assessment and monitoring of these coastal ecosystems in both countries.

Keys Words: Mangroves, Environment, water, Soil, aquatic Systems, Coastal Ecosystems, Rhizophora, Avicennia, Physicochemical Parameters.

I. Introduction

Mangrove Ecosystem are one of the most productive ecosystems, growing on sheltered shores and in estuaries in the tropics and can be found in some subtropical area (UNEP, 2007; Ajonina, 2008). Mangroves are important for coastal protection and as a source of fire wood and charcoal, and many of the coastal marine organisms in the mangrove ecosystem are natural sources of protein (Twilley et al., 1998; Mendelssohn et al., 2000).

In most tropical countries including Ghana and Cameroon, knowledge of ecological importance of mangrove ecosystem in terms of water and soil properties, has been qualitatively well documented and recognised. However, there is scanty quantitative scientific data to back this up. To assess the importance of mangrove ecosystems from a scientific perspective, it is quite necessary to attempt to determine some key parameters of ecological value such as water and soil properties (Crona, 2006; Ajonina, 2008; Spalding *et al.*, 2010).

The purpose of this research dissertation was to study and compare the ecological role of mangrove water and soil physicochemical properties in Cameroon and Ghana two contrasting coastal zones within the West and Central African ecoregion.

In addition to that, the interrelationships of those values in these two contrasting ecosystem within the West and Central African Ecoregion, will be established and definitely additional information generated, will contribute to the consolidation and increase of the knowledge in terms of water and soil characteristics of African mangrove ecosystems in the Global Mangrove Database and Information System(GLOMIS).

II. Materials and Methods

II.1 Description of the Study Area and Site selection

II.1.1 Songor Ramsar site in Ghana

Ghana is one of the states in West Africa with access to the Atlantic Ocean and lies along the Gulf of Guinea, 5.5 degrees north of the Equator, within longitudes 30 5' W and 1010' E and Latitudes 40 35'N and 110 N. It covers an area of about 239,000 km² and has a coastline of about 550 km., which is generally low lying and not more than 200 m above sea level (Spalding *et al.*, 2010). The total population is estimated at about 23 million inhabitants (FAO, 2009; Armah *et al*., 2009). The coastal area is drained by four major rivers and dotted with over 90 coastal lagoons. Most of the lagoons are very small and less than 5 km² in surface area. The largest lagoon, the Keta Lagoon however covers an approximate surface area of 350 km². The coastal area represents about 6.5% of the total area of Ghana, but houses over 60% of industries in the country (Armah and Amlalo, 1998).

The coverage of mangrove vegetation is unknown but it is believed to be in the region of 20 – 100 km^2 (Chidi Ibe, 1998; UNEP, 2007; Spalding *et al*., 2010). The Volta River Basin is located in West Africa and covers an estimated area of 400,000 km². It stretches from approximately latitude 5° 30' N in Ghana to 14° 30' N in Mali. The widest stretch is from approximately longitude 5° 30 W to 2° 00 E but the basin becomes narrower towards the coast of the Gulf of Guinea.

The climate of the region is controlled by two air masses: The North-East Trade Winds and the South-West Trade Winds. Three types of climatic zones can be identified in the region: the humid south with two distinct rainy seasons; the tropical transition zone with two seasons of rainfall very close to each other; and, the tropical climate, north of lat 9° N, with one rainfall season that peaks in August. Average annual rainfall varies across the basin from approximately 1600 mm in the south-eastern section of the basin in Ghana (Boubacar *et al*., 2005; FAO, 2009).

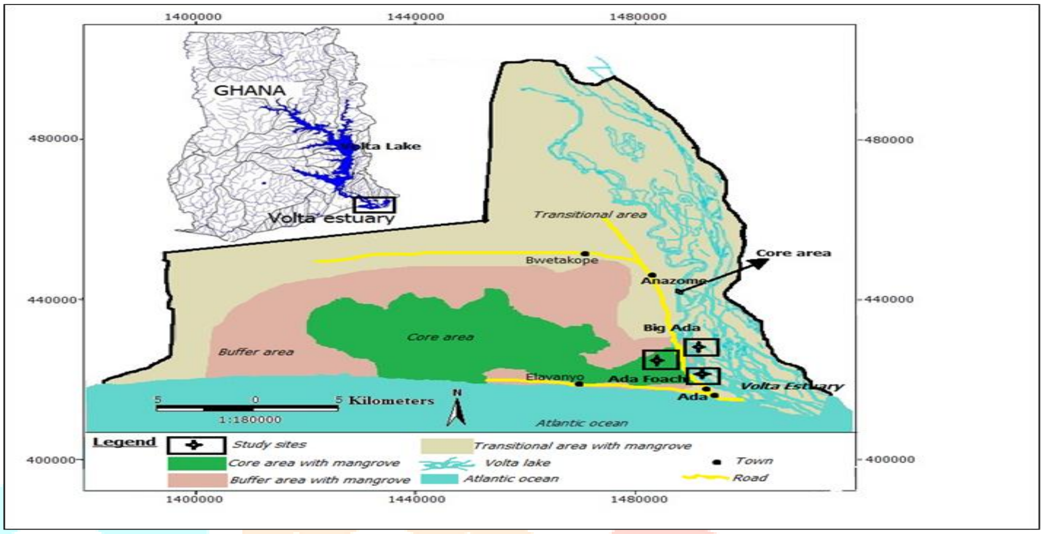


Figure 1: Map showing the Research Area at Ada Songor Ramsar site in Volta Estuary (Source: modified from EPA/UNOPS, 2004)

II.1.2 Douala- Edea Reserve in Cameroon

Cameroon is located at the extreme north-eastern end of the Gulf of Guinea and lies in the Bight of Biafra between longitudes 8° and 16° E and latitudes 2° and 13° N (Figure 2). The country has an approximate area of 475 000 km² of land, constituting about 1.47 % of the African Continent. The total population is estimated at about 19 million inhabitants (Saenger and Basco, 2008)
The Cameroon coastline is approximately 402 km long. It borders the Atlantic Ocean and extends from latitude 2° 20' N at the boundary with Equatorial Guinea to latitude 4° 40' N at the border with Nigeria. Cameroon has an inter-tropical climate which is characterized by generally hot, moist and dry conditions in the coastal zone. However, local factors, including proximity to the sea, may greatly affect the climate at various locations.

The study area has been described (see Figure 3) by Ajonina and Usongo (2001). Douala Edea Reserve (9°31'-10°05'E, 3°14'-3°53'N) is one of the largest and biologically rich mangrove reserves of Cameroon. It is situated within the Kribi-Douala Basin of the coastal Atlantic Ocean and covers a greater part of the coastal plains of the Cameroon Coast (160.000 ha). The Area has a very dense hydrological network being a meeting point of estuaries of Cameroon largest rivers (Rivers Sanaga, Nyong, Dibamba and Wouri). The Reserve is limited in the North by the rivers Wouri and Dibamba; East by rivers Sanaga, Dipombe and Kwakwa; the South by river Nyong; and the West by the Atlantic Ocean for some 100 km coastline from river Nyong to the Cameroon Estuary. The climate is equatorial type characterized by abundant rains (3000-4000 mm) and generally high temperatures with monthly average of 24-29 °C with a dry season spanning November to April.

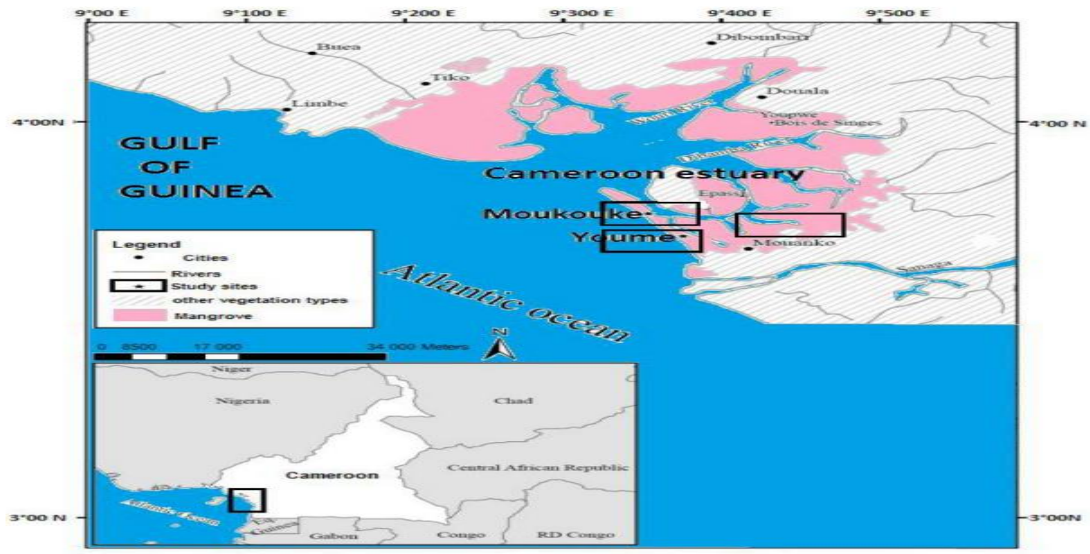


Figure 2: Map showing the sampling stations at Douala Edea Reserve in Cameroon Estuary (Source: modified from UNEP, 2007 and Nfotabong, 2011)

Prior to site selection, a preliminary survey was conducted in all of the existing mangrove ecosystems, in Ada estuary complex in the Greater Accra Region in Ghana, and in Cameroun estuary (Douala –Edea Reserve) in Cameroon. Both sites are protected areas and among the largest reserves, with a relatively high mangrove cover. The mangrove ecosystems were evaluated and identified based upon their main plant species (*Rhizophora racemosa*, *Avicennia germinans*) and their stability (very little degradation). Three study sites were then identified, based on the type of mangrove ecosystem vegetation: i) Pure red mangroves (*Rhizophora racemosa*); ii) Pure black mangroves (*Avicennia germinans*); and iii); mixed stand (red and black mangroves). These two Reserves in both countries were selected for investigation because the mangrove ecosystems are relatively well conserved.

II.2 Experimental Design and data collection

II.2.1 Survey and sampling design

Combinations of sampling approaches were used to achieve a nested design. Targeted sampling (TS) method was used to select areas of species agglomerations where three study sites representing the various species agglomerations (stands of pure *Rhizophora*, pure *Avicenina* and a mixture of them in equal proportion) were retained. This was followed by a three stage multistage sampling approach to subdivide the plots to a desired measurement level corresponding to the point-centred quarter method (PCQM) revised and described by Dahdouh-Guebas and Koedam (2006). That is at each site, each of the plots (20 m x 20 m = 400 m²) corresponding to one species or mixed, were marked out. Each plot was further divided into four 10 m x10 m (100 m²) subplots and each subplot into hundred 1m x 1m sampling quadrats, and forty of them were randomly selected for some measurements. Therefore, for this research in each country, a total of 3 plots and 12 subplots covering an area of 0.24 ha were established (Plate 1). Plots and subplots were then used, for some of the parameters as tree inventory, litterfall production, water and soil measurements. (Dahdouh-Guebas and Koedam, 2006; Armah *et al.*, 2009; Kairo and Bosire, 2009). After selecting and laying out the plots (Figure 3), they were monitored for 26 months selected ecological indices between November 2008 to November 2010 (Ghana and Cameroon).

Plate 1: Demarcation of sampling plots in Cameroon study site

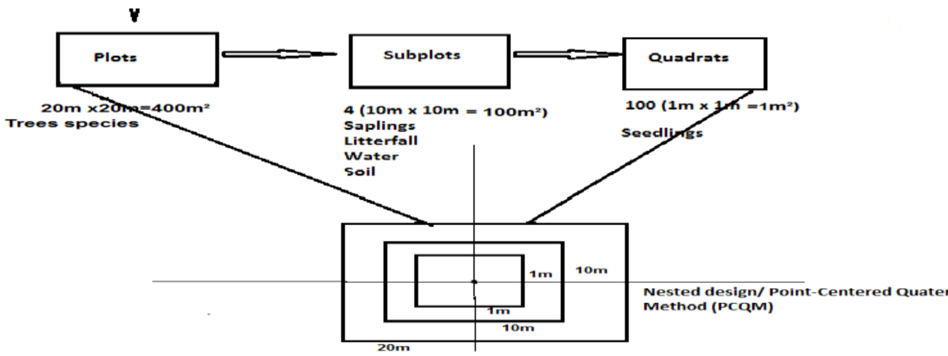


Figure 3: Sampling Design

II.2.2 Collection of water and soil samples

II.2.2.1 Mangrove surface water and porewater

Water samples were collected monthly, in six (6) plots for sampling of surface water and in twenty-four (24) subplots, for porewater. For porewater or soil water, holes of 10 to 15 cm of diameter were dugat low tide in each of the subplots, at a depth of 50 cm in each study site. Porewater was then collected 10 minutes after the hole had been dug. The soil samples collected, were put into labelled, airtight, plastic bags and kept in an ice box and brought back to the laboratory for chemical analysis.

Samples were mainly collected, for determination of parameters such as: (salinity, pH, temperature, Biochemical Oxygen Demand (BOD), Dissolved Oxygen (DO), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Conductivity, turbidity (bicarbonate, Chloride, sulphate, phosphate, nitrate, sodium and potassium). Fixing of DO samples (Dissolved Oxygen) was carried out in the field, where 100 ml of water were measured into clean oxygen bottles and flushed several times until all air bubbles escaped. Two (2) millimetres of Winkler's solution I (MnSO4 solution) and another 2 ml of Winkler's solution II (KI + NaOH solution) were added to each bottle respectively The bottles were closed and thoroughly shaken to ensure proper mixing. A brown precipitate formed at the bottom of each bottle after this process. The bottles were then, transported to the laboratory for further analysis. Data on rainfall for Ghana and Cameroon were obtained respectively from the Ghana Meteorological Agency at Legon in Accra, and the Cameroon Meteorological Agency at Douala.

II.2.2.2 Mangrove Soil properties

Soil sampling

Within each plot, four 0.5 x 0.5 m quadrats were ramdomly laid and soil samples taken from the middle of each quadrat, sediments were then sampled at three depths: 0-20 cm, 20-40 cm, 40-60 cm using a soil auger (Eijkelkamp Agrisearch Equipment BV, Giesbeek, The Netherlands). At each depth, about 200 g of soils were collected. At a random point along the perimeter of each plot, a soil pit of 60 cm deep (about 2 m long and 1.5 m wide) was dug to collect the soil samples at the three depths (Plate 4).

All collected field soil samples were brought to the laboratory of the Department of Soil Sciences within at the University of Ghana, Legon, registered and each given a serial number for easy identification. Soil samples collected on the field at low tide from depths of 0-20 cm, 20-40 cm and 40-60 cm in each 10 m x 10 m using a soil corer were put into labelled, airtight, plastic bags and taken to the laboratory for analysis. The samples were weighed before and after oven drying (on aluminium foil at 80 °C for 24 hours), to determine the physical (texture of soil, bulk density) and chemical (pH, EC, Ca, Mg, P, K, acidity, ECEC (Effective Cation Exchange Capacity), OC (Organic Carbon), OM (organic Matter) and Nitrogen (N)) properties.

Plate 2: Collection of soil at different depths with a soil Auger in *Avicennia* stand in Cameroon

II.2.2.3 Field monitoring of other physico-chemical parameters

Physico-chemical parameters monitored monthly in the field for water include salinity level, pH, temperature, BOD, DO, TDS, TSS, Conductivity, turbidity, bicarbonate, chloride, sulphate, phosphate, nitrate, sodium and potassium. The measurements of the physical parameters, (salinity, pH, temperature, conductivity, TDS, turbidity, and TSS) were carried out using the HACH 2010 machine, while the ELE-conductivity probe was used to measure the electrical conductivity (EC) and TDS. A portable pH meter and a Gel-Plast electrode which was calibrated with pH 4 and 7 standard buffers, was used to measure pH and temperature (Macintosh *et al*, 2003). Salinity was also measured using an optical refractometer (Atago, Japan). Dissolved Oxygen (DO) and Biological Oxygen Demand (BOD) were determined, by a modification of Winkler method (Chen *et al*., 2000; Fiagbezi, 2001).

II.3. Sample Analysis

II.3.1. Laboratory Analyses

Field sample Laboratory analyses in Ghana were mainly done, at Ghana Atomic Energy Commission (GAEC) at the Chemistry Department, and at the University of Ghana (Soil Department of the Ecology Laboratory Centre). In Cameroon, laboratory facilities of IRAD institute and University of Buea were used for analyses of the samples.

II.3.1.1 Physico-chemical parameters on Water and Soil

For the laboratory procedures, each sample was analyzed for the hydrochemical parameters such as total alkalinity and acidity, salinity, Dissolved Oxygen (DO), and Biological Oxygen Demand (BOD), Total Suspended and Dissolved Solids (TSS and TDS), were determined in the laboratory following methods of APHA (2005).

For cation determination, the flame photometer was using for potassium and sodium while for nutrients and anions, the UV spectrophotometer was used for phosphate, nitrate, sulphate bicarbonate and chloride determinations (Din, 2001; World Bank, 2003; Armah *et a*l., 2009).

II.3.1.1.1 Soil analyses

Before analysis, the samples were air-dried at room temperature and then sieved through a 2 mm mesh. The pH of soil was measured using a mixture of 10 g of soil with 25 ml of deionized water. Readings of the pH meter were taken only after the mixtures were stirred for one hour. The electrical conductivity (EC) measured in soil -water ratio of 1:5, and acidity were also determined. Particle size was measured on the sodium dithionite and sodium citrate treated soil. Mixture of 4 g of soil with 2 g of sodium dithionite, 22 g of sodium citrate and 100 ml of deionized water were shaken overnight and then allowed to settle for 12 hrs. The liquid was decanted and 100 ml deionized water with 1 g of calgon were added. The mixture was again shaken for one hour before being introduced to the particle size analyzer (Coulter LS 230, Coulter Electronics Limited). For the physical analyses, the proportions of clay, silt, sand, and the median value of particle size for each soil sample were determined.

The document on International Society of Soil Science size classes for the soil/sediment particle size classification was used as follows: particle size <0.002 mm was classified as clay; ≥0.002 mm and <0.02 mm was classified as silt; and >0.02 mm was classified as sand (Brady & Weil 1999). Bulk density was field-determined. A sample of weight (Wi) and volume (V) was driven into the soil. The soil around was excavated and the excess removed from the ends. The sample was dried at 105 ºC to constant weight and re-weighed (W2). Four of such samples were taken per plot and averaged. The bulk density was calculated in grams per cubic centimetre according to the procedure of Anderson and Ingram (1989) (Amatekpor, 1995; Allotey *et al*., 2008).

(1) *Bulk density*$=W_2-W_1/V$

For the chemical analyses, soil samples from the respective study plots were analysed for their moisture content (%), cation exchange capacity (Cmolckg-1), organic carbon (gkg-1), total nitrogen (gkg), available phosphorus (mgkg-1) and exchangeables Ca, Mg and K as follows:

Percentage Soil Moisture:

Gravimetric soil water content of each study plot was estimated. An empty metal tin of weight (W1) was driven into the soil. The soil around the tin was excavated and the excess removed from the opened end and weighed (W2). Four of such samples were taken per plot averaged. The soil so sampled were emptied into soil bags and labelled for laboratory analyses. Each soil sample was dried at 105° C to constant weight in free air circulation oven, at the laboratory and reweighed (W3). The percentage soil moisture was calculated as:

(2) Percentage Soil moisture = $(W_2 - W_3)/ (W_3 - W_1)$ x 100, after determining the percentage moisture content of all collected soil samples, they were air-dried, ground in a mortar sieved through a 1 mm mesh sieve and used for the chemical analyses (Amatekpor, 1995; Asiamah, 1995).

Percentage Organic carbon:

Percentage organic carbon content of soil samples, was determined using the Wet digestion method. Organic matter in each soil ample was oxidized with a mixture of standard potassium dichromate ($K_2Cr_2O_7$) and sulphuric acid (H_2SO_4). The excess dichromate was then titrated with ferrous sulphate

(Fe_2SO_4), using barium diphenyl-4-sulphate as indicator. The percentage organic carbon content in sample was subsequently computed as follows:

(3) *Percentage Carbon in Sample* = *M* (*V*2 – *V*1) x 0.39 *Weight of soil sample (g)*

Where *M* is the molarity of the ferrous sulphate solution (mol dm^3); 0.39 = 3 x 10^-3 x 1.3 (where 3 is equivalent weight of carbon and 1.3 is the factor due to 77% carbon recovery, *V*2= Volume of Fe_2SO_4 required for the blank (cm^3); *V*1= volume of Fe_2SO_4 required for the sample (cm^3). The percentage carbon in sample was converted to g/kg of soil by multiplying by a factor stock of each plot was then computed and expressed in $kgCha^{-1}$ (Spalding et al., 2010).

Available Phosphorus:

The Olsen ($NaHCO_3$) method was used for available phosphorus (Kevin, 2009). The available phosphorus in the soil sample, was extracted with 0.5M sodium hydrogen carbonate (pH 8.5) solution. To lower the pH of the $NaHCO_3$ to about 5.0 and to remove cloudiness due to the presence of organic matter in the soil sample, 1.0 ml of 2.5M sulphuric acid was added to the mixture. To develop colour for the extracts, a solution (labelled A) was prepared by mixing thoroughly solutions of 12 g ammonium molybdate in 250 cm^3 of distilled water and 100 cm^3 of 5 N sulphuric acid. The whole mixture was topped to 2000 cm^3 volume with distilled water. From solution A, another solution (labelled B) was prepared by dissolving about 1.056 g ascorbic acid in 200 cm^3 of solution A and used for colour development.

A 15 cm^3 aliquot of the extract containing about 20 µg of orthophosphate was pipetted into a 50 cm^3 volumetric flask, and its pH was adjusted by adding a few drops of p- nitrophenol indicator and a few drops of 4N – NH_4OH until the solution turned yellow. About 8 cm^3 of solution B was added to the yellow solution developed above and topped with distilled water to volume, and left for some time for colour development. Also, a 50 cm^3 blank solution was prepared with distilled water and 8 cm^3 of solution B.

