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Nitrate and ammonium levels of some water bodies and their interaction with some selected properties of soils in Douala metropolis, Cameroon

Aaron Suh Tening[1]*, George Bindeh Chuyong[2], Godswill Azinwie Asongwe[3], Beatrice Ambo Fonge[2], Lydia Likowo Lifongo[1] and Beatrice Ketchemen Tandia[4]

[1]Department of Chemistry, University of Buea, PO Box 63, Buea, Cameroon.
[2]Department of Botany and Plant Physiology, University of Buea, PO Box 63, Buea, Cameroon.
[3]Department of Environmental Science, University of Buea, PO Box 63, Buea, Cameroon.
[4]Department of Earth Sciences, University of Douala, PO Box 24157, Douala, Cameroon.

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The present study examined the nitrate (NO_3^-) and ammonium (NH_4^+) levels of Rivers Wouri and Dibamba and some streams that feed them. The interaction of NO_3^- and NH_4^+ with some soil properties was also investigated. It was necessitated by the usage of these rivers for livelihood, despite the deposition of discharges into these streams. Twenty eight (28) surface water and four soil samples were collected from various sites within the Douala metropolis. The water was analysed for pH, electrical conductivity (EC), NO_3^-, NH_4^+ while the soil was analysed for particle size and cation exchange capacity (CEC). In both cases, standard methods were used. The NO_3^- and NH_4^+ levels were higher than the WHO threshold levels in some sites. Nitrate and NH_4^+ levels of 341.6 and 632.8 mg/l, respectively, were observed in some sites in Dibamba River despite the high level of clay in this area. The values in the Wouri River were low, contrary to the low level of clay in this area. This trend was also reflected in the streams that feed both rivers. The NH_4^+/NO_3^- molar ratio was low in areas proxy to the industries reflecting industrial source of pollution. The continuous use of water from Rivers Wouri and Dibamba for domestic purposes is variably unsafe and needs attention.

Key words: Nitrate, ammonium, water bodies/quality, soils, Douala metropolis.

INTRODUCTION

Water is a fundamental human need and life on earth is impossible without this resource. It underlies our agriculture, economic activities, livelihood, health and environment on which all other services depend. Man most urgent need is drinking water and the former could not survive in a few days if deprived of it but could do so in many days without food (Faniran, 1991). Rivers are very important part of our natural heritage. They constitute major sources of water. Their usage constitutes a major criterion towards sustainable growth and development of regions and their economy (Katte et al., 2003; Gleitsmann et al., 2007). Rivers have been widely utilized by mankind over the centuries to an extent that over the world there are very few that are still in their natural conditions or unaffected by upstream transportation of their freshwater inflow (Boynton et al., 1995). During the last decades, unprecedented increase in population and rapid growth of urbanization has seen remarkable impact of man on the environment (Morris et al., 1994). Indiscriminate disposal of agricultural, industrial and

*Corresponding author. E-mail: suhtening@yahoo.com.

domestic wastes on mother earth slowly makes surface water and rivers susceptible to pollution. This has initiated progressive degradation of land and other vital resources. Sullivan et al. (2003) and Watson and Lawrence (2003) observed that per capita water demand is increasing while accessibility to available freshwater is on the decrease. Aderibigbe et al. (2008) observed that the human race was becoming increasingly vulnerable due to dependence on polluted water. Compounds of nitrogen have a significant contribution in this pollution. The most important of these compounds are nitrites (NO_2^-), NO_3^- and NH_4^+ (Howarth, 1988). These ions can be present naturally as a result of atmospheric deposition, surface and groundwater runoff, dissolution of nitrogen-rich geological deposits, N_2 fixation by certain prokaryotes and biological degradation of organic matter. Ammonium tends to be oxidized to nitrate in a two-step process ($NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$) by aerobic hemoautotrophic bacteria (Sharma and Ahlert, 1977). Anthropogenic activities have led to worldwide increasing concentrations of these species that can reach dangerous levels in surface and coastal waters (Porta et al., 1999). The largest anthropogenic source of NH_4^+ results from excessive use of nitrogenous fertilizers, increasing human and livestock excrements while major anthropogenic source of NO_3^- are nitrogen oxides (NO_x) emitted from fossil fuel combustion from power plants, automobiles and biomass burning (Zhao et al., 2009). About 80% of all diseases and deaths in developing countries are water related (Aderibigbe et al., 2008). Acute infant methemoglobinemia (blue babies) may be developed by children under six months when water with above 50 mg/l nitrate is mixed with their milk (Manson, 1994).

