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Influence of municipal and industrial pollution on the diversity and the structure of benthic macro-invertebrates community of an urban river in Douala, Cameroon

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Abstract

In the harbor city of Douala, urban land use has increased dramatically over years, resulting in high variability in aquatic ecosystems. In this study, we used benthic macro-invertebrates community structure to assess the impact of urban pollution on the aquatic health of an urban stream in Douala township. Samples were done monthly, from April 2011 to May 2012 in three sampling stations located on the watercourse Kondi and named K1, K2, and K3. Benthic macro-invertebrates were collected using a long-handled net (30 cm x 30 cm side, 400 µm mesh-size). Measurements of the environmental variables were done simultaneously. Physico-chemical analysis revealed the very poor health status of the Kondi stream with highly polluted water at station K2, which received the effluent of the Cameroon SABC brewery. A total of 2,258 individuals of benthic macro-invertebrates distributed into 28 families were identified. This macrofauna is dominated in the Kondi stream by pollution resistant taxa such as Chironomidae (21.70%) and Physidae (24.05%). Diversity indices, taxonomic richness, total abundance and relative abundance of insects were high in stations K1 and K3, revealing their slightly high diversity. These two stations receive mainly domestic wastes. Inversely, in station K2 which receives industrial and municipal effluents, benthic fauna is less diversified, with low diversity indices, lost of sensitive taxa, decrease of the abundance of aquatic insects. The results obtained in this study showed that bad management of municipal and industrial effluents contributes to degrade the water quality and to reduce biodiversity of benthic macro-invertebrates.

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Introduction

Among the crises touching the natural resources with which humanity is confronted, the crisis of water is at the center of the survival of human beings (UNESCO, 2003). This crisis arise from the fact that, the usable quantity of freshwater represents just a minim part (0.57%) of the world water reserve (Vikram Reddy, 2005), thus making the available quantities very limited. This crisis is exacerbated in developing countries, because of high anthropogenic pollution; with aquatic media being the final receptacles (Morel, 2007). Indeed, in many developing countries, urbanization is lawless without sanitation infrastructures (Monkiedje *et al.*, 2004). Furthermore, rivers are most often used as receptors of urban and industrial solid wastes and wastewaters. Such disturbance leads to a strong variability on the physical and chemical features of lotic ecosystems by increasing inputs of sediments, nutrients, organic matter, and pollutants (i.e., heavy metals) (Allan, 2004; Othoniel, 2006). This input of nutrients leads to the eutrophication of aquatic media characterized by an excessive proliferation of aquatic plants, a deoxygenation of the medium, and generally, a reduction of the biodiversity, and consequently, the dysfunction of the hydrosystem (Zébazé Togouet, 2008).

Because of the impairment of lotic aquatic ecosystems, the assessment of their ecological integrity become a key measure for the management and the conservation of such aquatic media, since it permit to reveal and highlight the impact of anthropogenic activities on the ecological functioning of these milieu (Amis *et al.*, 2007).

Nowadays, biomonitoring programs are worldwide used and broadly regarded as an important tool for water quality assessment (Barbour *et al.*, 1999). Contrary to the physico-chemical analyses which give only a partial or incomplete image of the water quality, the organisms which carry out the totality or a part of their life cycle in aquatic environment, testify better the conditions of the medium (Barbour *et al.*, 1999; Beyene *et al.*, 2009). Among the organisms used to describe changes in water quality and habitat, freshwater macro-invertebrates are broadly regarded as particularly sensitive indicators of the health of lotic ecosystems (Gresens *et al.*, 2007). Indeed, their high diversity and cosmopolitism, their sedentariness and their variable tolerance to pollution and habitat deterioration, issue them a good bio-indicator identity (Tachet *et al.*, 2010). Benthic macro-invertebrates can be used to assess organic and even metal pollution (Camargo *et al.,* 2004). Particularly, Plecoptera, Trichoptera and Ephemeroptera species are well documented as being good biological indicators in stream ecosystems since they are most sensitive to long-term environmental changes in water and habitat quality. They live in well oxygenated and unpolluted water (Song *et al.*, 2009; Nyamsi Tchatcho *et al.*, 2014). Inversely, other taxa such as Tubificidae, Chironomidae and Syrphidae are well adapted to polluted environment and can resist to worst condition like hypoxia, input of pollutants and increase of water temperature (Camargo *et al.*, 2004; Tachet *et al.*, 2010).

