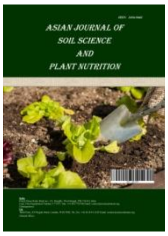

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Monitoring the Quality of Soils around Rivers Wouri and Meme of Cameroon Using Plasticity and XRF

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Authors' contributions

This work was carried out in collaboration among all authors. Authors NNF and AST conceived the study. All experiments were designed by authors NNF and AST. Sampling and preparation of samples were done by authors NNF, GAA and AN. Data analysis and interpretation were done by authors NNF, AST, KM, GAA and AN. Manuscript was prepared by authors NNF and AST. All authors read and approved the final manuscript.

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ABSTRACT

Mangroves play important roles in the environment such as sequestration, spawning of fishes and source of medicinal plants. Two rivers which feed the mangroves of Cameroon are Rivers Wouri and Meme. While River Wouri that feeds the Douala-Edea mangrove receives smaller water bodies that pass through an industrial environment, River Meme that feeds the Rio del Rey mangrove receives small water bodies that pass through an environment harbouring a lot of agricultural activities. The rural and urban communities use water from the rivers to grow vegetables (plant production). The quality of water that feeds the mangroves is of paramount importance. This in turn depends on the mineralogical content of the soils around the rivers and adjourning water sources. This is because soils act as sinks for pollutants. Different clay minerals have different capacities to

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retain and release chemical entities. Therefore, they contribute differently in the protection of catchment areas. This work was therefore aimed at investigating the role played by soils in controlling the movement of these chemical elements into the rivers. Clays extracted from soils around these water sources were analyzed for mineralogical composition. All analyses were carried out using standard plasticity and XRF methods. Clay content (2 to 7%) in Wouri was lower than in Meme (4 to 34%). The majority of the clay was dominated by SiO_2, Al_2O_3, Fe_2O_3, and TiO_2 and was a mixture of non-expandable (2:1 and 1:1) and sesquioxide clays. The soils have low pollutant retention capacity and are therefore vulnerable to anthropogenic activities. Hence, stringent measures should be taken to monitor soil/water quality with respect to waste disposal and use of agrochemicals. The use of compost in place of fertilizers by farmers should also be encouraged.

Keywords: Wouri; meme; plasticity; clays, XRF; soils; pollutant.

1. INTRODUCTION

Rivers Wouri and Meme serve in fishing, transportation, domestic, agricultural, as well as industrial purposes. They also feed the Cameroon mangroves. They are characterized by contrasting human activities. While the Wouri set up is dominantly industrial, that of Meme is dominated by agricultural plantations. One frequent ingredient in fertilizer is nitrogen, which if left in a heavy concentration in the soil can actually alter the acidity or pH, and so change the variety of plants able to grow in that environment [1]. It is perceived that water from these rivers and other sources that feed them could be contaminated considering the activities around them. Safe drinking water is essential to humans, animals, plants, and other life forms [2]. The quality of water needs continuous monitoring and one of the ways to monitor water quality is through monitoring of the soil quality.

The soil plays a great role in the environment. The quality of water often depends on the quality of soil. This in turn depends on the soil's physicochemical properties and mineralogical content. The colloids are critical in physicochemical adsorption and release agricultural nutrients as well as pollutants. The physical and chemical properties of soils are controlled largely by colloids (clays). They do so by attracting ions to their surfaces and temporarily protect essential nutrients from leaching and then release them slowly for plant use [3]. Clay and its minerals have played major roles in anthropogenic activities [4]. They are composed principally of silica, alumina, and water, often with iron, alkali, or alkaline earth metals [5].

Soils constitute a crucial component of rural and urban environments [6], and can be considered as an essential "ecological crossroad" in the landscape [7]. They function as a buffer where materials from the atmosphere are deposited and those precipitated from the hydrosphere get clung [8]. The soil's ability to play this role depends not only on some of its physicochemical properties, especially pH, cation exchange capacity (CEC), texture, but also on its mineralogical composition. The mineralogical composition varies considerably. These minerals include 1:1 clays such as kaolinites, 2:1 clays such as monmorilonite, etc. Different clay minerals have different capacities to retain and release chemical entities. Therefore, they contribute differently in the protection of catchment areas. 2:1 clay minerals have a much higher ability to retain positively charged ions than 1:1 clays [9].

It is therefore very imperative to evaluate the quality of water from the quality of soil. The quality of soil in turn depends on the quality or type of the clay. Among the methods used for the elucidation of the structure of clays are plasticity and X-Ray Fluorescence (XRF). The aim of this work was therefore to investigate the structure of the soils around Rivers Wouri and Meme of Cameroon and infer the quality of these important water sources and advise the Government and other environmental agencies.