Ingested nitrites (NO_2^-) and NO_3^- could lead to the development of the digestive tract and ovarian cancers (Camargo and Alonso, 2006). The indirect health hazards can occur as a consequence of algal toxins, causing nausea, vomiting, diarrhoea, pneumonia, gastroenteritis, hepatoenteritis, muscular cramps, and several poisoning syndromes.

The soil is the exchange medium of the environment. It controls the movement of chemical entities such as NO_3^- and NH_4^+ ions within the different environmental compartments. A good soil should therefore be rich in inorganic and organic colloids so as to retain the unwanted chemical entities by physicochemical adsorption. There is therefore need to relate the soil properties that are indicators to monitoring the levels of these chemical entities in the different water bodies.

Human activities that can alter the quality of river water within an urban area have been implicated (Ayemi et al., 2006). Teyim et al. (2006) associated high levels of NO_3^- and NH_4^+ observed along the Cameroon coast to industrial activities. Understanding and monitoring surface water quality of a region remains a better tool towards promoting sustainable development of water resources within the societal, economic, conservational and contextual needs. Douala, the most industrialised municipality in Cameroon, is becoming fragile and has been of concern due to increasing industrialisation, and population growth. Efforts made by Cameroon government to facilitate improvement in industrial pollution through restriction of waste deposition into natural drains by the 1996 Environmental Management Law are still at their infancy. It is therefore necessary to assess the quality of Rivers Wouri and Dibamba, and some streams that feed them for their safe use. This will go a long way to keeping the general public and the Government informed about their immediate environment. The objectives of this study, therefore, were to establish the nitrate and ammonium levels of the two rivers, and relate the former to streams, soils and human activities around the study area.

MATERIALS AND METHODS

Description of study area

Douala, the headquarters of the Littoral Region, is the most industrialized municipality in Cameroon. It lies between Latitude 4°2' N to 5°4' N and Longitude 9° 9' E to 11°5' E (Figure 1). It has a population of 1.8 million inhabitants (MINEPAT, 2010). Douala falls within the Douala-Edea mangrove ecosystem and could be receiving enhanced levels of nutrient-loading via release of sewage from the metropolitan city and runoff from agricultural establishments. The annual rainfall in 2010 was 3547 mm with the highest rainfall (787 mm) in August and the lowest rainfall (178 mm) in February, the month of sampling (MHD, 2010). The wet season in the study area lasts for approximately eight months (from April to November), while the dry season is comparatively shorter, typically occurring between December and March. In 2010, September had the least monthly temperature (24.7°C), while the highest temperature (29.0°C) was recorded in February (MHD, 2010).

Geology and soils

The zone is located within the Douala sub-basin of the Douala Basin, a sedimentary basin of Cretaceous to Tertiary age having a total surface area of 7000 km^2 and of maximum width of 60 km^2 (Dumort, 1968; Regnoult, 1986). The stratigraphy of the basin consists of the Cretaceous Mungo River Formation, overlain by the Tertiary Mpundu Formation (Ntamak-Nida et al., 2010). The Mungo River Formation consists mainly of sandstone with a few intercalations of limestone and shale while the Mpundu Formation consists of poorly consolidated grits and sandstones that occasionally display bedding. The Douala metropolis lies on the Wouri member of the Mpundu Formation, which is dominantly made up of gravely sandstone with clay matrix. The soils of this area are alluvial resulting from the decomposition of sedimentary rocks. The majority of the soils are therefore highly permeable to industrial and agricultural discharges.