A standard phosphorus solution containing 25 µg phosphorus was also prepared by pipeting 5 ml of a standard phosphorus and blank solution into a volumetric flask and made up to 50 ml with distilled water. This was also left for some time to develop colour. The standard phosphorus and blank solutions were used to calibrate the colorimeter at 712 nm wavelength (Quesada, 2009). After the calibration of the spectrophotometer (Spectronic 301) with standard solutions, the available phosphorus in the extracts were measured and calculated as:

(4) Phosphorus in soil sample (µg/g) = RxE / AxW

Where *R* = colorimeter reading in (µg/g), *E* = volume of extractant (cm^3), A = volume of aliquot (cm^3) and W = weight of soil (g).

Total Nitrogen

The Kjeltec Auto 1030 Analyzer (distillation) method (also called the Kjeldahl procedure) was used. In this method, NH^{+4}-N is liberated by distillation of the soil digest with 40 % NaOH solution and absorbed in unstandarddized boric acid to form ammonium borate. The borate was then titrated against 0.01M hydrochloridric acid (HCl) using a mixture of bromocresol green and methyl red solutions as indicator.

About 2 grams of soil sample were weighed into Kjedahl flask and a few drops of distilled water were added to moisten the soil. A scoop of digestion accelerator mixture and later 5 ml of concentrated sulphuric acid were added to the moistened soil in the flask. The result mixture was digested to obtain a clear solution; after which it was cooled with distilled water and transferred into a 50 ml volumetric flask and topped up with distilled water.

An aliquot of 5 ml was taken into a Markhan distillation apparatus. About 2 ml of 40% sodium hydroxide was added and distilled. The distillate was collected into a flask containing 5 ml of 2% boric acid. Three drops of a mixture of bromecresol green and methyl red solutions were added to the distillate; as indicator and titrated against 0.01M HCL. A change from green to pink end point was observed (Amatekpor, 1997;

Kevin, 2009). The procedure was repeated twice and the average titre computed was used to calculate the percentage nitrogen:

(5) %N in Soil= (Vs – Vb) x Molarity of Standard HCL x 1.401/ Weight of sample digested

Where Vs = Volume (ml) of standard HCl for titration of sample and Vb = Volume (ml of standard HCl for titration of blank. The percentage nitrogen was converted to gkg by multiplying by a factor of 10 (Rayment and Higginson, 1992; Amatekpor, 1997).

Cation Exchange Capacity (CEC)

After leaching out the exchangeable bases, excess ammonium acetate was removed with ethanol. The exchanged ammonium salts were leached out with 0.1M calcium chloride ($CaCl_2$) and the excess ammonium in the leachate titrated against standard hydrochloric acid (HCl). The CEC was then calculated as follows:

(6) CEC = V x M x 250/ 100 x 100/W

Where V= Volume of HCl for titration in millilitre, M = Molarity of HCl for titration,
W = sample weight in grams.

Exchangeable cations

The concentrations of calcium (Ca), potassium (K), and magnesium (Mg) in the sediment samples were determined by using a single extraction with silver-thiourea for measuring exchangeable cations. The exchangeable cations were extracted for 4 hrs from 5 g samples by 30 ml of silver-thiourea reagent, and analysed by inductively coupled plasma optical emission spectrophotometer (Optima S300 DV, Perkin Elmer) (Kelvin *et al*., 2000).

II.4. Statistical data analysis

For this study all statistical tests were performed using the statistical packages from, PRIMER-E (Plymouth routines in multivariate ecological research) version 6 (PRIMER-E, Ltd., UK), SPSS version 18 (Statistical Package for Social Sciences), STATISTICA 6.0 (Statsoft), MINTAB 15 and Microsoft OfficeExcel 2007 softwares. Analysis of the data was mainly carried out using univariate, bivariate (descriptive and correlation analyses) and multivariate techniques (multivariate statistical and regressions analyses).

II.4.1 Descriptive and inferential statistics

For this study, two types of statistics were mainly used: descriptive and inferential. The descriptive statistics were used to assess the strength of a relationship between two variables (bivarite analysis) or among a set of variables (Multivariate analysis) as measures of association or correlation. The inferential are measures of the significance of the relationship between two or more variables. Analysis for this research was then carried out through statistical techniques and visual analysis of graphs. This included a comparison of means using a 95% confidence Interval. Latitudinal rate of change among variables was computed by comparing percent change of variable means among sites. Bar graph analysis identified latitudinal changes to mangrove water and soil properties. Histogram analysis was done for an examination of water and soil properties, trends within each individual site. The analysis of variance (ANOVA) test statistics was used to test if more than 2 population means were equal. ANOVA of mangrove water and soil was done and the differences between and within groups assessed. For data gathered once (e.g., chemical and physicals parameters, water and soil characteristics.), means, standard deviations and coefficient of variation were calculated separately for those parameters recorded on the field in each site (*Rhizophora*, *Avicennia* and mixed stands) per country, and monthly, annual and site means were compared using One-way ANOVA.

Data were tested for homogeneity of variances; no transformations were necessary. Analysis of Variance (ANOVA) was applied to assess significant differences of Physico-chemical parameters, nutrients and heavy metals content in water and soil in addition to structural characteristics between mangrove forest types (*Rhizophora*, *Avicennia* and mixed stands).

To determine which variables are different from the others in each site or country, two main Post hoc tests LSD and Tukey HSD were used in this study. Significant differences between means, were determined by Post Hoc Least Significant Difference (LDS) test at 0.05 probability level to test main effects (sites, seasons, and where applicable, species) and all interactions. Comparisons within countries and between countries were based on Tukey's Honestly Significant Difference (HSD) method.

Tests were then run, to examine differences between the three sites (Pure *Rhizophora* sp vs Pure *Avicennia* sp vs. Mixed *Rhizophora sp* and *Avicennia sp*). The similar tests have been later run to examine the differences between Ghana and Cameroon stations.
The mean and standard error (S.E.) of three sites in each country, were calculated for monthly and annual litterfall, water and soil quality. Annual litterfal of leaves, branches/twigs, flowers and fruits/seeds, and water and forest structure Characteristics were analyzed using one-way ANOVA following two main post hoc tests (Fisher LSDand HSD.

To quantify significant relationships between different parameters recorded for mangrove forest, water and soil quality, correlation analyses were run and specifically, Pearson correlation coefficients were calculated and multiple linear regressions added to all were also used to study relationships between environmental and response variables (Joshi and Ghose, 2003; Gary, 2004; Lamptey and Armah, 2008).
The data used in correlation and multiple regression analyses were log10 (x+1) transformed to improve normality (Wiafe, 2002; FAO, 2009; Spalding *et al*., 2010). For cross sites/country analyses, Hierarchical Cluster Analysis (HCA), Principal Component Analysis (PCA) and Discriminant Functions Analysis (DFA) were run to assess differences in variables collected across sites and countries during the study period.

Hierarchical cluster analysis, used in this study, assisted in identifying relatively homogeneous groups of variables, using an algorithm that starts with each variable in a separate cluster and combines clusters until only one is left. As the variables have large differences in scaling, standardization was performed before computing proximities, which can be done automatically by the hierarchical cluster analysis procedure. A dendrogram was constructed to assess the cohesiveness of the clusters formed, in which correlations among elements can readily be seen.

Principal Component Analysis (PCA) is designed to transform the original variables into new, uncorrelated variables (axes), called the principal components, which are linear combinations of the original variables. The new axes lie along the directions of maximum variance. PCA provides an objective way of finding indices of this type so that the variation in the data can be accounted for as concisely as possible (Dahdouh- Guebas, 2011) . PC provides information on the most meaningful parameters, which describes a whole data set affording data reduction with minimum loss of original information (Fourqurean *et al.*, 2012; FAO, 2009). PCA is widely used to reduce data (Nfotabong, 2011; Spalding *et al*., 2010) and to extract a small number of latent factors (principal components, PCs) for analyzing relationships among the observed variables (Deborah, 2008; Nfotabong, 2011). For each Principal Component, different factor loadings are displayed. The terms "strong", "moderate", and "weak" were applied to factor loadings of PC and refer to absolute loading values as >0.75, 0.75-0.50 and 0.50-0.30, respectively, following the approach of (Liu et al., 2003; Mohammad *et al*., 2011).

Differences among the variables and stations related to mangrove litterfall, structural characteristics, water and soil properties were tested using a two-way crossed analysis of similarity (ANOSIM) without replication (a multivariate non-parametric analogue of ANOVA), which is a permutation-based test between a priori defined groups (stations) where generated R statistic values are indicative of how similar the groups are (the closer to 1, the greater the differences; 0 indicates no difference among groups).

Discriminant Function Analysis (DFA) was also done. Discriminant analysis is a multivariate technique used for two purposes, the first purpose is description of group separation in which linear functions of the several variables (discriminant functions (DFs) are used to describe or elucidate the differences between two or more groups and identifying the relative contribution of all variable to separation of the groups (Muzilla *et al*., 2011). Second aspect is prediction or allocation of observations to group in which linear or quadratic functions of the variable (classification functions (CFs) are used to assign an observation to one of the groups. Discriminant analysis is very similar to analysis of variance (ANOVA). When given a group of variables, F tests are conducted to decide which variables are significant to differentiate between groups. The analysis derives lineaires combinations of the discriminating variables which provide maximum separation between the groups (Kovacs *et al*., 2011). These linear combinations are termed as discriminant functions and have the form: D1= di1Z1 + di2Z2 +..... + dinZn', where Di is the score of a discriminant function i, d's are weighting coefficients, and the Z's are the standardized values of the discriminating variables (Singh and Suraj, 2012).The first discriminant function was inclined such that it represented the dimension along which the maximum group differentiation occurred. The second function was independant of the first and inclined along the largest group differences not represented by the first function. Two quantities measured the relative importance of a given discriminant function.

When discriminant function was plotted as an axis, then we observed a negative coefficient of variable strongly associated with a movement in the negative direction along this axis and a positive coefficient with movement in the positive direction. Plots of the group centroids (means) along the discriminant function or axes allow a ready comparison of the degree of separation of these groups along the plotted functions. Significant tests (assuming multivariate normality) were used to examine the total separation of the groups in multivariate space (Kovacs *et al.*, 2011; Singh and Suraj, 2012).

III. RESULTS

The results of this research are presenting mainly Mangrove water and soil quality. The assessments of qualities of water and soil consider also the pollution aspects of mangrove forest. Results are presented mainly in tables and graphs.

III.1 Climatological parameters

During the study period, variations of temperature and Rainfall were observed in the sampling areas of Ghana and Cameroon, from November 2008 to November 2010. The mean air temperature varied between 26 to 30.1 º C in Ghana and 26.80 to 29.5 º C in Cameroon with higher values from January to March. Generally, in both countries, most rainfall occurred between the months of July and October for Cameroon and May and June for Ghana. The lower values were between December and February in Ghana and Cameroon. The mean rainfall varied between 50 mm to 300 mm in Ghana and 100 mm to 620 mm in Cameroon, with higher values in August and September for Cameroon and May and June for Ghana (Figure 1).

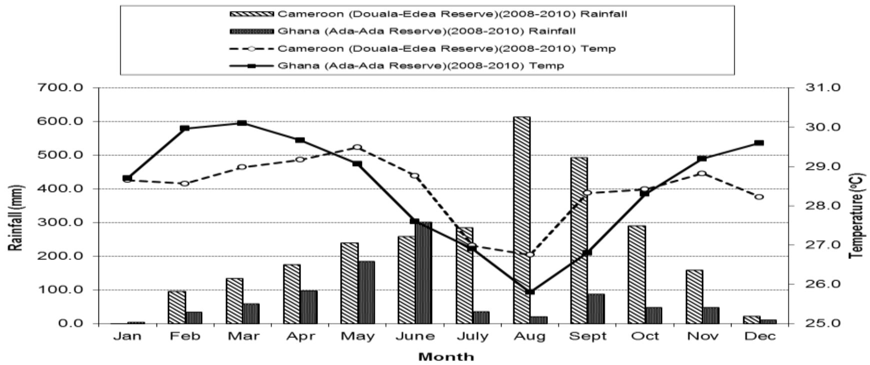


Figure 1: Annual rainfall and temperature variation in Cameroon and Ghana from November 2008 to November 2010

Data source: Ghana Meteorological Agency at Accra Legon and Cameroon Meteorological Agency at Douala.

III.2 Water quality on Mangrove Ecosystem

III.2. 1 Physico-chemical parameters in surface water

The physico-chemical characteristics of mangrove areas in Ghana and Cameroon are presented from Figure2 to Figure 9. The parameters are discussed based on the variation in both sites and countries as well as variations during the sampling months.

pH

For Cameroon, minimum average of pH values in River (June to August), *Rhizophora* (June to August), *Avicennia* (September and October) and mixed stands (June to August) were respectively: 6.92, 7.26, 7.05 and 7.21 **(**Figure 2**).** The maximum average of pH was 7.29 for *Rhizophora* (February, March, September and October), 7.37 for *Avicennia* (July), 7.39 for mixed stands (November and December) and 7.39 for River (November, December, January and February). Thus, lower values were recorded in the rainy season and higher values were observed in the dry season for River and Mixed stand. However, in *Rhizophora* stand It was observed that higher values were recorded in both the dry and rainy season. For *Avicennia*, the higher value was recorded in the rainy season.

In Ghana, water pH recorded was more or less similar only for *Avicennia* and mixed, the others fluctuated rather widely **(**Figure 2**)**. The pH for the water samples, in the four sites varied between 6.42 and 7.2 and these values ranged from a minimum average of 6.42 in *Rhizophora* stands (November, December, February, March and April) to a maximum average of 7.2 in River site on November and December. In the mangrove stands, the high value of pH was recorded respectively on August for *Rhizophora*, June to August for Mixed and November, February, March, April for *Avicennia* and November and December for River. In general, the high value of pH (7.2) was mainly observed in the rainy season and the least value in the dry season.

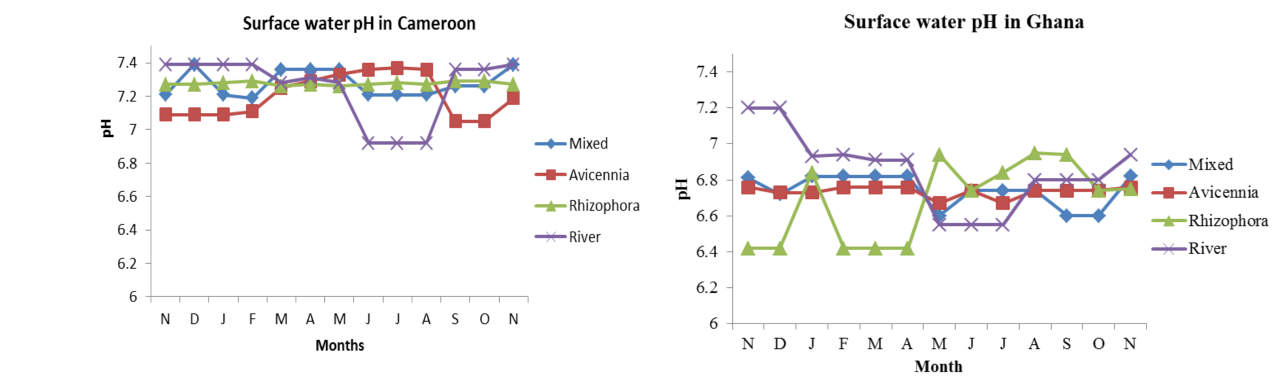


Figure 2: Seasonal changes in surface water pH in mangrove stands in Cameroon and Ghana.

Temperature

Water temperature for Cameroon during the sampling period varied from 22.3 to 26.3 ºC. The maximum temperature was observed in April 2009 in mixed stand and the minimum was recorded in March, April and May 2009 in the River (Figure 3). Water temperature showed the highest peak in: *Avicennia* (March), *Rhizophora (*July- October), mixed stands (April) and River (September- November). Seasonal variation of the temperature values presented higher values during dry season (In March for Avicennia (25.8 ºC) and in April for mixed stand (26.3 ºC) and during rainy season (In July for *Rhizophora* (24.6 ºC) in september- October for and River (25.8 ºC) (Figure3).

In Ghana, water temperature during the sampling of different seasons varied from 25.2 to 30 ºC (Figure 3). The maximum temperature was observed on November 2009 in *Rhizophora* stand and the minimum was recorded in November and December, 2008 in the *Rhizophora* stand and from January to April and November 2009 in the River. Water temperature showed the highest peak in: *Avicennia* (May and July), *Rhizophora (*November), Mixed (November) and River (August, September and October) and mixed stands (November- December on 2008 and September – October, 2009).

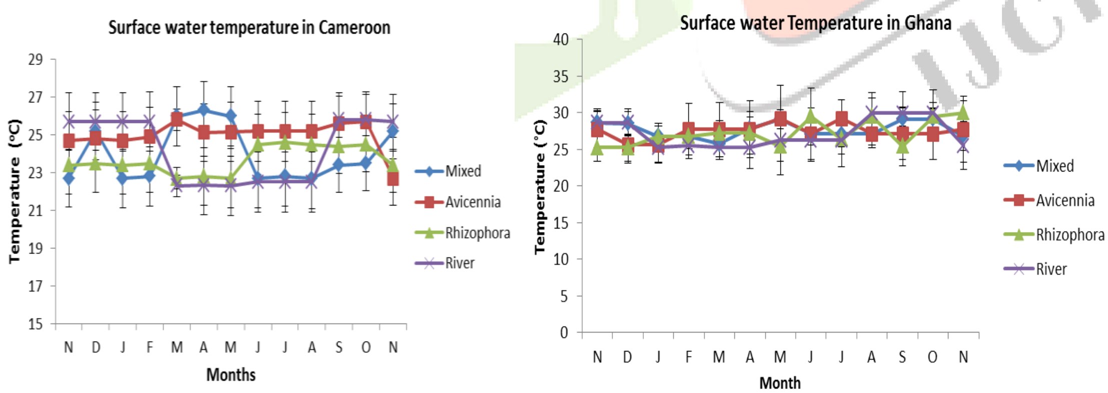


Figure 3: Seasonnal change in surface water temperature in mangrove stands in Cameroon and Ghana.

Electrical conductivity (EC)

For Cameroon, EC showed relatively great fluctuations in all the sites as well as seasons. The EC values varied between 220 µs/cm and 2550 µs/cm. The maximum value was recorded in the *Rhizophora* stand and the minimum in the *Avicennia* (Figure 4). Electrical conductivity showed the highest peak in: *Avicennia* (1852 µs/cm, from March to August), *Rhizophora* (2550 µs/cm, from March to May), mixed stands (2290 µs/cm, from March to May) and River (1313 µs/cm from March to May).

Also in Ghana, EC showed relatively high oscillations in all stations as well as seasons. The EC values varied between 284µs/cm and 4750 µs/cm. The maximum value was recorded in the *Avicennia* stand and the minimum in the mixed stand. Electrical conductivityshowed the highest peak in: *Avicennia* (4750 µs/cm, in June and July), *Rhizophora (*4002 µs/cm, March- May), mixed stands (1583 µs/cm in March) and Volta river (609 µs/cm, in May, June, July). The seasonal variation of the EC values was showed higher values during rainy season (May, June and July for *Avicennia* and Volta river) and during dry season (November, December and March for *Rhizophora* and Mixed (Figure 4).

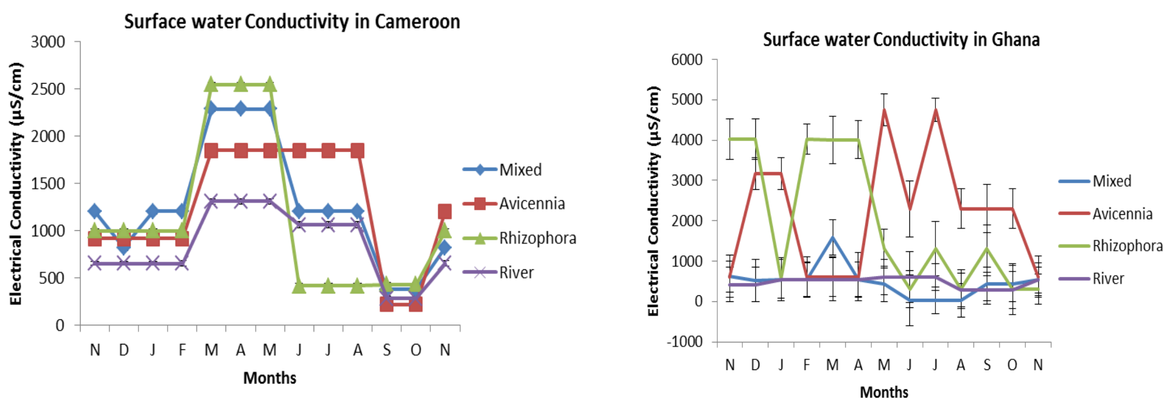


Figure 4: Seasonal changes surface water conductivity in mangrove stands in Cameroon and Ghana

Total dissolved solids (TDS)

The TDS varied between 303 and 2600 mg/l (Figure 29) for Cameroon. The maximum TDS was recorded during the months of March, April and May, in the *Rhizophora stand* and the minimum was observed during the month of September and October in the mixed and *Avicennia* stands. Total Dissolved Solids showed the highest peak in: *Avicennia* (2180 mg/l in March, April and May), *Rhizophora (*2600 mg/l in March, April and May), mixed stands (2350 mg/l in March, April and May) and River (2180 mg/l in March, April and May).
For Ghana, the TDS varied between 296 and 2220 mg/l (Figure 5). The maximum TDS was recorded during the month of June to July, in the *Avicennia* stand the minimum was observed during the month of May to July in the River. Total dissolved solids showed the highest peak in: *Avicennia* (2220 mg/l in June and July), *Rhizophora (*1675 mg/l in February, March, April), mixed stands (1112 mg/l in July) and River (296 mg/l in May, June, July). The seasonal variation of the TDS values was showed higher values during rainy season (*Avicennia* and River) and during dry season for *Rhizophora* and Mixed (Figure 5).

