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Selected physicochemical properties and quality of soils around some rivers of Cameroon

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Rivers Wouri and Meme feed the Wouri and Rio del Rey mangroves of Cameroon, respectively. This study examined the physicochemical properties of soils that were collected around the vicinity of these rivers. This was to ascertain the former's role in controlling the movement of chemical entities into these rivers and nutrient quality. Twenty-one surface soil samples were collected (0-20 cm depth) within the vicinity of both rivers and analyzed for their physicochemical properties using standard methods. All the soils were slightly acidic, probably dominated by kaolinitic clay minerals and sesquioxides. The mean ECEC (4.31 cmol/kg) of soils around River Wouri was higher than that (2.94 cmol/kg) of soils around River Meme. The average clay content of 11% in soils around River Meme was more than that (4%) in soils around River Wouri, suggesting that the higher ECEC of soils from Wouri could be contributed by organic matter and soil moisture content. The latter had a significant positive correlation ($r = 0.82$, $p<0.05$) with organic matter and clay, respectively, in soils from Wouri. There was also a significant difference ($p< 0.01$) in Mg (with higher levels in D soils) and in Na (with higher levels in M soils). There was yet other significant differences ($p< 0.05$) in sand (with higher values in M soils) and in clay (with higher contents in M soils). This again could be an indication that the mineralogical content of the soils could be different. The soils around both rivers have low major nutrients though more depleted around River Wouri and are vulnerable to increases in anthropogenic activities, such as farming practices, industrial and municipal waste disposal. A more stringent legislation about environmental management, as well as studies about the mineralogical composition of soils is recommended.

Key words: Soil, physicochemical properties, clays, rivers, Wouri, Meme.

INTRODUCTION

Soil is the dynamic link between the biosphere and lithosphere and constitutes a practically non-renewable (very low rate of formation) natural resource, with a key role for the environment and for the agriculture (Moraetis et al., 2016). Soil pollution is one of the major problems that threatens plant and people's lives, like seepage from landfills or solid waste, discharge of industrial waste into the soil, percolation of contaminated water into the soil, rupture of underground storage tanks or excess application of pesticides or fertilizers (Seifi et al., 2010). Untreated wastes are often channeled or piped from the industries and/or households to the ground or into surface water in coastal environments through which rivers flow. This could change the physicochemical properties of such water bodies rendering these waters undesirable to the surrounding ecosystem (Tening et al., 2013). This could also change the physicochemical properties of the soils onto which the wastes are disposed.

Some factors such as altitude, parent rocks, vegetation and anthropogenic activities influence the physicochemical properties of soil and water like pH, organic matter, cation exchange capacity (CEC), soil texture and water chemistry. Soil pH affects nutrients availability and the optimal condition for this is at pH 5 to 7 (Arp and Krausse, 2006). The potential for elements present in soils and sediments to be mobilized/ immobilized and be redistributed depends on several factors such as organic matter, type and amount of clay, pH and the prevailing redox conditions; and pathways. These elements can easily be mobilized and transmitted through for example, water and the food chain to humans (Manga et al., 2017). Therefore, there is great need to investigate the physicochemical properties of soils for agricultural and environmental purposes.

River Wouri that is formed by the joining of the Ykam and Makombe Rivers near Yabassi (Delancey et al., 2010), empties into the Atlantic Ocean. River Wouri feeds the Wouri-Dibamba Mangrove. Douala is the main town that harbours River Wouri. The numerous factories in Douala include food processing, breweries, metal works, cement production, oil processing and paper processing. Wastes from these factories and households are often channeled onto/into the soil or into the surface water courses that empty into River Wouri (Tening et al., 2013). River Meme is the largest river in the South West Region of Cameroon (UCCC, 2017). It runs through many towns in Meme Division including Mbonge. River Meme feeds the Rio del Rey Mangrove. The main activity along the River Meme ecosystem is agriculture (Folack, 1997). The use of fertilizers, insecticides, herbicides and other chemicals by farmers and agro-establishments may be a threat to the environment especially the soil and water quality. Unfortunately, the legislation on farming practices and or waste disposal in Cameroon are hardly implemented (Fonge et al., 2011; Forton et al., 2012).

The mangroves of Cameroon are relatively densely populated and are used for construction, food and medicinal purposes. 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).

Over-exploitation and pollution pose a threat to the mangrove ecosystem (FAO, 2017). Human activities through industrial, agricultural, traffic, domestic, mining and other anthropogenic processes have contributed to elevated and toxic levels of heavy metals when compared to those contributed from geogenic or lithological processes (Pam et al., 2013). Pollution may eventually result in a negative influence on plants, animals and humans through the food chain (Mtunzi et al., 2015). The dissolution and incorporation of heavy metals into the food chain depends on the physicochemical properties of soils, especially pH. Soil pH and other soil properties are especially important in soil processes responsible for solubility of heavy metals in soil and their transportation (Matthews-Amune and Kekulus, 2013).

This study was therefore designed to compare the physicochemical properties of soils around Rivers Wouri and Meme, to relate them to soil quality and to propose some policies on soil management.

MATERIALS AND METHODS

Study area

One of the areas of study is the vicinity of River Wouri (Figure 1). It harbours the Bassa and the Bonaberi Industrial Zones of Douala, a city with about 1.8 million inhabitants (Ministry of Employment, Planning and Territorial Development (MINEPAT), 2010). The rainy season runs from April to November while the shorter dry season lasts typically from December to March (Tening et al., 2013). In 2009, annual rainfall was 3392.2 mm. The coordinates as well as location and activities of the sampling sites around River Wouri are presented in Table 1.