In Cameroon, very few studies are carried out in benthic macro-invertebrates; available data are mainly reported from the streams of the Centre-South forest ecological region, particularly in urban and suburban streams of Yaoundé (Foto Menbohan *et al.*, 2010; Foto Menbohan *et al.*, 2012; Foto Menbohan *et al.*, 2013; Nyamsi Tchatcho *et al.*, 2014). Contrariwise, in the city of Douala which is the most densely populated and industrialized area of Cameroon, data on aquatic invertebrates are scarce and based separately on freshwater shrimps (Tchakonté *et al.*, 2014a), freshwater snails (Tchakonté *et al.*, 2014b) and aquatic insects (Tchakonté *et al.*, 2015). The aim of the present study is therefore to determine the benthic macro-invertebrate's community structure of the Kondi stream, a highly polluted urban stream which receives the effluent of the SABC brewery industry in Douala city. The specific objectives assigned to this study were (1) to determine species richness and abundance of benthic macro-invertebrates taxa in the Kondi stream and describe their structure, (2) to determine the distribution profile of characteristic taxa according to upstream-downstream pollution gradient, and (3) to identify the subset of environmental variables that might structure this benthic macro-invertebrates community.

Materials and methods

Study area and sampling stations

With an approximate surface of 18,700 ha, Douala, economic capital of Cameroon, has a population that is estimated at nearly 2,755,011 inhabitants. This city extends between 04°03' and 04°57' of latitude North and between 09°42' and 09°47' of longitude East, and presents a flat topography with a mean altitude of 13 m.

