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Contribution of some water bodies and the role of soils in the physicochemical enrichment of the Douala-Edea mangrove ecosystem

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The effect of enrichment of water bodies could be of serious crises to the mangrove ecosystem. Changes in physicochemical properties of some water bodies in the Douala-Edea mangrove ecosystem was investigated alongside the potential role of soils in controlling these parameters. Water and soil samples within the Douala industrial zones were collected in February 2010 and analysed using standard methods. The concentrations of cations and chlorides (Cl^-) in the rivers increased from upstream to downstream and with depth. These parameters were not distinct with other anions which showed higher fluctuations around confluences. Many anomalies were obtained in streams and wells at vicinity of the industries. Mean Cl^- concentrations in streams and wells around River Wouri (135.1 and 57.9 mg/l, respectively) were higher than those around River Dibamba (59.3 and 38,2 mg/l, respectively). A low retention capacity of the soils was observed by the non significant (P > 0.05) relationship between the clay fraction and cation exchange capacity (CEC). This makes the mangrove ecosystem vulnerable to the increase nutrient from anthropogenic activities as indicated by the occurrence of Nypa Palms (*Nypa fructicans*) and Water Hyacinths (*Echhornia cassipes*). It is therefore imminent that the Douala-Edea Mangrove Ecosystem is being degraded.

Key words: Soils, water, physicochemical properties, mangrove ecosystem.

INTRODUCTION

Rivers constitute a major source of water. Their usage constitutes a major criterion towards sustainable growth and development of a region and its economy (Katte et al., 2003; Gleitsmann et al., 2007). Over the world, a few rivers are unaffected by upstream transportation of their fresh water inflow (Boynton et al., 1995). Unprecedented increase in population and rapid growth of urbanization has seen remarkable impact of man on the environment (Morris et al., 1994). This has tended to a wide scale contamination of soil, water from industrial effluents and domestic sewage discharges (Morris et al., 1994; Lener, 1995). Untreated wastes are often channelled or piped from the industries and/or households onto and/or into the ground or into surface water in coastal environments

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lined by mangroves. This could change the physicochemical properties of such water bodies rendering these waters undesirable to the mangrove ecosystem.

Soils are natural components of the ecosystem which interact with other components by moving and cycling nutrients and energy (Yerima and Van Ranst, 2005). Soils serve many important functions in our society (Zhao et al., 2009). They serve as a vital "ecological crossroad" of the environment linking the atmosphere, lithosphere and hydrosphere (Rowel, 1994). Most plants survive by absorbing nutrients (essential elements) from the soil. The availability of these nutrients depends on the physiccochemical properties of the soil, which vary considerably in tropical soils (Yerima and Van Ranst, 2005). Soils rich in organic matter and clays such as montmorillonite hold nutrients and water better than sandy soils, which are deficient in absorptive sites.

Public attention is increasingly focused on environmental pollution and its effects on man and other entities of the ecosystem such as the mangroves. Among the major pollutants are excessive nutrients originating from waste from an urbanized or industrialized society. The soil is one of the primary recipients of these wastes. Once these materials enter the soil, some find themselves in water and become part of the cycle which could eventually affect the mangrove ecosystem.

The mangrove ecosystem is one of the unique features of intertidal zones throughout tropical and subtropical regions. It is located between latitudes 25°N and 25°S of the Equator (Choudbury, 2002) and covering an area of approximately 15 million hectares worldwide (FAO, 2005). The mangrove forest has been traditionally used by indigenous people of the tropics for a variety of purposes: fisheries, fuel wood, scenic beauty, cultural and inspirational well being, medicinal plants and the provision of food (Suratman, 2008). One of the most important aspects of the mangrove ecosystem is its role in the sequestration of carbon, which contributes to the global carbon cycle (Twilley et al., 1992). This role helps to maintain a healthy coastal environment by modifying the climate (UNFCCC, 1998). Despite the ecological importance of mangroves, they are exposed to effluents (potential pollutants in soils, water and vegetation) from households, industries and agricultural establishments (Chiras, 2000). Changes in the physicochemical properties of water have the potential to influence the chemistry of mangrove soils which is not desirable for the mangrove ecosystem. Excess of nutrient inputs (nitrogen) can shift the mangrove ecosystem from carbon sinks to carbon sources and vice-versa (Aurela et al., 2002). The nutrients are harmful to the pneumatophores and propagules (Lafleur et al., 2003; Roulet et al., 2007). Nutrient characterization equally influences regeneration (McGuinness, 1997), forest structure (Ball, 1988), the presence of invasive species such as the Nypa palms (Spalding et al., 2010), and increase in primary productivity (Wickramasinghea et al., 2009). Almost 225000 metric tons of carbon sequestration potentials is lost each year resulting from disturbed mangrove as mangroves take up about 1.5 metric tones of carbon per hectare per year from the atmosphere (Mangrove Action Project, 2010). Disturbed mangrove soils release greater than 11 million metric tones of carbon annually (Mangrove Action Project, 2010). When disturbed, carbon and other polluting substances from the mangrove soils are released back to the atmosphere, contributing to carbon emissions (Mangrove Action Project, 2010). Mangroves may be one of our last defences against the perils of climate change and global warming. The mangrove last stand may be humanity last stand.

Douala, the most industrialized municipality in Cameroon, has witnessed within the last decades a rapid increase in the growth of factories mainly in the Bassa and Bonaberi industrial zones. These factories include: food processing, breweries, metal works, cement production, oil processing and paper processing. Wastes from these industries and households are often channelled or piped onto/or into the soil or into the surface water courses that empty into Rivers Wouri and Dibamba, lined by the mangrove forest. According to Ajonina and Usongo (2001), the Douala-Edea mangrove forest has been declining at a rate of 0.33% under pressure mainly by human activities. Independent studies of water samples had been done by Ekane and Oben (2001) revealing high nitrate levels not desirable for fishes, while Asaah et al. (2006) studied soils of the Bassa Industrial Zone for trace metals and found out that they were contaminated.

Owing to soil-water-plant interaction, monitoring these compartments as a block remains a better tool towards understanding their relationships. This will enhance sustainable development within the societal, economic, conservational and climate contextual need.

This study was therefore designed to (i) examine the possible effects of the water chemistry of Rivers Wouri and Dibamba on the Douala-Edea mangrove ecosystem and (ii) assess the potential role of soils of this area in controlling the transportation of cations and anions into the different water bodies.