2 MATERIALS AND METHODS

2.1 Description of Study Sites

2.1.1 Location

The Wouri region lies between latitudes 3, 38, 30N and 04, 09, 34 N and longitudes 9, 35, 0E and 9, 45, 30 E (Fig. 1). In this area are found the Bassa and the Bonaberi Industrial Zones of Douala. The zones are located within the Douala Sub-Basin of the Douala Basin. The two industrial zones account for the bulk of industrial activity in the country, but depict contrasting features in terms of physical landscape [10; 11].

The other part of the study area is around River Meme that feeds the Rio Del Rey Basin in the South Western coast of Cameroon (Fig. 2). It takes its rise from the Rumpi hills and empties into the Rio del Rey estuary. The region lies in the Rio del Rey Basin. It lies between latitudes 040, 29.000 N and 040, 37.019N and longitudes 0090, 02.000E and 0090, 08.000E (Fig. 2).

2.1.2 Climate

The climate around Wouri is humid. The coast is covered by mangroves and dominated by *Rhizophora* and *Avicenia* species [12]. January and February are the hottest months with mean monthly temperatures of 32°C and 33°C, respectively [13]. The dry season runs from November to March. Mount Cameroon forms a great barrier to the rain-bearing winds causing the air to rise with the moisture it carries and falling back as relief rain in Douala. Daily rainfall is very heavy and occurs throughout the year, although heavy rains set in from April and subside in October [14].

Similarly to the Wouri area, there are two distinct seasons in the Meme area: a long rainy season that runs from March to October and a short dry season from November to February. The average annual temperature stands at 27 °C [15]. Annual rainfall stands at 3196.2 mm. August is the wettest month (857.2 mm) while December is the driest month (0.3 mm).