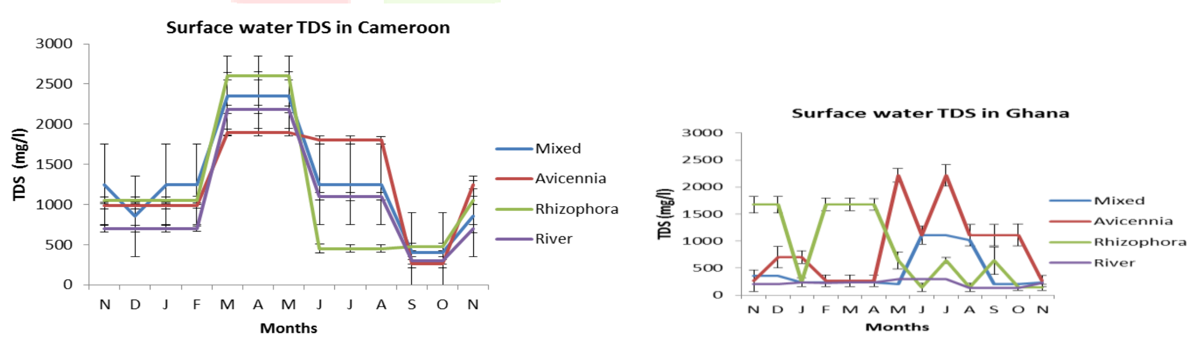


Figure 5: Seasonal variations in surface water TDS in mangrove stands in Cameroon and Ghana.

Total Suspended Solid (TSS)

In Cameroon, TSS showed relative great changes in all sites as well as seasons. The TSS varied between 20 and 294 mg/l (Figure 6). The maximum value was recorded in the *Avicennia* stand and the minimum in the *Rhizophora* stand. Total Suspended Solids showed the highest peak in: *Avicennia* (294 mg/l in May, July to September), *Rhizophora* (49 mg/l in May, July and September), mixed stands (103 mg/l in July) and River (51 mg/l from June to October). The seasonal variations of the TSS values in all sites showed higher values during rainy season (49- 294 mg/l, from june to October) and lower values mainly on the dry season (15-23 mg/l, from November to February) (Figure 6).

Similarly, in Ghana, TSS showed relative great changes*Avicennia* and Rhizophora. The TSS varied between 16 and 289 mg/l (Figure 30). The maximum value (289 mg/l) was recorded in the *Avicennia* stand and the minimum (16 mg/l) in the *Rhizophora* stand. Total Suspended solids presented the highest peak in: *Avicennia* (289 mg/l in June, August, September and October), *Rhizophora* (46 mg/l in July and September), mixed stands (98 mg/l in July) and Volta river (46 mg/l from June to October). The seasonal variations of the TSS values in all sites were showed higher values during rainy season and lower values during the dry season (46-289 mg/l, from November to February) (Figure 6).

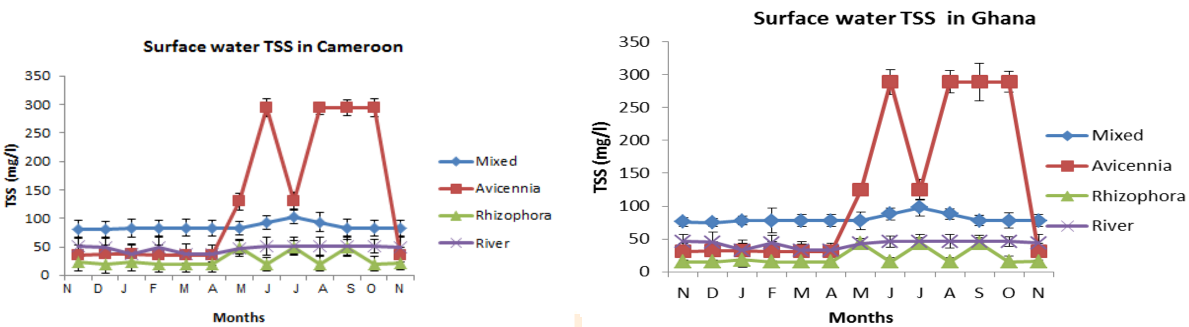


Figure 6: Seasonal variations in surface water TSS in mangrove stands in Cameroon and Ghana.

Turbidity

In Cameroon, the turbidity in the mangrove swamp varied between 23 to 255 NTU (Figure31). The maximum value (255 NTU) was observed in the *Avicennia* stand and the minimum (23 NTU) in the *Rhizophora* stand. The Turbidity showed the highest peak in: *Avicennia* (255 NTU in June, August, September and October), *Rhizophora* (42-62 NTU in May, July, September and October), Mixed stands (135 NTU in August) and River (62 NTU in February, May and November).

In Ghana, the turbidity in the mangrove swamp varied between 18 to 250 NTU (Figure 7). The maximum value was recorded in the *Avicennia* stand and the minimum in the *Rhizophora* stand. Turbidity showed the highest peak in: *Avicennia* (250 NTU in June, August, September and October), *Rhizophora* (42- 57 NTU in May, July and September). Mixed stands (130 NTU in August) and River (57 NTU in February, May and November). The seasonal variations of the Turbidity values in all sites were showed higher values during rainy season for all the mangroves stands and during the dry season (November to February) for Volta river. The seasonal variations of turbidity values in all sites, was showed higher values during rainy season (May to October) and lower values particularly during the dry season (November to February) (Figure 7).

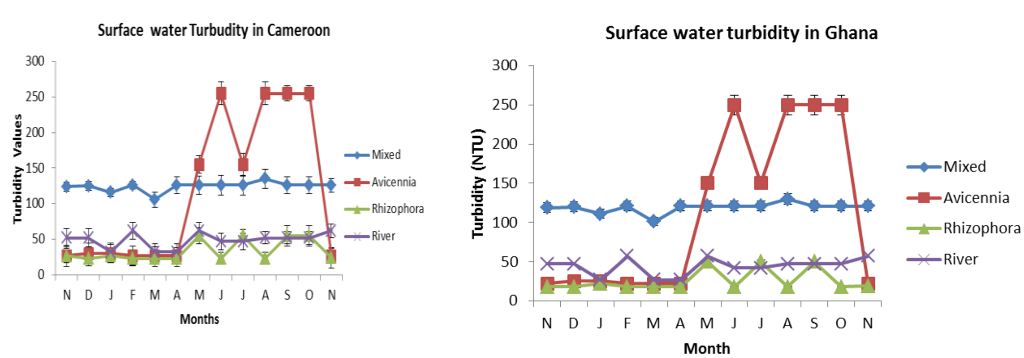


Figure 7: Monthly variations in Surface water turbidity in mangrove stands in Cameroon and Ghana.

Alkalinity

Alkalinity values for Cameroonian mangrove swamps ranged from a minimum of 35.13mg/l in June in the *Rhizophora* to a maximum of 1583.78 mg/l in March, April and May in *the* River, Alkalinity showed the highest peak in: Avicennia (70.17 mg/l from March to June), *Rhizophora* (167.75 mg/l from March to May), mixed stands (185.5 mg/l from June to August) and River (242.48 mg/l in July). The seasonal variations of the Alkalinity, values in all sites showed higher values during rainy season (May to August) for mixed stands and Wouri river (Figure8). Alkalinity values for Ghanaian mangrove swamps ranged from a minimum of 39.01mg/l in August. September and October in Volta river to a maximum of 287.72 mg/l in May and July in *Avicennia* Stand. Alkalinity showed the highest peak in: *Avicennia* (287.72 mg/l in May and July), *Rhizophora* (51 mg/l in June and July), mixed stands (85.34 mg/l in October). The seasonal variations of the Alkalinity values in all sites was showed higher values during rainy season (from July to October) and lower values during the dry season (November to February) (Figure 8).

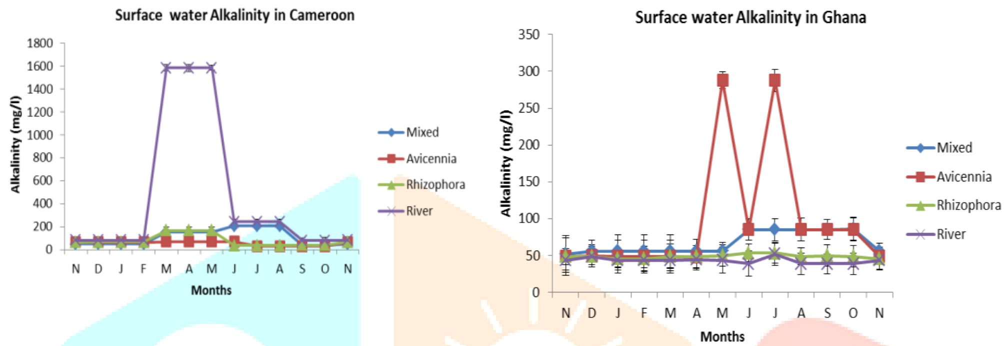


Figure 8: Seasonal changes in surface water alkalinity in mangrove stands in Cameroon and Ghana.

Salinity

Salinity in all sites for Cameroon varied between 0.04and 15.2 ‰ (Figure 35). The maximum salinity was recorded during the months of March, April and May in *Rhizophora* and the minimum was observed also during the months of March, April and May in River. Water salinity showed the highest peak in: *Avicennia* (11.3‰ in March and May), mixed stands (13.8‰ in March and May) and River (6.1‰ in June, July and August). The seasonal variations of the salinity values in all sites were showed little dependence on seasons (Figure 9).

In Ghana, salinity in at all sites varied between 0.13 and 2.6 ‰ (Figure 9). The maximum salinity was recorded during the months of May and July and the minimum was observed during the months of November and December for River Salinity showed the highest peak in: *Rhizophora* (2‰ in November, December, February, March and April), Mixed stands (0.7‰ from June to August) and River (March, May, June, August, Sept and October). The seasonal variations of the Salinity values in all sites were showed higher values mainly during rainy season and lower values during the dry season (Figure 9).

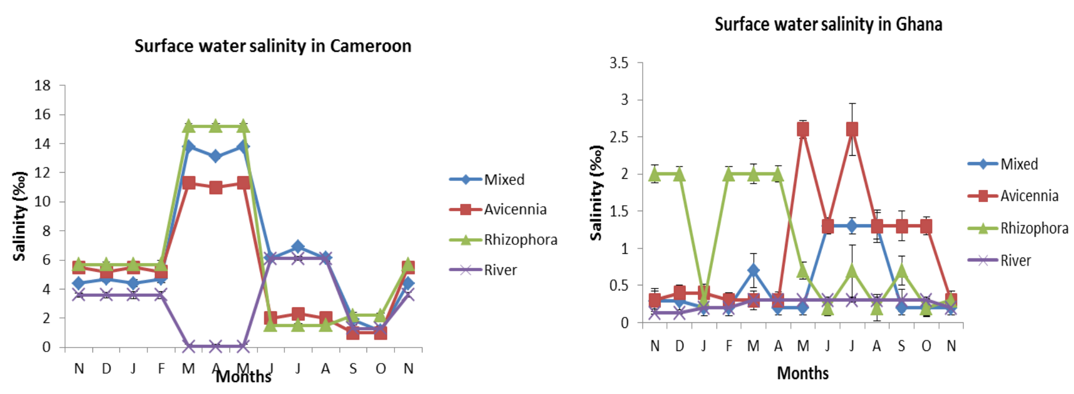


Figure 9: Monthly variations in Surface water salinity in mangrove stands in Cameroon and Ghana.

Dissolved oxygen (DO)

The Dissolved Oxygen content of Cameroonian mangrove swamps varied from 7.52 in *Avicennia* to 10.53 mg/l in *Rhizophora*. The seasonal maximum Dissolved Oxygen content in *Rhizophora* occurred in August. For *Avicennia*, the maximum value (9.5 mg/l) occurred in October. For mixed stands the maximum value (10 mg/l) occurred in October and River (9.92 mg/l) in December, January and November). The variations of the DO values among sites seasonal did not follow seasonal patterns (Figure 10).

The Dissolved Oxygen content in Ghanaian mangrove swamps varied from 2.52 to 5.53 mg/l. The maximum DO (5.53 mg/l) observed in Rhizophora occurred in February, May, July and September (Rainy season) and the minimum (2.52 mg/l) was observed inNovember in *Avicennia* (Dry season). The DO, showed the highest peak in: *Rhizophora* (5.53 mg/l) in February, May, July and September, *Avicennia* (4.1 mg/l) *August* to October in mixed stands (4.88 mg/l) from September to October and River (4.92 mg/l) from November to March The seasonal variations of the DO values among sites was showed higher values in *Rhizophora* and *Avicennia* stands mainly during rainy season and in mixed and River during dry season (Figure 10).

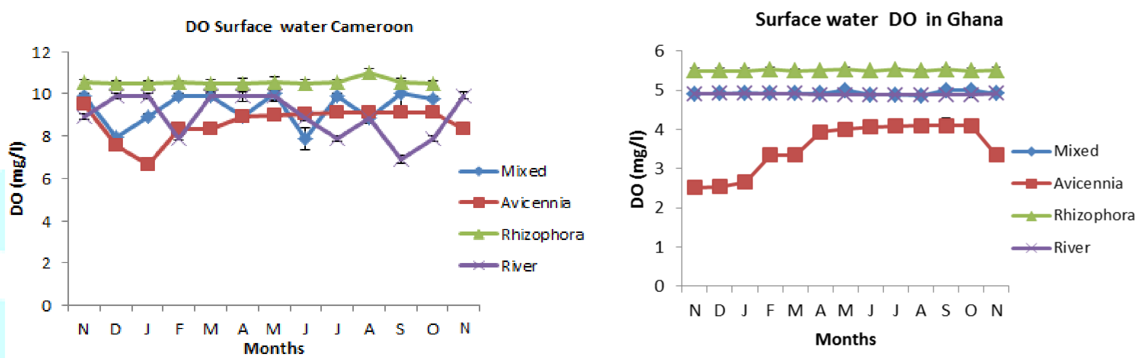


Figure 10: Surface water DO in mangrove stands in Cameroon and Ghana.

Biological Oxygen Demand (BOD)

In all sites in Cameroon, BOD values ranged from a minimum of 5.81mg/l in *Avicennia* in December, February March and to a maximum of 11.04 mg/l in *Rhizophora* in January. The BOD showed the highest peak in: *Avicennia* (9.04 mg/l) in October, Mixed stands (9.95 mg/l) in November and River (9.04 mg/l) in October. The seasonal variations of the BOD values among sites showed higher values in *Avicennia*, mixed stands and Wouri river in the rainy season and in *Rhizophora* in the dry season (Figure 11).

In all sites for Ghana, values ranged from a minimum of 0.81mg/l in *Avicennia* in November, February and March and to a maximum of 2.5 mg/l in *Rhizophora* on November. The BOD, showed the highest peak in *Avicennia* (2.04 mg/l) from August to October, mixed stands (2.02 mg/l) from June and Julyand River from April to October. The seasonal variations of the BOD values among sites was showed, higher values in Avicennia, mixed stands and Volta river mainly in the rainy season and in *Rhizophora* in the dry season (Figure 11). The lower values were particularly recorded in the dry season.

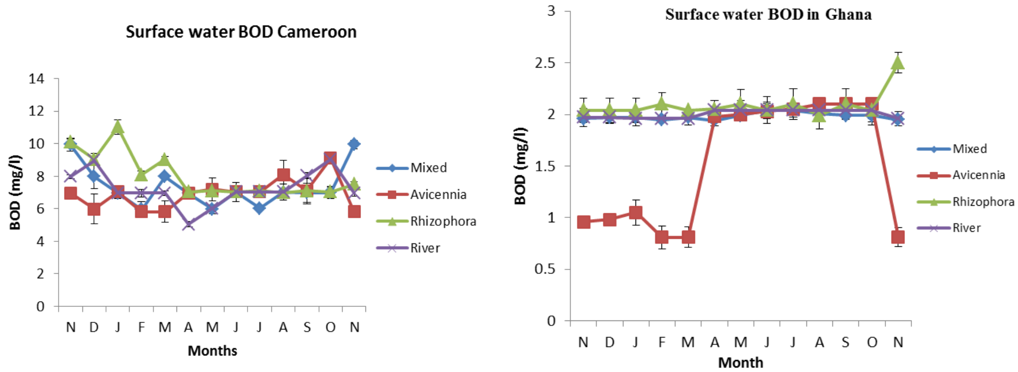


Figure 11: Monthly variations for surface water BOD in mangrove stands in Cameroon and Ghana.

Sulphate

In Cameroon, sulphate concentrations ranged from a minimum of 184 mg/l in to a maximum of 1445.58 mg/l in mixed stand from March to June. The Sulphate, showed the highest peak in: *Rhizophora* (755.22 mg/l) in April and May), *Avicennia* (583.8 mg/l) in April and May), and River (713 mg/l from July to August). The seasonal variations of the sulphate values among sites showed, higher values in *Rhizophora* and Mixed stands in the dry season. The variation of the content of sulphate in *Avicennia.Rhizophora* and Mixed stands did not relate to the seasonal patterns (Figure 12).

Sulphate concentrations for Ghana ranged from a minimum of 6.73 mg/l in River in November to a maximum of 808.956 mg/l in *Avicennia* from February to May and *Rhizophora* in November. The sulphate, showed the highest peak in: mixed stands (31.55 mg/l) in February) and River (39.82 mg/l in July). The seasonal variations of the sulphate values among sites showed higher values in *Rhizophora* and Mixed stands on the dry season. The variation of the content of sulphate in *Avicennia* and Volta river did not relate to the seasonnal patterns (Figure 12).

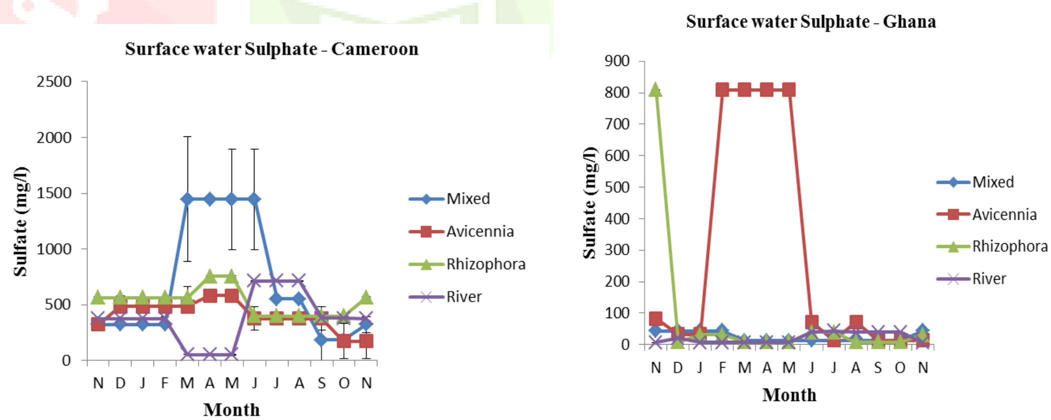
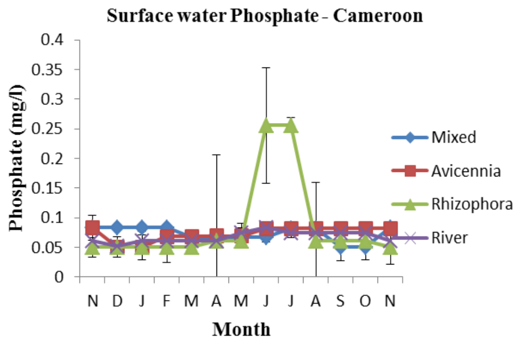


Figure 12: Seasonal changes in surface water sulphate concentrations in mangrove stands in Cameroon and Ghana.

Phosphate

The concentration of phosphates in Cameroonian mangroves varied from 0.05 to 0.256 mg/l. The maximum value was observed in *Rhizophora* in June and July and the minimum in the mixed stand in September to October and in *Rhizophora* from November to March (Figure 13). The Phosphate showed the highest peak in: *Avicennia* (0.083 mg/l) from November to January), mixed stands (0.083 mg/l) from November to February) and 0.083 mg/l River (July). The seasonal variations of the Phosphate values among sites were showed higher values in in *Rhizophora* and River in the rainy season.

The concentration of phosphates in Ghanaian mangroves fluctuated among the sites as well as between the seasons (Figure13). The phosphate values varied from 0.002 to 0.206 mg/l. The maximum value was observed in *Rhizophora* in June and July and the minimum in the *Avicennia* stand in December. The Phosphate showed low values for the rest of the year.



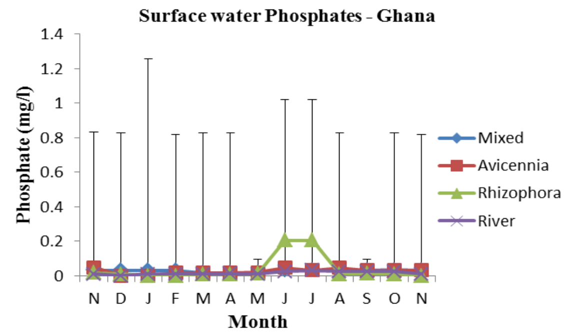
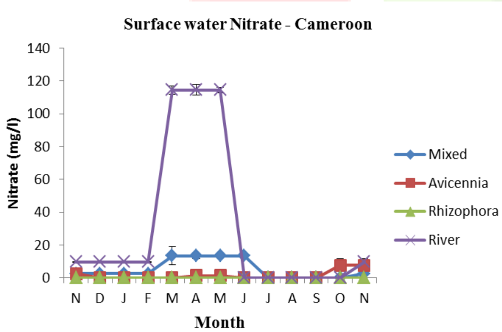


Figure13: Seasonnal variations in surface water phosphate concentrations in mangrove stands in Cameroon and Ghana.

Nitrate

Nitrate concentrations in Cameroon also fluctuated between the sites as well as the seasons (Figure14). The nitrate values varied from 1.48 to 114.38 mg/l. The maximum values were observed in March, April, Mayon the River and the minimum values were recorded on April and March in the *Avicennia* stand. Mixed stands had a peak of 13.38 mg/l from March to June and River from November to January. The variation of nitrate content in mixed stand and River did not show any seasonal patterns.