MATERIALS AND METHODS

Area of study

The area lies between latitudes 3° 14' and 4° 93' N and longitudes 9° 30' and 10° 05' E (Figure 1). It harbours the Bassa and the Bonaberi Industrial Zones of Douala, a city with about 1.8 million inhabitants (MINEPAT, 2010).

The two industrial zones account for the bulk of industrial activities in the country, but depict contrasting features in terms of physical landscape. The Bonaberi Industrial Zone evolved almost entirely on the aquatic terrain located on lagoon marginal depressions. This necessitated extensive land reclamation to obtain space on which industrial activities had to be built. The Bassa Industrial Zone terminates into estuarine creek formation of the Dibamba River to the East of the city. The Bonaberi Industrial Zone complex

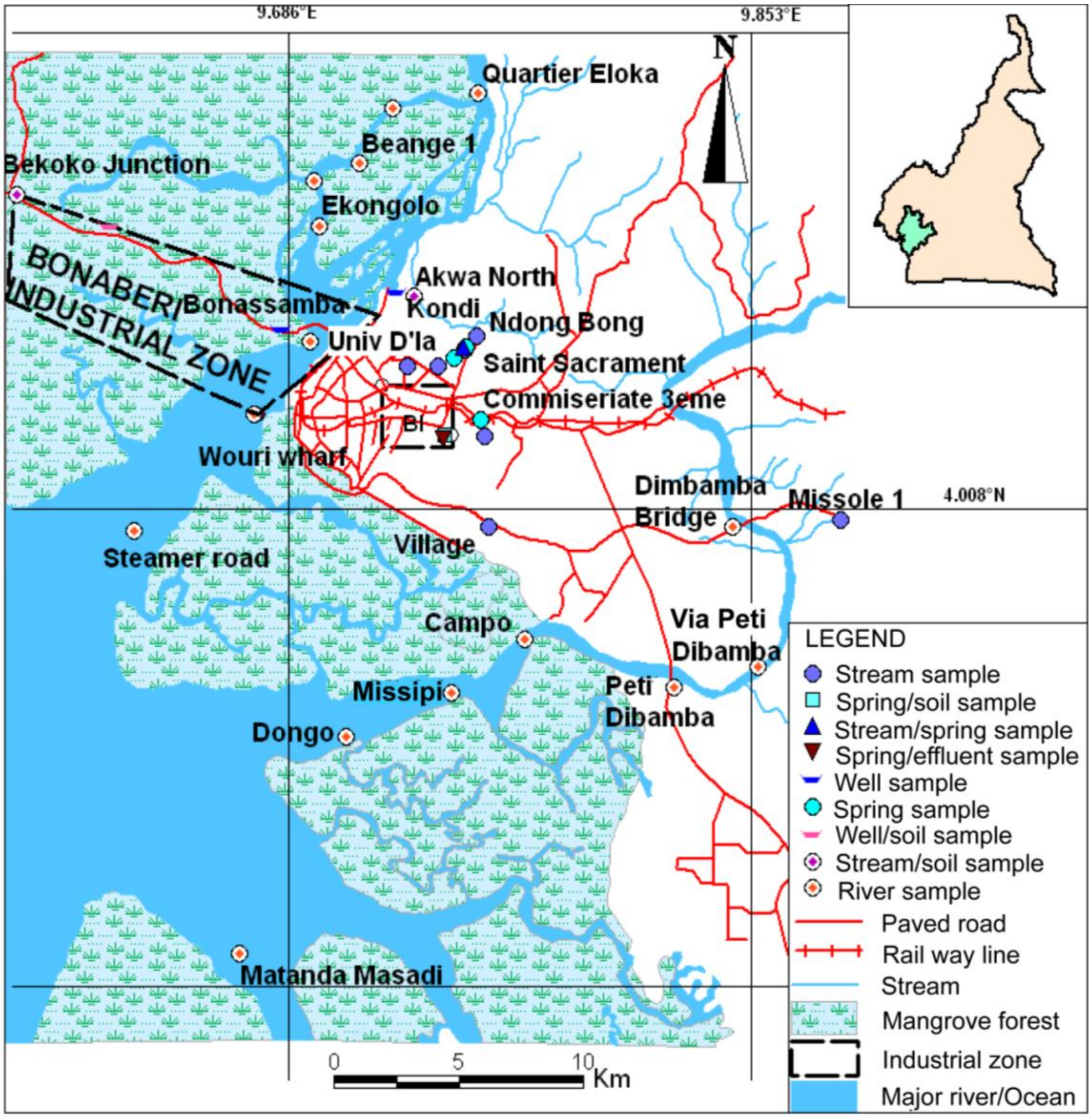


Figure 1. Map of study area showing the sampling sites (Tening et al., 2011). B.I. = Bassa Industrial Zone ; Univ. D'la = University of Douala.

has encroached into the Wouri River and this most likely provokes increased discharge of effluents into it.

Geology and soils

The zone is located within the Douala Sub-Basin of the Douala Basin, a sedimentary basin of Cretaceous to Tertiary age having a total surface area of 7000 km^2 and of maximum width of 60 km (Dumort, 1968; Regnoult, 1986). The origin and structure of this basin is associated with the opening of the South Atlantic Ocean, genetically related to the break-up of Gondwanaland. The stratigraphy of the basin consists of the Cretaceous Mungo River Formation, overlain by the Tertiary Mpundu Formation. The Mungo River Formation consists mainly of sandstone with a few intercalations of limestone and shale. The Mpundu Formation consists of poorly consolidated grits and sandstones that occasionally display bedding. However, the Douala metropolis lies on the Wouri member of the Mpundu Formation, which is dominantly made up of gravely sandstone with clay matrix. The soils of this area are alluvial resulting from the decomposition of sedimentary rocks. They are essentially sandy and commonly rich in quartz and clay minerals. These soils are very permeable in some areas. However, in other areas, the soils are very rich in clays to the extent that percolation of rainwater takes quite a long time.

Drainage

The Wouri and the Dibamba rivers constitute the drainage system in the entire Douala zone and flow all year round. The Wouri flows within the Akwa, Bonaberi and part of the Bassa while the Dibamba flows in the Eastern outskirt of the town. In the Bassa and Bonaberi Industrial Zones, there are many intermittent streams that are normally loaded with most of the solid and liquid waste channelled from industries, households as well as from waste dumps. These streams feed larger streams which empty into the Rivers Wouri and Dibamba.

Table 1. Major activities in the Douala metropolis adapted from Horan (1990) and Montgomery (1992).