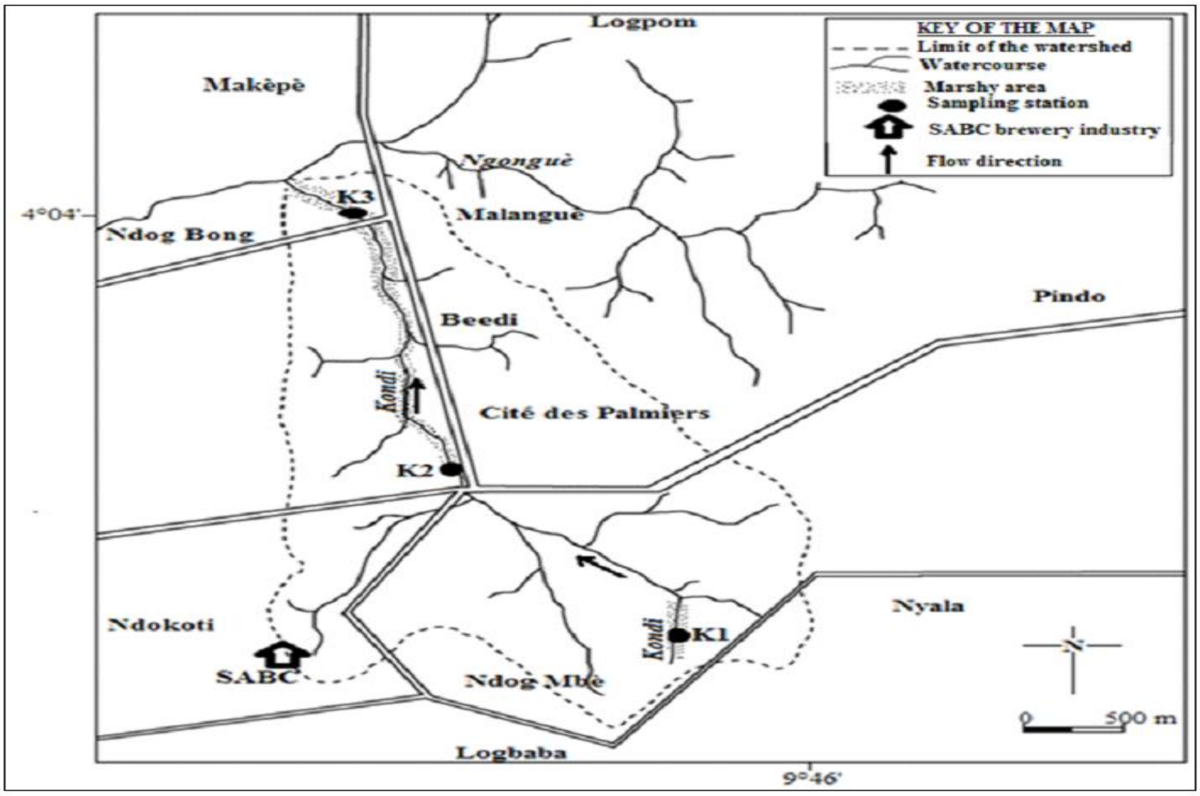

Fig. 1. River basin of the Kondi stream showing sampling stations; drawn from the topographic map of Douala township and its surroundings (INC, 1980, modified).

The climate of this region was classified by Suchel (1972) as equatorial climate of Guinean type, coastal Cameroonian subtype, characterized by a short dry season (December to February) and a long rainy season (March to November). Rainfalls are abundant and regular while the air temperature is relatively high and stable with a monthly average of 28 °C (Suchel, 1972).

The river basin of Kondi stream covers a surface of approximately 10.36 km². This watershed is characterized by the presence of many industries, particularly the SABC (brewery industry). Moreover, the Kondi river basin is densely populated with a high number of anarchical buildings without adequate sanitation system. Three sampling stations identified as K1, K2 and K3 were selected in this stream (Fig. 1). With a geographical location of 04°02'16.9"N and 09°46'20.5"E, and 16 m of altitude, station K1 is located in the upper part of the stream, at approximately 250 m from the spring. Many washing points are found on both sides of this station; the river receives domestic effluents from the waterside habitations. The station K2 is located in the middle part of the stream, at approximately 2.4 km from the spring, with a geographical coordinates of 04°02'46.6"N and 09°45'38.5"E, and 15 m of altitude. This station receives household refuses, municipal effluents from the PK8 market and wastewaters from the SABC brewery industry. The third station (station K3) is located in downstream, in a marshy zone, at nearly 5.3 km from the spring. His geographical coordinates are 04°02'46.6"N and 09°45'38.5"E, with an altitude of 11 m.

Physico-chemical analyses

The measurements of physico-chemical parameters of water at each sampling station were done following APHA (1998) and Rodier *et al.* (2009) standard methods. Measurements were carried out monthly from April 2011 to May 2012, between 08 and 10 a.m. Water temperature, pH, and dissolved oxygen (DO) were measured *in situ* using an alcohol thermometer, a HACH HQ11d pH-meter, and a HACH HQ14d oxymeter, respectively. Likewise, electrical conductivity (EC) was measured *in situ* using a HACH HQ 14d portable conductivity meter.

For the parameters to be measured in the laboratory, water samples were collected backward flow using a 1000 ml polyethylene container. Suspended solids (SS), turbidity, water color, ammonium (NH_4^+), nitrites (NO_2^-), nitrates (NO_3^-), and phosphates (PO_4^{3-}) were measured in the laboratory using HACH DR/2800 spectrophotometer. Oxydability and calcic hardness were measured by volumetric methods.
Four heavy metals including Zinc (Zn), Copper (Cu), Manganese (Mn), and Iron (Fe) were determined by atomic absorption spectrometry using a Buck Scientific flame spectrometer, following APHA (1998) and Rodier *et al.* (2009) standard methods.

Sampling and identification of benthic macro-invertebrates

Benthic macro-invertebrates samples were collected at each sampling station following the protocol described by Stark *et al.* (2001). A long-handled kick net (30 cm x 30 cm side,400 µm mesh-size, 45 cm depth) was used for this purpose. At each sampling station, 20 drags of the kick net were done in different micro-habitat, each corresponding to a surface of 0.15 m^2 (30 cm × 50 cm).