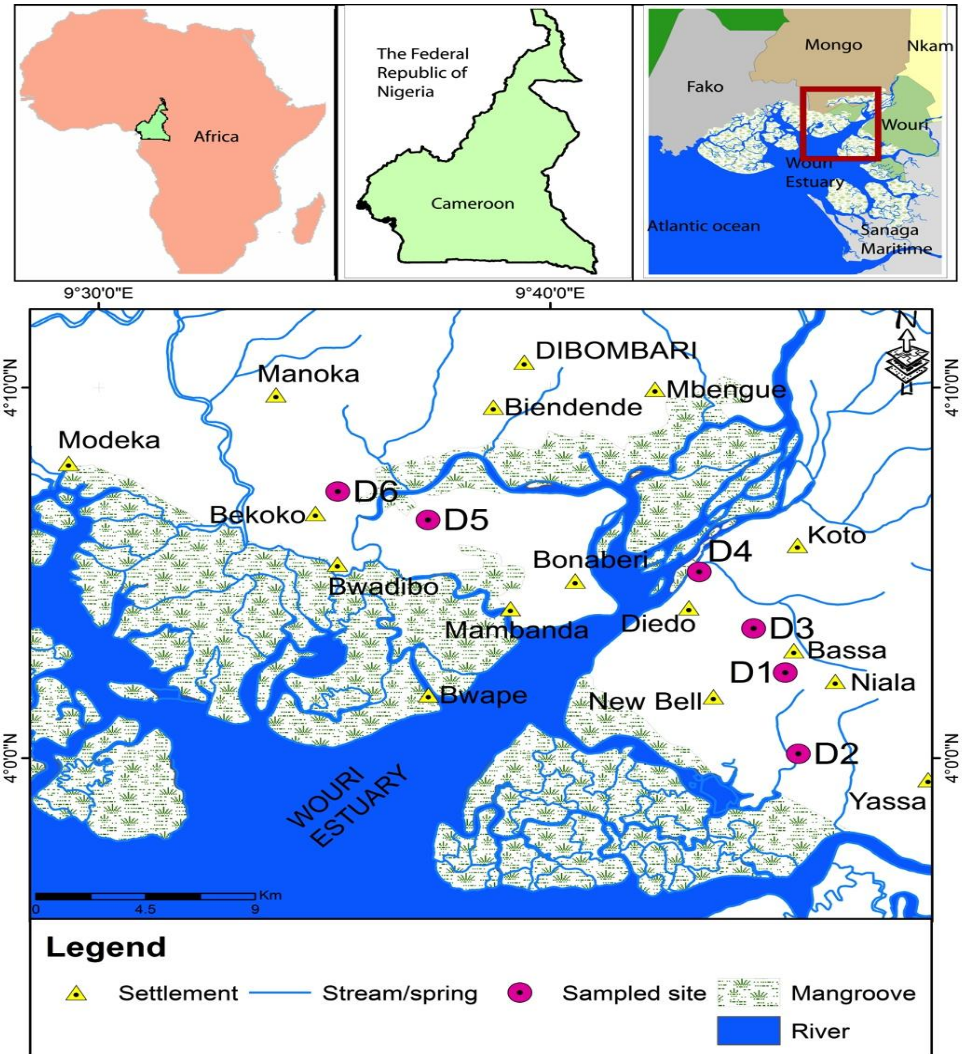

Fig. 1. Map showing River Wouri, soil sampling sites and drainage

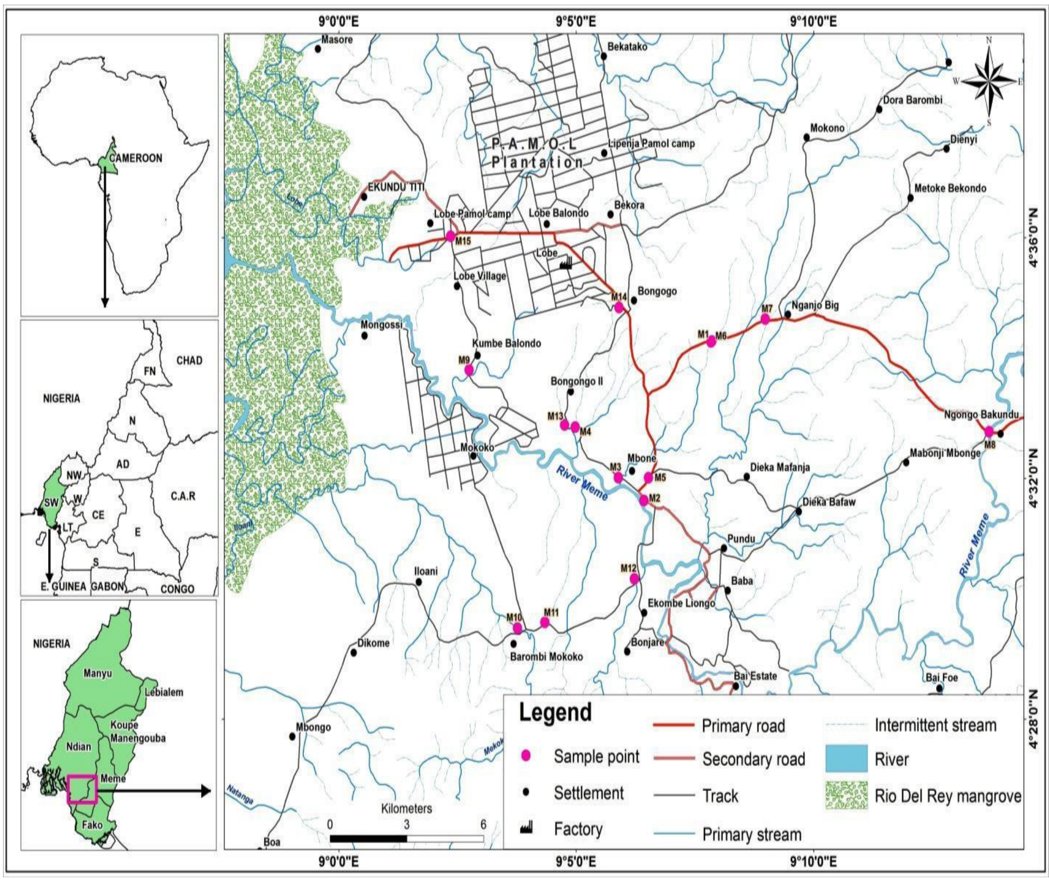

Fig. 2. Map showing River Meme, Soil sampling sites and drainage

2.1.3 Topography, geology and drainage

Across River Wouri, 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 in the 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 [14,16]. The river is fed by streams and passes through the Wouri Mangroves and terminates at the Atlantic Ocean with the formation of the Wouri Estuary (Fig. 1).

Around River Meme is a sedimentary basin of Cretaceous to Tertiary age. It has a total surface area of 7000 km^2 and maximum width of 60 km, [10,11]. 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 [14,16].

The basin is part of the Douala sedimentary basin. From south to north, the sedimentary basin is symmetrically divided by the Cameroon volcanic line (CVL) in two geomorphological settings: the Douala basin (7,000 km^2) to the south and the Rio del Rey basin to the North (2,500 km^2). Within the Rio del Rey basin, isobaths lie up to 80 km from the beach [16,17]. A map of sampling points and drainage is shown in Fig. 2.

2.1.4 Rock type and soils

The basin around River Wouri 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 [14,16]. However, the Douala metropolis lies on the Wouri member of the Mpundu Formation, which is dominantly made up of gravelly 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 the percolation of rainwater takes quite a long time [14,16].

The soils around River Meme are ferallitic [18], yellowish in colour, and varying from clayey, silty, sandy to lateritic clay sub-soils [16,17].

2.2 Human Activities

The human activities are mainly industrial in Wouri. Table 1 gives the location, coordinates and description of the soil sampling points around River Wouri. It also describes the activities around these sites.