The two industrial zones account for the bulk of industrial activities in the country (Table 2), but depict contrasting features in terms of physical landscape and lagoon marginal depressions and necessitate extensive land reclamation to obtain space on which industrial activities could take place. The Bassa Industrial Zone

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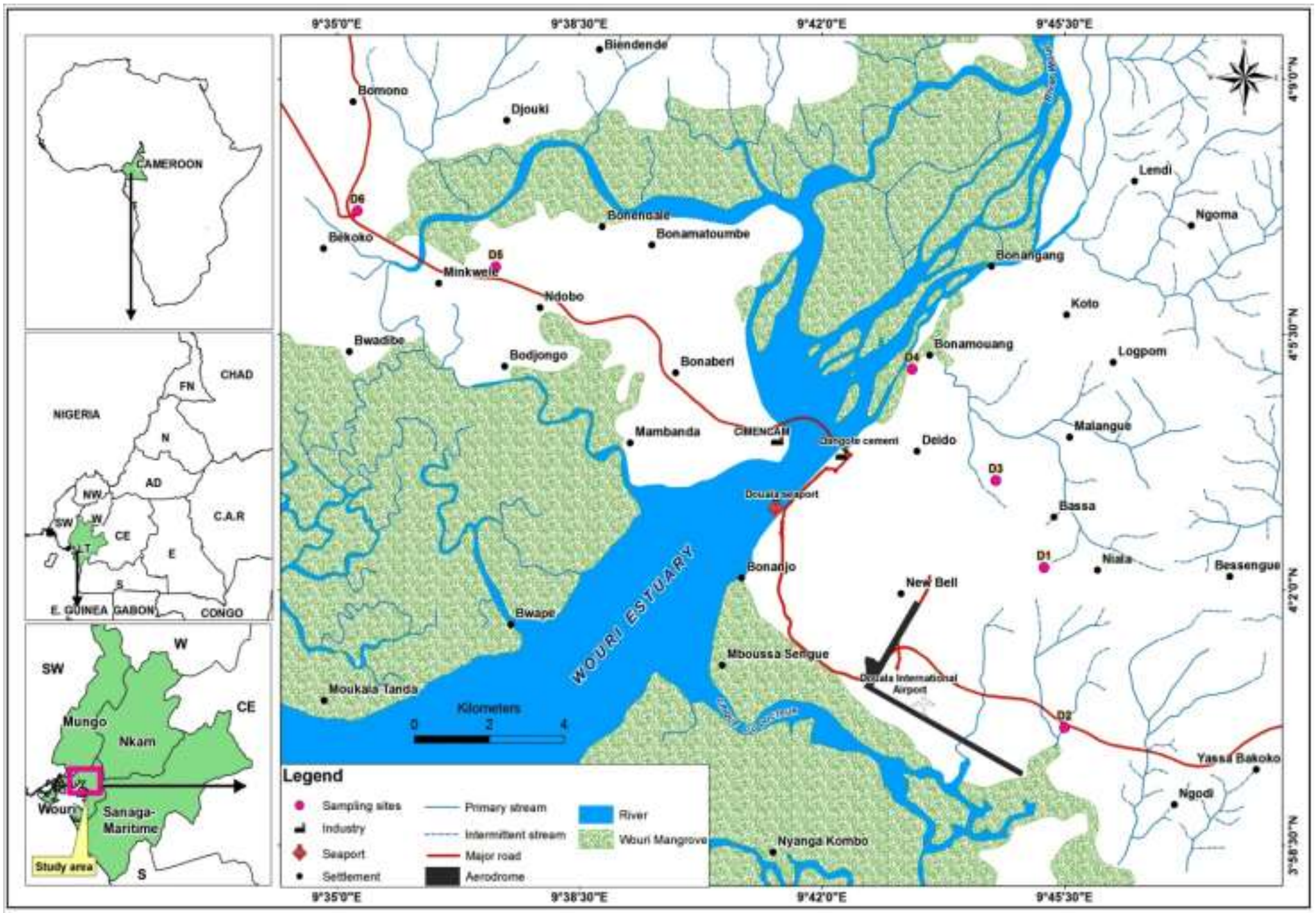

Figure 1. Map showing River Wouri sampling sites and drainage.

terminates into an estuarine creek formation of the Dibamba River to the East of the city. The Bonaberi Industrial Zone complex has encroached into the Wouri River and this most likely provokes increased discharge of effluents into it (Tening et al., 2013). There are also many streams and springs (Figure 1) from which water is collected for varied uses.

The other area is around River Meme (Figure 2). There are two distinct seasons in the area: a long rainy season that spans from March to October and a short dry season from November to February) (Gabche and Smith, 2002). In 2009, the rainy season lasted from April to October while the dry season lasted from November to March. Annual rainfall was 3199.9 mm, with average temperature of 28.6°C. August was the wettest month (857.2 mm) while the driest month was December (0.3 mm) (BWS, 2009). There are also many streams and springs from which inhabitants get water for various purposes (Figure 2). This section of the Cameroon coastal area is dominantly used for plantation agriculture [Cameroon Development Corporation (CDC) for rubber and PAMOL for oil palms] but not quite suitable for the cultivation of traditional cash crops. These agricultural practices involve the use of "glyphosate" herbicide and fertilizers. There are no proper housing conditions and no sewage systems in the area exerting enormous pressure on water resources. The coast is low and marshy (Tening et al., 2014). The coordinates, location and activities around the sampling points around River Meme are presented in Table 3.

Sampling and sampling techniques

Sampling was carried out within the Bassa and Bonaberi Industrial Zones, around River Wouri and around River Meme in December, 2015. Sampling sites were established using a 12-channel Garmin Etrex Global Positioning System (GPS) at a maximum distance of four kilometers from the rivers. Soil sampling was from areas of potential influence by industrialization, habitation and location with respect to the rivers.

Twenty-one top soil (0-20 cm) samples were collected using a spade around both rivers (six around River Wouri and fifteen around River Meme). The samples were collected into black polyethylene bags using a spade for digging and a hand trowel. They were air-dried and passed through a 2-mm sieve. Laboratory analyses were carried out using standard methods (Pauwels et al.,

Table 1. Location coordinates and description of the soil sampling points around River Wouri.

Code	Location	Latitude	Longitude	Description of site
D1	Com 3eme	04° 02.311 N	009° 45.201 E	Level land at the top of a hill, Farming activities (Cassava, Mango and Palm trees), close to MAGZI Indusrial Zone, human habitation
D2	Sacrament Ndongbong	04° 00.118 N	009° 45.494 E	Very hilly. Farming, Deposition of waste, habitation, Saw Mill, Drinking source of water below.
D3	Ndongbong, towards CARINA	04° 03.501 N	009° 44.503 E	Very slightly inclined at top of a hill, above a drinking source, Farming (Cassava, plantains).Human habitation, deposition of waste.
D4	Akwa Nord	04° 05.027 N	009° 43.298 E	Flat. Close to drainage, Farming, Dirty stream with offensive odour. Very close to human habitation
D5	Carrefour Mutzig	04° 06.431 N	009°37.293 E	Level land at Bonaberi, Behind EVERGREEN Company that produces flour, poultry feed, swampy, mangrove, Beside, there is cultivation of vegetable.
D6	Bikoko junction	04° 07.196 N	009° 35.293 E	Level land. Beside a Fenced house and stream. Human habitation.

