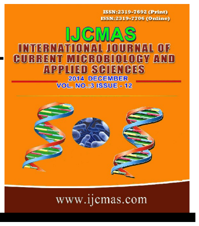

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Original Research Article

Heavy metal status in the Rio del Rey mangroves of Cameroon

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ABSTRACT

Keywords

Heavy metals, Rio del Rey Mangroves, soils, policy recommendations

This study examined some heavy metal concentrations in Rivers Meme and Ndian of the Rio del Rey mangroves of Cameroon. This was necessitated by the use of these rivers and some streams feeding them for livelihood, despite severe anthropogenic influences. Forty water samples from varied depths were collected in August 2009 and analysed for heavy metal accumulation. Six top soil samples from the catchment areas were also analysed using standard methods. Very high concentrations (16.19 to 20.50 mg/L) of Zn were obtained in some sites of River Meme. Lead concentrations were significantly ($P < 0.05$) lower than the maximum allowable concentrations for drinking water in both rivers. River Meme as opposed to River Ndian had higher concentrations in streams than in wells. Insignificant negative correlations existed between Cd and depth, depicting anthropogenic origin dominance in River Meme as opposed to River Ndian. Principal component analysis equally suggested this dominance. There was an insignificant ($P>0.05$) positive correlation ($r = 0.2575$) between the cation exchange capacity and organic matter of the soils in the Rio del Rey mangrove ecosystem. This makes the mangrove ecosystem vulnerable to increase anthropogenic activities. Separate policies adoptions for the management of both rivers are thus recommended.

Introduction

There are convincing evidences that water is a fundamental human need and life on earth is impossible without this resource (Faniran, 1991; Boynton *et al.*, 1995; Katte *et al.*, 2003; Gleitsmann *et al.*, 2007). Although Cameroon is endowed with abundant freshwater resources, water challenges in Cameroon are numerous. Studies from different parts of the country indicate that many water resources used for household consumption are polluted to varying degrees because waste disposal infrastructure is insufficient, and/or the capacity to enforce existing laws is very weak (Asongwe, 2010; Fonge *et al.*, 2011; Forton *et al.*, 2012; Tening *et al.*, 2013a, 2013b). Continual indiscriminate disposal of agricultural, industrial and domestic wastes on mother earth slowly makes surface water and rivers susceptible to pollution. This has also initiated progressive degradation of land and other vital resources. Aderibigbe *et al.* (2008) reported that the human race is particularly becoming increasingly vulnerable due to the dependence on polluted water. One of such notorious influences of change in this water chemistry is heavy metals which are major constituents of industrial, agricultural and household effluents and are frequently discharged into the aquatic environment. They biomagnify and cause a wide range of adverse effects on water, aquatic biota, and the severity of such effects depends on the properties, quantity and exposure duration of the metal (Kakulu and Osibanjo, 1986; Alloway, 1994; Fonge *et al.*, 2011). The level of these metals in the aquatic environment has increased tremendously in the past decades as a result of human inputs and activities (Lumborg and Windelin, 2003) but the soil plays a key role in controlling their availability in the environment. Soils rich in organic matter and clays such as montmorillonite hold nutrients and water better than sandy soils, which are deficient in absorptive sites (Yerima and Van Ranst, 2005). Once the toxic materials enter the soil, some find themselves in water and become part of the cycle which could eventually affect the mangrove ecosystem.

The Rio del Rey mangroves represent an important mangrove stand in Cameroon under protection. Mangroves are widely used traditionally by the indigenous people for a variety of purposes: fisheries, fuel wood, scenic beauty, cultural and inspirational wellbeing, medicinal plants exploitation, and the provision of food (UNFCCC, 1998; Twilley *et al.*, 1992; Suratman, 2008). Cameroon is a modest petroleum producer and possesses off-shore platforms in the Rio del Rey. Petroleum activities involve several operations that generate pollution, notably exploration drilling production drilling, placing of pipelines associated to notorious releases into these mangroves. Changes in the physicochemical properties of water are not only undesirable for drinking water quality but would also influence the mangroves.

Within the Rio del Rey, apart from the traditional cash crops such as cocoa, agro-industrial activities of the area concern essentially oil palm, rubber and banana which are in the hands of large scale agro-industrial establishments. These companies include CDC and PAMOL (Folack, 1997). Effluents from processing factories owned by these companies are piped or channelled directly into streams of their vicinity. Farm management practices also add enormous chemicals to the environments. These chemicals find themselves in water bodies and hence undesirable burdens to the mangrove ecosystem. Excess of inputs are harmful to the pneumatophores and propagules (Aurela *et al.*, 2002; Lafleur *et al.*, 2003; Roulet *et al.*, 2007). This mangrove last stand may be humanity last stand. Despite these challenges, Cameroon lacks comprehensive information, adequate legal and institutional framework, strong enforcement capacity and good coordination among agencies to enforce sustainable water management, which has a lot of implications to the fresh water resources and the Rio del Rey mangroves. Therefore, an early detection of high heavy metal concentrations in water bodies such as in rivers or wetlands is vital for human health.

This study was therefore designed to evaluate the heavy metal status of Rivers Meme and Ndian of the Rio del Rey mangroves of the Cameroon coast, trace the sources of these pollutants and propose some policies for the management of the Rio del Rey mangroves.