Around River Meme, the main activities are agricultural with two agro-industrial complexes: the CDC Rubber Plantation and the PAMOL Plantation. Table 2 gives the location coordinates as well as activities around the soil sampling sites around River Meme.

2.3 Soil Sampling

About 1 kg of surface soil (at a depth of 10-20 cm, equal to the depth of roots of most plants) was dug and collected using a spade. In all, twenty one soil samples were collected. In each of the collection points, five core samples were collected 2 m apart in a square (four at the corners of the square and one at the centre of the square). They were bulked to obtain a single sample, put in plastic bags, and labelled. They were taken to the Inorganic Chemistry laboratory of the University of Buea.

2.4 Preparation of Soil Samples and Plasticity Analysis

2.4.1 Preparation of samples

At the laboratory, the soil samples were spread on cardboard paper and air-dried for two weeks. They were then sieved using a 2 mm sieve (Figs. 3a and 3b) and packaged in plastic bags pending analysis. The portion that did not go through the sieve was discarded.

2.4.2 Determination of plasticity [19]

Two hundred grams of each soil sample was weighed. The water content of each sample was adjusted close to the liquid content of the soil by adding distilled water while mixing using a spatula. The sample was allowed to stand for at least 6 hours in a container.

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

Code	Location	Latitude	Longitude	Description of site
D1	Com 3eme	04^0 09.06N	009^0 17.286E	Flat, at the top of a hill. Close to MAGZI Industrial Zone, human habitation, close to a school, Farming (Cassava, Mango and Palm trees).
D2	Sacrament Ndongbong	04^0 00.118N	009^0 45.494E	Top of a hill. Very hilly. Farming, Deposition of waste, habitation, Saw Mill, Drinking source of water below the hill.
D3	Ndongbong, towards CARINA	04^0 08.931N	009^0 17.477E	Very slightly inclined. Drinking source below the hill. Human habitation, deposition of waste, farming (e.g... Cassava, plantains.)
D4	AKwa Nord	04^0 05.027N	009^0 43.298E	Flat Very close to habitation, Farming, close to drainage, Dirty stream with offensive odour.
D5	Carrefour Mutzig	04^0 06.431N	009^0 37.293E	Flat, situated at Bonaberi, behind EVERGREEN Company that produces flour, poultry feed, swampy, mangrove, Farm (vegetable).
D6	Bikoko junction	04^0 07.196N	009^0 35.293E	Flat. Beside a Fenced house and stream. Closed to a primary road with intense traffic

Table 2. Location coordinates and description of the soil sampling points around River Meme

Code	Location	Latitude	Longitude	Description of site
M1	Dieka (Diek), adjacent Mbonge	04^0 34.265N	009^0 07.841E	Flat. Around a stream passing through a cocoa farm. Water used for drinking, bathing, rubber farm, use of herbicides.
M2	Mutiti (small). After Ekombe Marumba	04^0 31.631N	009^0 06.415E	Flat, near stream that empties into river Meme and receives waste from CDC rubber factory, Farming.
M3	Bande (BAND) Mbonge -Ekondo – Titi bush Road	04^0 32.012N	009^0 05.886E	Flat, near stream used for drinking bathing, Farming (Cocoa and Rubber).
M4	Biribiri (BIRI), Mbonge	04^0 32.852N	009^0 04.980E	Flat. Near stream, Farming (Rubber).
M5	Mission water (MISS) Mbonge	04^0 32.012N	009^0 06.525E	Flat. Near stream that empties into river Meme and used as car washing point. Farming.
M6	Small Nganjo	04^0 34.281N	009^0 07.856E	Flat. Near stream and bridge, stream used for bathing, Farming (Private palm)
M7	Big Nganjo	04^0 34.644N	009^0 08.980E	Flat. Near bridge and stream. Farming (Plantains).
M8	Ngongo Bakundu	04^0 32.771N	009^0 13.694E	Flat, near stream. Farming (Cocoa farm).
M9	Kumbe, Ekondo Titi	04^0 33.799N	009^0 02.746E	Flat. Near Kumbe water used for washing, Banks used for vegetable farming. Other farming activities include plantains and palms.
M10	Barombi Mokoko, Bamuso	04^0 29.511.N	009^0 03.765E	Flat. Near stream used for bathing. Sand excavation. Mixed crop cultivation, other farming activities include palms and plantains. Mokoko forest reserve, river.
M11	Ekombe Mefako, Bamuso	$04\ ^0$ 29.607N	009^0 04.337E	Flat. Near Mekaki stream. Farming (Cassava).
M12	Ekombe Liongo, Bamuso	04^0 30.328N	009^0 06.227E	Slightly inclined. Near Komborani stream, Farming [cassava, Cover crop (Leguminous plant)].
M13	ESAKA (ESAK) EkondoTiti	04^0 32.888N	009^0 04.755E	Flat. Near Esaka stream that empties at River Meme, Farming(Palm Estate),
M14	Bongongo	04^0 34.837 N	009^0 05.903 E	Flat. Near stream, closer to habitation, Farming (plantains).
M15	Ekondo Titi town	04^0 36.019 N	009^0 02.355 E	Slightly inclined. Opposite a house with well, Farming (Palm Estate)

Twenty grams of the same sample used for the preparation of the liquid limit was placed in the same container above and on top of the wetter specimen. The height of the drop of the cup of the apparatus was adjusted so that the point of the cup that came in contact with the base rose to a height of 10 ± 0.2 mm.