Drainage

The Wouri and the Dibamba Rivers constitute the drainage system in the entire Douala metropolis and flow all year round. The Wouri flows within the Akwa, Bonaberi and part of the Bassa while the

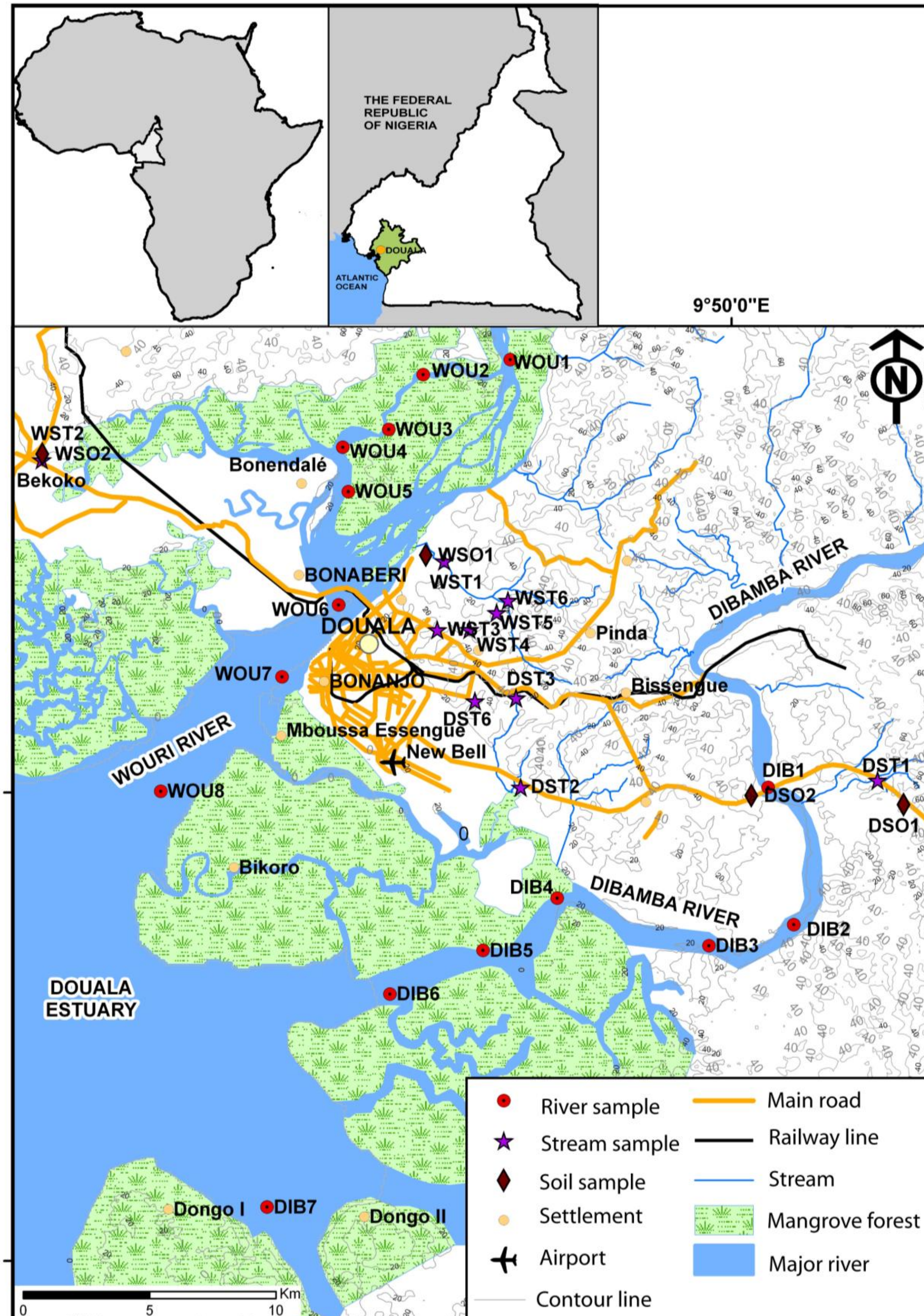

Figure 1. Map of Douala metropolis showing sampling sites (Tening et al., 2011)

Table 1. Physicochemical properties of water samples from Wouri River.