In Ghana, nitrate concentrations fluctuated among the sites as well as between the seasons (Figure14). The nitrate values varied from 0.047 to 0.595 mg/l. The maximum and minimum values were observed in the *Avicennia* mixed stands had highest nitrate peak (0.233 mg/l) in June, August and October) and River (December). The seasonal variations of the Nitrate values among sites showed higher values in the dry season and low values in the rainy season.



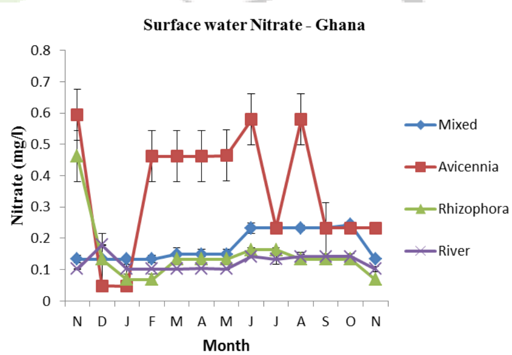


Figure 14: Seasonal changes in surface water nitrate concentrations in mangrove stands in Cameroon and Ghana.

Sodium

In Cameoon, sodium ion concentrations varied from 6 to 16.78 mg/l. The maximum value was recorded in the *Avicennia* from December to March and the minimum value was observed in the mixed stand in December – February and November (Figure 15). The Sodium, showed the highest peak in, *Rhizophora* (11.38 mg/l in April and May), mixed stands (7.37 mg/l from March to June) and River (6.86 mg/l in October). The seasonal variations of the Sodium values among sites showed higher values in the dry season. The fluctuation of Sodium content in *Rhizophora* Mixed stand and River did not depend on the seasonal patterns.

In Ghana, sodium ion concentrations fluctuated among the sites as well as between the seasons (Figure 15). The Sodium values varied from 111.4 to 2670 mg/l. The maximum value was recorded in the *Avicennia* in June and August and the minimum value was observed in River in December. The Sodium showed the highest peak in: *Rhizophora* (958 mg/l) in November), Mixed stands (356 mg/l in October) and River (354 mg/l June, August and October). The seasonal variations of the Sodium values among sites showed higher values in *Rhizophora* stands on the dry season and in *Avicennia*, mixed Stands and River on the rainy season.

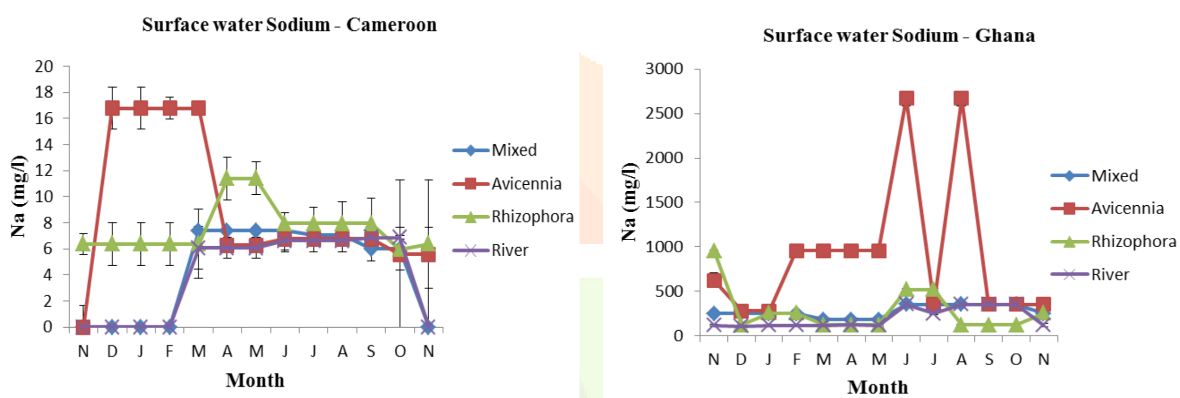


Figure 15: Seasonal changes in surface water sodium concentrations in mangrove stands in Cameroon and Ghana.

Potassium

In Cameroon, the levels of potassium in surface water fluctuated between the sites as well as the seasons. The potassium values varied from 1.19 to 46.6 mg/l. The maximum values were observed in the River (September and October) and *Avicennia* (June to September). The minimum value was recorded in the *Rhizophora* stand, in April and May (Figure 16). The Potassium showed the highest peak in: *Rhizophora* (28.4 mg/l from June to September), mixed stands (38 mg/l in July and August) and River (38 mg/l in September and October). The seasonal variations of the potassium values among sites were showed higher values in all the sites sampled in the rainy season and relatively low values in the dry season.

The levels of potassium in Ghanaian surface waters also fluctuated among the sites and in the seasons. Potassium levels varied from 1.2 to 209 mg/l. The maximum and minimum values were observed in the River respectively on June, July to August and November, January to March (Figure 16). The Potassium showed the maximum peak in: *Avicennia* (June and September), *Rhizophora* (64 mg/l) in January and February), mixed stands (208 mg/l from June to October) and River (209 mg/l June, August to October). The seasonal variations of the Potassium values among sites showed higher values in *Rhizophora* in the dry season and in mixed stand and River in the rainy season.

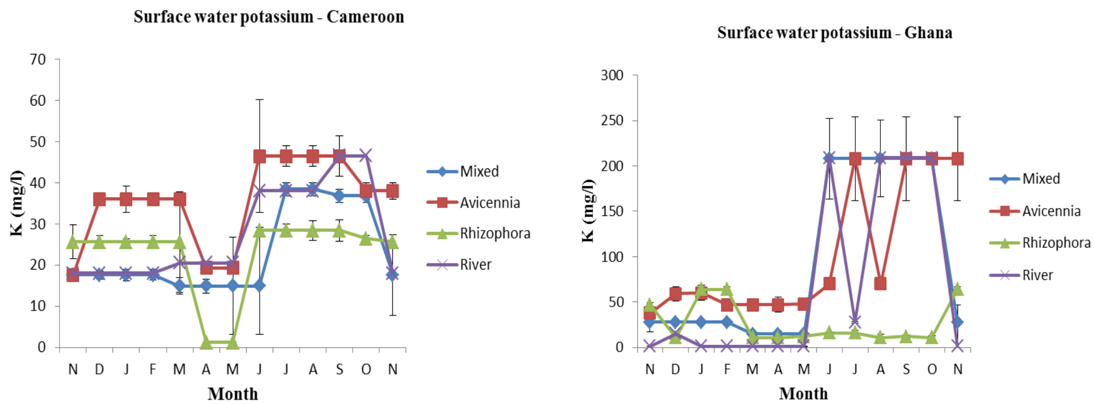


Figure 16: Seasonal changes in surface water potassium concentrations in mangrove stands in Cameroon and Ghana.

Chloride

In Cameroonian surface waters, chloride ion concentrations ranged from a minimum of 23.3 mg/l from March to April in the River and a maximum of 691.28 mg/l from October to November in the *Avicennia* stand. The Chloride showed the highest peak in: *Rhizophora* (193.2 mg/l from November to March). Mixed stands (226.88 mg/l from September to October) and River (109.9 mg/l in September and October). The seasonal variations of the Chloride values among sites showed higher values in mixed stands and River in the rainy season. In the *Rhizophor*a stand the high values were recorded in the dry season and in both seasons for *Avicennia* (Figure 17).

In Ghanaian surface waters, chloride ion concentrations ranged from a minimum of 1.5 mg/l in November in *Rhizophora* and from February in *Avicennia* stand to a maximum of 1699.43 mg/l in June and August in *Avicennia*. The Chloride alsoshowed the high peak in: *Rhizophora* (398.99 mg/l in June and July), mixed stands (1699.43 mg/l in June and August) and River (999.69 mg/l in December). The seasonal variations of the Chloride values among sites showed higher values in *Rhizophora* in the dry season and in mixed and River in the rainy season (Figure 17).

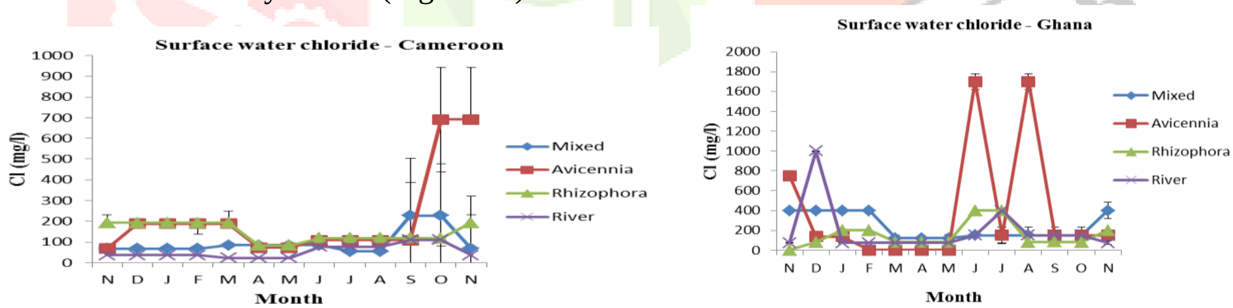


Figure 17: Surface water chloride concentrations in mangrove stands in Cameroon and Ghana.

It was observed that, no significant differences existed between mixed and *Avicennia* stands in Ghana for T°, P, K and Cl (P> 0.05), while the other paramaters presented significant differences (P<0.05). For mixed and *Rhizophora* stands in Ghana, only Cond, TSS, DO, Turb and K showed significant differences (P<0.05). Between mixed stands in Ghana and Cameroon, significant differences (P<0.05) were only found for T°, Cond, TDS, Sal, N, DO, DBO, P, and K. For *Avicennia* (Cameroon) and mixed (Ghana), significant differences (P<0.05)., were found only for T°, E.C and TDS, Sal, DO, BOD, K, P and N and Rhizophora in Cameroon and mixed stand in Ghana, no significant difference were found for Alk, Sul, and Cl. Significant Changes in soil water characteristics in both countries were therefore observed at all sites.

III.2. 2 Physico-chemical parameters in porewater

pH

The pH values in porewater for Cameroonian mangroves ranged from a minimum of 6.68 in March, April and May in the *Rhizophora* stand and a maximum of 7.43 from June to August in the mixed stand and River (September- November) (Figure 18**)**. The pH showed high peak in: *Avicennia* (7.40) in October, November, December, January and February, *Rhizophora* (7.16) from June to August, mixed stands (7.43) from June to August and River (7.39) in November and February. The seasonal variations of the mean pH values among sites showed higher values in *Rhizophora* and mixed stands in the rainy season and *Avicennia* and River in the dry season.

The mean pH values in porewater for Ghanaian mangroves ranged from a minimum of 4.81 inMarch in the mixed stand to a maximum of 7.2 from November to December in the River **(**Figure 18**)**. The pH, was just below the neutral in: *Avicennia* (6.54) in October, November, December, January and February, *Rhizophora* (6.40) on July, August, September and October, mixed stands (6.54) from July to October and River (7.2) in November and December. The seasonal variations of the mean pH values among sites showed higher values in *Rhizophora* and mixed stands on the rainy season, River in the dry season and *Avicennia* in both seasons.

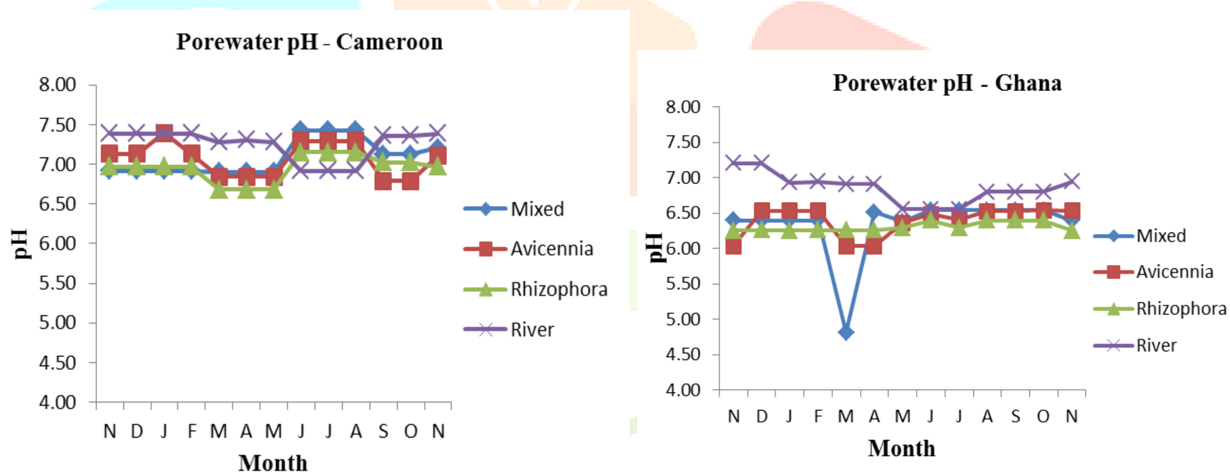


Figure 18: Seasonal changes in Porewater pH in mangrove stands in Cameroon and Ghana.

Temperature

The mean water temperature value during the sampling period in different seasons ranged, from 22.04±0.75 to 26.03±0.33ºC (Figure19). The maximum temperature was recorded from November to December in the mixed stand and the minimum was observed from June to August in the *Avicennia* stand. Mean water temperature showed the highest peak in: mixed (24.88± 0.91 ºC) from November to February. *Rhizophora* (25.25±0.91 ºC) from November to February and River (25.7 ºC) from November to February. The seasonal variations of the mean temperature values among sites showed higher values in dry season in all the studied sites. The mean water temperature value during the sampling period in different seasons fluctuated between 20.74± 13.79 and 29.9 ºC (Figure 19).

The maximum temperature was recorded from August to October in the River and the minimum was observed on March in the mixed stand. Mean water temperature showed the highest peak in: *Avicennia* (29.03± 0.10 ºC) in March, mixed (28.70±2.27 ºC) on May, *Rhizophora* (28.85±0.31 ºC) on June to August and River (29.0 ºC) 0n September to October. The seasonal variations of the mean Temperature values among sites showed higher values in *Rhizophora*, mixed and Volta river in the rainy season and *Avicennia* in the dry season (Figure 19).

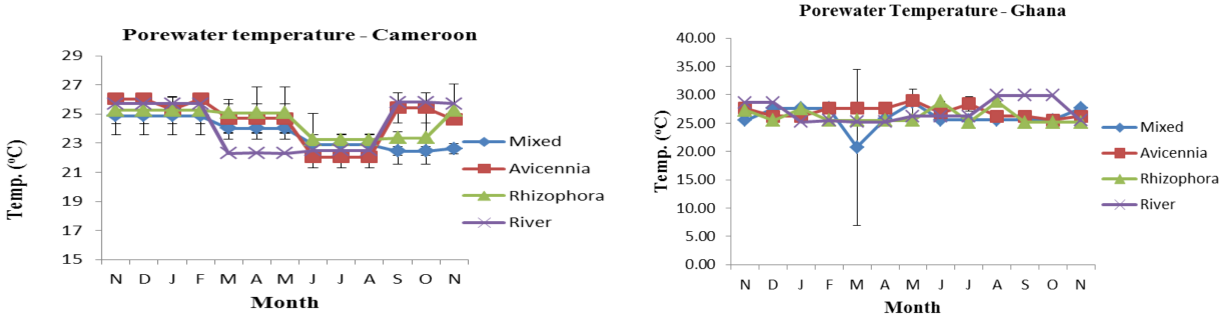


Figure19: Seasonal variations in porewater temperature in mangrove stands in Cameroon and Ghana.

Electrical conductivity (EC)

The mean EC values for porewater in Cameroon during the sampling period fluctuated between 27.75± 1.22 and 3672.50 ± 958.88 ms/cm (Figure 20). The maximum EC was observed from March to May the mixed stand and the minimum was recorded in March to May in the *Avicennia* stand. Mean EC values showed the highest peak in: *Avicennia* (1680.75 ± 379.82 ms/cm) November, December and February, *Rhizophora* (2642±193.31ms/cm) in September to October and River (1310 ms/cm) from March to May. The seasonal variations of the mean EC values among sites showed higher values in *Avicennia* in the dry season and River in the rainy season and *Avicennia*, Mixed *Rhizophora* and River in the rainy season.

In Ghana, mean EC value for porewater during the sampling period oscillated between 86.75 ± 76.15 and 10622.50 ± 3347.27 µs/cm (Figure 20). The maximum EC was observed in November, March and April in the *Avicennia* stand and the minimum was recorded in May in the mixed stand. Mean EC values showed the highest peak in: *Avicennia* (10622.50 ± 3347.27 µs/cm) November to March and April, mixed (2975.75±1649.51 µs/cm) from November to February, *Rhizophora* (4345±685.78 µs/cm) on May and River (609 µs/cm) from May to July (Figure20). The seasonal variations of the mean EC values among sites showed higher values in *Rhizophora* and River in the rainy season and *Avicennia* and mixed in the dry season.

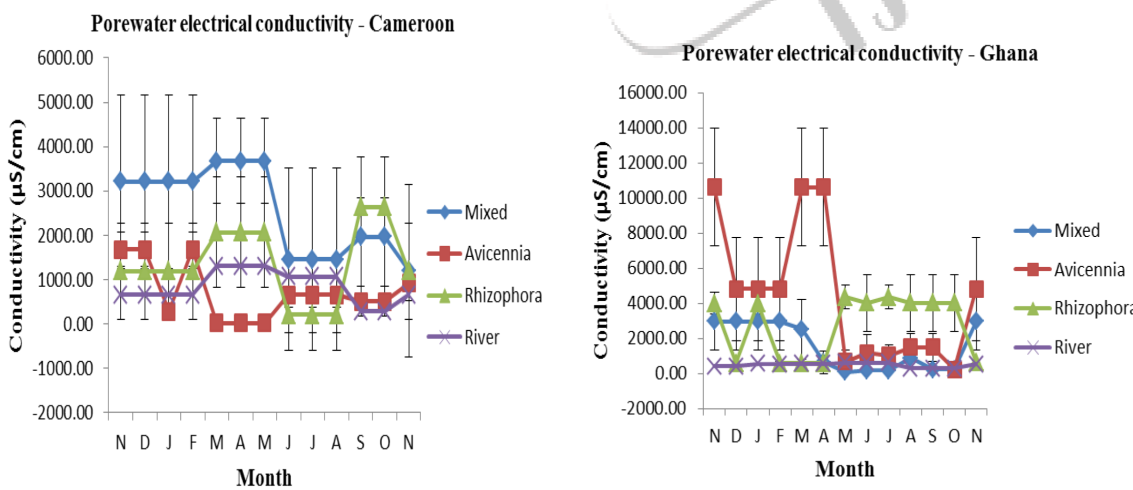


Figure 20: Monthly variations in Porewater electrical conductivity in mangrove stands in Cameroon and Ghana.

Total dissolved solids (TDS)

In Cameroon, mean porewater TDS values during the sampling period varied from 28.20 ±1.30 to 2807.50 ± 425.31 g/l (Figure 21). The maximum TDS was recorded from March to May in the *Rhizophora* stand and the minimum was observedfrom March to May in the *Avicennia* stand. Average TDS values presented the high values in: *Avicennia* (1737.75± 363.46 g/l) on November, December and February, mixed (2052.82±2095.28 g/l) from June to August and river (2180 mg/l) from March to May. The seasonal variations of the mean TSS values among sites presented higher values mainly in the rainy season for *Rhizophora*, mixed stands and River all the studied sites and in the dry season for *Avicennia*.

Mean porewater TDS values for Ghana during the sampling period were varied from 0.22 to 5875 ± 4830.67 mg/l (Figure 21). The maximum TDS was observed from in August and September in the *Avicennia* stand and the minimum was recorded on February in the River. Mean TDS values presented the highest peak in: mixed (1275.50±710.36 mg/l) from November to February, *Rhizophora* (2069.25±329.34mg/l) from May to October and River (296 mg/l) from May to July. The seasonal variations of the mean TDS values among sites presented higher values in *Rhizophora, Avicennia* and Volta river in the rainy season and Mixed in the dry season.

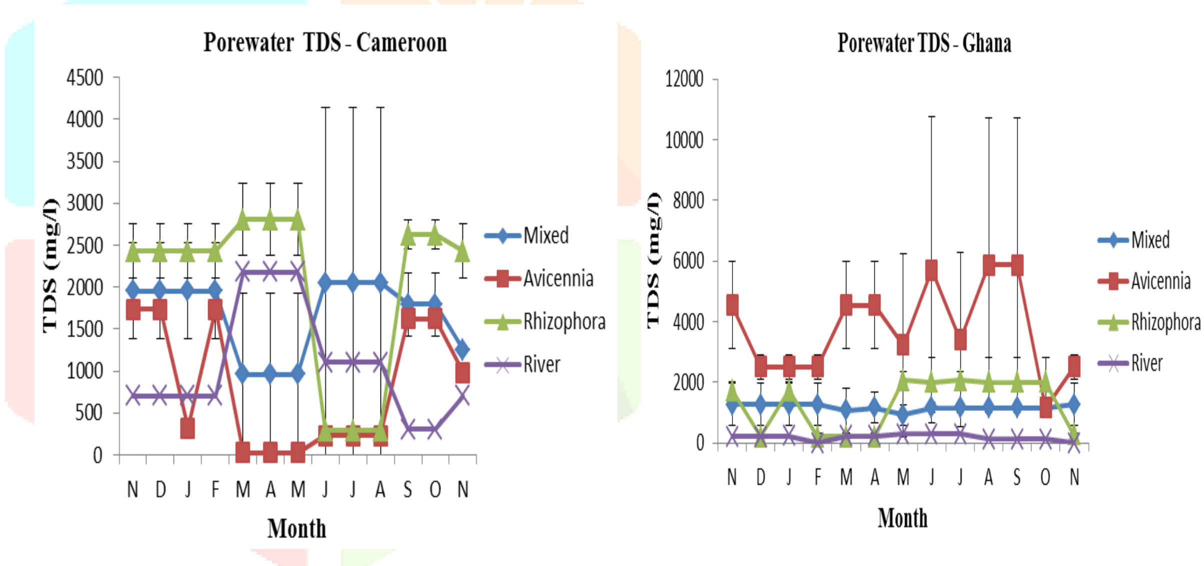


Figure 21: Seasonal variations porewater TDS in mangrove stands in Cameroon and Ghana.