Activity	Company	Product	Chemical entity
Agro-industry and food processing	Guinness Cameroon SA. Brasseries, La PASTA, ISEBERG, SIC CACAO.	Drinks/processed foods	NO_3^- NO_2^-, PO_4^{3-}, organic substances
Chemical/pulp	CIMENCAM, CEP, SAPCAM, UNALOR, SOPARCA, SIPCA, CCC, PILCAM, PLASTICAM. SOCAME, SCTB	Cement, oils, paints, detergents, vanish, soap, butter, plastics, matches, batteries, fertilizers	NO_3^-, acids, Hg, Cu, Pb, PO_4^{3-}, SO_4^{2-}, NO_2^-
Textiles	CICAM, SACC.	Cloths	Acids, Hg, organic compounds
Petroleum	SCDP, TEXACO	Aviation fuels, petrol, diesel fuel, wax.	Hydrocarbons, Pb, NO_3^-, PO_4^{3-}
Metallurgy alloys	ALLUCAM, SOCAAFERE,	Metals of various types.	As, Be, Bi, Cd, Cu, Pb, Hg, Ni, Zn.
Glass	SOCAVERE	Bottles	As, Be, Bi, Cd, Cu, Pb, Hg, Ni, Zn.
Domestic activities		Human waste and organic substances	PO_4^{3-}, SO_4^{2-}, NO_3^-

Climate

The climate is humid. The coast is covered by mangroves and dominated by Rhizophora and Avicenia species (Neba, 1987). Mean monthly temperature usually goes above 31°C. January and February are the hottest months with mean monthly temperature of 32 and 33°C, respectively (CWCS, 1998). The dry season runs from November to March accompanied by very high temperatures. Mount Cameroon forms a great barrier to the rain bearing winds causing the air to rise with moisture it carries and falling back as relief rain in Douala. Daily rainfall is very heavy and occurs throughout the year though heavy rains set in from April and subside in October.

Human activities

The metropolitan area is heavily loaded with diverse forms of human activities ranging from domestic, primary, secondary to tertiary industries (Table 1).

Sampling

Sampling was carried out within the Bassa and Bonaberi Industrial Zones and along the Wouri and Dibamba Rivers in February 2010. Sampling sites were established using a 12-channel Garmin etrex Global Positioning System (GPS). Sampling sites in rivers were areas of stream inflow, high coastal activities or near villages. Sample collection in the rivers was accomplished by the use of an engine boat. Land sampling included areas of potential influence by industrial activities.

Water samples

Surface water samples were collected from Rivers Wouri and Dibamba, and some streams, wells and springs feeding these rivers by dipping the containers in the water and filling them to the brim. Depth water samples (one, three and five metres) were collected at two points (upstream and downstream) in each river using a 1-L depth sampler (The Science Source: WIFFLE BALL KING, Reg. No. 1149044, USA). A total of 50 water samples were collected. In all cases, 0.5 L plastic containers were used. Before the samples were collected, the bottles were rinsed several times with the sample to be collected. The pH and electrical conductivity (EC) were measured *in situ* using a Tracer PockeTester^{TM} field conductivity meter, model pH/TDS/salts. They were then transferred immediately into a cooler containing ice blocks. Before chemical analysis was carried out, the samples were filtered using Whatman 40 filter papers. Determinations of Bray II phosphates, (PO_4^{3-}) by spectrometry, nitrates (NO_3^-) and ammonium (NH_4^+) by distillation, chlorides (Cl^-) by titration with silver nitrate, sulphates (SO_4^{2-}) by gravimetry, calcium (Ca^{2+}) and magnesium (Mg^{2+}) by compleximetry, potassium (K^+) and sodium (Na^+) by flame spectrophotometry, organic carbon (Org. C) by Walkley and Black method were carried out by methods largely described by Pauwels et al. (1992). In all the parameters determined, triplicate samples were analysed and their mean values were calculated.

Soil samples

Eight top soil (0 to 15 cm) samples were collected proxy to some of the water collection points to cut across all water bodies (streams, wells, rivers, springs and mangroves) with particular avoidance of points of disturbance. The samples were collected into black polyethylene bags using a hand trowel. They were air dried and passed through a 2-mm sieve. The samples were analysed for CEC by distillation using a Kjeldhal set. The pH in water and in 1 N KCl was determined by 1:10 soil: solution ratio. Particles size analysis was carried out by the hydrometer method as largely described by Pauwels et al. (1992).

Experimental data was analysed with the statistical package SPSS11.0 and EXCEL 2007 for Windows. Univariate statistics, factor analysis, descriptive and correlation analyses were performed on the various data to evaluate and trace the sources of the different chemical entities into the mangrove ecosystem.

RESULTS AND DISCUSSION

The composition of cations and anions vary at different sites of both Rivers Wouri and Dibamba (Tables 2 and 3). Variations in the physicochemical properties from upstream to downstream may be caused by changes in quantity and/or composition of freshwater discharges. This can

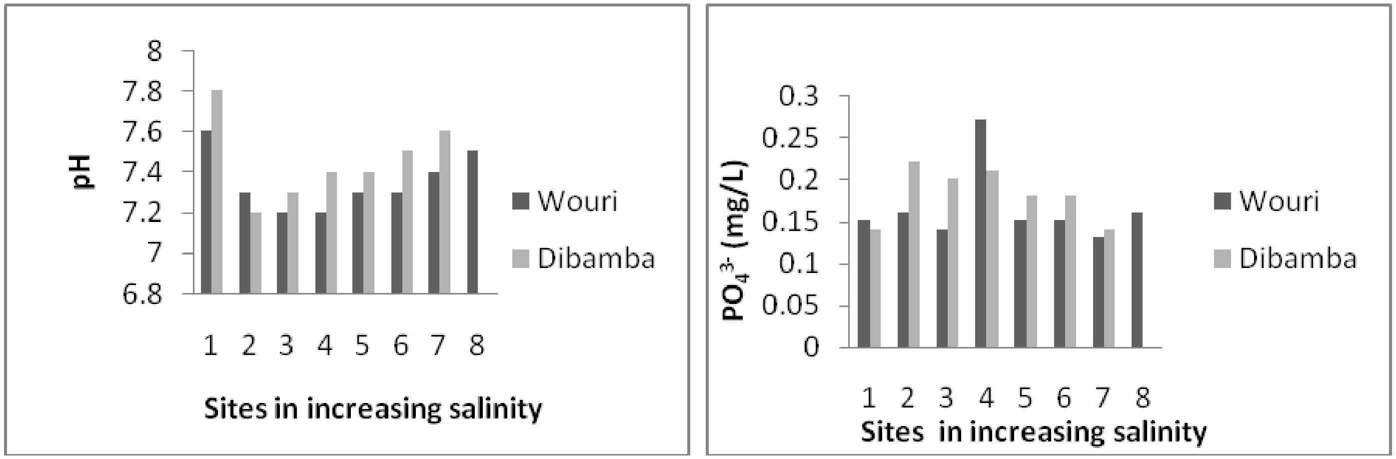
Table 2. Physicochemical properties of water samples from River Wouri.