Site	Site no.	Coordinates	pH	EC (µS/cm)	Org.C (%)	NH_4^+ mg/l	NO_3^- mg/l
Upstream							
Quartier Eloka	WOU1	04 09 14.2N 009 4516.3E	7.6	43	0.09	23.8	23.8
Beange	WOU2	04 08 54.8N 009 43 24.9E	7.3	244	0.06	29.4	15.4
Beange1	WOU3	04 07 44.7N 009 42 40.7E	7.2	801	0.08	22.4	23.8
Todo Njebale	WOU4	04 07 21.9N 009 41 41.9E	7.2	1127	0.07	18.2	30.8
Ekongolo	WOU5	04 06 25.1N 009 41 49.0E	7.3	1710	2.74	35.0	30.8
Downstream							
Wouri Bridge	WOU6	04 03 59.9N 009 41 36.3E	7.3	6960	0.11	39.2	22.4
Wouri Wharf	WOU7	04 02 27.8N 009 40 23.9E	7.4	9600	0.11	21.0	29.4
Steamer Road	WOU8	04 00 01.5N 009 37 48.4E	7.5	15000	0.14	33.6	25.2

Dibamba flows in the eastern outskirt of the town. These rivers are fed by many intermittent streams that are normally loaded with most of the solid and liquid wastes channelled from industries, household and waste dumps. Human activities within the river catchments range from subsistence farming and rural settlements to larger cities hosting a variety of industries (e.g. fertilizer, palm oil mill, cement, ceramics, gas, salt, metal work, soap, textiles, metallurgy, chemicals, brewery, glass, boat and ship repairs).

Water sampling

Sampling was carried out within the Bassa and Bonaberi Industrial zones and along the Wouri and Dibamba Rivers in February 2010. This period is within the dry season. Sampling sites were established using a Garmin etrex Global Positioning System (GPS). Sampling sites in rivers were either areas of stream inflow, high coastal activities or near villages. Sample collection in the riverswas accomplished using an engine boat. Sampling sites in streams included areas of potential influence by industrial or agricultural activities.

Using 0.5 L-plastic bottles, surface water samples were collected from Rivers Wouri, Dibamba, and some streams feeding these rivers. Before the samples were collected, the bottles were rinsed several times with the sample to be collected. At each site, the bottle was immersed in water until it was full. It was then corked and transferred into a cooler containing ice blocks. A total of 28 water samples were collected (8 from Wouri River, 7 from Dibamba River, 7 from streams feeding Wouri River and 6 from streams feeding Dibamba River). All samples were collected during the daytime. They were analysed in triplicates and their mean values were calculated.

The pH and electrical conductivity (EC) were measured *in situ* using a Tracer PockeTester^{TM} field conductivity meter. Before chemical analysis was carried out, the samples were filtered using Whatman 40 filter papers. Organic carbon (Org. C) was determined by the Walkley and Black method using dichromate for oxidation (Pauwels et al., 1992). The NO_3^- and NH_4^+ levels were determined by distillation using the Kjeldhal set as largely described by Pauwels et al. (1992). The NH_4^+/NO_3^- ratios of water samples from both rivers were determined by taking their molar ratios.

Soil sampling

Four top soil (0 to 15 cm) samples (one each from either side of Wouri and Dibamba Rivers) were collected with particular avoidance of points of disturbance (Figure 1). They were air dried and passed through a 2-mm sieve. The samples were analysed for CEC by distillation using Kjeldhal set. Particle size analysis was carried out by the hydrometer method as largely described by Pauwels et al. (1992).

Statistical analysis

Experimental data were analysed with the statistical package SPSS11.0 and EXCEL 2007 for Windows. Univariate statistics was used to compare the water quality with WHO (2008) standards.