Total Suspended Solid (TSS)

In Cameroon, mean TSS values during the sampling period were varied from 20.75 ± 6.24 to 68.50±20.49 g/l (Figure 22). The maximum EC was observed in June in the mixed stand and the minimum was recorded from November to April in the *Rhizophora* stand. The mean TSS values presented the high values in: *Avicennia* (68 ± 21.04 g/l) in October, *Rhizophora* (49.25±0.96 g/l) in June, August to October and River (51 g/l) in Nov, June to October. The seasonal variations of the mean TSSvalues among sites were presented, higher values in mixed mainly in the dry season and Rhizophora, Avicennia *and* River mainly in the rainy season.

The mean TSS values in Ghana for porewater varied from 15.75± 0.96 to 63.50 ± 20.49 mg/l (Figure 22). The maximum TSS was recorded from June to July in the mixedstand and the minimum was observed from November to April in the *Rhizophora.*Mean TSS values presented high values in: *Avicennia* (63 ± 21.04 mg/l) in October, mixed (63.50 ± 20.49 mg/l) from June to July, *Rhizophora* (44.25 ±0.96 mg/l) from August to October and River (46 mg/l) in November and June to October. The seasonal variations of the mean TSS values among sites were presented higher values mainly in the rainy season for all the studied sites.

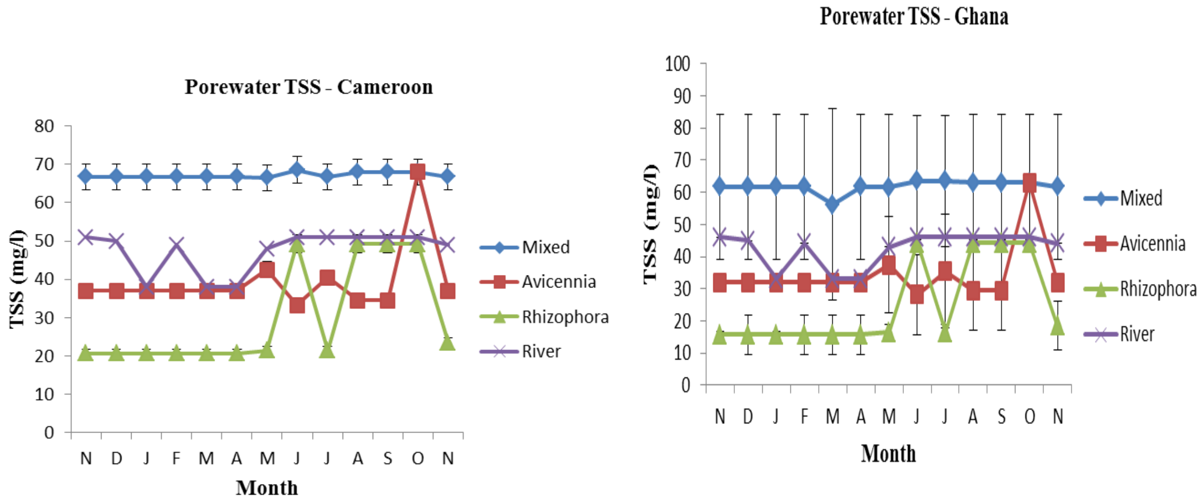


Figure 22: Seasonal variations in porewater TSS in mangrove stands in Cameroon and Ghana.

Turbidity

The mean Turbidity value for Cameroon during the sampling period varied from 22.72 ±2.22 to 118±13.13 NTU (Figure 23). The maximum Turbidity was recorded in January in the mixedstand, and the minimum was observed on December, February to April in the *Rhizophora* stand. The mean Turbidity values presented the high values in: *Avicennia* (116 ± 37.47 NTU) in October, *Rhizophora* (56 ±2.71 NTU) in June, April to October and River (62 NTU) in November, February and May. The seasonal variations of the mean Turbidity values among sites were presented, higher values in *Avicennia* and *Rhizophora* stands in the rainy season and mixed stand and River in the dry season.

Mean porewater Turbidity values for Ghana during the sampling period varied from 18± 2.45 to 107.25 ± 11.70 NTU (Figure 23). The maximum Turbidity was recorded on November. December andJanuary in the Mixedstand and the minimum was observed in November in the *Rhizophora*. Mean Turbidity values presented the high values in: *Avicennia* (111 ± 37.47 NTU) in October. *Rhizophora* (51 ±2.71 NTU) in June, August to October and River (57 NTU) in, November, February and May. The seasonal variations of the mean turbidity values among sites presented, higher values in *Avicennia* and *Rhizophora* stands in the rainy season and mixed stand in the dry season.

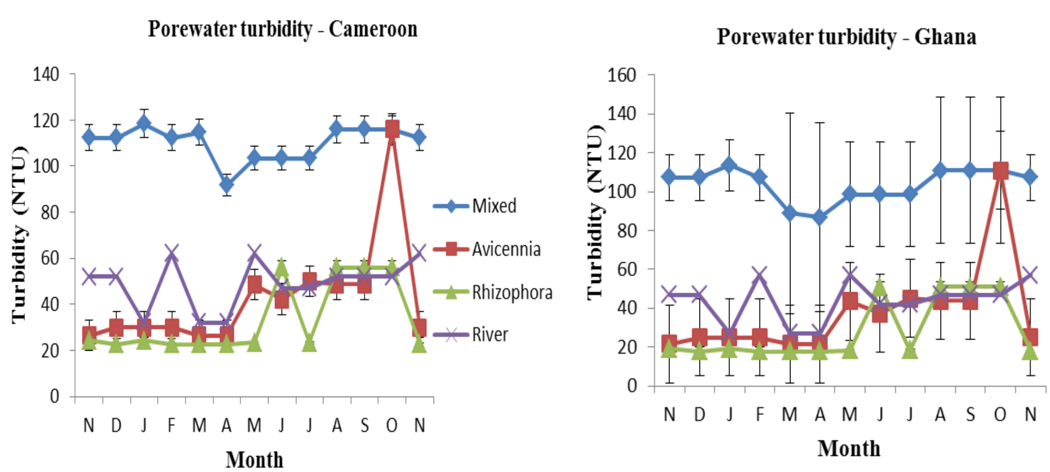


Figure 23: Seasonal changes in porewater turbidity in mangrove stands in Cameroon and Ghana.

Alkalinity

In Cameroon, the mean Alkalinity values during the sampling period varied from 77.78 to 1834± 444.33 mg/l (Figure 24). The maximum Alkalinity was observed from November to February in the mixed stand and the minimum was observed from September to October in the River. Mean Alkalinity values showed the high values in: *Avicennia* (361.43± 208.32 mg/l) in November to February. *Rhizophora* (767.08± 228.80 mg/l) from September to October and River (1583.78mg/l) from March to May. The seasonal variations of the mean Alkalinity values among sites were presented higher values mainly in the rainy season for *Rhizophora* and River and in the dry season for *Avicennia* and mixed stands.

In Ghana, mean Alkalinity values varied from 39.01 to 307.07±191.78 mg/l (Figure 24). The maximum Alkalinity was observed from June to October in the mixed stand, and the minimum was recorded from August to October in the River. Mean Alkalinity values showed high values in: *Avicennia* (287.11 ± 236.32 mg/l) on May, June and September. *Rhizophora* (304.15 ±27.52 mg/l) in June, August to October and River (52.08mg/l) in July. The seasonal variations of the mean Alkalinity values among sites presented higher values in the rainy season for all the studied sites.

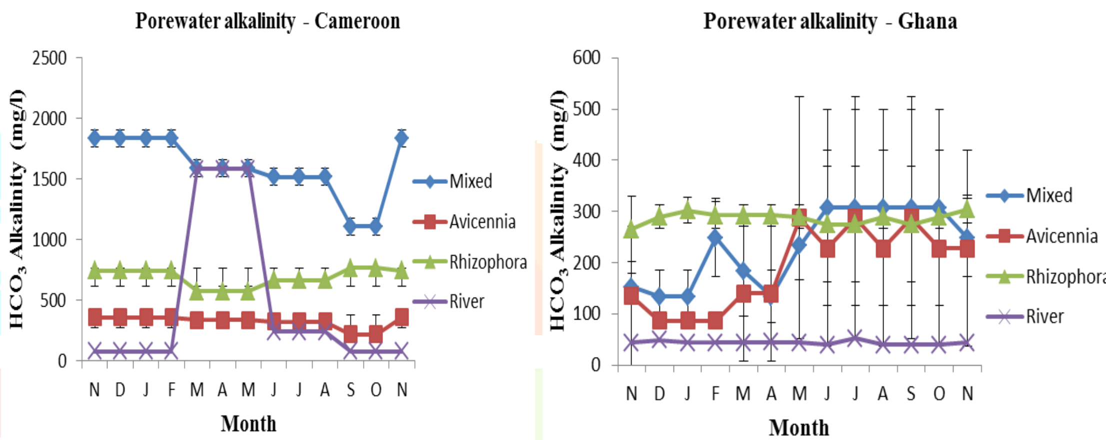


Figure 24: Seasonal variations in porewater alkalinity in mangrove stands in Cameroon and Ghana.

Salinity

In Cameroon, mean porewater salinity values during the sampling period varied from 3.6 to 28.03± 6.51 ‰ (Figure 25). The maximum mean salinity was observed from June to August in the mixed stand, and the minimum was observed from March to May in the River.Mean salinity values showed the high values in: *Avicennia* (17±0.80 ‰) from March to May, *Rhizophora* (17.43± 3.73 ‰) from June to August and River (6.1 ‰) From June to August. The seasonal variations of the mean salinity values among sites showed higher values in the rainy season for all the studied sites.

In Ghana, mean porewater salinity values varied from 0.13 to 20.95± 20.84 ‰ (Figure 25). The maximum mean salinity was observed in December in the *Avicennia* stand and the minimum was observed from November to December in the River. Mean salinity values showed the stated values in: mixed (1.48 ± 0.88 ‰) from November to February, *Rhizophora* (3.30 ± 0.88 ‰) on November 2009 and River (0.3 ‰) from March to October. The seasonal variations of the mean salinity values among sites showed higher values in the dry season for all the mangrove stands. The variation of the salinity in the River did not follow seasonal patterns.

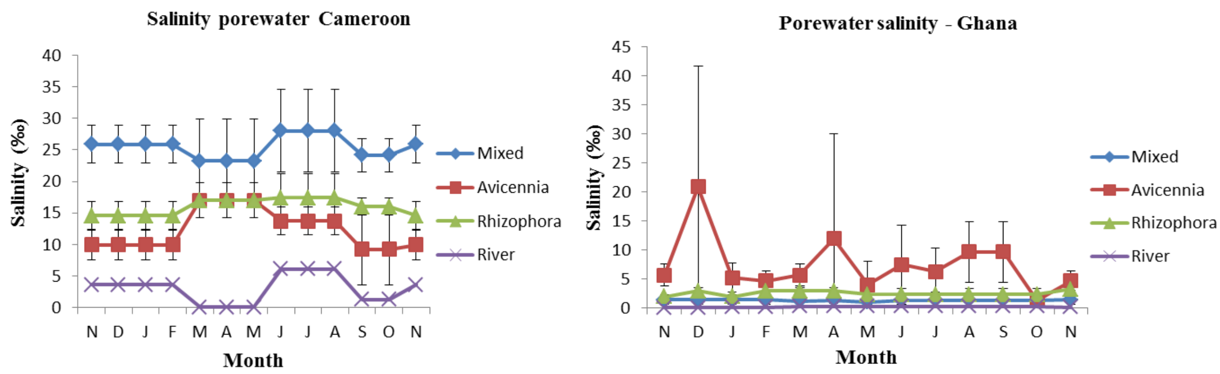


Figure 25: Porewater salinity in mangrove stands in Cameroon and Ghana.

A relatively strong relationship was established between soil water salinity, air temperature, rainfall and litterfall in both countries. Multiple regression analysis selected average rainfall, average air temperature and soil water salinity as independent variables which were important in explaining temporal litterfall variability over the study period. The equation that best describes litterfall variability in both countries is: Y= 232 –5.07 (X1) - 0.197 (X2) + 5.95 (X3) ; $R^2 = 0.66$, where X1 is Air temperature ($p< 0.001$) and X2 is rainfall ($p< 0.001$) and X3 is soil water salinity.

Dissolved oxygen (DO)

Mean DO concentrations in porewater from Cameroon during the sampling period, varied from 7.52 to 10.5 mg/l (Figure 26). The maximum mean value was recorded from March to April in the *Rhizophora* stand the minimum in November in the *Avicennia* stand. The mean DO values showed the highest peak in: *Avicennia* (9.09 mg/l) from June to September. Mixed (9.92 mg/l) from December to April, *Rhizophora* (10.5 mg/l) from March to April and River (9.92 mg/l) on December. The seasonal variations of the mean DO values among sites were shown higher values mainly in the dry season in mixed stand and River in the rainy season mainly in the *Rhizophora* and *Avicennia* stands.

Mean DO concentrations in porewater from Ghana during the sampling period varied from 2.52 to 5.53 mg/l (Figure 26). The maximum mean value was recorded on November, June to July in the *Rhizophora* stand the minimum in November in the *Avicennia* stand. The mean DO values showed the highest peak in: *Avicennia* (4.86 mg/l) in October. Mixed (4.97 mg/l) on May, and River (4.92 mg/l) on December. The seasonal variations of the mean DO values among sites were showed higher values in the dry season in *Avicennia* and River in the rainy season in the mixed stand. The highest values were shown in both seasons in the *Rhizophora* stand.

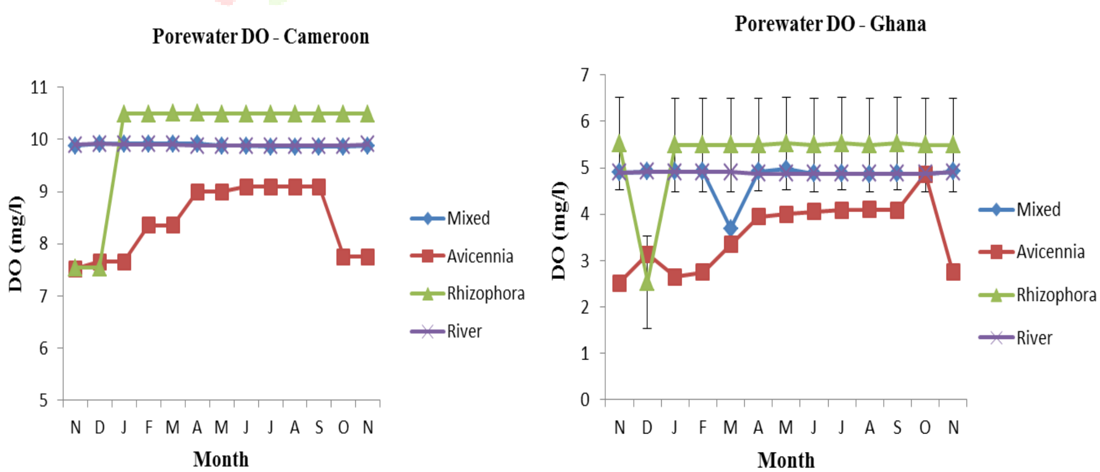


Figure 26: Porewater DO in mangrove stands in Cameroon and Ghana.

Biological Oxygen Demand (BOD)

Mean BOD values for Cameroon porewater during the sampling period varied from 5.81 to 7.05mg/l (Figure 27). The maximum BOD mean value was recorded from March to April in *Rhizophora* and *Avicennia* stands. The mean BOD showed the following values in: Mixed (7.04 mg/l) from March to July and River (7.04 mg/l) from July to October. The seasonal variations of the mean BOD values among sites were shown higher values mainly in the rainy season for all the studied sites.

Mean BOD values for Ghana porewater during the sampling period varied from 0.98 to 2.10 mg/l (Figure27). The maximum BOD mean value was recorded in May and July to October in *Rhizophora* and *Avicennia* stands. Mixed (2.04 mg/l) in June to July and and River (2.04 mg/l) from April to October. The seasonal variations of the mean BOD values among sites showed higher values in the rainy season in *Avicennia* and mixed. The *Rhizophora* and River did not show any seasonal patterns.

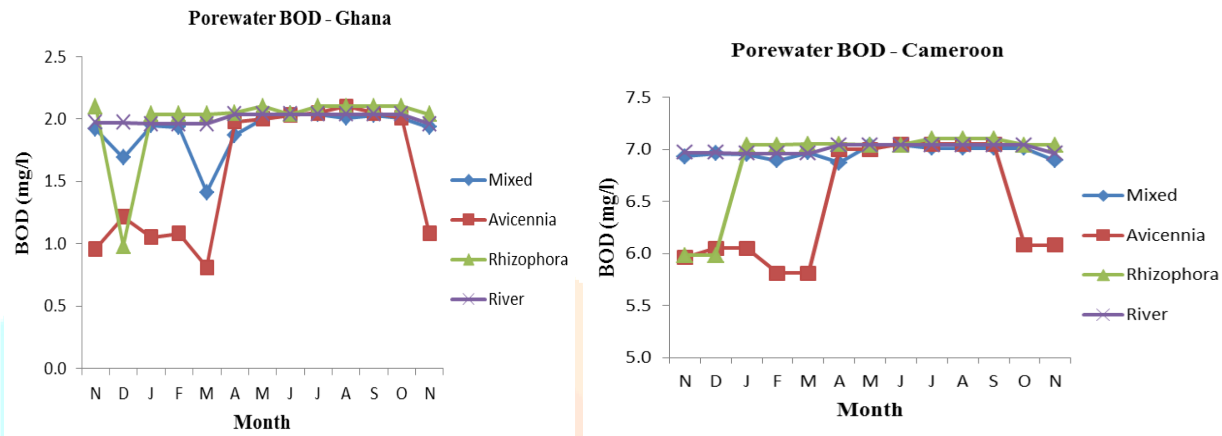


Figure 27: Seasonal changes in porewater BOD in mangrove stands in Cameroon and Ghana.

Sulphate

In Cameroon, mean sulphate concentrations recorded during the data collection period, fluctuated from 53.18 to 917.70 ± 205.30 mg/l (Figure 28). The maximum mean Sulphate value was observed in July to August in the *Rhizophora* stand and the minimum was observed from March to May in the River. Mean Sulphate values showed the high values in: *Avicennia* (808.59 ± 81.59 mg/l) in June to August, mixed (496.18±167.58 mg/l) in September, and River (713 mg/l) in July to August. The seasonal variations of the mean Sulphate values among sites showed higher values, in the rainy season for all the studied sites.

In Ghana, mean sulphate concentrations recorded in porewater during the data collection period fluctuated from 6.73 to178.33 ± 66.89 mg/l (Figure 28). The maximum mean Sulphate value was observed on January in the *Rhizophora* stand and the minimum was observed on November and January to May in the River. Mean Sulphate values showed other values in: *Avicennia* (154 ± 102.91mg/l) in March and April, mixed (125± 33.20 mg/l) in December, January and April and river (43.52 mg/l) in July. The seasonal variations of the mean Sulphate values among sites presented higher values in the dry season for *Rhizophora, avicennia* and mixed stand and river in the rainy season.

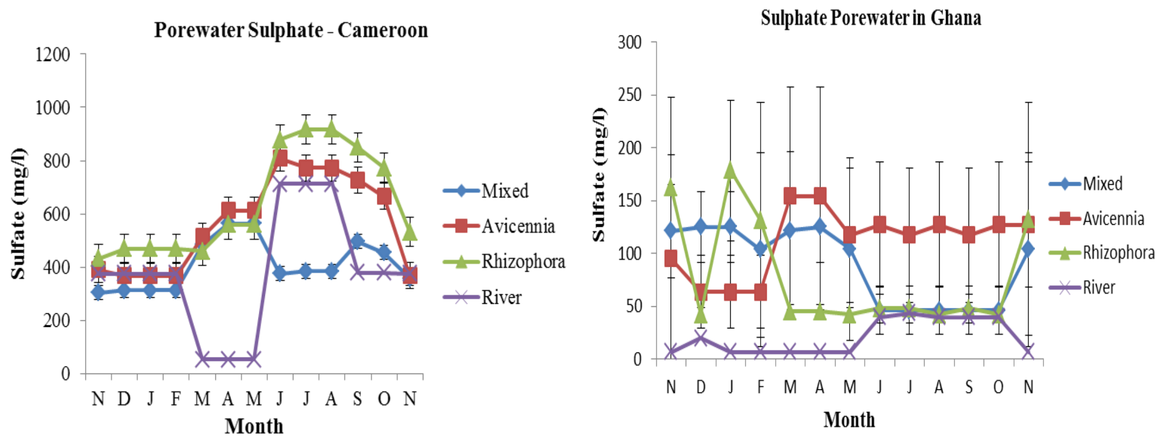


Figure 28: Seasonal changes in Porewater sulphate concentration in mangrove stands in Cameroon and Ghana.

Phosphate

Mean porewater phosphate concentrations in Cameroon during the data collection period varied from 0.052 to 0.23 ± 0.14 mg/l (Figure 29). The maximum mean phosphate value was observed in November 2009 and January in the *Rhizophora* stand and the minimum was observed in December in the Wouri river. Mean phosphate values showed other values in: *Avicennia* (0.12 ± 0.08 mg/l) in November, June, August and October; in Mixed (0.21±0.06 mg/l) from July to October, and Volta river (0.083mg/l) in July. The seasonal variations of the mean phosphate values among sites were presented, higher values mainly in the rainy season for mixed *Avicennia* and Volta river and in the dry season for *Rhizophora*.