Site	Location	pH	EC (μS/cm)	Organic C (%)	NH_4^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	NO_3^-	PO_4^{3-}	SO_4^{2-}	Cl^-
									(mg/l)				
Quartier Eloka	040914.2N 009 4516.3E	7.6	43	0.09	23.80	0.16	0.8	13.7	0.8	23.8	0.15	29.60	1.1
Beange	04 08 54.8N 009 43 24.9E	7.3	244	0.06	29.40	1.12	0.48	13.7	4.6	15.4	0.16	28.00	63.9
Beange1	04 07 44.7N 009 42 40.7E	7.2	801	0.08	22.40	7.84	75.36	25.1	17.4	23.8	0.14	23.00	85.2
Todo Njabale	04 07 21.9N 009 41 41.9E	7.2	1127	0.07	18.20	5.92	62.24	30.1	24.8	30.8	0.27	24.70	92.3
Ekongolo	04 06 25.1N 009 41 49.0E	7.3	1710	2.74	35.00	11.04	33.76	65.6	61.3	30.8	0.15	28.00	142.0
Wouri Bridge	04 03 59.9N 009 41 36.3E	7.3	6960	0.11	39.20	24.8	108.32	226.0	229.7	22.4	0.15	26.30	873.3
Wouri Wharf	04 02 27.8N 009 40 23.9E	7.4	9600	0.11	21.00	28.0	119.52	220.6	217.6	29.4	0.13	11.50	582.2
Steamer Road	04 00 01.5N 009 37 48.4E	7.5	15000	0.14	33.60	47.52	252.96	469.5	505.4	25.2	0.16	36.20	28.4
Mean		7.4	4436	0.43	27.83	15.80	81.68	133.0	132.7	25.2	0.16	25.91	233.6

alter the chemistry of the environment, such as hydrogeology and temperature not suitable for the mangrove ecosystem. Nutrients from fresh water inflow do not only affect water quality but equally species diversity (Doering, 1996). Average pH was 7.4 in River Wouri and 7.5 in River Dibamba indicating that the rivers were neutral with values within the permissible range advocated by WHO (2008). The pH decreased and increased from upstream to downstream in both rivers (Figure 2a). The decrease in pH could be associated to nearness of such areas to the industrial zones with probable releases and deposition of acidic gases. The EC of River Wouri were generally lower than those of River Dibamba with mean values of 4436 and 12496 µS/cm, respectively. Mean concentrations of the cations stood at $Na^+ > K^+ > Mg^{2+} > NH_4^+ > Ca^{2+}$ and $Na^+ > NH_4^+ > K^+ > Mg^{2+} > Ca^{2+}$ for Rivers Wouri and Dibamba respectively. Anions followed a trend of $Cl^- > NO_3^- > SO_4^{2-} > PO_4^{3-}$ for both rivers. There was a significant difference ($P<0.01$) between the means of both rivers. This could be an indication that from River Wouri the sampling scenario had no effect on the statistical detection of temporal trends in physicochemical properties of water samples implying that the higher values of River Dibamba could be accounted for by the nature of activities of the area. In both rivers, PO_4^{3-} concentrations were low. They ranged from 0.14 to 0.20 mg/l in River Wouri and 0.13 to 0.27 mg/l in River Dibamba.These current values seem to present no threat to the mangrove environment when compared with the 50 mg/l maximum advocated by the former Ministry of Mines and Energy in Cameroon. No consistent trend was observed in this parameter from upstream to downstream (Figure 2b). This inconsistency of values could be allied to addition by anthropogenic activities through stream flow which are continually increasing as a result of increase in population and urbanisation. However, sample number 4 located between Ekongolo and Beange 1 (Figure 1) had the highest PO_4^{3-} which could be ascribed to its location at a confluence with anthropogenic inputs from both stream flows. Nitrate concentration ranged from 15.4 to 30.8 mg/l (Table 2) and 42.0 to 341.6 mg/l (Table 3) for Rivers Wouri and Dibamba, respectively. These values were very high in some sites in Dibamba when compared with the Russian (40 mg/l) maximum permissible values for fisheries and other aquatic plants. Increase NO_3^- concentration as a consequence of Industrialisation puts a considerable burden on forest,

Table 3. Physicochemical properties of water samples from River Dibamba.

Site	Location	pH	EC (µS/cm)	Organic C (%)	NH_4^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	NO_3^-	PO_4^{3-}	SO_4^{2-}	Cl^-
					(mg/l)								
Dibamba Bridge	04 00 6.5N 009 50 46.9E	7.8	2210	0.10	497.0	11.04	67.36	84.8	82.0	63.0	0.14	29.60	255.6
Via Peti Dibamba	03 57 10.4N 009 51 19.6E	7.2	6250	0.11	74.2	18.72	108.00	168.9	242.2	56.0	0.22	32.90	284.0
Peti Dibamba	03 56 43.7N 009 46 30.6E	7.3	9810	0.13	86.8	35.04	195.36	384.0	452.0	58.8	0.20	29.60	773.9
Campo	03 57 44.7N 009 46 16.6E	7.4	14300	0.15	78.4	40.80	239.84	458.5	505.4	60.2	0.21	32.90	1107.6
Missipi	03 56 37.6N 009 44 41.8E	7.4	16500	0.15	78.4	60.00	216.80	651.9	771.2	341.6	0.18	36.20	582.2
Dongo	03 55 41.8N 009 42 23.6E	7.5	18500	0.15	63.0	53.28	298.72	506.0	662.3	60.2	0.18	29.60	1192.8
Matanda Masadi	03 51 09.0N 009 40 04.8E	7.6	19900	0.15	632.8	63.84	341.28	530.5	864.3	42.0	0.14	24.70	1249.6
Mean		7.5	12496	0.13	215.8	40.39	209.62	397.8	511.3	97.4	0.18	30.79	778.0



(a) (b)

Figure 2. Variation of (a) pH and (b) PO_4^{3-} with salinity gradient.