A portion of the prepared sample in the cup of the liquid limit device was placed at the point where the cup rested on the base and spread so that it was 10 mm deep at its deepest point. A horizontal surface was formed over the soil. Care was taken to eliminate air bubbles from the soil specimen. The unused portion of the specimen was kept in the storage container. A groove was formed on the soil by drawing a groove on the grooving tool, bevelled edge forward, through the soil from the top of the cup to the bottom of the cup. In forming the groove, the tip of the grooving tool was held against the surface of the cup and the tool was kept perpendicular to the surface of the cup. The cup was lifted and dropped at a rate of 2 drops per second. Cranking continued until the two halves of the soil specimen met each other at the bottom of the groove. The two halves must me*et al*ong a distance of 13 m. The number of drops required to close the groove was recorded. A slice of soil was removed and its water content, w determined.

The steps were repeated with a sample of soil with slightly higher or lower water content. Whether water was added or removed depended on the number of blows required to close the grove in the previous sample.

Note: The liquid limit is the water content at which it will take 25 blows to close the groove over a distance of 13 mm. At least five tests were run to increase the water content each time. As the water content increased, it took fewer blows to close the groove.

Two grams were collected from the 20 g sample for testing. The test specimen was rolled between the finger and the ground glass plate to form a thread of uniform diameter. The rolling of the thread continued until it reached a uniform diameter of 3.2 mm. At this diameter, the thread was reformed into a ball. The soil was knitted for a few minutes to reduce its water content slightly.

The steps were repeated until the thread crumbled when it reached a uniform diameter of 3.2 mm. The water content was determined at this point, which was the plastic limit.

Note: The procedure was repeated three times to compute an average plastic limit for the sample.

A plot of the relationship between the water content, w, and the corresponding number of drops, N, of the cup on a semi logarithmic graph with water content as the ordinate and arithmetical scale, and the number of drops on the abscissa on a logarithmic scale. A best fit straight line was drawn through five or more plotted points. The water content corresponded to the intersection of the line with the 25 drop abscissa as the liquid limit, LL, of the soil.

The water contents obtained from the three plastic limit tests were computed. The plastic limit, PL, is the average of the three water contents.

Plasticity index was calculated as follows: *PI = LL – PL:* LL = liquid limit and PL = plastic limit.

Calculation of Activity, A = PI/F where PI = Plasticity index and F = Clay fraction.

2.5 Preparation of Soil Samples and Analysis by XRF

2.5.1 Preparation of soil samples: Destruction of organic matter

To prepare the samples for analysis of the clays, organic matter had to be removed from the soil samples. This was done according to Cassidy & Mankin [20]. A 25 mL aliquot of NaOCl solution freshly prepared at 3.8% and adjusted to pH 8.5 was added to a five grams soil sample in a 50 mL centrifuge tube. The tube was shaken for 4 hours at 220 rpm in an Edmund Buhler 7400 Tubingen SM25 shaker. The content was centrifuged at 4000 rpm for 20 minutes. The supernatant was discarded and the treatment was repeated over five times until bubbles seized to exist on further addition of NaOCl.

$$C_{(s)} + 2NaOCl_{(aq)} \rightarrow CO_{2(g)} + 2NaCl_{(aq)} \quad (1)$$

Fig. 3a. A 2 mm Sieve samples

Fig. 3b. Sieving of soil using a 2 mm Sieve

After the final decantation of the samples, NaOCl was replaced with distilled water and the new supernatant was tested with drops of 0.1M $AgNO_3$, and the presence of a white precipitate implied chlorites were still present in the treated soil sample as indicated by the presence of chloride ions in solution.

$$NaCl_{(aq)} + AgNO_{3(aq)} \rightarrow AgCl_{(s)(white\ ppte)} + NaNO_{3(aq)} \quad (2)$$

This treatment was repeated until the complete disappearance of the white precipitate.

Sand, silt, and clay were separated in layers at the bottom of the centrifuge tube. A small twisted spatula was used to collect the clay at the top of the sediment. The clay samples were air dried, ground, and were used for analysis as treated samples.