In Ghana, mean porewater phosphate concentrations recorded during the data collection period, varied from 0.002 to 0.20± 0.02 mg/l (Figure 29). The maximum mean phosphate value was observed in November in the *Rhizophora* stand, and the minimum was observed on December in the River. Mean phosphate values shown elsewhere were in: *Avicennia* (0.07± 0.08 mg/l) on November 2009, May, July, September to October, mixed (0.16± 0.04 mg/l) from June to September, and River (0.024 mg/l) from August to October. The seasonal variations of the mean phosphate values among sites presented higher values mainly in the rainy season for *Avicennia* and mixed stand and River, *Rhizophora* in the dry season.

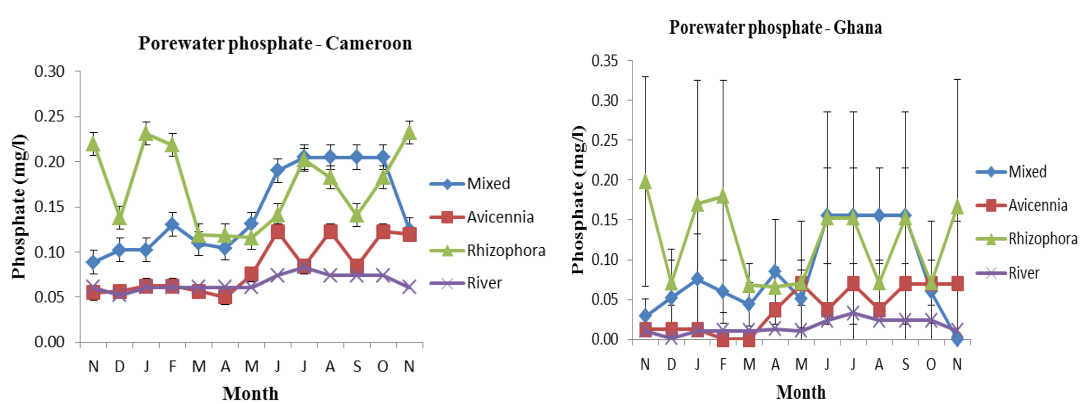
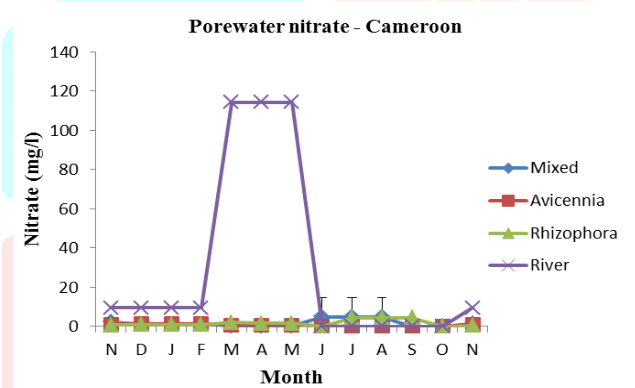


Figure 29: Seasonal changes in porewater phosphate concentration in mangrove stands in Cameroon and Ghana.

Nitrate

Mean nitrate concentrations for Cameroon porewater during the data collection period, fluctuated between 0.16 ± 0.32 to 114.38 mg/l (Figure 30). The maximum mean nitrate value was observed from March to May in the River and the minimum was recorded in October in the mixed stands. Mean nitrate values showed other values in: *Avicennia* (1.38 ± 1.68 mg/l) from December to February, Mixed (4.93± 9.87 mg/l) from June to August, *Rhizophora* (4.46± 8.91 mg/l) from July to September. The seasonal variations of the mean nitrate values among sites
presented higher values mainly in the rainy season for mixed, *Rhizophor*a and River and in the dry season for *Avicennia*.

The average nitrate concentrations for porewater in Ghana during the data collection period varied from 0.102 to 2.18± 1.84 mg/l (Figure 30). The maximum mean nitrate value was recorded on November in the mixedstand and the minimum was observed in November, January to March and May in the River. The mean nitrate values elsewhere wereshowed the highest peak in: *Avicennia* (0.87± 0.17 mg/l) on April. June and August, mixed (2.18± 1.84 mg/l) in November, *Rhizophora* (0.97± 0.59 mg/l) on February and River (0.179 mg/l) on December, the seasonal variations of the mean nitrate values among sites presented, higher values mainly in the rainy season for, *Avicennia* stand and for River, *Rhizophora* and mixed in the dry season.



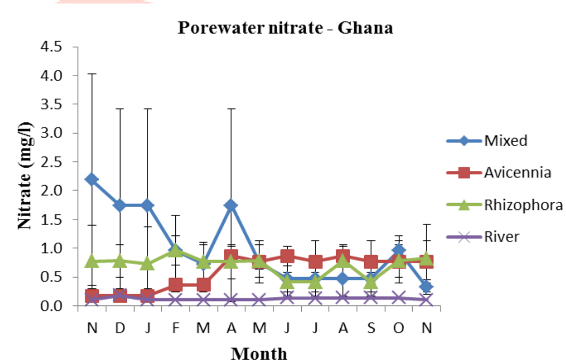


Figure 30: Variation in porewater nitrate concentration in mangrove stands in Cameroon and Ghana.

Sodium

Mean porewater sodium ion concentrations for Cameroon during the data collection period, varied from 1.75± 0.49 to 54.31± 18.94 mg/l (Figure 31). The maximum mean Sodium value was observed from April to June in the mixed stand and the minimum was recorded on November 2009 in the *Avicennia* stands. From November 2008 to February 2009, no values of Sodium were observed in the *Avicennia* stand. Mean Sodium values elsewhere were in: *Avicennia* (9.72± 4.67mg/l) in September, Mixed (54.31± 88.94 mg/l) from April to June, *Rhizophora* (13.31±7.06 mg/l) from December to February and River (6.86mg/l) from September to October. The seasonal variations of the mean Sodium values among sites were presented higher values mainly in the rainy season for *Avicennia*, mixed, and River and in the dry season for *Rhizophora.*

Mean porewater sodium ion concentrations for Ghana during the sampling period, oscillated from 111.4 to 4235 ± 1182.50 mg/l (Figure31). The maximum mean Sodium value was recorded on February to March in the *Avicennia* stand and the minimum was observed on December in the River. The mean Sodium values showed the highest peak in: *Avicennia* (4235 ± 1182.50 mg/l) in February to March, mixed (3449.50± 3176 mg/l) on May, *Rhizophora* (2267.50 ± 1032.84 mg/l) in June, July and September and River (354 mg/l) in June, August to September. The seasonal variations of the mean Sodium values among sites showed higher values in the rainy season, for *Rhizophora* and River and *Avicennia* mixed in the dry season.

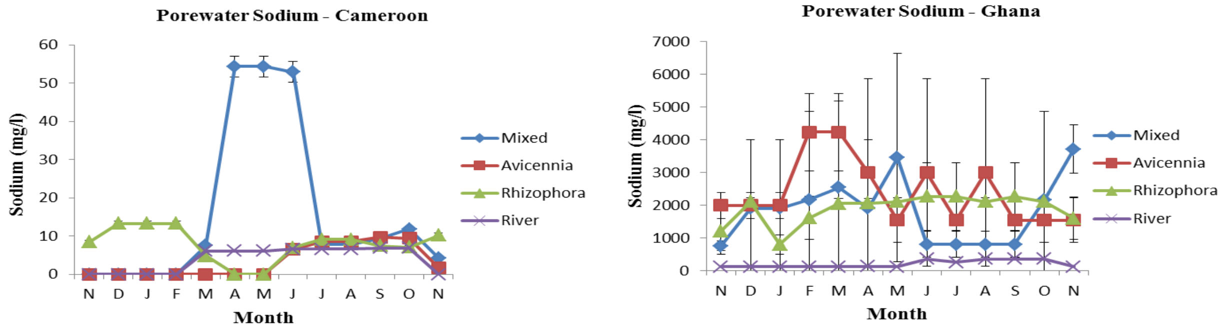


Figure 31: Seasonal changes in porewater sodium concentration in mangrove stands in Cameroon and Ghana.

Potassium

Mean potassium ion concentrations for Cameroon recorded during the sampling period varied from 20.53 to 112.25 ± 22.85 mg/l (Figure 32). The maximum mean Potassium value was recorded from July to August in the *Rhizophora* stand, and the minimum was recorded March to May in the River. Mean Potassium values elsewhere were in: *Avicennia* (66.05± 7.04 mg/l) from July to August. Mixed (57.15± 17.16 mg/l) from July to August, and River (20.53mg/l) from September to October. The seasonal variations of the mean Potassium values among sites indicated high values mainly in the rainy season for all the studied sites.

In Ghana, mean potassium ion concentrations recorded during the sampling period, varied from 1.2 to 517.50 ± 177.27 mg/l (Figure 32). The maximum mean Potassium value was recorded on February to March in the *Avicennia* stand, and the minimum was observed on November and January to March in the River. The mean Potassium values showed the highest peak in: *Avicennia* (517.50 ± 177.27 mg/l) on February to March. Mixed (432.50 ± 145.69 mg/l) in November 2009, *Rhizophora* (168.50± 168.20mg/l) on November and River (209 mg/l) on June, August to October. The seasonal variations of the mean Potassium values among sites showed higher values in the rainy season, for River and for mixed, *Rhizophora*, *Avicennia* and mixed stands in the dry season.

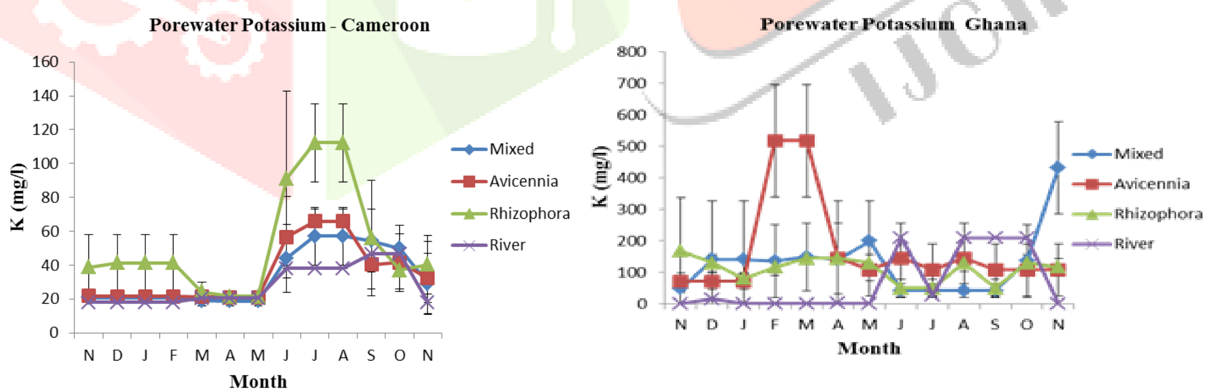


Figure 32: Seasonal variations in porewater potassium ion concentration in mangrove stands in Cameroon and Ghana.

Chloride

Concentrations of mean chloride ions recorded for Cameroon during the data collection period, varied from 23.3 to 109.9 mg/l (Figure 33). The maximum mean Chloride values was found in the River from September to October and the minimum occurred from March to May. Mean Chloride values in: *Avicennia* (85.53 ± 12.65 mg/l) in March, mixed (99.26± 21.32 mg/l) in October, *Rhizophora* (105.91± 59.54 mg/l) on November 2009 and he seasonal variations of the mean Chloride values among sites presented higher values mainly in the rainy season for mixed and River and in the dry season, for *Rhizophora* and *Avicennia.*

Concentrations of mean chloride ions recorded for Ghana during the sampling periods, fluctuated between from 73.98 and 4323.19 ± 3417.43 mg/l (Figure 33). The maximum mean Chloride value was observed on May, July and September to November in the *Avicennia* stand and the minimum was observed in November, February, March and May in the River.
The mean Chloride values elsewhere were: mixed (2899.10 ± 962.34 mg/l) in November 2009, *Rhizophora* (1637± 160.03 mg/l) on March, April and River (999.69 mg/l) in December. The seasonal variations of the mean Chloride values among sites showed higher values in the rainy season for *Avicennia*, mixed and *Rhizophora* standsin the dry season.

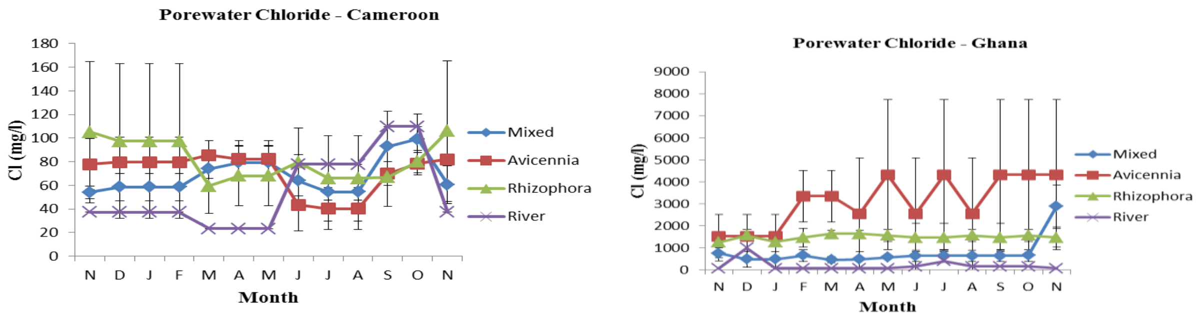


Figure 33: Changes in porewater chloride ion concentration in mangrove stands in Cameroon and Ghana.

It was observed that, no significant differences existed between mixed and *Avicennia* stands in Ghana for temperature (T°) (P> 0.05), while the other paramaters presented significant differences (P<0.05). For mixed and *Rhizophora* stands in Ghana, only TSS and Turbidity showed significant differences (P<0.05).

Between mixed stands in Ghana and Cameroon, no significant differences (P> 0.05), were only found for Cond, TSS, Turb, N and Cl. For *Avicennia* (Cameroon) and mixed (Ghana), no significant differences (P> 0.05), were found only for Cond and TSS, and for N and Rhizophora in Cameroon and mixed stand in Ghana, no significant differences were mainly found for N, Na and Cl. Significant Changes in soil water characteristics in both countries were therefore observed at all sites.

4.2.10 Relationships among variables for water quality in Cameroon and Ghana

Cluster analysis with Similarity Proficiency (SIMPROF) test for surface water and porewater physico-chemics properties of the mangrove stands revealed that all mangrove stands from Cameroon and Ghana (*Rhizophora* Cameroon (RhCA), *Avicennia* Cameroon (AVCA), Mixed Cameroon (MxCA), *Rhizophora* Ghana (RhGH), *Avicennia* Ghana (AVGH) and Mixed Mixed (MxGH)) are significantly different from one another at a 50% Euclidean distance (Figure 34). However, at a Euclidean distance of about 7, two groups of mangrove stands could be seen, with one group comprising only stands in Ghana and the other group comprising only stands in Cameroon. These groups are further explained by Principal Component Analysis.

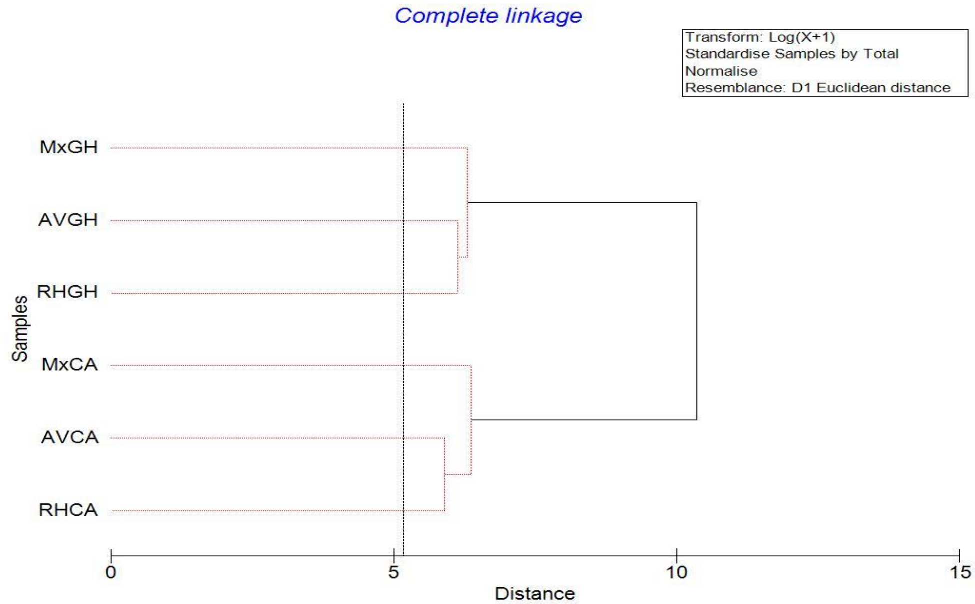


Figure 34: Dendrogramm showing the clustering of sampling sites for water quality.

Principal Component Analysis for surface water and porewater physico-chemical properties **(Figure 35)** indicates that five principal components (PCs) explain 100 % of the variability in the data, with PC1 and PC2 contributing to 53.4% and 17.5 %, respectively.

Parameters that are strongly distributed on PC1 included surface water DO (SW_DO), surface water BOD (SW_BOD), surface water sulphate (SW_Sul), surface water phosphate (SW_P), surface water sodium (SW_Na), porewater alkalinity (PW_Alk), porewater DO (PW_DO), porewater BOD (PW_BOD), porewater sulphate (PW_Sul), porewater phosphate (PW_P), porewater potassium (PW_K) and chloride (PW_Cl). On the other hand, SW_pH, temperature, SW_TSS, SW_turbidity, PW_pH and PW_temperature was strongly loaded on PC2.

Using PC1 and PC2, which contribute to a total of 70.9% of the variability in the data, it was observed that, the water and porewater physico-chemical properties from mixed Cameroon (MxCA), are contributed to the variability by SW_TSS and SW_turbidity, while those of *Avicennia* Cameroon (AVCA) and *Rhizophora* Cameroon (RHCA) mainly contributed to the variability by SW_pH, SW-temperature, PW_pH and PW_temperature. Similarly, the variability at *Avicennia* Ghana (AVGH) and mixed Ghana (MxGH) were mainly contributed to by SW_sulfate and PW_TDS, while that of *Rhizophora* Ghana (RHGH) was mainly contributed to by SW_conductivity, SW_Na, PW_sulphate, PW_K and PW_Cl.

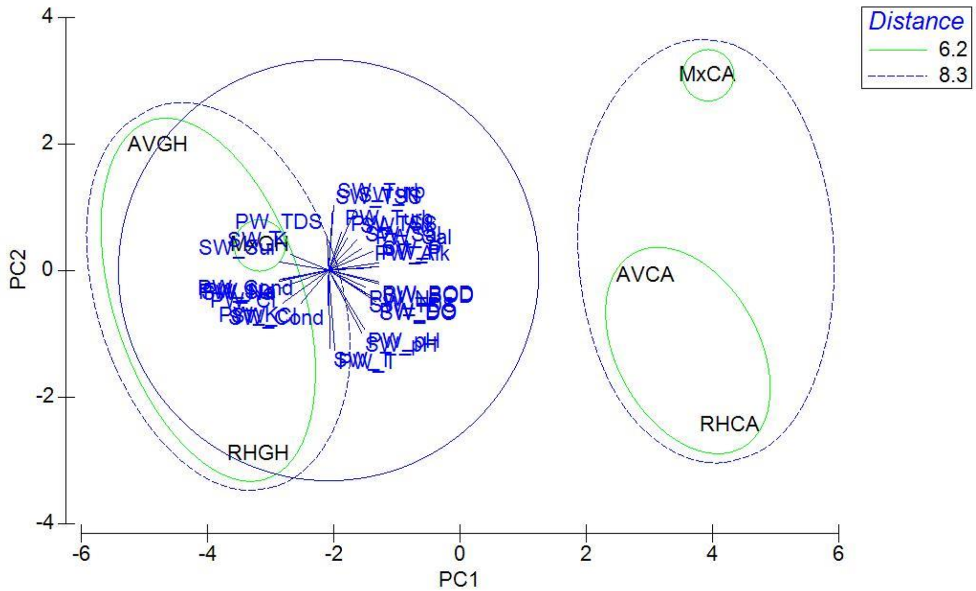


Figure35: Principal component analysis (PCA) ordination plot of sampling stations based on water quality.

A One-way Analysis of Similarity (ANOSIM) performed for surface water and porewater physico-chemical parameters indicated a Global R of 0.729 at a significant level of 0.1%, indicating high dissimilarity among the mangrove stands from Ghana and Cameroon. A Parewise test indicated higher similarity between mangrove stands in Ghana, as well as mangrove stands in Cameroon, but high dissimilarity between those formed by a mixturof Ghana and Cameroon sites.

In order to explain the disparate patterns of mangrove water quality between the two countries, Discriminant Function Analysis (DFA). The group centroids of the six sites representing, *Avicennia* GH, *Rhizophora* GH, Mixed GH, *Avicennia* CA, *Rhizophora* CA, Mixed CA, were significantly different from each other (Wilks' lamba =0.00000, P<0.00001). For the first two axes, Mixed GH group overlapped with those of Avicennia GH and Rhizophora GH. Mixed CA group overlapped with those of Avicennia CA and Rhizophora CA. Within each country, the separation of the groups was bad, and good between the countries (Figure 36). A total variation 88% was expressed by the 1st canonical variate axis (Root1), whereas 12% of the total variance was explained by the 2nd axis.

The first canonical variate axis tended to discriminate with a high score Mixed GH from the five others groups (*Avicennia* GH, *Rhizophora* GH, Mixed CA, *Avicennia* CA, and *Rhizophora* CA). The first Character- axis correlations (Table 26) indicated that Alkalinity, Sulphate, Cadmium, Chloride, Chromium, Lead, Salinity and Total Dissolved Solids were the variables the most positively correlated with this axis (r=0.75, 0.63, 0.55, 0.46,0.26, 0.20) and turbidity and nitrate were the variables the most negatively correlated with this axis (r=-0.62 and -0.22) respectively.