grassland and aquatic plants thereby causing undesirable changes in biodiversity and acidification of soils and water (Stevens et al., 2004). Calcium concentration ranged from 0.16 to 47.52 mg/l with a mean value of 15.80 mg/l in River Wouri (Table 2) and 11.04 to 63.84 mg/l with a mean value of 40.39 mg/l in River Dibamba (Table 3). These values are below the 700 mg/l guideline set by WHO (2008) for domestic and industrial use. Mean Mg^{2+} concentration stood at 81.68 mg/l in River Wouri and 209.62 mg/l in River Dibamba. Major sources of magnesium in water include amphiboles, olivine, pyroxene, dolomites and clay minerals (Todd, 1980). Todd (1980) observed that dolomites have high concentration of Mg^{2+} while clay minerals have low concentration. If the concentration of this element were from clay mineral alone, concentrations would have been low. Thus, the high concentration could be from the combination of these sources and anthropogenic activities. Potassium had an average concentration of 133.0 mg/l in River Wouri and 397.8 mg/l in River Dibamba. Major sources of potassium in water include feldspers (orthoclase and microclin) and clay minerals (Todd, 1980). The concentration of potassium should be 10 mg/l in natural water. The high concentrations of potassium in these rivers could partly be from industrial sources such as the salt producing industry (Sel Camerounaise (SELCAM)) in this area.

Streams (Tables 4 and 5) revealed concentrations that vary considerably with the characteristics of the areas in which they are situated. Sulphates ranged from 0.00 to 26.30 mg/l in streams feeding River Dibamba and 23.00 to 32.90 mg/l in streams feeding River Wouri. The concentrations were lower than the 250 mg/l advocated by WHO (2008). These values varied proportionately with sites of varying activities, implying that their main source could be anthropogenic activities. Sample number 4 (Table 4) had a pH value of 11.2 with an EC of 1800 µS/cm. Similar high values were obtained from sample number 6 (Table 5). The EC value and Na^+ ion concentration of sample number 6 were of values 5540 µS/cm and 242 mg/l, respectively. These values were higher than the 1000 µS/cm and 200 mg/l maximum allowable values set by WHO (2008) for EC and Na^+, respectively. Major sources of Na^+ include: feldspar, clay mineral, evaporates such as halites (NaCl), and industrial waste. Long term discharge of these ions which function as dispersants into the mangrove environment can change the structural properties of the swamp land leading to stress events. Mean Ca^{2+} and Mg^{2+} ions concentrations of 2.24 and 1.65 mg/l, respectively, in River Dibamba and 3.59 and 1.58 mg/l, respectively in River Wouri were lower than the 700 mg/l and 250 mg/l, respectively, set by WHO (2008). Sample number 1 (Table 5) had the lowest EC value of 9 µS/cm and the highest NH_4^+ ion concentration of value 660.8 mg/l as compared to other streams in the area. This could be attributed to the decay of luxuriant natural vegetation in the area. In all the streams, NH_4^+ ion concentrations were higher than the 0.5 mg/l maximum level stipulated by WHO (2008). The mean Cl^- concentration of 135.1 mg/l in streams feeding River Wouri was higher than the mean value of 59.3 mg/l in streams feeding River Dibamba. The mean Cl^- concentration in streams feeding River Wouri was highly influenced by samples numbers 3 and 4 (Table 4). Probable sources of Cl^- here include sea spray from Atlantic Ocean, and industrial waste which could produce point source. The mean NO_3^- concentrations of the streams feeding both rivers were generally higher than the recommended standards of 40 mg/l by WHO (2008). These NO_3^- concentrations might have been a consequence of agricultural activities (excess application of inorganic nitrogenous fertilizers), waste water disposal, oxidation of nitrogenous waste products in human and animal excreta, septic tanks and deposition from industrial establishments. High NO_3^- concentrations promote vegetative growth in trees such as mangroves but equally increase vulnerability to lodging. High NO_3^- values are undesirable in water bodies as they can result in eutrophication and incidences of metamoglobinemia (Kross et al., 1993). Mean K^+ concentrations stood at 46.2 and 20.0 mg/l in Rivers Wouri and Dibamba, respectively. These values are higher than the maximum permissible values advocated by WHO (2008). The variation in physicochemical properties in streams influenced by human activities could be some of the major sources on changes in properties along the rivers.

Physicochemical properties of wells of Wouri and Dibamba (Tables 6 and 7) were generally lower than those of the streams. This is an indication that ground water contamination is minimal and thus human activities are responsible for the high levels in streams. Wells feeding both Rivers Wouri and Dibamba were acidic with an average pH of 5.8 and 6.3, respectively. Sample number 1 (Table 6) had the highest EC value (450 µS/cm). This is probably due to the fact that it is an open well and located near a cement block industry. Sample number 4 (Table 6) had the least pH value of 4.3 for wells and springs feeding River Wouri. This could have been enhanced by its proximity to the Bassa Industrial zone with probable deposition of acidic gases. Sample number 3 (Table 6) had the highest ammonium ion concentration (365.40 mg/l). This could be associated to its proximity to la Pasta, the food processing industry and breweries. Sample number 3 (Table 7), was the most acidic with a pH value 4.7 for wells and springs feeding River Dibamba. Average Cl^- concentration of wells feeding River Wouri (57.9 mg/l) was higher than those feeding River Dibamba (38.2 mg/l). Though these values are lower than the 250 mg/l set by WHO (2008), higher Cl^- concentrations of wells feeding River Wouri could represent a good example of human disturbance (Gove et al., 2001).

Cation concentration increased with depth in both rivers (Figures 3). This could be an indication that one of the

Table 4. Physicochemical properties of streams feeding River Wouri.