Table 2. Major activities in the Douala metropolis adapted from Horan (1990) and Montgomery (1992) by Tening et al. (2013).

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, BOCOM, etc	Aviation fuels, petrol, diesel fuel, wax.	Hydrocarbons, Pb, NO_3^-, PO_4^{3-}
Metallurgy alloys	ALLUCAM, SOCAAFERE,	Metallic ions of various types.	As^{3+}, Be^{2+}, Bi^{3+} , Cd^{2+} , Cu^{2+}, Pb^{2+}, Hg^{2+} , Ni^{2+}
Zn^{2+}.	SOCAVERE		
		Bottles	As^{3+} , Be^{2+} , Bi^{3+} , Cd^{2+} , Cu^{2+} , Pb^{2+} , Hg^{2+} , Ni^{2+} , Zn^{2+}.

1992). Particle size distribution was determined by Bouyoucos hydrometer method (Bouyoucos, 1962). Soil pH was measured in

Soil organic carbon (SOC) was estimated by oxidation with potassium dichromate and titration with ferrous sulfate using diphenylamine as indicator (Walkley and Black, 1934). Since the mean annual rainfall in the regions were >2200 mm, and soil depth of 0-20 cm, a correction factor ($WBRF_c$) of 1.15 (Bhattacharyya et al., 2015) was used to obtain corrected results. Soil organic matter (SOM) was calculated from SOC from the equation: % SOM = % OC x 1.724 (Walkley and Black, 1934). The colour of the indicator will change from violet to green at the end point of the titration. Available phosphorus was determined by Bray-2 method (Bray and Kurtz, 1945). Exchangeable bases were determined by percolating 2.5 g of soil with 100 mL of 1N ammonium acetate buffered at pH 7. Potassium (K), sodium (Na), calcium (Ca), and magnesium (Mg) were determined in the extract using Absorption Atomic spectrophotometer (Rayleigh AA Spectro-photometer, WFX-130B). Electrical conductivity (EC) was determined in a ratio 1:5 with soil distilled water solution with a WTW model conductimeter. ECEC was calculated by summation of exchangeable bases and exchange acidity. Exchange acidity was determined by titration with NaOH after extraction with 1N KCl in the ratio 1:20. Total N was determined by the Kjeldhal method as described by Pauwels et al. (1992).

Experimental data was analyzed with the statistical package SPSS17.0 and EXCEL 2007 for Windows. Correlation and regression analyses were performed on the various data to evaluate and trace the sources of the different chemical entities into the ecosystems.

RESULTS AND DISCUSSION

Rivers Wouri and Meme are two very important

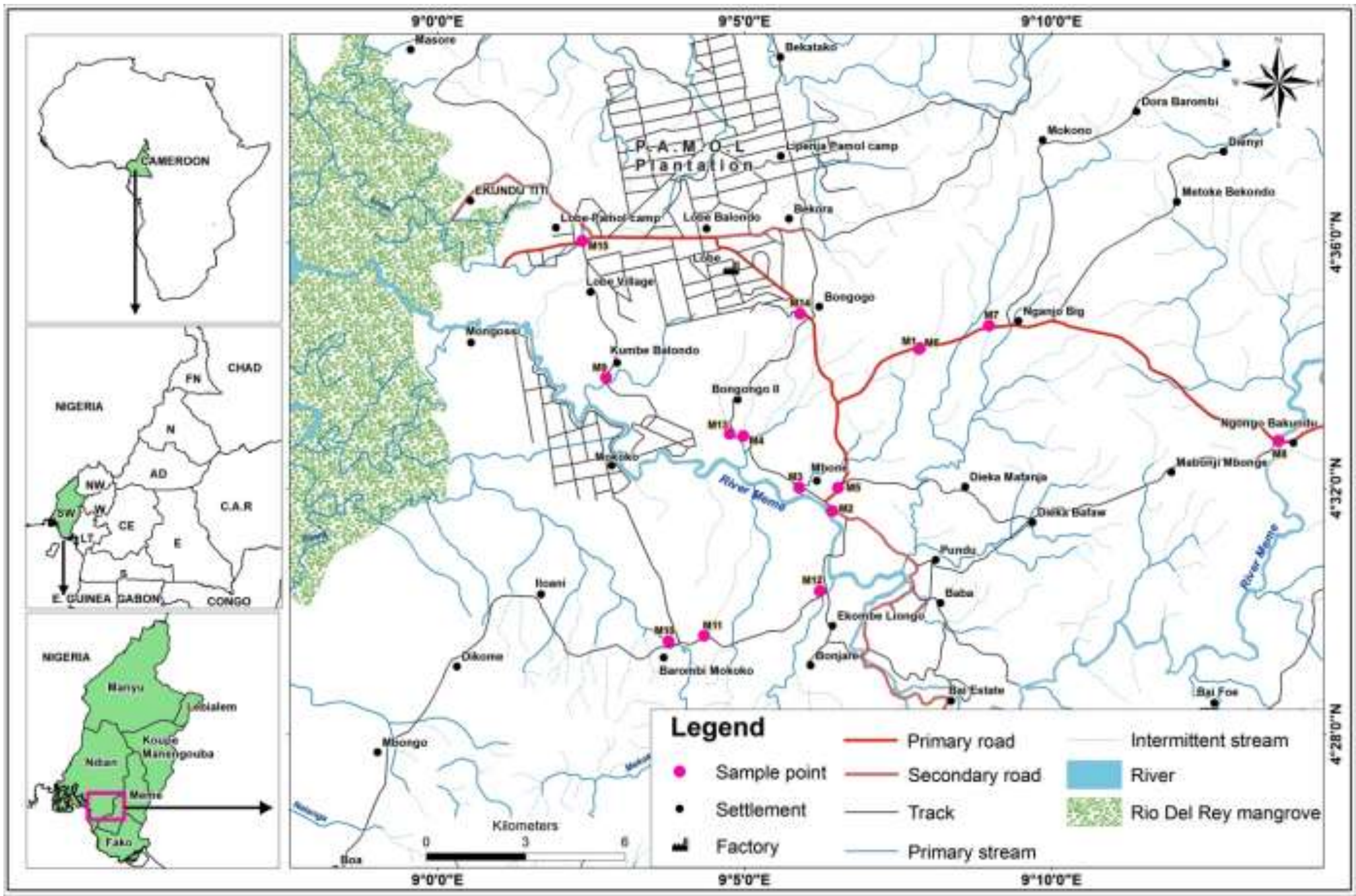

Figure 2. Map showing River Meme, Sampling sites and drainage.