The second canonical variate axis discriminated the group *Avicennia* GH, from the six others (Mixed GH, *Rhizophora* GH, Mixed CA, *Avicennia* CA and, *Rhizophora* CA) with low canonical scores. This canonical variate axis was positively correlated with the variables Dissolved Oxygen, Total Suspended Solids, Lead, water temperature, Salinity (r=0.98, 0.46, 0.33, 0.26, 0.21) and negatively correlated with Total Dissolved Solids (r= -0.27) respectively.

This discriminant analysis clearly showed discrimination between the different groups in both countries: Mixed GH, Avicennia GH, Rhizophora GH, Mixed CA, Avicennia CA, and RhizophoraCA). Alkalinity, Sulphate, Cadmium, Chloride, Chromium, Lead, Salinity, Total Dissolved Solids, turbidity and nitrate exhibited strong contribution in distinguishing the two countries and account for most of the expected variations in the quality of mangrove water, while the other parameters, Dissolved Oxygen, water temperature, Total Suspended Solids showed less contribution in explaining the variation between Ghana and Cameroon.

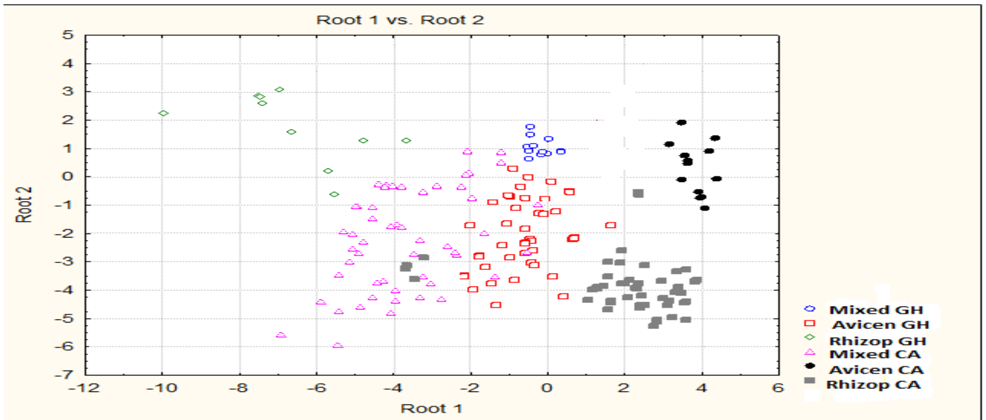


Figure 36: Scatter plot to indicate the six groups of Ghana (GH) and Cameroon (CA) for water quality.

III.3 Soil physical and chemical characteristics

III.3. 1. Characteristics of mangroves' soils in Cameroon and Ghana

Soil pH

In Ghana, the values obtained varied between 4.46±0.55 in the *Rhizophora* stand and 4.62±0.52 in the mixed stand (Table 1). The soils in the *Rhizophora* stand were the most acidic. In Cameroon Soil pH in the three mangrove sites was moderately acidic. The values obtained varied between 5.02±1.09 in the*Rhizophora* stand and 6.22±0.64 in the mixed stand (Table 1).

Conductivity (mS/m)

Conductivity of soils in Ghana varied between 6.37±1.03 mS/cm in the *Rhizophora* Stand and 11.44±1.21 mS/ m in the Mixed. Mean values of conductivity in *Rhizophora* stand was relatively lower than in the *Avicennia* and mixed stands (Table 1). The soil in *Rhizophora* stand was most acidic (low pH), and had the lowest conductivity in the other hand. Soil in the mixed stand which had the highest pH value recorded also the highest conductivity.

Conductivity of soil in Cameroon varied between 1.18±0.72 mS/cm in the *Avicennia* Stand and 2.72±2.72 mS/ m in the *Rhizophora*. Mean values of conductivity in Avicennia and mixed stands were relatively lower than in the *Rhizophora* (Table 1). The soil in *Rhizophora* stand was most acidic (low pH) and had the highest conductivity, while soil in the mixed stand which had the highest pH value recorded a low conductivity.

Soil Organic Carbon and Organic matter

Mean values of organic carbon in Ghana varied between 4.32±0.25 in the Avicennia Stand and 9.11±1.02% in the *Rhizophora* stand (Table 1). The mean values of organic carbon content in the *Rhizophora*, *Avicennia* and mixed stands are high (values above 2.9%). The range of Organic Matter of the soil was between a low value of 7.42±0.42 % in the *Avicennia* stand and to a high value of 15.43±1.76 % in *the Rhizophora*.

For the mean values of Organic Carbon and Organic matter, the *Rhizophora* stand had the highest standard deviation followed by mixed stand. The variance analysis showed that the difference between those sites was statistically significant.

Mean values of organic carbon varied be`tween 2.70±0.38 in the *Avicennia* Standand 5.31±2.61%in the *Rhizophora* stand (Table 1). It appeared that, the mean values of organic carbon content in the *Rhizophora* and mixed stands are High (values above 2.9%) and in the *Avicennia* Stand the content of Organic carbon is medium (values between 1.5% to 2.9%). The range of organic matter of the soils was between a low value of 4.64±0.66% in the *Avicennia* stand and a high value of 10.43±5.79% in the *Rhizophora*.

For the mean values of organic carbon and organic matter, Rhizophora stand had the highest standard deviation followed by mixed stand. The variance analysis showed that the difference between those sites was statistically significant.

Total organic nitrogen available phosphorus and C/N

Mean values of Total Nitrogen content in Ghana varied between 0.69±0.48% inthe *Rhizophora* Standand 3.36±0.60%in the mixed stand (Table1). The average values of phosphorus fluctuated between 5.75±0.61 mg/kg in the *Rhizophora* stand and 18.91±6.95 mg/kg in the *Avicennia* stand. The relative maximum value of C/N ratio was observed as 31.67±3.33 in the *Rhizophora* stand and the minimum 1.38±0.21 in the *Avicennia*.

Mean values of Total Nitrogen content in Cameroon varied between 0.07±0.04 in the *Avicennia* Standand 0.16±0.11%in the *Rhizophora* stand (Table 1). The average values of phosphorus fluctuated between 6.06±1.53 mg/kg in the Rhizophora stand and 10.46±6.33 mg/kg in the mixed stand. The Maximum value of C/N ratio was observed 47.18±26.24 in the *Avicennia* stand and the minimum 39.73±11.09 in the *Rhizophora*.

Available P levels were low in the *Avicennia* and *Rhizophora* stands with values ranging from 6.06 to 7.72 mg/kg indicating deficiency level in all the profiles.

Cation Exchange Capacity and percent base saturation

In Ghana the lowest mean value of Exchangeable Ca content was 3.14±0.29 cmol/kg and inthe *Avicennia* and the highest mean value in the *Rhizophora* stand was 3.60±1.24 cmol/kg (Table 5). The average value of Exchangeable Mg varied between 1.43±0.18 in *Rhizophora* stand and 27.72±43.26 cmol/kg in the mixed stand. The average value of Exchangeable K, varied between 0.83±0.48 cmol/kg in *Rhizophora* stand and 2.69±0.06cmol/kg in the *Avicennia* stand. The highest mean value of Effective Cation Exchange Capacity (ECEC) observed in the mixed mangrove was25.53±2.59 cmol/kg and the lowest value 6.88±1.18 in the *Rhizophora* stand.

Exchangeable Ca (3.14–3.60 cmolkg-1) Mg (1.43–27.72 cmolkg-1) and K (0.83– 0.48 cmolkg-1) values reflect the overall influence of regular replenishment by seepage and tides. ECEC values ranged from moderate to very high (6.88– 25.53 cmolkg-1) and reflect the high exchange acid conditions in mangrove swamp soil on air drying.

In Cameroon the lowest mean value of Exchangeable Ca content was 2.64±0.70 cmol/kg and 2.64±0.1.49 cmol/kg in the *Avicennia* and *Rhizophora* stands, and the highest mean value in the mixed stand was 3.07±1.29 cmol/kg (Table5**)**. The average value of Exchangeable Mg varied between 0.29±0.11 in Avicennia stand, and 1.84±0.94 cmol/kg in the mixed stand. The Maximum value of Exchangeable Mg was 0.55±0.34 cmol/kg and the minimum0.32±0.15 cmol/kg in the *Rhizophora* stand. The average value of Exchangeable K, varied between 0.32±0.15 in *Rhizophora* stand and 0.55±0.34 cmol/kg in the mixed stand.

The Maximum value of Exchangeable K was 0.55±0.34 cmol/kg and the minimum,0.32±0.15 cmol/kg in the *Rhizophora* stand. The highest mean value of Effective Cation Exchange Capacity (ECEC) observed in the mixed mangrove was, 6.62±2.35 cmol/kg and the lowest value 4.57±2.48 in the *Rhizophora* stand. Exchangeable Ca (2.64–3.07cmolkg-1), Mg (0.29–1.84 cmolkg-1) and K (0.32– 0.55 cmolkg-1) values reflect the overall influence of regular replenishment by seepage and tides.

Soil Texture

The sand fraction in Ghana for all the mangrove stands ranged between 4.14% in *Rhizophora* stand to 5.36% in the mixed **(**Table 1**).** On the other hand, Analysis of variance (ANOVA**)** **(**Table7**),** revealed that with the exception of dissolved solids, that showed significant variations at ($p< 0.05$) **(**Table 1**),** in the six sampling stations, all other parameters showed no significant variations ($p> 0.05$). Silt was relatively abundant in the *Avicennia* (61.68±0.88%) and less in the mixed stands (37.92±23.71%). The clay was most abundant in the *Avicennia stand* (17.89±1.08%) and less in the *Rhizophora* Stand (14.27±2.28). The mean of the fractions for the different classes was shown that, the combined amount of sand. Silt and clay was 28.22% in *Avicennia* stand. 26.13% in *Rhizophora* and 20.09 % in mixed stand. Soil in *Avicenna* had the highest percentage of silt (61.68±0.88%), while the other two stands had a relatively low percent silt. In addition, the tidal movement are restricted in this site. The sand fraction in Cameroon for all the mangrove stands ranged between 17.56% in the mixed stand to 41% in the *Rhizophora* **(**Table 1**),** On the other hand, silt was relatively abundant in the *Avicennia* (32.80±9.93%) and *Rhizophora* stands (25.43±5.10).

The clay was most abundant in the mixed stand (52.01±5.92) and the *Avicennia* Stand (40.01±8.75). The mean of the fractions for the different classes showed that, the combined amount of sand, silt and clay was 34% in *Avicennia* stand. 33% in *Rhizophora* and 30% in mixed stand. Soils in *Avicennia* had the highest percentage of silt (32.80±9.93%), while the other two stands had a relatively low percent silt

Table1: Soil Characteristics in Ghana and Cameroon (mean ±sd).

Variables	***Avicennia*** **Ghana**	***Avicennia*** **Cameroon**	***Rhizophora*** **Ghana**	***Rhizophora*** **Cameroon**	**Mixed Ghana**	**Mixed Cameroon**
Soil pH	5.80±0.64	4.56±0.63	5.02±1.09	4.46±0.55	6.22±0.64	4.62±0.52
EC(mS/m)	1.18±0.72	10.87±1.36	2.72±2.72	6.37±1.03	1.50±0.72	11.44±1.21
ExCa	2.64±0.70**	3.14±0.29	2.64±1.49	3.60±1.24	3.07±1.29	3.48±0.50
ExMg	0.29±0.11	13.10±0.83	1.04±0.60	1.43±0.18	1.84±0.94	27.72±43.26
ExK	0.45±0.25	2.69±0.06	0.32±0.15	0.83±0.48	0.55±0.34	2.51±0.62
Acidity	1.42±0.34	2.98±2.64	1.44±0.54	2.90±0.71	1.16±0.28	10.86±16.39
ECEC	4.81±1.05	22.48±1.11	4.57±2.48	6.88±1.18	6.62±2.35	25.53±2.59
`%OC	2.70±0.38	4.32±0.25	5.31±2.61	9.11±1.02	3.42±1.63	5.16±0.55
%OM	4.64±0.66	7.42±0.42	10.43±5.79	15.43±1.76	5.28±3.42	8.35±0.61
%ON	0.07±0.04	3.20±0.31	0.16±0.11	0.69±0.48	0.09±0.06	3.36±0.60
Av. C/N	4 7.18±26.24**	1.38±0.21**	39.73±11.09**	31.67±3.33**	40.78±15.03**	2.34±0.52**
Av. P	7.72±1.32*	18.91±6.95*	6.06±1.53*	5.75±0.61*	10.46±6.33*	11.22±1.68*
Sand	28.19±7.72*	5.10±0.83*	41.78±4.92*	4.14±0.65*	17.56±5.86*	5.36±0.89*

Variables	*Avicennia* Ghana	*Avicennia* Cameroon	*Rhizophora* Ghana	*Rhizophora* Cameroon	Mixed Ghana	Mixed Cameroon
Silt	32.80±9.93	61.68±0.88	25.43±5.10	59.98±13.96	21.62±12.80	37.92±23.71
Clay	40.01±8.75	17.89±1.08	32.57±5.45	14.27±2.28	52.01±5.92	16.99±0.97

* $p<0.05$ **$P<0.001$

Analysis of variance (ANOVA) based on the mean values observed in Ghana and Cameroon (Table5), revealed that Exchangeable Calcium (ExCa), available C/N ratio showed strong significant variations (**) and available phosphorus and sand that presented significant variations (*) in the sampling stations of both countries, all other variables showed no significant variations (p> 0.05).

III.3. 2. Relationships among variables for mangrove soil description in Cameroon and Ghana

Cluster analysis with Similarity Proficiency (SIMPROF) test for soil characteristics of the mangrove stands revealed that all mangrove stands from Cameroon and Ghana (RhCA, AVCA, MxCA, RhGH, AVGH and MxGH) were significantly different from one another at 50% Euclidean distance (Figure 37). However, at a Euclidean distance of about 6, two groups of mangrove stands could be seen, with the two groups, one of them comprising only the stands from Ghana and the other group consisting of stands from Cameroon. These groups are further explain by principal component analysis.

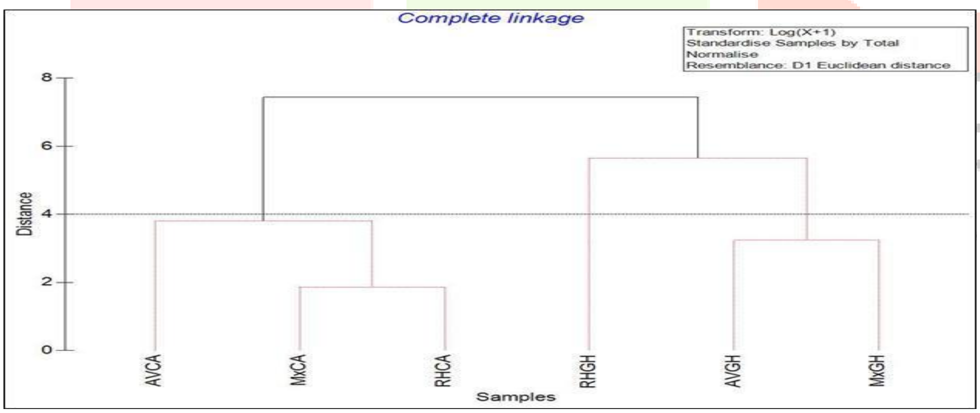


Figure 37: Principal component analysis (PCA) ordination plot of sampling stations based on soil characteristics.

Principal Component Analysis (PCA) for soil characteristics **(**Figure.38) indicated that five principal components (PCs) explain 100 % of the variability in the data, with PC1 and PC2 contributing to 62.8% and 20.1%, respectively (Appendix12.). Parameters that are strongly distributed on PC1 included pH, EC, ExCa, ExMg, ExK, acidity, ECEC, ON, AVCN, sand and clay. On the other hand, ExK, ECEC, OM, OC, AVP, Silt and Bulk density were found to be strongly loaded on PC2. Using PC1 and PC2, which contribute to a total of 82.9 % of the variability in the data, it was observed that, soil characteristics from *Rhizophora* Ghana (RHGH) were contributed to the variability by OM, OC and bulk density, while those from mixed Ghana (MxGH) and *Avicennia* Ghana (AVGH) were contributed by AVP, AV C/N, ExCa, pH, clay, sand and silt and mixed Cameroon (MxCA), *Avicennia* Cameroon (AVCA) and *Rhizophora* Cameroon (RHCA) were contributed to the variability by Mg, ExK, Acidity, ON and EC.

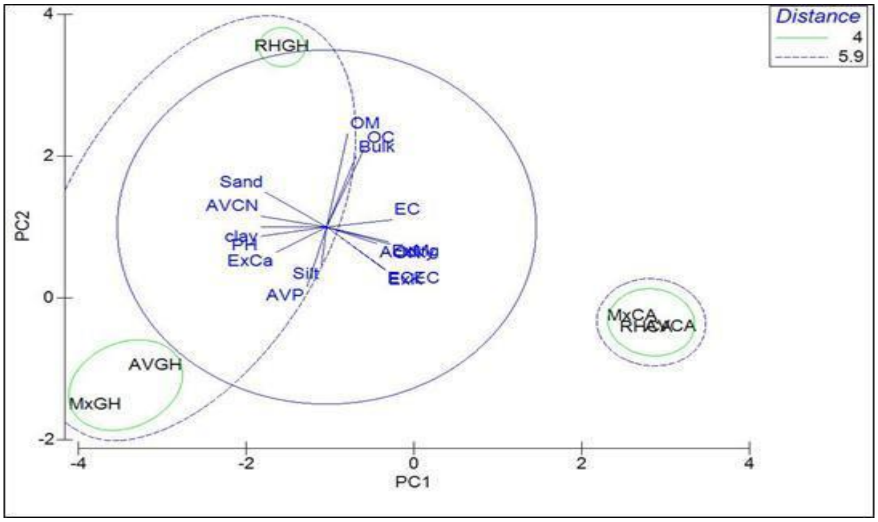


Figure38: Principal component analysis (PCA) ordination plot of sampling stations based on soil characteristics.

A One-way Analysis of Similarity (ANOSIM) performed for soil parameters presented a Global R of 0.824at a significant level of 0.1%, indicating high dissimilarity among the mangrove stands from Ghana and Cameroon. A Parewise test indicated higher similarity between mangrove stands in Ghana, as well as mangrove stands in Cameroon, but high dissimilarity between those of Ghana and Cameroon put together.

In order to explain the disparate patterns of mangrove soils' quality within and between the two countries, Discriminant Function Analysis (DFA) was performed. The group centroids of the six sites representing, *Avicennia* GH, *Rhizophora* GH, Mixed GH, *Avicennia* CA, *Rhizophora* CA, and Mixed CA were significantly different from one another (Wilks' lamba =0.00001, $P<0.00001$). For the first two axes, Mixed GH group overlapped with those of *Avicennia* GH and *Rhizophora* GH, Mixed CA group overlapped with those of Avicennia CA. *Rhizophora* CA is not mixed with one of them. Within each country the separation of the groups slightly was bad, and good between the countries (Figure 39).

A total variation of 74% was expressed by the 1st canonical variate axis (Root1), whereas 26% of the total variance was explained by the 2nd axis. The first canonical variate axis tended to discriminate with a high score Mixed GH from the five others groups (Avicennia GH, *Rhizophora* GH, Mixed CA, *Avicennia* CA, and *Rhizophora* CA). Character- axis correlations indicated that %0N, EC, acidity, Ex Mg, were the variables, the most positively correlated with this axis (r= 0.97; 0. 63;0.43, 0.24, 0.20, and respectively).

The second canonical variate axis discriminated the group *Avicennia* GH, from the five others (Mixed GH. *Rhizophora* GH, Mixed CA, *Avicennia* CA, and *Rhizophora* CA) with low canonical scores. This canonical variate axis was positively correlated with the variables, Sand, %OM, Clay, Ex Mg, acidity, pH, ECEC (r=0.99, 0.50, 0.46, 0.31 ,0.23 ,0.21, 0.20, and respectively). This discriminant analysis clearly showed discrimination between the different groups in both countries: Mixed GH, *Avicennia G*H, *Rhizophora* GH, Mixed CA, Avicennia CA and *Rhizophora* CA). It was found that %0N, EC, acidity, Ex Mg, ECEC, and Av P exhibited strong contribution in distinguishing the two countries and accounted for most of the expected variations in the soil characteristics of mangrove forest, while the other parameters, Sand, %OM, Clay, pH, showed less contribution in explaining the variation between Ghana and Cameroon.

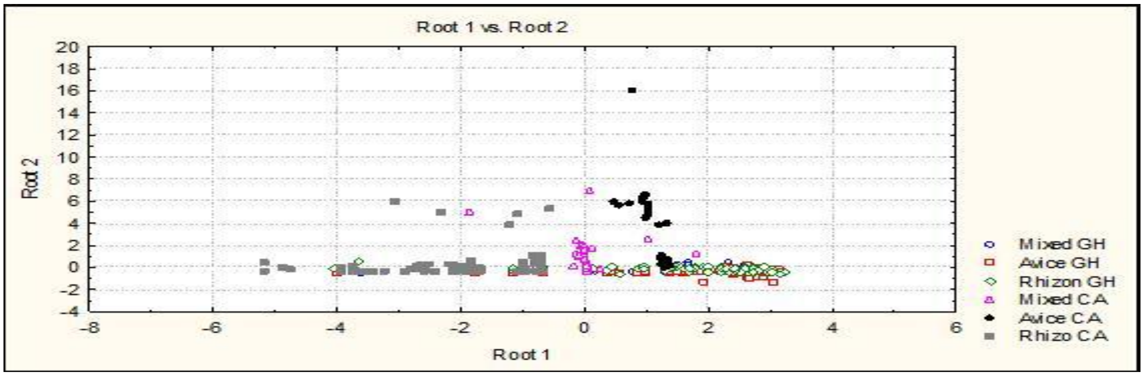


Figure 39: Scatter plot to indicate the six groups of Ghana (GH) and Cameroon (CA) for description of soil.