RESULTS AND DISCUSSION

Results indicated that average pH values were 7.4 in Wouri River and 7.5 in Dibamba River (Tables 1 and 2). These values indicate that the rivers were neutral with values within the permissible range advocated by the World Health Organisation (WHO, 2008). The pH decreased and then increased from upstream to downstream in both rivers. Electrical conductivities of Wouri River were generally lower than those of the Dibamba River, indicating more ions in the latter. The presence of organic carbon in these water bodies reflects the presence of the soluble form of organic materials in them. The dissolved organic carbon (DOC) could be coming from vegetation and soils within the catchment areas. The high value of organic carbon in WOU5 (Table 1) could be associated with the activities around the fishing port in

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

Site	Site no.	Coordinates	pH	EC (µS/cm)	Organic C (%)	NH_4^+ (mg/l)	NO_3^- (mg/l)
Upstream							
Dibamba Bridge	DIB1	04 00 6.5N 009 50 46.9E	7.8	2210	0.10	497.0	63.0
Via Peti Dibamba	DIB2	03 57 10.4N 009 51 19.6E	7.2	6250	0.11	74.2	56.0
Peti Dibamba	DIB3	03 56 43.7N 009 46 30.6E	7.3	9810	0.13	86.8	58.8
Downstream							
Campo	DIB4	03 57 44.7N 009 46 16.6E	7.4	14300	0.15	78.4	60.2
Missipi	DIB5	03 56 37.6N 009 44 41.8E	7.4	16500	0.15	78.4	341.6
Dongo	DIB6	03 55 41.8N 009 42 23.6E	7.5	18500	0.15	63.0	60.2
Matanda Masadi	DIB7	03 51 09.0N 009 40 04.8E	7.6	19900	0.15	632.8	42.0

that area. Organic carbon increased from upstream to downstream in both rivers (Tables 1 and 2) indicating anthropogenic sources. The org C. levels were generally higher in Wouri River than in Dibamba River. This could be an indication that the dissolved form of org C in Dibamba River is less than that in Wouri River.

Nitrate concentration ranged from 15.4 mg/l in WOU2 (Table 1) to 30.8 mg/l in WOU4 and WOU5 (Table 1) in Wouri River. All the sites had NO_3^- values that were below the 45 mg/l advocated by WHO (2008). In Dibamba River, the NO_3^- ranged from 42.0 mg/l in DIB7 to 341.6 mg/l in DIB5 (Table 2). The majority of the sites in Dibamba River had NO_3^- values that were above the 45 mg/l advocated by WHO (2008). Acute infant metamoglobinaemia (blue babies) may be developed by children under six months when water with above 50 mg/l NO_3^- is mixed in their milk (Manson, 1994). Concentrations greater than 100 mg/l in water may also result in the formation of nitroamins in the stomach. Nitroamines have caused gastrointestinal cancer in animal experiments but epidemiological studies have, as yet failed to find a link between exposure to NO_3^- and cancer in humans (Manson, 1994). Algal blooms resulting from high NO_3^- concentrations in water have led to the most ominous symptoms of water quality degradation including bottom water anoxia and hypoxia, odour, taste and toxicity problems, destruction of the aesthetic and recreational values of water and structural shift in communities in some locations (Oben and Oben, 2006). Ammonium ion levels in all rivers were astronomical when compared with the WHO (2008) 0.5 mg/l maximum (Tables 1 and 2). These values were lower in Wouri River than Dibamba River ranging from 18.2 to 39.2 mg/l and 63.0 to 632.8 mg/l, respectively. The high concentrations of NH_4^+ ions could be associated to decaying of plant from agricultural activities and refuse dumps. High concentration of NH_4^+ ions concentration could result to gastrointestinal complications (Ojosipe, 2007). The very high levels of NH_4^+ in DIB1 and DIB7 (Table 2) could be due to the fishing activity from the neighbouring villages that brings in a lot of nitrogenous organic materials. The mineralisation of the latter will increase the NH_4^+ level.

The variation in NO_3^- and NH_4^+ in both rivers is also reflected in the streams that feed them (Tables 3 and 4). This could be an indication that human activities around these areas could be affecting the NO_3^- and NH_4^+ levels in these rivers. The differences in NO_3^- and NH_4^+ levels in water bodies could be attributed to the fact that around Dibamba River, agricultural activities outweigh industrial activities (Zhao et al., 2009). Fluctuations in the concentrations of NO_3^- and NH_4^+ could be allied to heterogeneity in human activities in the area. Sample WTS4 (Table 3) receiving effluents from the Guinness Brewery Company had a pH value of 11.2 with an EC value higher than other properties. Similarly, sample DST6 (Table 4) receiving effluents from the Cameroon Chemical Company (CCC) had a pH value of 11.8. The EC of DST6 (Table 4) had a value of 5540 µS/cm, a value higher than the 1000 µS/cm maximum allowable (WHO, 2008). Sample DST1 (Table 4) had the least EC of 9 µS/cm and the highest NH_4^+ ion concentration of 660.8 mg/l as compared to other streams in the area.