2.5.2 Analysis of clay samples by XRF

Analysis by XRF was conducted at Ecole des Mines de Nantes et Telecom Bretagne, France. This was to determine major oxides in clay fractions (<2 µm), namely, SiO_2, $A1_2O_3$, Fe_2O_3, MgO, CaO, K_2O, Na_2O, TiO_2, Cr_2O_3 and P_2O_3, and carried out according to standard methods described by Norrish & Hutton [20]. The 'grab' weight method was employed in the preparation of the calibration soil samples. Approximately 0.28 g of each of the finely ground powders were weighed into glass vials with 1.5 g (also accurately weighed) of Norrish/Hutton lithium tetraborate + lanthanum oxide flux [21]. The mixture was fused into a homogeneous glass in a Pt-Au crucible over an oxypropane flame at a temperature of approximately 1050 °C and the molten material was then quench-pressed into a glass disc between a graphite mould and an aluminium plunger. The resulting glass discs were analyzed on a Philips PW1480 XRF spectrometer using a control program developed by Philips and algorithms according to Norrish & Hutton [21].

The Chemical index of alteration [22] and SiO_2:Al_2O_3 ratios were calculated as complementary parameters in assessing weathering intensity and degree of kaolinization [23]. CIA was computed from the formula

$$CIA = [Al_2O_3/ (Al_2O_3 + CaO + Na_2O + K_2O)] \times 100 \quad (3)\ [22].$$

Experimental data was analysed with the statistical package SPSS11.0 and EXCEL 2007 for Windows. Correlation and regression analyses were performed on the various data to evaluate the relationships.

3 RESULTS AND DISCUSSION

3.1 Types of Clay Around the River with Plasticity Limits

Majority of the soils around both rivers could contain illites or interstratified clay (as shown in Table 3). Illites are 2:1 non-expandable clays. The presence of K in the interlayer prevents its expansion and hence could account for the display of 1:1 clay properties shown in the physicochemical properties. In the absence of definitive evidence that clay is interstratified, it is probably best to consider it as a mixture of discrete species as was reported by Mills & Zwarich [24].

The results also showed that some of the clays could be kaolinite, Attapulgite, or Allophane (Table 4). Allophanes occur where a large amounts of weathered products exist. They are common in soils formed from volcanic ash. The volcanic ash from eruptions could be responsible for the presence of allophones in the region. Attapulgites are 2:1 clays.

According to the ratings established by Hazelton & Murphy [25], all soils in these regions were in the range of low plasticity index (< 25%). This shows that they can change from solid to liquid with little change in moisture content. These soils may be prone to mass movement. Therefore, the clays are not good sinks for pollutants.

3.2 Mineralogy of Clays from XRF

XRF analyses showed that the clays contained SiO_2, Al_2O_3 and Fe_2O_3 as major oxides. TiO_2 and MgO were also present in all clays extracted in appreciable amounts. K_2O, Na_2O, CaO, P_2O_3, MnO, and Cr_2O_3 occurred in trace amounts and in all clays. The results also revealed significant enrichment of magnesium over the other alkali and alkali earth metals (Table 4).

Roy et al. [27] and Mitchell & Sheldon [28] postulated that CIA values for unaltered rocks and minerals are always around 50. Weathering products with CIA values < 60 suggest low chemical weathering, between 60 and 80, moderate, whereas CIA values > 80 extreme chemical weathering [27]. The CIA values were all >90. This is an indication that the rocks or minerals have undergone extreme chemical weathering or kaolinization. The results contrasted with those of Diko & Ekosse [29] where the degree of kaolinization was moderate. The difference is associated to the different regions from which the soil samples were collected.

The Si_2O_3:Al_2O_3 ratio reflects the abundance of quartz and aluminosilicates in weathered products, with low values indicating a relative enrichment of argillites at the expense of quartz and vice versa according to Wu et al. [30]. The Si_2O_3:Al_2O_3 ratios of the clays from the soils are higher than the 1.18 value reported for theoretical kaolinite by Ekosse [31].

About 20% of the studied clays around River Wouri had SiO_2/Al_2O_3 values around 1.18, a value reported for theoretical kaolinite by Ekosse [31]. Around River Meme, 36.36 % of the soil samples had values around it.

These percentages represent pure kaolinite while the rest were kaolinite with mixtures of other clays. It was also an indication that there was a relative enrichment of argillites at the expense of quartz. The relative abundance of the oxides in both regions were same and in the order SiO_2 > Al_2O_3 > Fe_2O_3 >TiO_2 > MgO >MnO>K_2O> CaO >Na_2O>P_2O_3 >Cr_2O_3. Sample D5 had an exceptional high amount of Cr_2O_3, 18%.

The Loss on Ignition (LOI) values indicated that there was considerable carbonaceous matter as was reported by Nayak & Singh [32] in the clay sample.