Materials and Methods

Study area

The study area is part of the Rio del Rey basin located in the south western coast of Cameroon (Figure 1). 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). Mean annual rainfall stands at 5,000 mm (Zimmermann, 2000) with 86 mm per month during the dry season and 326 mm per month during the rainy season (Gabche and Smith, 2002). The average annual temperature stands at 27°C. August is the coldest month with mean monthly maximum temperatures of 25°C, while February is the hottest month with mean monthly maximum of 33°C. The soils are ferallitic (Gavaud and Muller, 1980), yellowish in colour, and varying from clayey, silty, sandy to lateritic clay sub soils.

The Rio del Rey basin is part of the Douala sedimentary basin. From south to north, this sedimentary basin is symmetrically divided by the Cameroon volcanic line (CVL) into two gomorphological settings: the Douala basin (7,000km^2) to the south and the Roi del Rey basin to the North (2,500km^2). Within the Rio del Rey basin, isobaths lay up to 80 km from the beach.

The continental shelf in this area is twice as broad as it is in the south east of mount Cameroon. This section of the Cameroon coastal area is dominantly used for plantation agriculture but not quite suitable for the cultivation of traditional cash crops. These agricultural practices involve the use of Round Up and Fertilizers. There are no proper housing conditions and no sewage systems in the area exerting enormous pressure on water resources. The coast is once more low and marshy. The drainage pattern is dendritic dominated by Rivers Ndian, Moko, Meme, Mungo and Akwayafe, which have watersheds from the Rumpi hills, the Manengouba Mountains and the highlands of the Korup National Park with altitudes ranging from 800 to 1050 m. These rivers form the Rio-del-Rey estuary. They are often used as means of communication with other neighbouring countries such as Nigeria. The vegetation consists of mangroves and swampy species. In the hinterland, the Atlantic forest includes the Korup rainforest National Park, a vital gene bank in the area.

The area has a varied geological setting comprising of cretaceous limestone, tertiary and quaternary sediments which principally consist of sands, sandstones, conglomerates, limestone, shale, clays and alluvium. These are terminated landward by basaltic lava flows from the Rumpi hills and by Precambrian basement rocks composed of gneisses, micaschists and quartzites (Dumort, 1968; Obenesaw *et al.*, 1997).

Directly overlying the cretaceous sediments offshore, is the lowest tertiary unit known as the Isongo Formation, which is equivalent to the Akata Formation in the Niger Delta. This unit is composed mainly of dark grey marine shale ranging from Paleocene to Recent. The Agbada Formation is characterized by a lower shale section and an upper section, composed of an alternation of sandstones and shale. It ranges from Oligocene, Miocene to Recent. The Benin Formation forms the upper continental sequence in this basin and is composed of a few intercalations of shale towards the base, and rich in sands and sandstones.

Experimentation

Sampling was carried out within the Meme and Ndian Rivers in in August 2009. 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. Soil sampling was carried out around the streams and wells feeding both Rivers Meme and Ndian. This was done taking into consideration areas of potential influence by human activities. Surface water samples were collected from Rivers Meme and Ndian, and some streams, wells and springs feeding these rivers. This was done by first rinsing the sampling bottle several times with some of the water to be collected, dipping the bottle in the water and filling it 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 bottles were used. The pH and electrical conductivity (EC) were measured in situ using a Tracer PockeTesterTM field conductivity meter, model pH/TDS/salts. They were then transferred immediately into a cooler containing ice blocks. Before chemical analysis was carried out with the Gas chromatography - mass spectroscopy, the water samples were filtered using Whatman 40 filter papers**.**

Soil samples

Six representative soil samples were collected using a hand trowel in the catchment areas of the two rivers. All samples were air-dried and sieved through a 2 mm sieve. Soil pH was measured both in water and KCl (1:2.5 soil/water mixture) using a glass electrode pH meter. Part of the fine soil was ball-milled for organic carbon (OC) and Kjeldahl-N analysis (Pauwels *et al.*, 1992). Available P (Olsen P) was determined by method of Bray 2, Mg^{2+} and Ca^{2+} by complex metric titration, CEC (CEC7) using ammonium acetate at pH 7 (Pauwels *et al.*, 1992).

Experimental data was analysed with the statistical package SPSS14.0 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.