Site	Location	pH	EC (µS/cm)	Organic C (%)	NH_4^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	NO_3^-	PO_4^{3-}	SO_4^{2-}	Cl^-
					(mg/l)								
Akwa North	04 04 56.5N 009 43 51.8E	7.5	404	0.08	44.80	2.08	1.44	58.3	20.9	33.6	1.83	24.70	71.0
Bekoko Junction.	04 07 06.1N 009 35 16.1E	7.5	10	0.07	30.80	2.40	0.16	4.2	0.2	19.6	0.13	23.00	1.2
CamTel	04 03 28.7N 009 43 43.0E	7.0	361	0.07	32.20	11.68	5.28	105.2	8.7	37.8	2.15	32.90	376.3
Univ. Douala	04 03 28.9N 009 44 24.1E	11.2	1800	0.07	44.80	2.72	1.44	65.6	89.5	46.2	4.64	31.30	284.0
Ndog Bong 1	04 03 50.6N 009 44 58.9E	6.7	170	0.07	44.80	1.76	1.44	32.7	1.7	53.2	0.44	28.00	71.0
Ndog Bong 2	04 03 53.3N 009 44 56.8E	6.5	156	0.08	42.00	1.76	0.48	24.7	1.7	40.6	0.37	24.70	71.0
Kondi	04 04 06.3N 009 45 13.5E	7.3	283	0.08	67.20	2.72	0.80	32.7	6.5	50.4	0.45	26.30	71.0
Mean		7.7	455	0.07	43.80	3.59	1.58	46.2	18.5	40.2	1.43	27.27	135.1

Table 5. Physicochemical properties of streams feeding River Dibamba.

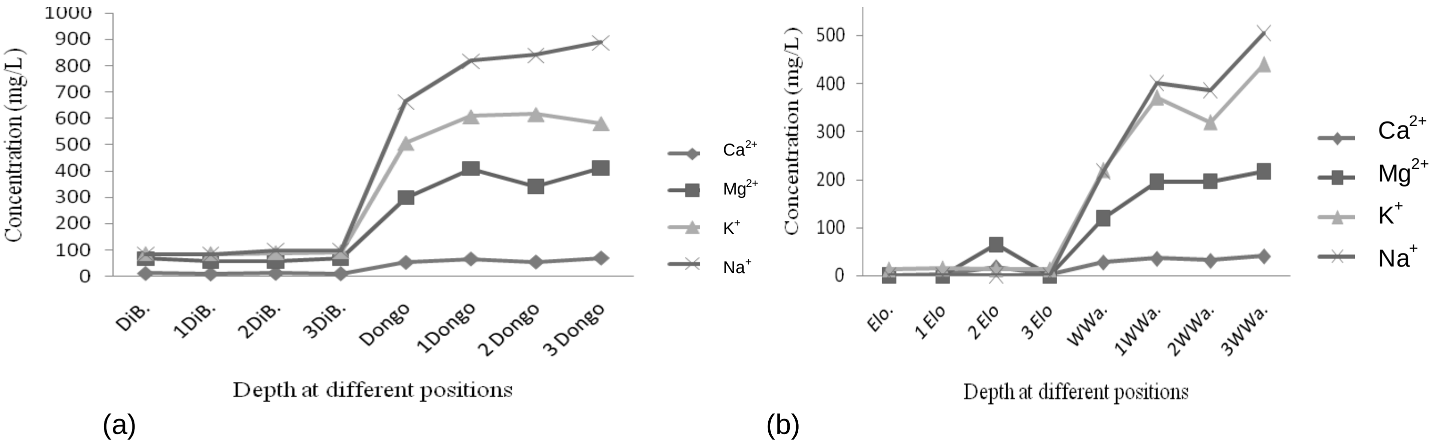
Site	Location	pH	EC (µS/cm)	Organic C (%)	NH_4^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	NO_3^-	PO_4^{3-}	SO_4^{2-}	Cl^-
					(mg/l)								
Stream Missole	04 00 16.0N 009 53 07.2E	7.6	9	0.09	660.8	0.80	2.40	4.6	0.2	25.2	0.13	0.00	0.7
Stream Village	04 00 07.1N 009 45 29.6E	7.6	246	0.09	120.4	2.40	1.12	31.2	4.6	43.4	0.23	26.30	42.6
Stream Nkongi	04 02 01.2N 009 45 23.7E	5.9	69	0.08	54.6	2.08	1.76	9.1	0.8	204.4	0.20	18.10	28.4
Spring and Stream CCC	04 02 02.2N 009 44 32.3E	6.7	223	0.09	47.6	3.04	1.44	24.3	4.6	37.8	0.72	24.70	56.8
Stream CCC	04 02 02.2N 009 44 32.3E	6.8	187	0.09	46.2	3.68	1.12	29.9	6.5	103.6	0.78	21.40	28.4
Stream and Effluent CCC	04 01 57.3N 009 44 31.0E	11.8	5540	0.22	81.2	1.44	2.08	24.3	242.0	98.0	10.03	26.30	198.8
Mean		7.7	1046	0.11	168.5	2.24	1.65	20.6	43.1	85.4	2.02	19.47	59.3

Table 6. Physicochemical properties of wells and springs feeding River Wouri.

Site	Location	pH	EC (µS/cm)	Organic C (%)	NH_4^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	NO_3^-	PO_4^{3-}	SO_4^{2-}	Cl^-
					(mg/l)								
Well Akwa North	04 05 02.7N 009 43 29.8E	7.5	450	0.09	92.40	20.32	40.48	112.5	4.6	89.6	0.19	24.70	56.8
Well Bonassama	04 04 15.2N 009 41 00.6E	7.5	382	0.09	53.20	12.32	34.72	66.8	4.6	75.6	0.18	23.00	85.2
Well C. Mutzig	04 06 25.9N 009 37 17.6E	6.4	75	0.08	365.40	1.44	1.12	12.6	0.8	67.2	0.20	24.70	2.2
Spring Saint Sacrament	04 03 39.7N 009 44 45.2E	4.3	143	0.09	32.20	18.08	1.26	31.1	1.7	44.8	0.26	36.20	142.0
Spring Ndog Bong	04 03 53.7N 009 44 59.8E	4.8	92	0.09	44.80	2.40	0.48	12.6	0.8	47.6	0.16	21.40	56.8
Spring Commesarait	04 02 21.8N 009 45 19.0E	4.5	61	0.22	92.40	1.44	0.80	10.4	0.2	75.6	0.19	26.30	4.3
Mean		5.8	201	0.11	113.40	9.33	13.14	41.0	2.1	66.7	0.20	26.05	57.9

Table 7. Physicochemical properties of wells and springs feeding River Dibamba.