This could be attributed to decay of luxuriant natural vegetation in the area. In all of the streams, NH_4^+ concentrations were higher than the 0.5 mg/l maximum stipulated by WHO (2008). The mean NO_3^- concentrations

Table 3. Physicochemical properties of some streams feeding Wouri River.

Site	Site no.	Coordinate	pH	EC (µS/cm)	Organic C (%)	NH_4^+ (mg/l)	NO_3^- (mg/l)
Akwa North	WST1	04 04 56.5N 009 43 51.8E	7.5	404	0.08	44.8	33.6
Bekoko Junction	WST2	04 07 06.1N 009 35 16.1E	7.5	10	0.07	30.8	19.6
CamTel	WST3	04 03 28.7N 009 43 43.0E	7.0	361	0.07	32.2	37.8
Univ. Douala	WTS4	04 03 28.9N 009 44 24.1E	11.2	1800	0.07	44.8	46.2
Ndog Bong	WST5	04 03 50.6N 009 44 58.9E	6.7	170	0.07	44.8	53.2
Kondi	WST6	04 04 06.3N 009 45 13.5E	7.3	283	0.08	67.2	50.4

Table 4. Physicochemical properties of some streams feeding Dibamba River.

Site	Site no.	Coordinates	pH	EC (µS/cm)	Org. C (%)	NH_4^+ (mg/l)	NO_3^- (mg/l)
Stream Missole	DST1	04 00 16.0N 009 53 07.2E	7.6	9	0.09	660.8	25.2
Stream Village	DST2	04 00 07.1N 009 45 29.6E	7.6	246	0.09	120.4	43.4
Stream Nkongi	DST3	04 02 01.2N 009 45 23.7E	5.9	69	0.08	54.6	204.4
Spring/Stream CCC	DST4	04 02 02.2N 009 44 32.3E	6.7	223	0.09	47.6	37.8
Stream CCC	DST5	04 02 02.2N 009 44 32.2E	6.8	187	0.09	46.2	103.6
Stream/Effluent CCC	DST6	04 01 57.3N 009 44 31.0E	11.8	5540	0.22	81.2	98.0

of the streams feeding both rivers were generally higher than the recommended standards by WHO (2008). These NO_3^- ion concentrations might have been a consequence of agricultural activities (excess application of inorganic nitrogenous fertilizers), waste water disposal, oxidation of nitrogenous waste products in human and animal excreta, septic tanks, and deposition from industrial establishments. The concen-trations of NO_3^- of streams feeding Wouri River proxy to the Bassa Industrial Zone were higher than NH_4^+ concentration, a reflection of industrial source of pollution. This could be an indication that industries along the Wouri area have a great influence on NO_3^- pollution. In Dibamba streams, while NH_4^+ concentration sharply reduces indicating transitions from agricultural to industrial activities, the concentration of NO_3^- rises steadily.

The soil samples (WSO1 and WSO2) within the Wouri area are low in clay (Table 5). This is not uncommon as the soils of this area are alluvial, resulting from the weathering of sedimentary rocks. They range from Sandy loam to Loamy sand. These soils are therefore highly permeable to industrial and agricultural discharges. On the other hand, the soil samples (DSO1and DSO2) within the Dibamba area range from silt loam to clay (Table 5). Soils of this area are mostly basement complex. The high clay values of these soils may be as a result of variation in the stratigraphy within the Douala basin (Ntamak-Nida et al., 2010). With relatively high clay content, these soils are expected to have a high retention capacity and hence low levels of NH_4^+ and NO_3^- in the water bodies from this area. The reverse is true as the concentrations of these ions were higher in the Dibamba River than in the Wouri River (Tables 1 and 2). There is therefore need for profile and mineralogical analyses of soils, and monitoring the disposal of industrial and agricultural wastes within the Douala metropolis.