Result and Discussion

The composition of heavy metals varies considerably at the different sites of both Rivers Meme and Ndian of the Rio del Rey Estuary from upstream to downstream (Tables 1 and 2). Variations in the physicochemical properties from upstream to downstream may be caused by changes in quantity and/or composition of freshwater discharges. According to Walling and Foster (1975), chemical concentrations in rivers and streams exhibit responses, evidencing increased and decreased different activities even in small catchments. This can alter the chemistry of the environment, such as hydrogeology and temperature. Doering (1996) reported that, nutrients from fresh water inflow affect both water quality and species diversity. Average pH values of both rivers were 7.2. This indicates that the rivers were neutral with values within the permissible range advocated by WHO (2008) for drinking as well as for plants production (FAO, 1975). The pH of the rivers is greater than 7.0 indicating that the main source of nutrients into these rivers is not mainly from precipitation and onsite decomposition of organic matter (Kem and Idler, 1999). This indicates that contributions from agricultural farms in this area are significant. There was no significant difference ($p>0.05$) in the observed pH values from upstream to downstream in both rivers. The EC of River Meme were significantly ($p<0.01$) higher than those of River Ndian. The values of conductivity ranged from 47.20 to 205.00 with an overall mean of 109.33 μS/cm in the Meme River and 20.50 to 115.7 μS/cm with a mean of 38.2 μS/cm in the Ndian River (Table 1 and 2, respectively). This could be an indication that the sampling scenario had no effect on the statistical detection of temporal trends implying that the higher values of Meme are accounted for by the nature of activities of the area which are continually increasing as a result of increase in population. The EC values increased inconsistently from upstream to downstream in both rivers with very high values at the down streams. The inconsistency could be associated to inputs from streams feeding the rivers while the very high values at downstream stations might have been due to the inundation resulting from sea water from the Atlantic Ocean during tidal time. All water samples were analysed for some heavy metals (Fe, Mn, Zn, Cu, Cd, Cr, and Pb) but Cr was not detected in all of the samples. Iron, Mn, Zn and Cu which were detected in the samples of River Meme, had concentrations within the ranges of 0.58-9.97, 0.23-5.67, 0.21-20.50, 0.10-0.64 mg/L, respectively and mean values of 4.17, 2.06, 6.88 and 0.29 mg/L, respectively (Table 1). The concentrations of Mn in all of the samples were significantly ($p<0.01$) higher than the 0.2 mg/L maximum allowable concentration advocated by FAO (1985) for potable r water. Similarly, Zn showed very high concentrations at some sites such as at Masore Junction and Matutu 2 with concentrations of 16.19 and 20.50 mg/L, respectively (Table 1). These sites are located near villages with intensive human activities. The concentration of Cu was the least amongst the heavy metals of River Meme. In River Ndian, the concentrations of the heavy metals ranged from 1.98-6.11, 1.12-4.21, 0.11-3.45 and 0.11-0.62 mg/L for Fe, Mn, Zn, and Cu, respectively. Their overall means stood rat 3.33, 2.04, 1.99, and 0.24 mg/L, respectively (Table 2). Most of the heavy metals were higher than the maximum allowable concentrations for potable water. The concentrations of these minerals were lower in River Ndian when compared to those the Meme River. For the notorious heavy elements Pb, Cd, and Al in both rivers, the concentrations of Pb were significantly lower than the 5 mg/L maximum allowable concentration (MAC) by FAO (1985). The concentration of this metal ranged from 0.03 - 0.60 mg/L in River Meme and 0.02-0.10mg/L in River Ndian. Cadmium was generally absent in upstream samples of both rivers. At down streams, their concentrations exceeded MAC. Al had concentrations that ranged from 0.68 – 7.50 mg/L in River Meme with an average of 4.23 mg/L. In River Ndian, this concentration ranged from 0.68 – 7.95 mg/L with a mean of 3.32 mg/L which is lower than that of River Meme. The relative dominance of the heavy metals in water was observed in the following sequence: Zn > Al > Fe > Mn > Cu > Pb > Cd for River Meme and Fe > Al > Mn > Zn> Cu > Pb > Cd for River Ndian. The highest concentrations of most of the heavy metals in the rivers may be attributed to the discharge of industrial effluents and municipal wastes, geology of river bed and catchment areas. Similar findings were also observed by Shah, *et al.* (2005). Correlation analysis of the surface samples of River Meme showed that, most of the heavy metals were significantly positively related at the one percent probability level in the order of Al and Pb>Mn and Fe> Fe and Cu> Fe and Mn (Table 3). This could be an indication that a single policy developed for the handling of one of these heavy metals will automatically resolve problems associated to the other metals. However, in this river, Zn and Cu showed a weak positive correlation (r = 0.250) with each other at the 5% probability level. Though most of the elements have common sources, the uptake of either of them by aquatic plants could have reduced the uptake of the other elements from the river. This will thus reduce the strength of the correlation coefficient existing between them. Apart from pH and Cd that exhibited a significant negative correlation (r = - 0.705) at the 5% probability level (Table 3), there were no significant correlations observed in the changes of heavy metal concentrations with the pH of water. These relationships are similar to those of Kar *et al.* (2008) who assessed heavy metal pollution in the Ganga River in West Bengal, India. In River Ndian, highly significant (p,0.01) positive correlations were observed in the sequence Mn and Cu> Cu and EC > Fe and Mn > Fe and Cu > Cu and EC > Cd and Pb. This indicates that Cu and Mn are notorious heavy metals in this river. Similar to River Meme, pH did not show any significant correlations with the metals.

Considering the status of heavy metal concentrations in water, it may be concluded that the water from these rivers is not suitable for drinking purpose due to the excess concentrations of Fe, Mn, Cd and Al. It may not also be suitable for irrigation due to the excess concentration of Mn.