The materials that were collected in the sampling net were rinsed through a 400 µm sieve bucket and all macro-invertebrate individuals were sorted and preserved in plastic sampling bottles with 70% ethanol.

In the laboratory, all aquatic macro-invertebrates in the samples were identified to the family level under a Wild M5 stereomicroscope, with the use of appropriate taxonomic keys (Durand and Levêque, 1981; De Moor *et al.*, 2002; De Moor *et al.*, 2003a, b; Moisan, 2006; De Moor *et al.*, 2007; Tachet *et al.*, 2010).

Data analyses

Eight metrics were calculated to describe the structure of benthic macro-invertebrates community at each sampling station; these are total taxa richness (S), Diptera taxa richness (S.Dip), Ephemeroptera-Trichoptera-Odonata taxa richness (S.ETO), Insect taxa richness (S.Ins), total abundance (TA), relative abundance of Ephemeroptera-Trichoptera-Odonata (%ETO), relative abundance of Insects (%Ins), and ETO density/Chironomidae density ratio (ETO/Chir). The Shannon-Weaver's diversity index and the Piélou's evenness were calculated at each sampling station, so as to highlight the numerical importance and distribution of taxa, and to compare community diversity among stations (Dajoz, 2000).

The influence of organic pollution on the benthic macrofauna was appreciated by the used of Hilsenhoff biotic index which is calculated based on the tolerance quote of each taxa of the community (Hilsenhoff, 1988; Barbour *et al.*, 1999; Bode *et al.*, 2002).

Relationships between physico-chemical and biological variables were determined by Spearman correlation test.

The Kruskal-Wallis H-tests followed by the Mann-Withney U-test were performed to verify significant differences in water quality factors and macro-invertebrate abundances among sampling stations. Principal Component Analysis (PCA) was conducted with physico-chemical data. This PCA permitted to group sampling stations according to their physico-chemical characteristics.

All the statistical analyses were performed using XLSTAT software, version 2007.

Results

Environmental variables

Mean values and standard deviation of environmental variables measured at each sampling station of the stream Kondi are reported in Table 1. Water temperature ranged from 23.5 °C to 32.4 °C, with thermal amplitude of 8.9 °C. High values of SS and turbidity were observed in station K2, while lowest values were recorded in station K1. Values of electrical conductivity ranged from 56 µS/cm (K1) to 978 µS/cm (K2). The pH values varied between 5.42 and 10.18. Ammonium and phosphates concentration fluctuated respectively between 0 and 19.2 mg/L NH_4^+, and between 0 and 5.18 mg/L PO_4^{3-}. Values of nitrites recorded during the study were globally low and most often fell beneath 0.3 mg/L NO_2^-. The percentage of dissolved oxygen saturation ranged from 3 % to 115%. Concerning oxydability, the lowest mean value (3.08 ± 2.17 mg/L) was observed at station K1, whereas the maximum mean value was recorded at station K2 (6.68 ± 3.11 mg/L). In all stations, calcic hardness remained below 30 mg/L $CaCO_3$, except the maximum value of 174 mg/L $CaCO_3$ registered at station K2. Mean values of nitrates recorded were 2.76±3.27, 4.30±5.40 and 2.32±3.43 respectively for stations K1, K2 and K3. Concerning heavy metals, values of Zn and Cu were very low and fall below 0.05 mg/L. Iron (Fe) concentration were slightly high and found above 0.10 mg/L, with the highest value (10.24 mg/L) registered in station K2. The concentrations of manganese varied between 0 and 0.97 mg/L during the study period.

Table 1. Mean values of physical and chemical variables recorded at each sampling station during the study period.