In Dibamba River, NO_3^- showed an insignificant ($P > 0.05$) negative correlation ($r = -0.286$) with NH_4^+ ion concentration (Table 6). This could be an indication that most NO_3^- from this area are from organic origin. The negative correlation could be explained from the fact that NO_3^- ions are obtained from NH_4^+ oxidation through nitri-

Table 5. Some physical and chemical properties of soils in the Wouri and Dibamba area.

Site	Site no.	Coordinate	CEC (cmol/kg)	Sand (%)	Silt (%)	Clay (%)	Textural class
Wouri River							
Akwa North	WSO1	04 05 02.7N 009 43 29.8E	13.2	64.4	30.8	4.8	Sandy loam
Bekoko Junction	WSO2	04 07 11.8N 009 35 17.6E	7.98	78.2	17.8	4.0	Loamy sand
Dibamba River							
Missole	DSO1	03 59 46.4N 009 53 41.5E	11.7	20.2	72.0	7.8	Silt loam
Dibamba	DSO2	03 59 54.8N 009 50 25.4E	11.3	37.2	13.8	49.0	Clay

Table 6. Correlation coefficients (r) between some water parameters in Rivers Wouri and Dibamba.

	pH	EC	Org C	NH_4^+
Wouri River				
EC	0.367	-		
Org C	-0.128	-0.175	-	
NH_4^+	0.103	0.334	0.395	-
NO_3^-	0.082	0.166	0.444	-0.278
Dibamba River				
EC	-0.065	-		
Org C	-0.145	0.959**	-	
NH_4^+	0.769*	-0.300	-0.187	-
NO_3^-	-0.128	0.232	0.298	-0.286

**Significant at the 0.01 level; *significant at the 0.05 level.

Table 7. Correlation coefficients (r) between NO_3^- and NH_4^+ in streams and some soil parameters within the Wouri and Dibamba areas.

	NO_3^-	NH_4^+	Sand	Silt	Clay
NH_4^+	-0.225	-			
Sand	-0.331	-0.836	-		
Silt	-0.357	0.933	-0.659	-	
Clay	0.833	-0.135	-0.396	-0.430	-
CEC	0.583	0.235	-0.452	0.356	0.109

fication. On the other hand, there was an insignificant (P > 0.05) positive relationship (r = 0.298) between organic carbon and NO_3^-. This could be allied to the fact that as plant materials along the river course increase, NO_3^- concentration also increases. In Wouri River, just like in Dibamba River, NO_3^- had an insignificant (P > 0.05) negative correlation (r = -0.278) with NH_4^+ ions. However, there was a stronger insignificant (P > 0.05) positive relationship (r = 0.444) between organic carbon and NO_3^- than was witnessed in Dibamba. This could be due to an additional source of NO_3^- possibly from refuse dump as the greater part of this area is residential.

Clays around the Dibamba and Wouri areas showed a negative and positive non-significant relationship with NH_4^+ and NO_3^-, respectively (Table 7). The positive relationship between the clays and NO_3^- could be an indication that the soil colloids in the Douala metropolis are generally negatively charged. The non-significant relationships could be attributed to the fact that the amount of NO_3^- and NH_4^+ from anthropogenic activities outweighs that from the natural sources.

Sources of properties

A high NH_4^+/NO_3^- molar ratio (51.9) was obtained from sample DIB7 (Table 8), a point located furthest into the sea, which could be ascribed to the fact that the area is dominated by natural vegetation without forgetting its distant location from industrial areas. This implies that NH_4^+ deposition from agriculture and excrements is the larger portion as compared with NO_3^- from fossil fuel combustion from industry and transportation. These results are similar to the 4.1 molar ratio obtained by Zhang et al. (2006) in the Guangzihong plain of North West China dominated by agriculture. The least molar ratio of 0.79 from sample DIB5 (Table 8) could be attributed to its nearness to the urban centre while additional amount of NO_3^- might have been transported by the stream of this area of sampling. Transportation of nitrates by streams had been reported by Doering (1996). Results of NH_4^+/NO_3^- molar ratio of Wouri River at WOU2 (Table 9), stood at 6.57 which could not be unconnected to the fact that this area is located at the suburbs entirely covered with mangroves. A value of 2.47 at WOU7 (Table 9) with high concentration of port and industrial activities with associated companies like CIMENCAM,

Table 8. Ammonium/nitrate molar ratio of water sampled from Dibamba River.