Sources of contaminants

Concentrations in streams and wells

The results show that around River Meme, the streams had concentrations that are generally higher than those of wells except for Al (Table 5). This is an indication that ground water contamination is minimal. The higher concentrations in these streams that feed the Meme River implies that most of the pollutants in the River are highly accounted for by anthropogenic activities around the catchment areas of these streams than the basement rocks. Despite these variations, both the streams and the wells were neutral with average pH values of 7.3 in the streams and 7.2 in the wells. There were highly significant differences at the 1% probability level in the concentrations of Fe, Mn and Cd of the streams and wells of River Meme. On the contrary, chemical concentrations of heavy metal ions around River Ndian streams and wells (Table 6) revealed that the wells had concentrations higher than the streams. This implies that most streams in this area have been minimally imparted by anthropogenic activities. This has thus resulted to a little disturbance of the Ndian River when compared to the Meme River. The minimal impact on the streams could be attributed to the fact that the population density in the Ndian area is lower than that of Meme (MINEPAT, 2010), thus the waste generated in the Ndian area is minimal. The wells of Ndian at moment are thus also major contributors of the chemical contaminants in this river. There were significant differences ($p<0.01$) in the concentrations of Mn, Fe, Cu and Pb of the Ndian River. The mean concentrations of these metals in the streams and wells feeding the Meme River were significantly different from those of streams and wells feeding the Ndian River. Both rivers could therefore be managed using different policies.

Depth profiling (Table 7 and 8) of Rivers Meme and Ndian revealed that the concentrations of heavy metals vary with depth considerably. In River Meme, concentrations of most of the metals (Figure 2) increased with depth. Significant ($p<0.05$) positive correlations was observed between Mn and depth. On the other hand, insignificant ($p>0.05$) negative correlation was observed between mPb and depth (r =0.3804). This river is used for the transportation of petroleum products, which could contain Pd. Lead is often added to fuel as an antifouling agent despite worldwide ban on the use of this metal (Gleitsmann *et al.*, 2007). Petroleum products are equally less dense than water. As such accidental spills and/or combustion by-products from engine boats transporting such products would have been additional sources of these contaminants in the river. On the other hand, depth sampling of River Ndian revealed that there were insignificant ($p>0.05$) variations in the heavy metal contents of the rivers with depth (Figure 3). However there was a slight increase in average Pb concentration with depth. The positive insignificant increase in the concentration of Pd could be highly contributed by the direct channelling of waste oil from a palm oil processing factory at the Ndian beach into subsurface water (Figure 4). Negative insignificant ($p>0.05$) correlations (r = 0.074, and r = 0.0595) existed between, Cu and depth, and Mn and depth, respectively. This means that as compared to River Meme, River Ndian though also contaminated is relatively pristine and thus could be easily remediated by sound policies intervention. Principal component analysis (PCA) constitutes the minimum dataset required to group river surface water in the Roi del Rey Mangroves of Cameroon. Three components explained 78.5% of the total variance in River Meme (Table 9). Principal component 1 contributed 38.1% (PC1), 27.9% for PC2, and 12.5% for PC3. The PCA yielded 3 components (Table 10) were retained for interpretation. The principal component (Table 10) factor 1 (PC1) was encompassed of pH, Fe, Mn, and Cu. It is principally an organic matter based factor. It had high positive loadings of, Fe (0.905), Mn (0.921), and Cu (0.874), but a moderate positive loading for pH (0.624). The grouping of these sites could be allied to anthropogenic activities that results to a mix released of heavy metals that would combined with the organic matter in these agricultural areas to the formation of organo-metal complexes. Factor 2 included Al, Pb, and Cd. It had positive loadings of Al (0.827), and Pb (0.784), but a moderate loading of Cd (0.684). It could have resulted from discharges of oil and/or the wear and tear of machineries. Factor 3 was made of pH and Cd with moderate loadings of (0.592) and (0.573), respectively. This could be linked to weathering activities given that soils of the area are covered by vegetation not too exposed to be highly influenced by physical weathering activities. For River Ndian (Tables 11 and 12), three factors accounting for 86.85.8% of the total variance, also explained parameter groupings. Factor 1 accounted for 44.10% of the total variance. It consisted of EC, Fe, Mn, Al, cu, Pb. Positive loadings were obtained from EC (0.765), Fe (0.915), and (0.962), Cu (0.898), but negative moderate loadings of Al (-0.581) and Pb (- 0.521). Major sources of the metals could be the breakdown of materials natural weathering processes giving that the most undesirable metals, Al and Pb were negatively correlated with the micronutrients. Factor 2 which accounted for 28.97% of the total variance consisted of CE, Zn, Pb, and Cd. It had positive loadings of, Zn (0.823), Pb (0.706), and Cd (0.947) but a moderate loading of EC (0.549). It could have resulted from anthropogenic activities given than it encompasses the most undesirable metals. Factor 3 was a single element factor of pH, accounting for 13.49% of the total variance.

Table.1 Physicochemical properties of water samples from River Meme

Site	**pH**	**EC**	**Fe**	**Mn**	**Al**	**Zn**	**Cu**	**Pb**	**Cd**
		µS/cm				**mg/L**			
CDC Pump station	7.2	78.8	4.08	1.15	0.68	0.21	0.21	0.05	0.00
Mokoko Beach	7.2	74.3	3.37	2.78	5.45	2.96	0.32	0.11	0.00
Kumbe Beach	7.2	78.0	0.58	0.23	1.36	2.57	0.02	0.03	0.00
Mongossi Beach	7.2	72.6	4.72	3.57	4.77	4.72	0.51	0.10	0.06
One Man House	7.1	74.0	0.91	0.42	4.55	7.37	0.08	0.09	0.07
Matutu	7.1	74.6	5.07	1.91	6.36	4.82	0.37	0.12	0.05
Via Masore Junction	7.1	152.1	1.02	0.71	5.23	8.55	0.10	0.11	0.06
Masore Junction	7.2	141.4	2.28	1.08	7.50	16.19	0.17	0.16	0.02
Matutu 2	7.2	142.5	9.97	5.67	1.36	20.50	0.64	0.03	0.02
Big Belly	7.2	205.0	9.70	3.11	5.00	0.90	0.47	0.11	0.04
Mean	**7.2**	**109.3**	**4.17**	**2.06**	**4.23**	**6.88**	**0.29**	**0.09**	**0.03**
Standard deviation	**0.0**	**47.20**	**3.40**	**1.70**	**2.30**	**6.70**	**0.20**	**0.00**	**0.03**
Maximium	**7.2**	**205.0**	**9.97**	**5.67**	**7.50**	**20.5**	**0.64**	**0.16**	**0.07**
Minimium	**7.1**	**72.6**	**0.58**	**0.23**	**0.68**	**0.21**	**0.10**	**0.03**	**0.00**
MAC by FAO (1985)	**0.0**	**0.0**	**0.0**	**0.2**	**0.0**	**2.0**	**0.2**	**5.0**	**0.01**