Elements involved in soil formation such as Si, Al, and Fe have high concentrations contrary to easily mobilized (exchangeable bases) like calcium, magnesium, potassium, and sodium. The major elements involved in soil formation were known to be the major constituents of kaolinite clay minerals.

3.3 Data Analysis

Correlation analysis showed no correlation between silica and alumina in both regions. This was an indication of the presence of silica and alumina in significant amounts in the region. The correlation matrices for both regions are shown in Tables 5 and 6, respectively.

Table 3. Plasticity of soil around the rivers

		Limits test					
	code	**WL**	**WP**	**IP**	**CF**	**A**	**Predicted Mineral**
1	D1	28.3	23.3	5.0	6.20	0.81	Illite
2	D2	28.7	22.1	6.6	9.07	0.73	Illite
3	D3	25.6	21.8	3.8	6.76	0.56	Illite
4	D4	26.8	25.0	1.8	5.00	0.45	Kaolinite
5	D6	34.7	29.2	5.5	8.79	0.63	Attapulgite
6	M1	66.6	59.8	6.8	20.00	0.34	Kaolinite
7	M2	37.9	32.5	5.4	16.10	0.33	Kaolinite
8	M3	34.8	32.7	2.1	12.55	0.17	Halloysite (Hydrated)
9	M4	43.4	34.6	8.8	9.00	0.97	Illite/Attapulgite/Allophane
10	M5	42.9	36.5	6.4	6.00	1.06	Illite/Attapulgite/Allophane
11	M6	36.9	31.5	5.4	10.00	0.54	Illite/Attapulgite/Allophane
12	M7	42.9	32.4	10.5	14.00	0.75	Illite/Attapulgite/Allophane
13	M8	68.0	55.2	12.8	34.00	0.38	Kaolinite
14	M9	57.7	45.8	11.9	17.00	0.70	Illite/Attapulgite/Allophane
15	M10	35.5	28.5	7.0	15.04	0.47	Kaolinite
16	M11	28.5	24.0	4.5	8.00	0.56	Halloysite (dehydrated
17	M12	28.5	26.3	2.2	4.00	0.55	Illite/Attapulgite/Allophane
18	M13	35.2	28.1	7.1	9.26	0.77	llite/Attapulgite/Allophane
19	M14	48.4	36.3	12.1	8.49	1.43	Illite
20	M15	64.5	56.2	8.3	9.00	0.92	Illite/Attapulgite/Allophane

WL = Liquidity limit. WP = Plasticity limit. IP =Plasticity index CF = Clay fraction A = Activity
Skempton [26] defined the activity (A) of clay as:
1. Inactive clays: A<0.75; 2. Normal clays: 0.75<A<1.40; 3. Active clays: A> 1.40

Table 4. Major element Geochemistry of the clays with XRF in % (LOI = Loss on Ignition)

	SiO_2	Al_2O_3	Fe_2O_3	MgO	TiO_2	K_2O	Na_2O	CaO	P_2O_3	MnO	Cr_2O_3	LOI*	Si/Al	Si/Fe	CIA
D1	31.18	22.88	20.81	1.28	7.06	0.84	0.09	0.22	0.09	0.91	0.04	19.3	1.36	1.50	95.21
D2	34.72	26.07	18.05	1.94	6.19	0.35	0.16	0.18	0.12	0.75	0.01	16.8	1.33	1.92	97.42
D3	28.15	29.48	23.17	1.82	8.47	0.91	0.08	0.28	0.05	0.82	0.07	21.1	0.96	1.22	95.87
D5	39.07	31.36	21.42	1.96	4.52	0.39	0.39	0.31	0.16	0.62	18	20.4	1.25	1.82	96.64
D6	29.62	21.78	19.42	1.26	7.09	0.57	0.13	0.32	0.04	0.37	0.02	17.4	1.36	1.53	95.53
Av.	32.55	26.31	20.57	1.65	6.67	0.61	0.17	0.26	0.09	0.69	0.04	19.0	1.25	1.60	96.13
M2	30.06	26.38	19.15	1.22	4.68	0.79	0.07	0.15	0.06	0.73	0.05	16.7	1.14	1.57	96.49
M3	35.17	29.74	22.06	1.94	5.67	0.64	0.02	0.09	0.09	0.52	0.07	19.1	1.18	1.60	97.54
M4	38.64	32.11	26.11	1.38	7.21	0.49	0.27	0.28	0.11	0.84	0.08	21.4	1.2	1.48	96.86
M5	32.28	24.39	17.19	1.38	5.19	0.38	0.13	0.07	0.01	0.38	0.06	15.4	1.32	1.88	97.68
M6	43.17	40.02	34.18	1.97	6.38	0.67	0.18	0.21	0.09	0.93	0.06	26.3	1.08	1.26	97.42
M7	36.13	33.28	26.32	1.61	4.89	0.22	0.14	0.18	0.04	0.68	0.03	21.5	1.09	1.37	98.46
M10	40.62	26.31	18.04	1.32	6.08	0.67	0.04	0.35	0.07	0.48	0.07	17.3	1.54	2.25	96.13
M11	38.44	23.88	21.64	1.94	5.96	0.11	0.09	0.66	0.09	0.86	0.02	17.6	1.61	1.78	87.25
M13	36.95	31.61	18.27	1.37	6.97	0.63	0.07	0.38	0.02	0.62	0.08	15.1	1.17	2.02	96.08
M14	37.41	28.73	22.39	1.66	5.21	0.81	0.18	0.76	0.07	0.19	0.03	18.7	1.3	1.67	94.26
M15	39.73	29.53	23.81	1.41	6.86	0.44	0.14	0.09	0.05	0.78	0.07	21.9	1.35	1.67	97.78
Av	37.15	29.64	22.65	1.56	5.92	0.53	0.12	0.29	0.06	0.64	0.06	19.2	1.27	1.69	96.00