Physical and Chemical variables	Sampling stations		
	K1	K2	K3
Temperature (°C)	27.04 ± 1.64	27.02 ± 2.10	26.59 ± 2.34
SS (mg/L)	10.5 ± 6.38	37.07 ± 19.45	15.43 ± 13.29
Turbidity (NTU)	13.75 ± 14.54	26.57 ± 23.51	25.29 ± 21.2
pH (UC)	6.52 ± 0.65	7.25 ± 0.92	7.17 ± 1.0
EC (µS/cm)	172.5 ± 126.4	321.7 ± 218.5	326 ± 223.1
NH_4^+ (mg/L)	1.29 ± 2.33	2.89 ± 2.2	3.57 ± 4.8
PO_4^{3-} (mg/L)	0.8 ± 1.31	2.42 ± 1.64	1.1 ± 1.36
NO_2^- (mg/L)	0.18 ± 0.17	0.08 ± 0.1	0.05 ± 0.08
NO_3^- (mg/L)	2.76 ± 3.27	4.30 ± 5.40	2.32 ± 3.43
DO (%)	69.36 ± 28.79	32.61 ± 34.99	38.17 ± 35.36
Oxydability (mg/L)	3.08 ± 2.17	6.68 ± 3.11	4.65 ± 2.45
Calcic hardness (mg/L $CaCO_3$)	7.71 ± 4.43	23.42 ± 43.63	10.86 ± 5.64
Zn (mg/L)	0.01 ± 0.0189	0.01 ± 0.0189	0.02 ± 0.02
Cu (mg/L)	0.01 ± 0.008	0.015 ± 0.01	0.015 ± 0.01
Mn (mg/L)	0.24 ± 0.37	0.14 ± 0.13	0.28 ± 0.46
Fe (mg/L)	0.01 ± 0.006	1.78 ± 2.26	0.76 ± 1.31

Overall, the highest values of the majority of physico-chemical parameters measured were recorded in station K2 which received the effluent of the SABC brewery industry. Moreover, the Kruskal-Wallis test revealed that values of SS, pH, electrical conductivity, ammonium, phosphates, dissolved oxygen and oxydability differed significantly ($P < 0.05$) between stations K1 and K2.

Table 2. Abundance of different benthic macro-invertebrate families identified in each sampling station of Kondi stream.

Phyla / Families	Sampling stations			Total abundance (relative abundance)
	K1	K2	K3	
ANNELIDA	30	18	19	67 (2.97%)
Glossiphoniidae	-	-	4	4 (0.18%)
Hirudidae	-	-	1	1 (0.04%)
Haplotaxidae	-	8	1	9 (0.40%)
Tubificidae	6	1	4	11 (0.49%)
Lumbricidae	-	-	4	4 (0.18%)
Lumbriculidae	24	9	5	38 (1.68%)
MOLLUSCA	234	321	332	887 (39.28%)
Lymnaeidae	40	18	113	171 (7.57%)
Physidae	107	302	134	543 (24.05%)
Planorbidae	86	1	79	166 (7.35%)
Melaniidae	1	-	6	7 (0.31%)
ARTHROPODA	681	113	510	1,304 (57.75%)
Dytiscidae	3	35	53	91 (4.03%)
Hydrophilidae	3	7	20	30 (1.33%)
Chironomidae	372	25	93	490 (21.70%)
Dixidae	2	-	-	2 (0.09%)
Psychodidae	1	10	-	11 (0.49%)
Scatophagidae	1	-	-	1 (0.04%)
Syrphidae	-	9	-	9 (0.40%)
Ameletidae	16	-	4	20 (0.89%)
Gerridae	1	3	-	4 (0.18%)
Nepidae	6	4	1	11 (0.49%)
Naucoridae	43	14	175	232 (10.27%)
Notonectidae	1	-	72	73 (3.23%)
Pleidae	-	-	5	5 (0.22%)
Veliidae	-	-	3	3 (0.13%)
Cordulegasteridae	22	-	5	27 (1.20%)
Coenagrionidae	208	6	78	292 (12.93%)
Libellulidae	2	-	-	2 (0.09%)
Atyidae	-	-	1	1 (0.04%)

The PCA performed with the dataset of the 17 physico-chemical parameters measured at the three sampling stations during the 14 months of the study, revealed that the first two axes (F1=23.92%; F2=16.08%) explained 40% of the total cumulative percentage variance expressed (Fig. 2). Suspended Solids, color, turbidity, pH, electrical conductivity, phosphates, and oxydability are highly and positively correlated to the first axis (F1). This axis characterizes turbid and colored waters, with high organic matter and ions contents; thus highlighting organic pollution. Temperature, Zn, Mn and Fe are positively correlated with the second axis (F2). This axis characterizes metal pollution (Fig. 2A).