rivers of Cameroon. They have transportation, domestic, industrial and commercial purposes. The huge quantities of fish from them also serve as food. It is important to monitor their quality. One way of doing this is the monitoring of the soils around them.

Physicochemical properties of soils around River Wouri

The results of the physicochemical properties of soils around River Wouri are presented in Table 4. All the soils in the area were slightly acidic (Hazelton and Murphy, 2007) (Table 4). The degree of acidity and/or alkalinity is considered a master variable that affects nearly all soil properties-chemical, physical and biological. While some organisms are unaffected by a rather broad range of pH values, others may exhibit considerable intolerance to even minor variations in pH (Obasi et al., 2012). The average soil pH was 5.9 in water and 5.0 in KCl meaning the soils were moderately acidic according to the ratings from Hazelton and Murphy (2007). In a similar study in Nigeria, Osakwe and Okolie (2015) found that the soil pH had a mean value of 5.15 ± 0.48. In all samples the pH in water was higher than the pH in KCl. According to Sanchez (1976) and Yerima and Van Ranst (2005), in soils where pH in water is higher than pH in KCl, the exchange complexes of such soils are dominated by negatively charged colloids and as a consequence, cation exchange capacity prevails. Therefore the soils could contain negatively charged colloids that could trap positively charged ions but allow negatively charged ions like sulphate, chloride, nitrate and phosphate to pass into water systems. The latter would cause eutrophication in streams and rivers. Soil pH plays a great role in the occurrence of some mangrove species such as Nypa palms (Tening et al., 2013).

The electrical conductivity (EC) of the soil samples ranged from 0.043 to 0.148 (ds m^{-1}). The soils had relatively low salinity. The range of values obtained in this study is higher than that reported by Osakwe and Okolie (2015). These values indicated significant presence of inorganic ions or ionisable materials in the soil (Fuller et

Table 3. Location, coordinates and activities around soil sampling points around River Meme.

Code	Location	Latitude	Longitude	Description of site
M1	Dieka (Diek) adjacent Mbonge	04° 34.265N	009° 07.841E	Level land found below Dieka Village. Water used for drinking, bathing passes through cocoa farms. Use of herbicides, Farming (rubber, Cocoa).
M2	Mutiti (small). After Ekombe Marumba	04° 31.631N	009° 06.425E	Level Land near Mutiti stream that empties into river Meme and receives waste from factory, Farming (CDC rubber).
M3	Bande(BAND) Mbonge -Ekondo –Titi bush Road	04° 32.012N	009° 05.886E	Level land at Mbonge, near Bande stream used for drinking bathing, cocoa farms at the banks. Crosses rubber plantations. Farming (rubber).
M4	Biribiri (BIRI)	04° 32.852N	009° 04.980E	Level land near stream, Farming (CDC Rubber)
M5	Mission water (MISS) Mbonge	04° 32.012N	009° 06.525E	Level land near stream that empties into river Meme and used as car washing point. Farming (e.g. Cassava).
M6	Small Nganjo	04° 34.281N	009° 07.856E	Level land near stream and bridge, stream used for bathing, (Farming e.g. Private palm Estate).
M7	Big Nganjo	04° 34.644N	009° 08.980E	Level land near stream and bridge. Stream used for bathing, farming, Farming (e.g. Plantains).
M8	BRIC	04° 32.771N	009° 13.694E	Level land. Near stream and bridge used for bathing. Human habitation. Farming (e.g. Cocoa)
M9	Kumbe	04° 33.799N	009° 02.746E	Level land near Kumbe water, banks used for vegetable farming, water used for washing. Farming (e.g. Okra, plantains).
M10	Barombi Mokoko, Bamuso	04° 29.511.N	009° 03.765E	Level land near stream, stream for bathing.Originate from Reserve, Sand excavation, Mixed crop cultivation. Mokoko forest reserve river. Farming (e.g. Palms).
M11	Ekombe Mokako,	04° 29.607N	009° 04.337E	Level land near Mekaki stream, Farming (e.g. Cassava).
M12	Ekombe Liongo,	04° 30.328N	009° 06.227E	Slightly inclined land near Komborani stream. Farming [e.g. cassava, Cover crop (Leguminous plant)].
M13	ESAKA (ESAK)	04° 32.888N	009° 04.755E	Level land near Esaka stream that empties at River Meme. Farming (e.g. private Palm Estate).
M14	Bongongo	04° 34.837 N	009° 05.903 E	Level land near stream, closer to human habitation, Farming (e.g. plantains).
M15	Ekondo Titi town	04° 36.019 N	009° 02.355 E	Slightly inclined land, opposite a house with a well, Farming (e.g. Private palm Estate).

al., 1995). All the soils had bulk densities which ranged from 1.0 - 1.4 g/cm^3 except sample D5 that had a bulk density of 0.3 g/cm^3 (Table 3).