Table 5. Correlation Matrix for oxides for soils around River Wouri

	SiO_2	$Al2O_3$	Fe_2O_3	MgO	TiO_2	K_2O	Na_2O	CaO	P_2O_3	MnO	Cr_2O_3
SiO_2	1										
Al_2O_3	-0.54	1									
Fe_2O_3	-0.43	0.05	1								
MgO	-0.36	0.71	0.39	1							
TiO_2	-0.63	-0.06	-0.11	-0.45	1						
K_2O	-0.32	-0.59	0.1	-0.48	0.73	1					
Na_2O	0.5	0.1	0.31	0.54	-0.98**	-0.7	1				
CaO	0.08	-0.38	0.78	-0.14	-0.22	0.08	0.35	1			
P_2O_3	0.64	0.2	-0.13	0.47	-0.96**	-0.82	0.90*	-0.04	1		
MnO	-0.15	-0.09	-0.34	0.18	0.24	0.46	-0.31	-0.67	-0.15	1	
Cr_2O_3	0.07	-0.32	0.68	0.41	-0.45	0.18	0.55	0.52	0.23	0.17	1

***. Correlation is significant at the 0.01 level (2-tailed).*
**. Correlation is significant at the 0.05 level (2-tailed).*

Table 6. Correlation Matrix for oxides for soils around River Meme

SiO_2	Al_2O_3	Fe_2O_3	MgO	TiO_2	K_2O	Na_2O	CaO	P_2O_3	MnO	Cr_2O_3	
SiO_2	1										
$Al2O_3$	-0.21	1									
$Fe2O_3$	-0.85**	0.01	1								
MgO	0.03	-0.46	0.09	1							
TiO_2	-0.19	-0.41	-0.16	0.05	1						
K_2O	-0.07	0.15	0.06	-0.36	-0.19	1					
Na_2O	-0.23	-0.2	0.27	-0.3	0.04	-0.09	1				
CaO	0.53	-0.37	-0.49	0.33	-0.04	0.02	0.14	1			
P_2O_3	0.28	-0.32	-0.1	0.32	-0.27	0.03	0.27	0.25	1		
MnO	0.04	0.42	-0.14	-0.15	-0.2	-0.42	0.22	-0.31	0.38	1	
Cr_2O_3	-0.16	0.12	-0.11	-0.5	0.46	0.39	-0.02	-0.54	-0.04	0.1	1

***. Correlation is significant at the 0.01 level (2-tailed).*

There was a significant negative correlation (r = -0.85, $p < 0.01$) between SiO_2 and Al_2O_3 among Meme soils and none among Wouri soils. This implies the soils were highly weathered. Sesquioxides come from clay and their source of charge is pH dependent. There was also another significant positive correlation (r = 0.90, $p < 0.05$) between P_2O_3 and Na_2O among Wouri soils but none among the Meme soils. This could be an indication that there Na_2O could be coming from the weathering of rocks that contain P_2O_3.

4. CONCLUSIONS

The majority of the clay was dominated by SiO_2, Al_2O_3, Fe_2O_3, and TiO_2 and was a mixture of non-expandable (2:1 and 1:1) and sesquioxide clays. The relative abundances of the major oxides in both regions were the same and in the order SiO_2 > Al_2O_3 > Fe_2O_3 >TiO_2. The Wouri River is more polluted than River Meme. The soils have low pollutant retention capacities and are therefore vulnerable to increased anthropogenic activities. Hence, stringent measures should be taken to monitor soil/water quality with respect to waste disposal and use of agrochemicals. The Municipalities should revise the means of waste disposal and open centres for the transformation of municipal waste into compost. Farmers are also advised to refrain from using acid-forming fertilizers and use more of compost,

DATA AVAILABILITY

All data generated or analyzed during this study have been included in this published article.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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