Table.2 Physicochemical properties of water samples from River Ndian

Site	**pH**	**EC**	**Fe**	**Mn**	**Al**	**Zn**	**Cu**	**Pb**	**Cd**
		µS/cm				**mg/L**			
Baracks	7.1	45.3	2.77	1.12	6.36	2.08	0.11	0.040	0.02
Ndian Junction	7.2	115.7	6.11	4.21	0.68	2.27	0.62	0.020	0.02
Okonama	7.2	34.7	2.24	1.31	5.45	3.45	0.21	0.110	0.04
Ngomo Island	7.2	22.6	3.91	2.46	0.91	0.11	0.23	0.020	0.00
Mosongesele Junction	7.2	21.6	3.87	1.88	2.73	2.08	0.15cv	0.060	0.00
Ikassa Village	7.2	20.6	3.11	1.72	1.59	2.27	0.13	0.030	0.00
Buba Beach	7.2	22.2	2.65	2.31	7.95	1.59	0.23	0.020	0.00
Ndian Beach	7.2	23.1	1.98	1.33	0.91	2.08	0.21	0.020	0.00
Means	**7.2**	**38.2**	**3.33**	**2.04**	**3.32**	**1.99**	**0.24**	**0.04**	**0.01**
Standard Deviation	**0.0**	**32.5**	**1.30**	**1.00**	**2.90**	**0.90**	**0.20**	**0.00**	**0.01**
Maximium	**7.2**	**115.7**	**6.11**	**4.21**	**7.95**	**3.45**	**0.62**	**0.10**	**0.04**
Minimium	**7.1**	**20.6**	**1.98**	**1.12**	**0.68**	**0.11**	**0.11**	**0.02**	**0.00**
MAC for drinking by FAO (1985)	**-**	**-**	**-**	**0.2**	**-**	**2.0**	**0.2**	**5.0**	**0.01**

Table.3 Correlation matrix of some physicochemical properties of water samples from River Meme

	pH	EC	Fe	Mn	Al	Zn	Cu	Pb	Cd
pH	1								
EC	0.133	1							
Fe	0.375	0.510	1						
Mn	0.421	0.272	0.859**	1					
Al	-0.346	0.180	-0.155	0-.134	1				
Zn	-0.004	0.304	0.186	0.378	0.104	1			
Cu	0.353	0.265	0.903**	0.963**	-0.031	0.250	1		
Pb	-0.257	0.225	0-.154	-0.185	0.969**	0.044	-0.064	1	
Cd	-0.705*	0.110	0-.048	-0.045	0.460	0.074	0.063	0.384	1

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

Table.4 Correlation matrix of some physicochemical properties of water samples from River Ndian

	pH	EC	Fe	Mn	Al	Zn	Cu	Pb	Cd
pH	1								
EC	0.107	1							
Fe	0.219	0.929**	1						
Mn	0.336	0.700*	0.849**	1					
Al	-0.405	-0.043	-0.204	-0.364	1				
Zn	0.097	0.376	0.572	0.720*	-0.232	1			
Cu	0.334	0.818**	0.842**	0.933**	-0.323	0.572	1		
Pb	0.059	0.376	0.219	-0.178	0.406	-0.118	-0.014	1	
Cd	-0.128	0.670*	0.467	0.209	0.316	0.168	0.425	0.781**	1

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

Table.5 Physicochemical properties of water samples of some streams and wells feeding River Meme

	Site	**pH**	**EC**	**Fe**	**Mn**	**Al**	**Zn**	**Cu**	**Pb**	**Cd**
			µS/cm	**mg/L**						
Streams Meme	Small Nganjo	7.3	49.1	5.55	1.73	0.23	3.94	0.18	0.05	0.03
	Ekondo Titi-Meme bridge	7.3	66.3	3.15	0.97	4.09	5.09	0.38	0.09	0.07
	Average for streams	**7.3**	**57.7**	**4.35**	**1.35**	**2.16**	**4.52**	**0.28**	**0.07**	**0.05**
Wells Meme	Ekondo Titi town	7.2	91.4	1.80	0.37	5.68	0.67	0.07	0.01	0.00
	Bogongo	7.2	34.6	1.08	0.53	4.77	1.02	0.10	0.10	0.02
	Meme bridge-Pa Balamba	7.3	73.8	0.44	0.32	5.45	0.60	0.03	0.01	0.01
	Meme bridge-Susan Cook	7.3	139.6	0.26	0.18	6.14	0.60	0.07	0.03	0.02
	Average for Wells	**7.2**	**84.9**	**0.90**	**0.35**	**5.51**	**0.72**	**0.07**	**0.04**	**0.01**