Soil Organic Carbon (SOC) ranged from 0.46 to 2.05% (Table 4). According to the rating established by Hazelton and Murphy (2007), the SOC contents were in the low to high range. The effect on soil quality is the existence of degraded or severely eroded topsoil with poor structural condition and stability (Hazelton and Murphy, 2007). SOC not only affects soil fertility, but also has influence on releasing or holding CO_2 from the atmosphere through various channels, thereby possibly affecting the atmosphere-soil carbon balance (Eswaran et al., 1993; Wu et al., 2001; Jiang et al., 2007). The low values could be attributed to the sandy nature of most of the soils, as indicated in a similar study (Sandip et al., 2016). Particle size was dominated by sand, followed by silt and then clay, which revealed coarse soils with low supply of nutrients and moisture (Osakwe and Okolie, 2015). A sixth of the soils were loam while 83.33% were loamy sand. Samples D6, D2 and D1 had clay contents of 4, 3 and 4% respectively. This corroborates the results of Tening et al. (2013) who in a similar study in the same region found two soils, among a total of eight, with clay content 4 and 4.8%. SOM is the storehouse of plant nutrients and mineral recycling (Rattan et al., 2005). The highest organic matter content of 3.53% (D5) was recorded at Carefour Mutzig behind the EVERGREEN Industrial Complex. This could be an indication that waste from this industrial zone could contain fulvic and humic acids that make up organic matter.

Soil nutrients such as nitrogen (N), phosphorous (P) and potassium (K) ranged from 0.65 to 2.10%, 20.6 – 28.9 mg/kg and 0.12 – 0.14 (cmol/kg) respectively. The soils were generally low in major nutrients (Benton, 1999). This explains the application of fertilizers by the inhabitants. Sandip et al. (2016) in a similar study on physicochemical properties of soils found them to range from 100-350 (mg/kg), 33 – 84 (mg/kg) and 1118 – 1436

Table 4. Physicochemical properties of soils around River Wouri.

S/No.	Moisture content (%)	EC (x10^{-3} Org. C ds m^{-1})	pH		Bd (g/cm^3)	Org. C	Tot. N	OM	Avail. P (mg/kg)	Exchangeable bases (cmol/kg)				Exchangeable acidity	ECEC	Sand	Silt	Clay	Textural Class*
			H_2O	KCl		(%)				Ca	Mg	K	Na	(cmol/kg)		(%)			
D1	19.3	52	6.0	4.9	1.2	0.47	0.65	0.81	20.6	3.20	1.05	0.13	0.09	0.45	4.92	76	20	4	LS
D2	9.9	43	5.9	4.8	1.1	1.08	0.97	1.86	24.6	3.44	1.00	0.14	0.06	0.19	4.83	68	29	3	LS
D3	5.0	48	6.0	5.0	1.2	1.09	1.10	1.88	25.1	2.88	1.06	0.14	0.05	0.21	4.34	75	23	2	LS
D4	6.4	70	6.0	5.0	1.4	0.82	0.75	1.41	23.9	2.93	1.00	0.12	0.06	0.30	4.41	71	24	5	LS
D5	73.7	148	5.1	4.5	0.3	2.05	2.10	3.53	28.9	2.59	0.97	0.12	0.02	0.76	3.70	44	49	7	L
D6	35.7	55	6.4	5.9	1.0	1.46	1.30	2.52	25.3	2.13	1.01	0.13	0.01	0.38	3.66	68	28	4	LS
AV	**25.0**	**69**	**5.9**	**5.0**	**1.0**	**1.16**	**1.15**	**2. 00**	**24.73**	**2.86**	**1.02**	**0.13**	**0.05**	**0.38**	**4.31**	**67**	**29**	**4**	

*LS = Loamy sand, L = Loam.

(mg/kg) respectively.

The values were significantly lower than those of Sandip et al. (2016). The difference could be attributed to the different locations and activities. The highest value for nitrogen of 2.10% was found in sample D5. The relatively high nitrogen content could be attributed to waste from the complex. Nitrogen fertilizers are applied extensively in agriculture to increase crop production, but excess nitrogen supplies can cause air, soil, and water pollution (Wick et al., 2012). The relatively higher nitrogen content could also be attributed to nitrogenous fertilizers being applied in the vegetable garden found behind the industrial complex. Nitrogen is an essential element for plant growth and development; however, due to environmental pollution, high nitrate concentrations accumulate in the edible parts of these leafy vegetables, particularly if excessive nitrogen fertilizer has been applied. Consuming these crops can harm human health (Liu et al., 2014).

The soils showed varying effective cation exchange capacity (ECEC). ECEC just like CEC gives the soil a buffering capacity which may slow down the leaching of nutrient cations and positively charged pollutants because they affect both soluble and exchangeable metal levels (Yoo and James, 2002). The ECEC ranged from 3.66 to 4.92 cmol/kg and were rated low according to Benton (1999). Wild (1996) reported that soils, where ECEC or CEC range from 2 - 6 cmol/kg, are dominated by kaolinitic minerals. Such minerals have low retention capacity and toxic elements, which find themselves in such soils, will be easily leached out and thus would be a threat to water bodies (Tening et al., 2014). Thus the soils could be dominated by kaolinitic minerals or sequioxides (Benton, 1999), have low retention capacities and, as such, toxic substances could easily be leached into waterways.

Physicochemical properties of soils around River Meme

The results of the physicochemical properties of soils around River Meme are presented in Table 5. The highest electrical conductivity, 0.064 ds m^{-1} was recorded in M15 (Table 5). M15 was collected from a palm estate in Ekondo Titi. The relatively high electrical coductivity could be attributed to ions from fertilisers applied in the palm estate. The lowest electrical conductivity of 0.021 ds m^{-1} was recorded in sample M11, located at Ekombe Mefako, Bamuso. The relatively high electrical conductivities could point to the fact that they contained ionisable salts or trace metals.

About 60% of the soils in the area were moderately acidic while less than 40% were slightly acidic (Hazelton and Murphy, 2007) (Table 5). The average pH was 5.7 in water and 4.8 in KCl. In all samples the pH in water was higher than the pH in KCl. This was same observation with the soils around River Wouri.

Organic carbon ranged from 0.67 to 2.55%. About 20% of the soils had SOC<1% which was low, with poor structural condition and stability (Hazelton and Murphy, 2007); 46.7% of the soils had SOC which ranged from 1.0 to 1.8% which was moderate with moderate structural stability, condition, pH buffering, nutrient levels, water

Table 5. Physicochemical properties of soils around River Meme.