Site	Site no.	Coordinate	NH_4^+ (mmol/l)	NO_3^- (mmol/l)	NH_4^+/ NO_3^-
Upstream					
Dibamba Bridge	DIB1	04 00 6.5N 009 50 46.9E	27.6	1.02	27.1
Via Peti Dibamba	DIB2	03 57 10.4N 009 5119.6E	4.12	0.903	4.56
Peti Dibamba	DIB3	03 56 43.7N 009 46 30.6E	4.82	0.948	5.08
Downstream					
Campo	DIB4	03 57 44.7N 009 46 16.6E	4.36	0.971	4.49
Missipi	DIB5	03 56 37.6N 009 44 41.8E	4.36	0.5.51	0.79
Dongo	DIB6	03 55 41.8N 009 42 23.6E	3.50	0.971	3.60
Matanda Masadi	DIB7	03 51 09.0N 009 40 04.8E	35.2	0.678	51.9

Table 9. Ammonium/nitrate molar ratio of water sampled from Wouri River.

Site	Site no.	Coordinate	NH_4^+ (mmol/l)	NO_3^- (mmol/l)	NH_4^+/NO_3^-
Upstream					
Quartier Eloka	WOU1	04 09 14.2N 009 45 16.3E	1.32	0.384	3.44
Beange	WOU2	04 08 54.8N 009 43 24.9E	1.63	0.248	6.57
Beange 1	WOU3	04 07 44.7N 009 42 40.7E	1.24	0.384	3.23
Todo Njebale	WOU4	04 07 21.9N 009 41 41.9E	1.01	0.497	2.03
Ekongolo	WOU5	04 06 25.1N 009 41 49.0E	1.94	0.497	3.90
Downstream					
Wouri Bridge	WOU6	04 03 59.9N 009 41 36.3E	2.17	0.361	6.01
Wouri Wharf	WOU7	04 02 27.8N 009 40 23.9E	1.17	0.474	2.47
Steamer Road	WOU8	04 00 01.5N 009 37 48.4E	1.87	0.406	4.60

POD is an indication of relative larger effect of NO_X emissions from industries and transportation. The results are similar to the molar ratio of 0.94 obtained at Nanjing site in North China located near the city centre (Zhang et al., 2006).

The NH_4^+/NO_3^- molar ratio reflects relative contribution of industries and agriculture to pollution (Fahey et al., 1999; Liu et al., 2006; Anderson and Downing, 2006; Larson et al., 2006). The ratio is lower in areas with advanced industrialization than in those dominated by agriculture and natural vegetation (Fahey et al., 1999). Contributors of the degradation of the Wouri and Dibamba rivers include domestic, industrial and agricultural wastes that are deposited directly or indirectly into streams at various locations without treatments due to poor implementation and enforcement of environ-mental laws. With continuous increase in urbanization, there is the need for continuous check of water quality so as to foretell the outbreak of diseases. Environmental education programmes, seminars and workshops should be held for awareness creation by various stakeholders in water management.

Conclusions

The quality of the Wouri and Dibamba Rivers from upstream to downstream shows evidence of NO_3^- and NH_4^+ pollution arising from industrial and agricultural activities within the estuarine areas. Soils of the Douala metropolis which were low or high in clay did not reflect their corresponding retention capacity of NH_4^+ and NO_3^-. Hence, there is need for profile and mineralogical analyses of these soils. While managers of industries and agricultural establishments take responsible actions in managing their waste facilities, residents along the rivers should embrace the culture of using the appropriate means of waste disposal rather than discharging their waste into streams channelling into these rivers.

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