Table.6 Physicochemical properties of water samples of some streams and wells feeding from River Ndian

	Site	**pH**	**EC µS/cm**	**Fe**	**Mn**	**Al**	**Zn**	**Cu**	**Pb**	**Cd**
							mg/L			
Ndian Streams	Mundemba town	7.2	26.3	0.22	0.09	5.23	1.09	0.08	0.01	0.02
	Mundemba-Ekondo Titi Road	7.2	26.5	0.91	0.55	0.68	0.80	0.09	0.01	0.02
	Average for streams	**7.2**	**26.4**	**0.57**	**0.32**	**2.95**	**0.95**	**0.09**	**0.01**	**0.02**
Ndian Wells	Pres. Church Mundemba	7.2	106.3	1.48	0.62	1.82	1.29	0.05	0.04	0.02
	Council Chambers	7.2	35.6	6.27	3.21	7.27	1.09	0.55	0.15	0.01
	Average for wells	**7.2**	**71.0**	**3.88**	**1.92**	**4.55**	**1.19**	**0.30**	**0.10**	**0.01**

Table.7 Variation of physicochemical properties of water samples with depth from River Meme

Site	**pH**	**EC µS/cm**	**Fe**	**Mn**	**Al**	**Zn**	**Cu**	**Pb**	**Cd**
						mg/L			
CDC Pump station	7.2	78.8	4.08	1.15	0.68	0.21	0.21	0.05	0.00
1 m depth	7.2	73.4	0.39	0.21	4.77	2.27	0.02	0.12	0.02
3 m depth	7.2	79.8	0.40	0.15	2.50	0.21	0.12	0.05	0.00
5 m depth	7.2	73.1	4.81	1.53	3.86	1.09	0.44	0.08	0.00
Masore Junction	7.2	141.4	2.28	1.08	7.50	16.19	0.17	0.16	0.02
1 m depth	7.2	138.7	4.15	1.92	2.05	10.80	0.33	0.04	0.05
3 m depth	7.1	129.0	7.35	3.57	2.27	8.94	0.51	0.05	0.02
5 m depth	7.2	129.1	8.87	4.17	3.41	15.50	0.57	0.07	0.04
Average surface	**7.2**	**110.1**	**3.18**	**1.12**	**4.09**	**8.20**	**0.19**	**0.11**	**0.01**
Average 1 m depth	**7.2**	**106.1**	**2.27**	**1.06**	**3.41**	**6.54**	**0.18**	**0.08**	**0.03**
Average 3 m depth	**7.2**	**104.4**	**3.90**	**1.9**	**2.40**	**4.60**	**0.30**	**0.10**	**0.00**
Average 5 m depth	**7.2**	**101.1**	**6.80**	**2.9**	**3.60**	**8.30**	**0.50**	**0.10**	**0.00**

Table.8 Variation of physicochemical properties of water samples with depth from River Ndian

Site	**pH**	**µS/cm**	**Fe**	**Mn**	**Al**	**Zn**	**Cu**	**Pb**	**Cd**
						mg/L			
Okonama	7.2	34.7	2.24	1.31	5.45	3.45	0.21	0.11	0.04
1 m depth	7.2	35.3	1.78	0.85	2.73	1.59	0.17	0.06	0.00
3 m depth	7.2	36.8	2.67	1.71	2.95	0.31	0.28	0.06	0.00
5 m depth	7.2	35.7	1.92	1.02	5.45	8.74	0.19	0.11	0.01
Ndian Beach	7.2	23.1	1.98	1.33	0.91	2.08	0.21	0.02	0.00
1 m depth	7.2	24.8	9.15	4.35	0.45	1.78	0.38	0.01	0.00
3 m depth	7.2	24.2	8.80	4.68	4.09	1.68	0.42	0.07	0.03
5 m depth	7.2	24.3	0.72	0.42	8.18	1.49	0.10	0.20	0.02
Average surface	**7.2**	**28.9**	**2.1**	**1.3**	**3.2**	**2.8**	**0.2**	**0.1**	**0.02**
Average 1 meters	**7.2**	**30.1**	**5.5**	**2.6**	**1.6**	**1.7**	**0.3**	**0.0**	**0.00**
Average 3 Meters	**7.2**	**30.5**	**5.7**	**3.2**	**3.5**	**1.0**	**0.4**	**0.1**	**0.02**
Average 5 meters	**7.2**	**30.0**	**1.3**	**0.7**	**6.8**	**5.1**	**0.1**	**0.2**	**0.01**

Table.9 Total variance explained from physicochemical properties of water samples from River Meme

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.429	38.103	38.103	3.429	38.103	38.103
2	2.515	27.947	66.050	2.515	27.947	66.050
3	1.120	12.450	78.500	1.120	12.450	78.500
4	0.919	10.209	88.709			
5	0.732	8.136	96.845			
6	0.206	2.293	99.138			
7	0.055	.610	99.748			
8	0.018	.203	99.951			
9	0.004	.049	100.000			

Extraction Method: Principal Component Analysis.