S/No.	Moisture content (%)	EC ($x10^{-3}$ ds m^{-1})	pH		Bd (g/cm^3)	Org. C	Tot. N	OM	Avail. P (mg/kg)	Exchangeable bases (cmol/kg)				Exchangeable acidity	ECEC	Sand	Silt	Clay	Textural Class*
			H_2O	KCl		(%)				Ca	Mg	K	Na	(cmol/kg)		(%)			
M1	29.6	62	5.7	5.0	0.9	1.78	11.20	3.07	13.4	0.25	0.11	0.14	0.10	1.50	2.10	38	42	20	L
M2	09.6	50	6.0	5.1	1.1	1.09	0.98	1.88	10.9	0.30	0.12	0.15	0.18	1.42	2.17	58	27	15	SL
M3	10.4	40	5.4	4.9	1.1	2.58	1.40	4.45	13.4	0.48	0.12	0.15	0.29	1. 10	2.14	66	25	9	SL
M4	33.5	48	5.8	5.1	0.9	3.46	1.50	5.97	15.9	0.78	0.58	0.15	0.26	1.33	3.10	40	51	9	L
M5	29.0	51	5.2	4.5	1.0	1.35	0.91	2.33	11.3	1.03	0.71	0.16	0.25	0.65	2.15	72	22	6	LS
M6	18.8	46	5.4	4.5	0.8	1.71	1.30	2.95	13.0	1.00	0.72	0.16	0.22	0.38	2.10	42	48	10	L
M7	19.4	49	5.4	4.4	1.1	2.90	1.90	5.00	19.6	1.16	0.74	0.15	0.22	0.34	2.27	30	56	14	SiL
M8	46.8	61	6.6	5.9	0.8	3.63	2.10	6.26	26.0	1.85	0.57	0.13	0.26	0.72	3.53	34	32	34	CL
M9	66.8	55	5.2	4.5	0.7	1.63	1.80	2.81	16.8	1.84	1.00	0.12	0.01	0.75	2.97	37	46	17	L
M10	08.9	40	5.0	4.3	0.9	1.37	1.80	2.36	15.9	1.55	1.04	0.13	0.02	0.96	2.74	66	28	6	LS
M11	10.6	21	5.6	4.5	1.1	0.67	0.99	1.16	14.9	1.27	1.08	0.14	0.03	1.10	3.89	65	30	5	LS
M12	05.8	45	6.5	5.7	1.2	0.67	12.30	1.16	16.8	0.98	1.10	0.15	0.08	1..20	3.51	74	22	4	LS
M12	19.4	39	5.5	4.9	0.9	0.91	10.90	1.57	15.3	1.16	1.15	0.14	0.10	1.05	3.60	64	32	4	LS
M14	23.7	47	6.5	5.3	1.0	2.55	11.80	4.40	17.8	1.50	1.13	0.15	0.09	0.97	3.84	38	54	8	L
M15	43.1	64	5.6	4.7	0.8	1.17	11.10	2.02	13.5	1.81	1.12	0.14	0.09	0.76	3.92	79	12	9	LS
Av	**25.0**	**48**	**5.7**	**4.8**	**0.9**	**1.83**	**4.68**	**3.16**	**15.6**	**1.13**	**0.75**	**0.14**	**0.15**	**0.95**	**2.94**	**54**	**35**	**11**	

Bd = Bulk density *LS = Loamy sand, L = Loam, SL = Sandy loam, CL = Clayey loam, and SiL = Silty loam.

holding capacity (Hazelton and Murphy, 2007); while 33.33% had high SOC(>2.5%) with good structural condition and stability, high pH buffering capacity, high nutrient levels, and high water holding capacity. The highest content of 3.63% which was relatively high (Hazelton and Murphy, 2007), was recorded in sample M8 in a cocoa farm. This could be as a result of household waste dumped here since the cocoa farm was located close to habitation.

The ECEC ranged from 2.10 to 3.92 cmol/kg, which was low (Nicholas, 2004; Benton, 1999). Like the soils around River Wouri, the soils may be dominated by kaolinitic minerals and sesquioxides (Benton, 1999), have low retention capacities and as such toxic substances could easily be leached into waterways. The highest clay content of 34% was recorded in sample M8. This could be ascribed to the reason given above.

Samples M1 and M6 were collected from very closed locations (Figure 2). Although closed, they had some different values e.g. in total N (11.20 and 1.30% respectively) and in clay (20 and 10% respectively). The difference could be ascribed to the locations and farming activities. M1 was located at Dieka where the main crops were rubber and cocoa (Table 3). M6 was sampled at small Nganjo where the main farming activity was palm. M1 may also have been excavated or type of cultivated land ((Adugna and Abagaz, 2015) leading to comparatively higher clay content.

Comparative analysis of soils around Rivers Wouri and Meme

The results of a comparative study of physicochemical properties of soils around both rivers are presented in Table 6. The highest electrical conductivities around rivers Wouri and Meme were 0.148 and 0.064 (ds m^{-1}) respectively. The mean electrical conductivity (0.069 ds m^{-1}) of the Wouri was higher than that of the Meme 0.048 ds m-1). This could be an indication (that the soils

Table 6. Correlation matrix for physicochemical properties of soils around River Wouri.

Correlation	Moist_C	EC	pH (H_2O)	pH (KCl)	Bulk D.	Tot_N	OM	Av._P	Ex Acidity	ECEC	Clay
Moist_C	1										
EC	0.398	1									
pH (H_2O)	-0.052	-0.870*	1								
pH (KCl)	-0.426	-0.485	0.832*	1							
Bulk D.	-0.610	-0.859*	0.779	0.340	1						
Tot_N	0.555	0.837*	-0.695	-0.206	-0.950**	1					
OM	0.559	0.749	-0.572	-0.065	-0.883*	0.975**	1				
Avail#_P	0.311	0.731	-0.613	-0.180	-0.786	0.923**	0.959**	1			
Ex._Acidity	0.651	0.896*	-0.914*	-0.538	-0.938**	0.894*	0.798	0.765	1		
ECEC	-0.670	0.414	-0.046	-0.577	0.446	-0.605	-0.667	-0.559	-0.348	1	
Clay	0.491	0.896*	-0.677	-0.325	-0.677	0.607	0.543	0.481	0.806	-0.405	1

Moist_C = Moisture content , Av. P = Available phosphorus **, *: Correlation significance at the 0.01 and 0.05 levels (2-tailed), respectively.

around River Wouri may contain more soluble salts and could be more contaminated from these salts than those around River Meme.