IV. Discussion

Many qualitative ecological studies have been conducted on mangrove ecosystems but less quantitative information is available in Africa mainly in the West and Central African ecoregion. Few researchers have tried hard to give some insights in the ecology of mangrove ecosystems. This limits more or less the comparability of results from this study. The following discussions are carried out by comparing the results obtained with available information from mangrove ecosystem studies all over the world under the headings, i) water quality assessment, and ii) Soil quality assessment.

IV. 1 Water Quality of mangrove forest

IV. 1.1 Physico- chemical parameters

In the present study, air temperature varied between varied between 26 to 30.1 º C in Ghana and 26.80 to 29.5 º C in Cameroon and water temperature ranged from 25.2 to 30 ºC in Ghana and 22.3 to 26.3 ºC in Cameroon.
From this study, it has been observed that, temperature values were within the acceptable levels for survival metabolism and physiology of aquatic organisms. Water temperature has some positive and negative effects on plant growth. The most suitable water temperature for plant growth is 20-35°C Temperature over 30°C can cause regression in growthand decay in plants (Krauss *et al.,* 2008; Luo *et al.*, 2010; Lawson, 2011).

The monthly rainfall recorded in this study was varied between 50 mm and 300 mm in Ghana and 100 mm to 600 mm in Cameroon. Rainfall greatly affects the dynamics of the environments transports nutrients and allochthonous materials and alters the water's visual physical and chemical characteristics (Krauss *et al.,* 2008; Conchedda *et al*., 2011).
The pH ranged from 4.81 to 7.43 in the mangrove studied. The pH values recorded in the study fell within ranges reported for rivers flowing through areas with mangrove vegetation. pH has direct or indirect effects on photosynthesis and growth of water plants. In water with low pH, solution dissociation of iron phosphate decreases and vice versa. High pH causes more carbonate and bicarbonate in water (Adriamalala, 2007; UNEP, 2007; Spalding *et al*., 2010; Lawson, 2011).

Lawson (2011) confirmed that organic acids resulting from decaying vegetation might be responsible for the low pH in most aquatic ecosystems. Drinking water pH level varies between 6.5 and 9.5. The safest pH level of drinking water would be 7 which is the pH level of pure water. Based on this, waters from the mangrove swamps studied are relatively not really suitable for drinking.

It was observed that salinity was sometimes relatively high in the present study. The values of salinity observed in this study were sometimes out of the range advisable. Higher salinities were recorded across the research stations during the dry months than wet months this may be due to dilution of the water by the increased freshwater input during these wet months (Luo *et al.*, 2010; Ramsar-Mava-Unep, 2012). This was also in agreement with reports made by Lawson (2011) on the evaluation of mangrove water quality in Lagos in the Central African ecoregion.

The values recorded for Dissolved Oxygen (DO) in the present study were similar to those reported for many other polluted Nigerian waters including 6.9 - 8.8 mg/l for Lagos lagoon, 4.00-7.50 mg/l for Luubara creek in Niger Delta and 1.20 - 9.40 mg/l documented in Victor and Onmivbori and Edokpayi and Osimen for some polluted water bodies in Nigeria (Spalding *et al*., 2010; Lawson, 2011; Ramsar-Mava-Unep, 2012).

All the values recorded fell outside the "no effect" range of 0–0.3 mg/l for drinking water However, the values fell within the 0.1–10 mg/l range for which slight adverse health effects can be expected in children and sensitive individuals. High organic content from human faeces decayed plant materials and domestic and sawmill wastes that found their ways intothe lagoon may be responsible for the low dissolved oxygen. The level of oxygen depletion depends primarily on the amount of waste added, the size velocity, turbulence of the stream and the temperature of the water. Frequent deaths of fish in water in fact do not come from toxicity of matters but from deficit of consumed oxygen from biological decomposition of pollutants (UNEP, 2007; FAO, 2009; Luo *et al*., 2010; Lawson, 2011). Various studies suggestthat dissolved oxygen in waters depends on water temperature, partial pressure of oxygen in atmosphere and salt contents in waters (Spalding *et al*., 2010; Lawson, 2011). It has been proved that higher Dissolved Oxygen concentration might be due to the cumulative effect of higher wind velocity coupled with heavy rainfall and the resultant freshwater mixing (Adriamalala, 2007; FAO, 2009; Luo *et al.*, 2010; Lawson, 2011).

The Biological Oxygen Demand (BOD) values ranged from 0.98 to 7.03 in the present study and similar results were found for other African mangrove forest (UNEP, 2007; FAO, 2009; Spalding *et al*., 2010; Lawson, 2011). BOD is an indicator for the amount of the biodegradable organic substances. BOD also accounts the oxygen that is required in organic matter decomposition (Amadi *et al*., 2010). BOD value will rise when there is more organic matter such as leaves; wood, waste water or urban storm water runoff took place at the river water (Seca Gandaseca *et al*., 2011).

Alkalinity in the present study values ranged from 39.01 to 1834 mg/l 307.07±191.78 mg/l in Ghana and 77.78 to ± 444.33 in Cameroon. Moderately alkaline water (less than 350 mg/L) in combination with hardness forms a layer of calcium or magnesium carbonate that tends to inhibit corrosion of metal piping. High alkalinity (above 500 mg/l) is usually associated with high pH values, hardness and high dissolved solids. Water with low alkalinity (less than 75 mg/l) especially some surface waters and rainfall is subject to changes in pH due to dissolved gasses that may be corrosive to metallic fittings. This study revealed that, mangrove waters were more alkaline in Cameroon than in Ghana.

The observed changes in EC values were due to fresh water influx and mix up with ebb and flow. The relatively high Electrical Conductivity in Cameroon may be due to high organic residue in the water body, as high temperature favours degradation of organic pollutants. Similar results were reported by Amadi *et al*. (2010), Gandaseca *et al*. (2011), Lawson (2011).

Total Dissolved Solids (TDS) varied between 0.22 and 5875 ± 4830.67 mg/l in Ghana and 28.20 ±1.30 to 2807.50 ± 425.31 g/l in Cameroon. The EPA Secondary Regulations advise a maximum contamination level (MCL) of 500 mg/liter for TDS. When TDS levels exceed 1000 mg/L it is generally considered unfit for human consumption. A high level of TDS is an indicator of potential concerns and warrants further investigation. Most often high levels of TDS are caused by the presence of potassium, chlorides and sodium. These ions have little or no short-term effects but toxic ions (lead arsenic, cadmium, nitrate and others) may also be dissolved in the water. Most aquatic ecosystems involving mixed fish fauna can tolerate TDS levels of 1000 mg/l (Alongi *et al*., 2011; Conchedda *et al*., 2011).

High TDS indicates hard water. High TDS results is undesirable taste which could be salty, bitter, or metallic. It could also indicate the presence of toxic minerals. Some Dissolved Solids come from organic sources such as leaves, silt plankton and industrial waste and sewage (Spalding *et al*., 2010; Ramsar-Mava- UNEP, 2012).

Others include runoff from urban areas road salts used on street and in fertilizers and pesticides used in farms; inorganic materials such as rocks and air that may contain calcium bicarbonate, nitrogen, iron, phosphorous, sulfur and other minerals (FAO, 2009; Lawson, 2011). Many of these materials form salts which are compounds that contain both metals and nonmetals. Salts usually dissolve in water forming ions. Ions are particles that have a positive or negative charge which form the total dissolved Solids (Amadi *et al.*, 2010; Gandaseca *et al*., 2011).

Total Suspended Solid (TSS) values ranged from 15.75± 0.96 to 63.50 ± 20.49 mg/l in Ghana and 20.75 ± 6.24 to 68.50±20.49 g/l in Cameroon. It is clearly known that TSS are solid materials including organic and inorganic, that are suspended in the water. These would include silt, plankton and industrial wastes. Sources of total suspended solids include erosion from urban runoff and agricultural land industrial wastes, bank erosion, bottom feeders, algae growth or wastewater discharges (UNEP, 2007; FAO, 2009). High concentrations of suspended solids can lower water quality by absorbing light. Waters then become warmer and lessen the ability of the water to hold oxygen necessary for aquatic life. Because aquatic plants also receive less light, photosynthesis decreases and less oxygen is produced (Amadi *et al.*, 2010; Gandaseca *et al*., 2011).
The combination of warmer water less light and less oxygen makes it impossible for some forms of life to exist. Suspended solids clog fish gills reduce growth rates decrease resistance to disease and prevent egg and larval development. Particles that settle out can smother fish eggs and those of aquatic insects as well as suffocate newly-hatched larvae. The material that settles also fills the spaces between rocks and makes these microhabitats unsuitable for various aquatic insects such as mayfly nymphs, stonefly nymphs and caddis fly larva (Spalding *et al.*, 2010; Ramsar-Mava- UNEP, 2012). TSS and TDS are strongly correlated. The more salts are dissolved in the water; the higher is the value of the electric conductivity. High purity water that contains no salts or minerals has a very low electrical conductivity (Crona *et al.*, 2009; FAO, 2009).

For turbidity, Cameroon and Ghana recorded the highest values mainly in the dry season because the volume of the water was getting smaller as the dry season was reaching its peak and most of the tributaries were getting turbid because of anthropogenic activities. Lower values recorded in both countries at the end of dry and the beginning of the rainy seasons can be explained by the fact that at that time all the tributaries had dried up thus reducing the influx of suspended matter for the dry season and for the rainy season the occurrence of dilution by rainwater.

The low values recorded in May which was the beginning of the rainy season could be due to dilution by the rainwater. The turbidity values for Ghana and Cameroon (both in the dry season) were far higher than the no effect range of 0-1 NTU for drinking water use (WRC, 2003). This indicates that in the dry season the water carried an associated risk of disease transmission due to infectious disease agents and chemicals absorbed on to particulate matter. In addition, turbidity was visible and had aesthetic effects on appearance (Spalding *et al*., 2010).

Turbidity is a measure of the cloudiness of water. It is used to indicate water quality and filtration effectiveness (e.g. whether disease-causing organisms are present). Higher turbidity levels are often associated with higher levels of disease-causing microorganisms such as viruses, parasites and some bacteria. These organisms can cause symptoms such as nausea cramps diarrhoea and associated headaches (Singh *et al.*, 2011; Singhard Suraj. 2012).

Some of the sulphate values fell out of ‘’the no effect range’’ of 0-200mg/l for drinking water use (WRC, 2003). This implies that no adverse health aesthetic effects were expected. Sulphate when added to water tends to accumulate to progressively increasing concentration (WRC, 2003). This could account for the high levels recorded in both countries under anaerobic conditions bacteria use sulphate as an oxygen source. The much lower sulphate values recorded in Ghana could be because sulphate easily precipitate and settles to the bottom sediment of the river (Kairo and Bosire, 2009; Conchedda *et al*., 2011).

For phosphate, all the sampling locations were above the detection limit (<0.001 mg/l) of the method used. This indicated that the farmers along the river surrounding the mangrove forest probably used N-P-K fertilizer at least during the sampling period which has the potential to being leached or washed into the river.

For nitrate, the high levels of nitrate recorded in Cameroon, may have been due to surface run- off from farms and animal pens into the river from the early rains. All the nitrate values were within the ‘’no effect’’ range of 0-6 mg/l for drinking water in Ghana but partially in Cameroon. (WRC, 2003; Singare *et al*., 2010; Singh *et al*., 2011). This indicated that no adverse health effects were expected in Ghana, but most of the time in Cameroon during the sampling period.

The lower values of chloride in May could be justified by the fact that, there were little or no irrigation returns flows. It was just the beginning of the rainy season. Most of the values recorded were out of the ‘’no-effect’’ range of 0-100mg/l for drinking water use (WRC, 2003; Abdul- Razak *et al*., 2009). This means that adverse health affects aesthetic effects and effects on household items were sometimes expected.

For potassium, all the sampling locations were above the detection limit (<0.001 mg/l) of the method used. This indicated that the farmers along the river surrounding the mangrove forest, probably used N-P-K fertilizer at least during the sampling period which has the potential to being leached or washed into the river. (Abdul- Razak *et al*., 2009; Singare *et al*., 2010; Lawson, 2011)

IV. 2. Soils Characteristics

It was observed that, the soils in the *Rhizophora* stands were the most acidic in Ghana and Cameroon. The relative low pH levels observed in these soils are attributable to the presence of pyrites Pyrites upon oxydation and hydration generally produce hydrogen sulphide which hydrolyses into sulphuric acid to reduce the soil pH (Amatekpor, 1989; Allotey, 2008). PH of the soil was near neutral due to the dynamic water percolation in the soil which is influenced by tides (UNEP- WCMC, 2012). The results obtained in this study corroborate the findings of other studies (MacDonald *et al.*, 1987; Amatekpor, 1989; Spalding *et al.*, 2010; Ramsar-MAVA- UNEP, 2012).

The results for conductivity obtained for the sediment in the mangrove sites indicated that, the sediments can be classified as moderately saline in Ghana, and strongly saline in Cameroon. Salinity in excess of 4 ‰ has been reported to be detrimental to plant growth; Salinity is also known to cause low water permeability for roots, ion toxicity, drought stress, and non-availability of nutrients high concentrations of soluble salts are then detrimental to plant growth. Soils are definitely rated based on their degree of salinity (Flower & Imbert, 2006; Allotey, 2008; Spalding *et al.*, 2010).

For Organic Matter (OM), the high content in *Rhizophora* in Ghana and Cameroon implies that the soils may have adequate supply of N, P and S among other nutrients elements. Organic matter is known to supply most of the N and S and half of P taken up by fertilizers crops (Davies *et al*., 1993; UNEP, 2007). Furthermore, the role of Organic matter in soil aggregation, general improvement of physical chemical and hydrological properties of soils, and reduction of susceptibility of soils to erosion are well known (Davies *et al*., 1993; FAO, 2009; Conchedda *et al.*, 2011). The relatively high percentage of Organic Matter recorded in the mangrove sites could primarily also be attributed to input from the mangrove form of dead leaves and decaying stilt roots (Amatekpor, 1989; Ajonina, 2008; Allotey, 2008;).

ECEC and base saturation have been used to indicate the fertility status of the soils. According to FAO (1976) soils with ECEC of > 20 cmol/kg are indicative of high suitability of the soils for crops production (Edem and Ndon, 2001; FAO, 2009). From the results of this study, the soils of Cameroon are more fertile compared to those of Ghana. Values of cation Exchange capacity in both countries reflect the overall influence of regular replenishment by seepage and tides. In all the mangrove stands, the value of Exchangeable Ca content was below 4.0 cmolkg-1 regarded as critical level for fertile soils (UNEP, 2007; FAO, 2009; Spalding *et al*., 2010).

Available P levels were low in the *Avicennia* and *Rhizophora* stands with values ranging from 6.06 to 7.72 mg/kg indicating deficiency level in all the profiles since the mean value of 7.72 mg/l P is below the critical level of 10mg/l Bray P-1 (Effiong *et al*., 2010; Spalding *et al*, 2010; Conchedda *et al*., 2011). The apparent acid nature of the soil, suggests that Al and iron (Fe) become very soluble and increase to toxic level, forming very insoluble phosphate compounds, and thus are unavailable to plants (Allotey, 2008; Effiong *et al*., 2010).

The soils generally have narrow C/N ratios; this implies that microbial activities which are necessary for the release of nutrient element may not be hindered. This is consonant with the report of Allotey (2008) that plant residues with C/N ratios of 20:1 or narrower have sufficient N supply micro-organisms responsible for decomposition and also to release N for plant use while residues with C: N ratios of 20:1 to 30:1 supply sufficient N for decomposition but enough to result in much release of N for plant use.

It was observed that, *Avicennia* had the highest percentage of silt, while the other two stands had relative low percent silt. This high accumulation of silt in *Avicennia* stand provides a suitable habitat for the settling of sediments and detritus from the water column to the bottom. In addition, the tidal movement are relatively restricted in this site (UNEP, 2007; Allotey, 2008; Spalding *et al*., 2010). The silt/ clay ratio values were higher in Cameroon, compared to Ghana. According to Amatekpor (1989) and Allotey (2008), soil with silt/ clay ratio below 0.15 is of old parent materials, while soils with silt/ clay ratio above 0.15 are of young parent materials. Also Asiamoa (1973) reported that soil with silt/ clay ratios of less than 0.25 are at an advance stage of weathering, while those with ratio greater than 0.25 indicated a low degree of weathering. Generally, the results showed that, the soils had silt/ clay ratios greater than 0.25 indicating that they are likely to have weatherable minerals needed for plants.

V. Conclusion and Recommendations

V. 1 Conclusion

As the season changes there is a fluctuation in the physicochemical characters of the water, this will be due to ebb and flow, flushing of rain water, change in the temperature and salinity as season changes. In addition, intense pollution from both agricultural inputs and shrimp culture ponds deteriorate the water quality of mangrove ecosystem. The present information of the physico-chemical characteristics of water would form a useful tool for further ecological assessment and monitoring of these coastal ecosystems

All physicochemical parameters, except for DO, meet the requirements for marine protected waters' standard water quality as specified by DAO 2016- 08. Due to the monsoon seasons, temperatures were higher in July and August, while DO levels were higher in October and November. Moreover, higher pH levels were observed in lagoonal stations, likely influenced by reduced freshwater input. Overall, the study provides a broad picture of Del Carmen's mangrove forest's current state through a four-month trend of its water quality. These parameters were selected for cost-effective monitoring of local stakeholders, long-term data collection, and community involvement. The study's baseline assessment, along with future monitoring efforts, can aid local authorities in formulating sustainable ecosystems and enhancing current implementations.

In this case study, different physico-chemical parameters were successfully applied and compared with the respective standards to monitor the water quality of Mahanadi river delta. Water analysis of pH, conductivity, TDS, D.O, chloride, calcium, magnesium, total hardness are the most important parameters represent the pollution
status of the water.

The pollutants are due to the release of effluents from several sources into the estuary, which causes significant changes in the quality of water and pose some deleterious effect to the mangrove ecosystem in a long run. The immediate need is to maintain existing sewage treatment plants so that effluent discharge has a minimum of suspended solids. As a result, it is essential that Mahanadi mangrove health in coastal environment monitoring is urgently required.

The values of Physical parameters (DO, BOD, EC, TDS, TSS), and nutrients were most often high in Cameroon, compared to Ghana. Mangrove waters were also found more alkaline in Cameroon than in Ghana. (5)

It was observed that in both countries, *Avicennia* had the highest percentage of silt.

In addition to that, nitrate, Biochemical Oxygen Demand, pH, Phosphate, salinity, Conductivity (Mangrove Water), percentage organic nitrogen, electrical conductivity, acidity, Exchangeable magnesium, ECEC Effective Cation Exchange Capacity, and available phosphorus Av P (Mangrove Soil), water and soil variables indicated that mangrove ecosystem within and across the countries respond differently to environmental conditions.

This study contributes to a better understanding of how mangrove ecosystems function. Additional work in other geographic areas within the West and Central African ecoregion is needed to provide a broader perspective on the ecological importance of mangrove ecosystem
and their impact on the nearby marine and coastal areas.
It was appeared that:

Water Quality

- In the present study air temperature varied between varied between 26 to 30.1 º C in Ghana and 26.80 to 29.5 º C in Cameroon and water temperature ranged from 25.2 to 30 ºC in Ghana and 22.3 to 26.3 ºC in Cameroon.

- The Rainfall recorded in this study varied between 50 mm to 300 mm in Ghana and 100 mm to 600 mm in Cameroon. Rainfall greatly affected the dynamics of the environments transports nutrients and allochthonous materials and alters the water's visual physical and chemical characteristics

- The study revealed that, mangrove waters were more alkaline in Cameroon than in Ghana and most of the physico-chemical parameters were high in Cameroon compared to Ghana

Soil Characteristics

- In both countries sediments in *Avicennia* had the highest percentage of silt (32.80±9.93%), while the other two stands had a relatively low percent silt.
- Soil pH values in Ghana ranged from 5.02±1.09 in the *Rhizophora* stand to 6.22±0.64 in the mixed stand and in Cameroon 4.46±0.55 in the *Rhizophora* to 4.62±0.52 in the mixed stand. The soils in the *Rhizophora* stands were the most acidic in Ghana and Cameroon.

- Accumulation of silt in Avicennia stand provides a suitable habitat for the settling of sediments and detritus. In addition, the tidal movement were restricted to this site and soils had silt/ clay ratios greater than 0.25.

- Effective Cation Exchange capacity (ECEC) valuesranged from 4.57 to 6.62 cmolkg-1 in Ghana and 6.88 to 25.53 cmolkg-1 in Cameroon. The mangrove soils of Cameroon were more fertile compared to those of Ghana.

V. 2 Recommendations

While the study provided a valuable snapshot of the water quality status of Del Carmen's mangrove forest, further research is necessary for a comprehensive understanding. A sustained, long term monitoring effort spanning several years is crucial to reveal seasonal trends and fluctuations in water quality over time. Additionally, investigating the influence of anthropogenic activities on water quality is essential for identifying potential threats and implementing targeted conservation measures.

Results from this study are very preliminary owing to the limited time of two years (One year in each country). However, they indicate encouraging insights into assessing the importance of mangrove using parameters of ecological value (water and soil properties) in the two countries of the West and Central ecoregion. The following recommendations can be made for further studies:

- Deeply address the **v**ariability of the mangrove forests in terms of soil water salinity, knowing that salinity is one of the major factors influencing and structuring life in the mangrove ecosystem. A specific study on spatial and temporal variation in soil water in the studied mangrove forest needs to be carried out, with adequate number of measurements covering the local variation in space and time.

- Integrate the local communities' knowledge or perceptions of the mangrove biodiversity functions, when studying the ecological processes. There is a need to understand and include the knowledge of how mangrove ecosystem is influenced by socio-economy and livelihoods perspectives.

- Address the adaptation to climate change/variability on mangrove ecosystem via a participatory action research on issues relevant to the daily life of coastal communities and on their adaptive capacity to deal with the high degree of uncertainty that characterizes African mangrove ecosystems subjected to the consequences of climate change.

- Conduct a research on ecological linkages within mangrove ecosystems as well as between mangrove and other coastal ecosystems.

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