Site	Location	pH	EC (µS/cm)	Organic C (%)	NH_4^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	NO_3^-	PO_4^{3-}	SO_4^{2-}	Cl^-
					(mg/l)								
Well Missole	03 59 46.4N 009 53 41.5E	7.6	159	0.09	44.8	0.8	1.76	11.5	0.2	53.2	0.16	28	56.8
Well Camdem	03 59 48.7N 009 50 29.2E	7.6	208	0.1	39.2	2.4	0.48	2.4	0.2	49	0.14	29.6	0.9
Well Nkongi	04 02 02.0N 009 45 20.4E	4.7	92	0.1	37.8	0.8	2.72	13.9	1.7	50.4	0.18	26.3	52.4
Spring CCC	04 02 02.2N 009 44 32.3E	5.2	199	0.07	67.2	2.7	1.44	13.9	4.6	36.4	0.13	24.7	42.6
Mean		6.3	164	0.09	47.3	1.7	1.6	10.4	1.7	50.9	0.16	27.97	38.2



(a) (b)

Figure 3. Cation concentration with depth in (a) River Dibamba (b) River Wouri. DiB. = Dibamba Bridge 1, 2 and 3= 1, 3 and 5 m depths, respectively. Elo = Quartier Eloka, WWa = Wouri 1, 2, and 3 = 1,3 and 5 m, respectively.

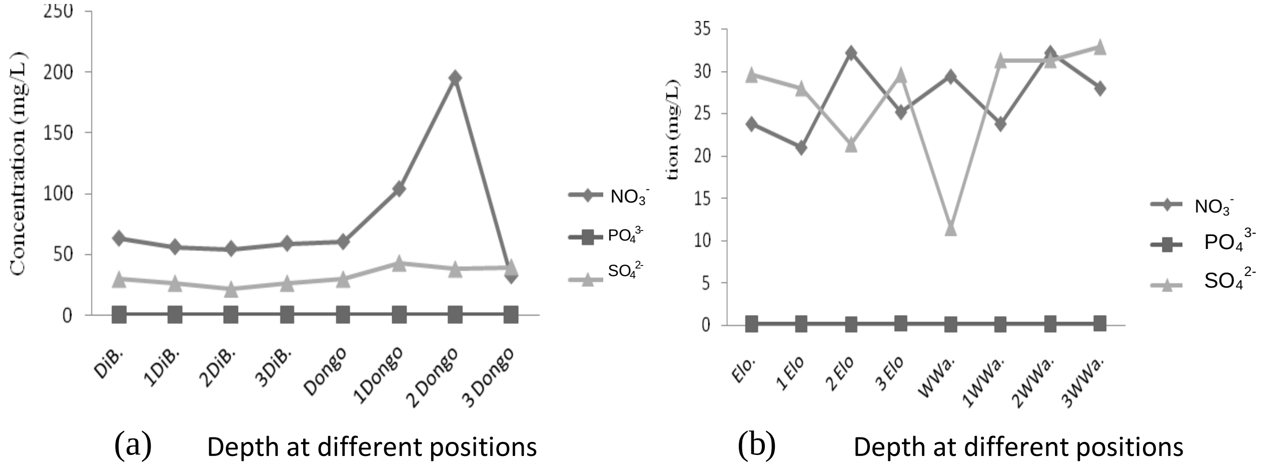


Figure 4. Variation of anions with depth in (a) River Dibamba (b) River Wouri. DiB. = Dibamba Bridge, 1, 2 and 3 = 1, 3 and 5 m, respectively. Elo. = Quartier Eloka, WWa = Wouri Wharf ,1, 2, and 3 = 1, 3 and 5 m, respectively.

major sources of the cations is the breakdown of bedrock materials. There were positive relationships ($P<0.01$) within the cations when correlation analysis was carried out indicating that these cations were coming from the same source. On the other hand, anions did not show an increase with depth in both rivers except chlorides (Figure 4). Salinity profiling revealed perturbations at sampling sites, a probable indication of anthropogenic origin with severity in River Wouri. Correlation analysis showed that anions from both rivers were significantly correlated ($P<0.01$) with each other except the chlorides. Therefore, the major sources of cations and anions are not the same.

From factor analysis for River Wouri (Tables 8 and 9), three factors accounting for 97.4% of the total variance, explained how the various sites could be associated. Factor 1 consists of all the sites of River Wouri and contributed 87.2% of the total variance. The grouping of these sites could be allied to anthropogenic activities as phosphates and nitrates were within a close range. Factor 2 contributed 8.2% of the total variance and was made of sample number 1 (Table 9) alone. This could be partly due to domestic discharges, which are rich in phosphates and nitrates in the remote areas with the presence of water hyacinths in areas of enhanced nutrients. Factor 3 was a single factor and made up of sample number 5 (Table 9). It contributed 2.0% of the total variance. This could be linked to food processing activities that generate high organic carbon content.

For River Dibamba (Tables 10 and 11), three factors accounting for 99.8% of the total variance, also explained site groupings. Factor 1 accounted for 98.4% of the total variance and was composed of all sites (Table 11). The association of these sites could be due to natural activities which could be from the weathering of bedrock material and the decomposition of natural vegetation. Fac-

Table 8. Total variance, cumulative Eigen values and percentage contribution from various sites of water samples from River Wouri.

Site	Initial Eigen values (%)			Extraction sums of squared loadings (%)		
	Total	Variance	Cumulative	Total	Variance	Cumulative
Quartier Eloka	6.972	87.210	87.210	6.972	87.210	87.210
Beange	0.654	8.174	95.384	0.654	8.174	95.384
Beange 1	0.158	1.980	97.364	0.158	1.980	97.364
Todo Njebale	0.141	1.761	99.125			
Ekongolo	0.055	0.682	99.807			
Wouri Bridge	0.009	0.116	99.924			
Wouri Wharf	0.004	0.050	99.973			
Steamer Road	0.002	0.027	100.000			

Extraction method: Principal component analysis.

Table 9. Three component matrix (a) from various sites of water samples from River Wouri.

Site	Component		
	1	2	3
Quartier Eloka	0.757	0.631	-0.058
Beange	0.906	0.334	0.166
Beange 1	0.983	-0.048	-0.015
Todo Njebale	0.984	-0.032	-0.129
Ekongolo	0.930	-0.199	0.311
Wouri Bridge	0.977	-0.187	0.004
Wouri Wharf	0.944	-0.228	-0.002
Steamer Road	0.974	-0.119	-0.130

Extraction method: Principal component analysis.

Table 10. Total variance explained from various sites of water samples from River Dibamaba.

Site	Initial Eigen values (%)			Extraction sums of squared loadings (%)		
	Total	Variance	Cumulative	Total	Variance	Cumulative
Dibamba Bridge	6.890	98.435	98.435	6.890	98.435	98.435
Via Peti Dibamba	0.073	1.036	99.471	0.073	1.036	99.471
Peti Dibamba	0.026	0.376	99.847	0.026	0.376	99.847
Campo	0.008	0.116	99.963			
Missipi	0.002	0.032	99994			
Dongo	0.000	0.004	99.999			
Matanda Masadi	0.000	0.004	100.000			

Extraction method: Principal component analysis.