All the soils around both rivers were slightly acidic (5.0 - 6.6). The optimal range for plant availability of nutrients is 5 to 7 (Arp and Krausse, 2006). This could suggest that fertilizer application is needed for maintenance. The pH values in soils around River Wouri and River Meme did not significantly differ ($p>0.05$). Around both rivers, the pH in water was higher than the pH in KCl, being the variation of ΔpH [pH (KCl) – pH (H_2O)] negative throughout. This indicates that the net charge on the exchange complex is negative, and thus exhibits cation exchange capacity (Asongwe et al., 2016). Asongwe et al. (2016) reported similar results in the wetlands of Bamenda, Cameroon. Like pH, the bulk densities around both rivers were very similar and did not differ among them ($p>0.05$), with mean values of 1.0 g/cm^3 for soils around River Wouri and 0.9 g/cm^3 for soils around River Meme.

Soils around River Meme registered a higher organic matter content with a mean 3.16%, while those around River Wouri had a mean of 2.00%. The soils around River Wouri may have been more depleted in organic matter than those around River Meme because of far more industrialization and human habitation. Like organic matter content, the soils around River Meme were richer in Nitrogen with mean 4.68% than those around River Wouri with mean 1.15%. The reason for this difference could be the far more industrialization and human habitation in Douala. River Wouri runs through a highly industrialized city than the villages or towns through which River Meme runs. Samples M9 - M11 had relatively lower N content (0.99 - 1.80%). This could be attributed to the less farming practices: Cassava, plantains, hence less application of fertilizers. Soils M12 - M15 had comparatively higher N (10.90 - 12.30%). This points to the fact that there was more plantation agriculture here e.g. palms, hence greater use of fertilizers. Here, there were also leguminous plants that increase the nitrogen content of soils.

The desired range for ECEC is between 5 and 25 cmol/ kg according to Landon (1991). The soils from both regions had low (< 5 cmol/ kg) ECEC, consequently low CEC. Soils with a low value (CEC<5 cmol/ kg) generally have a low fertility status and a low resistance to changes in soil chemistry caused by land management practices (Brown and Lemon, 2014). These results corroborate the assertion that "generally, tropical soils have low CEC, especially for high sandy and low pH soils" (Lorandi, 2012). Minerals as oxides of aluminum, iron and manganese, that are very abundant in tropical soils, could also contribute to the low CEC (Lorandi, 2012). The soils around both rivers may be dominated by kaolinitic minerals and sesquioxides (Benton, 1999). ECEC was higher around River Wouri with an average of 4.31 cmol/kg than around River Meme with an average of 2.94 cmol/kg. This could be an indication that the former soils shall be able to retain more cations than those around the latter.

Exchangeable bases in soil samples around River Wouri showed the following trend: $Ca^{2+} > Mg^{2+} > K^+ > Na^+$ and were generally low, especially K^+ and Na^+, according to the ratings by Hazelton and Murphy (2007). These low concentrations could be attributed to the heavy rainfall in the area under study that leaches the bases. Similar trends were observed around the Eastern flank of Mount Cameroon (Mbene et al., 2017). For soils around River Meme the trend was different, generally $Ca^{2+} > Mg^{2+} > Na^+ > K^+$. The mean Na^+ (0.15 cmol/kg) around River Meme was greater than the mean Na^+ (0.05 cmol/kg) for soils around River Wouri. Accordingly, with high moisture, the soils around River Meme could be more prone to landslides than those around River Wouri.

As it concerns the other nutrients, available phosphorus was medium according to Beernaert and Bitondo (1992) around River Meme (average 24.43 mg/kg), higher than around River Meme (average 15.6 mg/kg), considered low (Beernaert and Bitondo, 1992). This suggests more P fertilizers could be applied around River Meme than around River Wouri or that there could be more P adsorption around the latter than around the former. Total nitrogen around river Meme (mean 4.68%) was more than that around River Wouri (mean 1.15%). This indicates that the top soils around River Wouri were far more eroded or depleted of these nutrients than those around River Meme.

Particle size around both rivers was dominated by sand, followed by silt and clay though to different extents. 40% of the soils around River Meme were loamy sand while 33.33% were loam. Of the soils around River Wouri, 83.33% of were loamy sand and 16.67% were loam. This showed that the predominant texture in both was loamy sand although greater around River Wouri. The average clay content, 11% around River Meme was more than that around River Wouri, 4%.

A simple ANOVA considering two groups of soils indicated significant differences ($p<0.05$) in EC (with higher levels corresponding to D soils) and ($p<0.01$) in Total Nitrogen (with higher levels in M soils). This could be an indication that the D soils contained more soluble salts (or were located around industries that produced more soluble ions) that was responsible for the higher EC. The D soils had been depleted of nitrogen because of more habitation and industrialization, hence less nitrogen than M soils. There was also a significant difference ($p< 0.01$) in Mg (with higher levels in D soils) and in Na (with higher levels in M soils). This could mean that mineralogical content of the soils were different. There was yet other significant differences ($p< 0.05$) in sand (with higher values in M soils) and in clay (with higher contents in M soils). This again could be an indication that the mineralogical content of the soils could be different or reasons stated above.

Correlation analysis and results

Correlation results for properties of soils around River Wouri

Moisture content had significant positive correlation (0.97, $p<0.01$) with electrical conductivity (Table 6). As moisture content increases, the amount of soluble salts increases and hence electrical conductivity increases. It also had a positive relation with organic matter and clay with same value (0.82, $p<0.05$). This could mean that these properties affect the soil water holding capacity of the soil, as well as its porosity, and therefore will modify the soil moisture content. Moisture content equally had a very significant correlation with total nitrogen (0.91, $p<0.05$). The total nitrogen in the soil is in the form of NH_4^+ and NO_3^- ions. Salts containing these ions in the soil are very soluble, hence the observed correlation between moisture content and total nitrogen. There was a significant negative correlation (-0.96, $p<0.05$) between moisture content and bulk density. This may be due to the fact that a low moisture level is an indication for the existence of few pore spaces thus, higher bulk density. There was a very significant negative correlation (-0.99, $p<0.01$) between moisture content and percent base saturation. This implies that most or all of the bases present in the soil are present in their insoluble states.