Table.10 Three component matrix (a) from Physicochemical properties of water samples from River Meme

	Component		
	1	2	3
pH	**0.624**	-0.393	**0.592**
EC	0.388	0.488	0.274
Fe	**0.905**	0.255	-0.069
Mn	**0.921**	0.234	-0.144
Al	-0.368	**0.827**	0.332
Zn	0.319	0.356	-0.095
Cu	**0.874**	0.332	-0.150
Pb	-0.368	**0.784**	0.447
Cd	-0.294	**0.684**	**-0.573**

Extraction Method: Principal Component Analysis.
a 3 components extracted.

Table.11 Total variance explained from physicochemical properties of water samples from River Ndian

Component	Initial Eigen values			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.996	44.396	44.396	3.996	44.396	44.396
2	2.607	28.972	73.368	2.607	28.972	73.368
3	1.214	13.485	86.853	1.214	13.485	86.853
4	0.586	6.507	93.360			
5	0.375	4.167	97.528			
6	0.206	2.287	99.815			
7	0.017	0.185	100.000			
8	1.19E-016	1.32E-015	100.000			
9	-2.36E-016	-2.62E-015	100.000			

Extraction Method: Principal Component Analysis.

Table.12 Three component matrix (a) from physicochemical properties of water samples from River Ndian

	Component		
	1	2	3
pH	0.341	-0.105	**0.878**
EC	**0.765**	**0.549**	-0.302
Fe	**0.915**	0.131	-0.101
Mn	**0.962**	0.091	-0.019
Al	**-0.581**	0.255	-0.454
Zn	-0.293	**0.823**	0.187
Cu	**0.898**	0.363	0.000
Pb	**-0.521**	**0.706**	0.316
Cd	-0.169	**0.947**	0.013

Extraction Method: Principal Component Analysis.
a 3 components extracted.

Table.13 Physicochemical properties of soils from the catchment areas of Rivers Ndian and Meme in the Rio del Rey mangroves of Cameroon

Site	**pH**	**pH**	**EC**	**OC**	**OM**	**CEC**	**Ca**	**Mg**	**N**	**P**
	(H_2O)	**(KCl)**	**µS/cm**	**%**		**(meq/100g)**	**mg/kg**			
Pa Balemba	4.5	3.7	310	2.54	4.37	3.76	0.24	1.84	1.59	2.28
P.C. Mundemba	5.2	4.2	45	2.54	4.37	5.20	0.08	0.72	2.17	4.52
Bogongo	5.5	4.6	53	2.30	3.97	9.52	0.44	3.96	1.83	2.28
ETT	5.2	4.6	89	2.91	5.02	11.52	0.24	2.64	2.15	10.34
METR	5.6	4.8	40	2.25	3.89	5.12	0.40	0.56	0.47	2.26
NCC	5.3	4.1	55	3.94	6.8	9.92	0.32	0.88	1.41	2.90
Mean	**5.2**	**4.3**	**98.7**	**2.7**	**4.7**	**7.5**	**0.3**	**1.8**	**1.6**	**4.1**

ETT= Ekondo Titi Town, METR= Mundemba Ekondo Titi Road, NCC= Ndian Council Chanbers
Samples were collected near ground water sources except at METR which was collected near surface water.

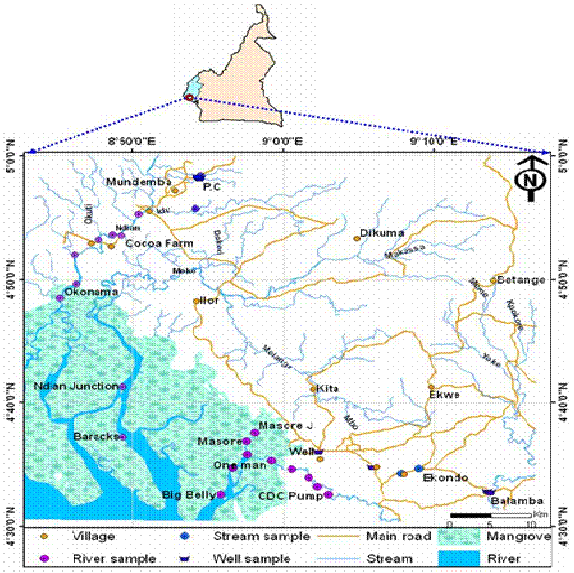


Figure.1 Map of the study area showing sampling sites in the Rio del Rey mangroves

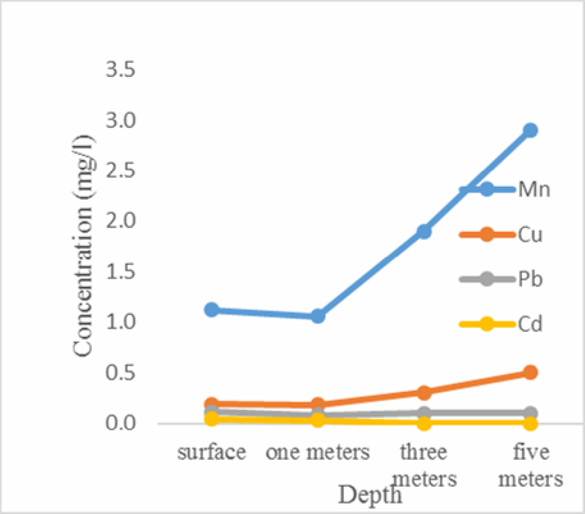


Figure.2 Variation of physicochemical properties of water samples with depth from River Meme