Table 11. Three component matrix (a) from various sites of water samples from River Dibamba.

Site	Component		
	1	2	3
Dibamba Bridge	0.974	0.225	0.032
Via Peti Dibamba	0.998	0.005	0.041
Peti Dibamba	0.999	-0.042	-0.013
Campo	0.997	-0.064	-0.023
Missipi	0.991	-0.071	0.102
Dongo	0.995	-0.095	-0.030
Matanda Masadi	0.992	0.047	-0.107

Extraction method: Principal component analysis.

Table 12. Some physicochemical properties of soils in the Wouri and Dibamba area.

Site	Location	pH (Water)	pH (1 N KCl)	CEC (cmol/kg)	Sand (%)	Silt (%)	Clay (%)
Akwa North	04 05 02.7N 009 43 29.8E	5.5	4.8	13.2	64.4	30.8	4.8
Bekoko Junction	04 07 11.8N 009 35 17.6E	5.7	4.3	7.98	78.2	17.8	4.0
Commesariate 3eme	04 02 21.8N 009 45 19.0E	4.3	3.7	22.2	52.2	25.4	22.4
Saint Sacrament	04 03 39,7N 009 44 45.2E	5.3	4.6	5.0	74.0	14.8	11.2
Ndog Bong	04 03 50.6N 009 44 58.9E	4.5	3.7	5.9	79.0	14.2	6.8
Carrefour Mutzig	04 0625.9N 009 3717.6E	4.3	3.9	2.16	72.8	14.0	13.2
Missole	03 59 46.4N 009 53 41.5E	5.7	4.5	11.7	20.2	72.0	7.8
Dibamba	03 59 54.8N 009 50 25.4E	5.5	4.3	11.3	37.2	13.8	49.0

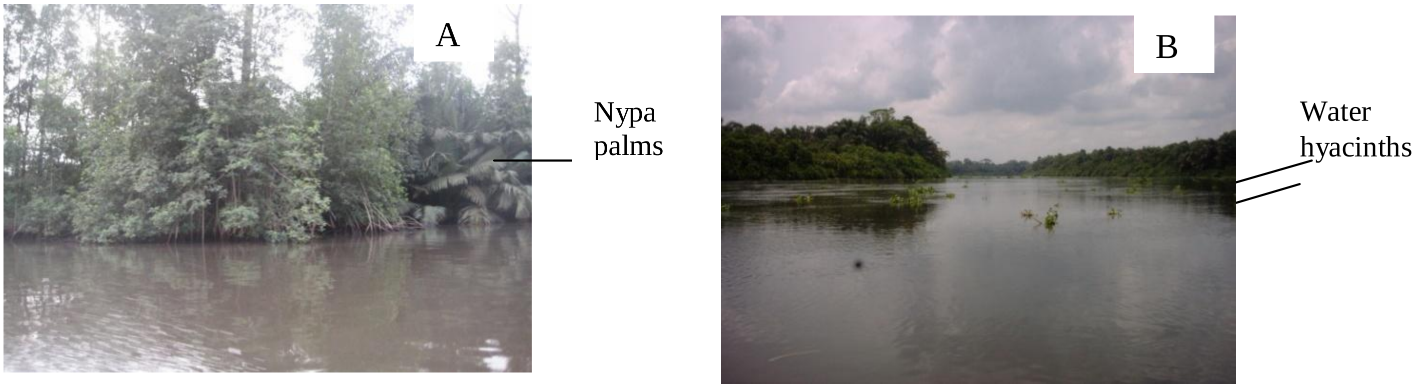


Figure 5. Nypa palms along the banks or River Dibamba(a) and floating water hyacinths in River Wouri (b).

tor 2 accounted for 1.0% of the total variance. It was made up of sample number 1 (Table 11) alone with high NH_4^+ concentration which might have resulted from remains of living tissues used by humans in the nearby Dibamba village. Factor 3, contributing 0.4% of the total variance, was not dominated by any site. This could be an indication of the effects of distant activities.

All soils of the area were acidic (Table 12). The soil pH in water ranged from 4.3 to 5.7 in water and 3.7 to 4.8 in 1N KCl. Soil pH plays a great role in the occurrence of some mangrove species such as the Nypa palms. Generally, soils of Wouri area are high in sand while those of Dibamba area are rich in clay. The high clay values of Dibamba soils may be as a result of variation in the stratigraphy within the Douala basin (Ntamak-Nida et al., 2010). The soils also showed varying CEC values. There was a positive correlation (P<0.05) between Wouri clays and CEC. On the other hand, correlation between Dibamaba clays and CEC showed a highly significant negative correlation (P<0.01). This implies that Dibamba clays have mostly positively charged colloids, which can retain anions but have low cation retentive capacity. Cations released into these bodies will easily find themselves into water bodies. On the other hand, the clays of Wouri have negatively charged colloids and will therefore retain cations and will not retain anions (PO_4^{3-} and NO_3^-) sent into the environment. These anions will easily find themselves into water bodies exposing them to threats such as eutrophication. The presence of these substances within the mangrove environment changes the hydrology resulting in the emergence of less desirable species such as the Nypa palms and Water hyacinths (Figure 5). Though beautiful plants, water hyacinths are regarded as pests in tropical and subtropical regions, they reproduce very rapidly in water environments with enhanced nutrient concentrations and are therefore abundant in eutrophicated water bodies. The presence of these plants in Rivers Wouri and Dibamba is an evidence of changes in physicochemical properties of these water bodies. Though NO_3^- and PO_4^{3-} were lower in River Wouri than River Dibamba, the presence of water hyacinths, which are high consumers of these entities, might have been responsible for their low levels in River Wouri. Similar appearances were identified in the Kafue River in Zambia (Alsterhag and Petersson, 2004). Changes in hydrology of the mangrove environment due to influx of cations and anions can equally convert the mangrove environment from carbon sinks to carbon sources (Roulet et al., 2007).

Conclusions

A greater proportion of cations in the Douala-Edea mangrove ecosystem came from weathering of soils and rocks while anions came from anthropogenic activities. With variability in the retentive capability of soils in the area, there is the need for an elaborate characterization of wastewaters and water bodies, and evaluation of treatment facilities of municipal and industrial waste to assess the status and control of water pollution. Clay mineralogical studies should be conducted to ascertain the retention capacity of the soils and used like a tool in the demarcation of industrial areas or land for waste disposal.

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