Electrical conductivity presented a significant negative correlation (-0.86, $p<0.05$) with bulk density. This may be due to the fact that a soil with high bulk density will contain low moisture and as a result will contain less soluble salts. Like moisture content, there was a significant negative correlation (-0.97, $p<0.01$) between electrical conductivity and base saturation. This again implies most of the bases were insoluble. There was a significant positive correlation (0.90, $p<0.05$) between electrical conductivity and clay. Among the soil particles, sand have a low conductivity, silt a medium conductivity and clays high conductivity. This may be attributed to the fact that clays are phyllosilicates that contain variable amounts of cations on their colloidal surfaces that diffuse into solution increasing the conductivity, even at the relatively low clay content of the soils. Bulk density was negatively correlated (-0.88, $p<0.05$) with organic matter. Organic matter or organic carbon increases soil aggregation and porosity that reduces bulk density.

Organic matter had a significant positive correlation ($r = 0.96$, $p<0.05$) with available P. This may be due to the fact that organic matter inhibits aluminum oxide crystallization and reduces the soil surface area. In acid soils, part of the P is adsorbed by secondary minerals of the clay fraction (mostly Fe and Al oxyhydroxides), and another part is precipitated with Fe and Al ions into soil solution. The inhibition of aluminum oxides and soil surface area could be the justifications for the increase in available P since the P retention sites are reduced.

Correlation results for properties of soils around River Meme

The results for correlation analysis of soils along River Meme are presented in Table 7. Moisture content was positively correlated ($r = 0.65$ $p<0.01$) with electrical conductivity, as in the case of River Wouri. It was also negatively correlated ($r = -0.79$, $p<0.01$) with bulk density. There was a positive correlation ($r = 0.62$, $p<0.05$) between electrical conductivity and clay, due to the reasons above mentioned.

Organic matter had a significant positive correlation (r =

Table 7. Correlation matrix for physicochemical properties of soils around River Meme.

Correlation	Moist_C	EC	pH (H_2O)	pH (KCl)	Bulk D	Tot_N	OM	Avail._P	EX.Acid	ECEC	Clay
Moist_C	1										
EC	0.646**	1									
pH(H_2O)	-0.029	0.202	1								
pH(KCl)	0.033	0.287	0.925**	1							
Bulk D	-0.785**	-0.503	0.240	0.155	1						
Tot._N	-0.019	0.255	0.429	0.398	0.037	1					
OM	0.308	0.332	0.302	0.360	-0.164	-0.245	1				
Avail._P	0.331	0.172	0.484	0.481	-0.185	0.016	0.619*	1			
Ex. Acid	0.108	-0.071	-0.729**	-0.643**	-0.241	-0.501	-0.083	-0.129	1		
ECEC	0.381	-0.036	0.020	-0.094	-0.383	0.143	-0.057	0.482	185	1	
Clay	0.543*	0.617*	0.342	0.415	-0.407	-0.186	0.559*	0.586*	-0.133	-0.106	1

Moist_C = Moisture content Av. P = Available phosphorus **, *: Correlation significance at the 0.01 and 0.05 levels (2-tailed), respectively.

0.60, $p<0.05$) with available P, and ($r = 0.57$, $p<0.05$) with clay. No significant relationship was found between clay and ECEC ($p>0.05$).

Comparative study of correlation of properties of soils around both rivers

Moisture content showed a significant positive correlation with electrical conductivity both around River Wouri ($r = 0.97$, $p<0.01$) and around River Meme ($r = 0.65$ $p<0.01$). The difference in the coefficient of correlation could be attributed to the fact that the salts around River Wouri were more soluble than those around River Meme, in accordance with the higher electrical conductivity. It could also be attributed to the fact that around River Wouri, there were more anthropogenic sources of contamination considering more habitation and industrialization. It also had a significant positive correlation with organic matter and clay with same value ($r = 0.82$, $p<0.05$) around River Wouri, while around River Meme, it was not significantly related with organic matter ($p>0.05$) but showed a significant positive correlation ($r = 0.54$, $p<0.05$) with clay. This suggests that the composition of the clays and of the organic matter of soils around both rivers is different.

There was a significant positive correlation between electrical conductivity and clay around River Wouri ($r = 0.90$, $p<0.05$) and River Meme ($r = 0.62$, $p<0.05$). This could be an indication that some of the components of clay were soluble. The difference in the coefficient of correlation could mean that the clays around River Wouri were more soluble thus confirming that they were different as mentioned above. This aspect should be confirmed by establishing the clay mineralogy.

Around both rivers, there was a strong correlation between organic matter (OM) and available P. The positive correlation existing between organic matter and plant available phosphorus could be because OM has been known to be a constituent of the soil adsorption complex, which is responsible for binding anions in the soil (Tan, 1986), besides other soil properties.

Conclusion

All the soils around River Wouri were slightly acidic while around River Meme soils ranged from slightly acidic to moderately acidic. They had a similar variation of ΔpH, [pH (KCl) – pH (H_2O)] which was negative throughout. They had low ECEC and are probably dominated by kaolinitic minerals and sesquioxides, with low retention capacities, although the mean ECEC was higher around River Wouri. The soils around River Wouri had more Ca and Mg ions, but the Ca around both rivers could be of both natural and anthropogenic origins. Among the soils around River Meme; 40% were loamy sand and 33.33% were loam. Those around River Wouri were 83.33% loamy sand and 16.67% were loam. This indicated that the predominant texture in both was loamy sand although larger around River Wouri. The average clay content, 11% for the soils around River Meme, was larger than that around River Wouri, 4%. Moisture had a significant positive correlation with organic matter and clay ($p<0.05$) around River Wouri, while around River Meme it was only significantly correlated (0.54, $p<0.05$) with clay. This suggests that the composition of the clays and organic matter of soils around both rivers are different.

There was also a significant difference ($p<0.01$) in Mg (with higher levels in D soils) and in Na (with higher levels in M soils). This could mean that mineralogical content of the soils were different. There was yet other significant differences ($p<0.05$) in sand (with higher values in M soils) and in clay (with higher contents in M soils). This again could be an indication that the mineralogical content of the soils could be different.

The soils around both rivers have low major nutrients though those around River Wouri are more depleted and are therefore more vulnerable to an increase in anthropogenic activities. Stringent legislation on management of soils along the rivers and adjacent mangroves, as well as a study about the mineralogical composition of the clays, is recommended.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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