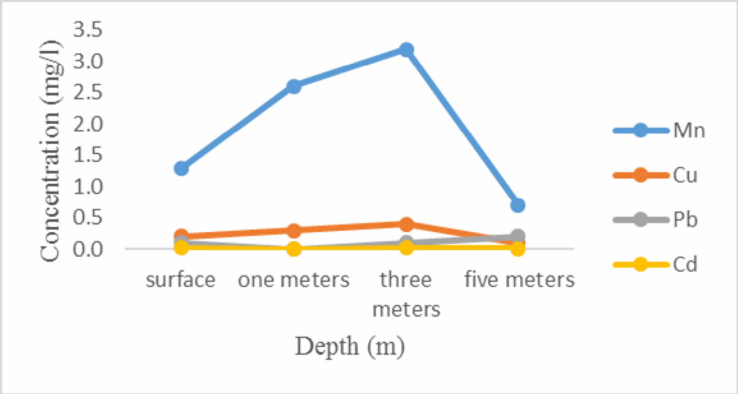
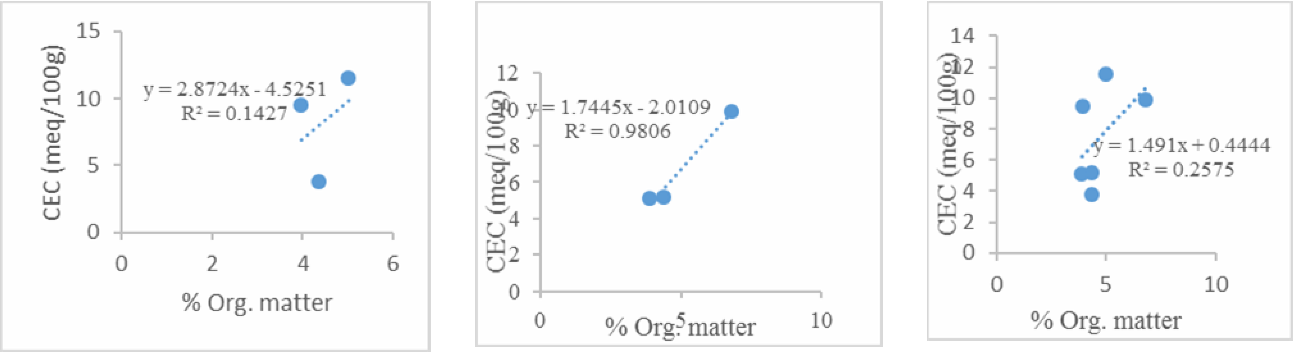


Figure.3 Variation of physicochemical properties of water samples with depth from Rivers Ndian

Figure.4 Piping of waste into the Ndian River at the Ndian Beach, Mundemba



a b c

Figure.5 Correlation between organic matter and CEC in (a) River Meme, (b) River Ndian and (c) Rivers Meme and Ndian combine

From PCA just as depth profile studies, whereas contamination of the Meme River is highly accounted for by anthropogenic activities, that of the Ndian River highly depends on natural processes.

Evaluation of the soils of the area (Table 13) indicated that the soils are slightly acidic with an average pH water of 5.2. In all cases, pH water was higher than pH in KCl. According to Sanchez (1976) and Yerima and Van Ranst (2005) in soils where pH 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. This would be the case of these soils. The CEC of the soils in this area range from 3.76 to 11.52 meq/100g. Wild (1996) reported that in soils where CEC soil range from 2 – 6 meq/100g, such soils 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 find themselves in water bodies. This is a serious threat to the Ndian and Meme Rivers of the Rio del Rey and as a consequence human beings. The slightly higher CEC values observed at some sites in this area could be associated to interstratification of minerals commonly reported in most environments (Yerima and Van Ranst, 2005a). Organic matter and clay colloids are the major sources of CEC. There was an insignificant positive correlation ($P < 0.05$) of R value of 0.1427 between CEC and organic matter from soils of the River Meme catchment area (Figure 5a) while there was a significant positive correlation ($p<0.05$) of r value of 0.9806 between organic matter and CEC from the Ndian River catchment area (Figure 5b). This imply that organic matter is the major source of CEC in the Ndian catachment area characterised by forests reserves such as the Korup National Park and the Mokoko Mangrove Reserve while clay minerals are the major sources in the Meme catchment area. Generally, there was an insignificant positive correlation ($P>0.05$) between CEC and organic matter ($r = 0.2575$) in the Rio del Rey mangrove area (Figure 5C). This further justifies the kaolinitic nature of soils of the area. The high intensive rainfall in the area would further lead to the leaching of silicon and other exchangeable bases in the exchange complexes resulting in the formation of oxides and hydroxides of Fe and Al with very low retentive sites. This will accelerate the vulnerability of the Rio del Rey Mangroves.

Conclusively, the results highlighted considerable anthropogenic influences on the Rio del Rey Mangroves in Cameroon. The Meme and their tributaries are more contaminated than the Ndian and its tributaries. It further revealed insignificant positive correlation ($P<0.05$) between CEC and organic matter ($r = 0.2575$) in the Rio del Rey mangrove area. This makes the mangrove ecosystem of the Roi del Rey additionally vulnerable to the increase anthropogenic activities. Separate policies adoption for the management of the Meme and Ndian River are thus recommended

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