The projection of the 42 samples collected during the study period on the F1xF2 factor axes, permitted to discriminate two groups, A and B (Fig. 2B). Group B is made up mainly of the samples collected at station K2 which received the effluent of the SABC brewery industry. This group is characterized by turbid and colored waters, with low dissolved oxygen concentration, high organic matter and ions contents. Group A is composed of samples from stations K1 and K3, mainly characterized by relatively high value of dissolved oxygen.

Benthic macro-invertebrates community structure and diversity

During the study period, benthic macro-invertebrates identified belong to 3 phyla and 28 families (Table 2). Arthropoda is the most diversified phylum with 18 families, representing 64.29% of the total number of families. They are followed by the phylum Annelida with 6 families (21.43%), and Mollusca which count 4 families (14.28%). Concerning abundances, a total of 2,258 individuals of benthic macro-invertebrates were collected. Arthropoda is the most abundant phylum with 1,304 individuals (57.75%), followed by Mollusca with 887 individuals (39.28%) and Annelida with 67 individuals (2.97%) (Table 2). The orders of Basommatophora and Diptera are the most abundant with respectively 38.97% and 22.72% of total individuals. They are followed by Hemiptera (14.53%) and Odonata (14.22%).

Table 3. Values of the metrics that describe the structure of the benthic macro-invertebrates communities.

Metrics	Sampling Stations		
	K1	K2	K3
TA	945	452	861
S	20	15	22
%Ins	72.06	25	59.12
%ETO	26.24	1.33	10.10
S. ETO	4	1	3
S. Dip	4	3	1
S. Ins	14	9	11
ETO/Chir	0.62	0.24	0.89
H'	2.67	2.02	3.32
E	0.62	0.52	0.74
HBI	7.44	7.52	6.38

Spatial distribution of benthic macro-invertebrates fauna showed the preeminence of the family Physidae in station K2, with 66.81% of relative abundance. In station K1, macrofauna is dominated by the families Chironomidae (39.37%), Coenagrionidae (22.01%) and Physidae (11.32%). The benthic fauna at station K3 is dominated by the families Naucoridae (20.33%), Physidae (15.56%), Lymnaeide (13.12%), Chironomidae (10.80%), Planorbidae (9.18%) and Coenagrionidae (9.06%) (Fig.3).

Regarding the spatial distribution of benthic macro-invertebrates, the highest numbers of families are recorded in stations K1 and K3, with respectively 20 and 22 families. The station K2 situated downstream of the outlet of the SABC brewery effluent, registered only 15 families. The abundance dynamic of benthic macro-invertebrates show a similar profile to that of taxonomic richness. The highest number of individuals (945; 41.85%) is registered in station K1, while just 452 individuals (20.02%) are recorded in station K2. In station K3, 861 individuals (38.13%) are identified (Table 3). These abundances varied significantly ($P < 0.05$) between stations K2 and K3, and stations K1 and K2.

Shannon-Weaver diversity index was high in stations K3 (3.32 bits/ind.) and K1 (2.67 bits/ind.), while the lowest value was found in station K2 (2.02 bits/ind.). Likewise, the Pielou evenness index was high in stations K3 (0.74) and K1 (0.62) and showed a good distribution of macro-invertebrates individuals. Inversely, in station K2, this index was very low (0.52), highlighting the dominance of a few number of taxa. Furthermore, other benthic macro-invertebrates metrics revealed the degradation of water quality and the decrease of diversity in station K2. The taxonomic richness (S.Ins), relative abundance of Insects (%Ins), the relative abundance of Ephemeroptera-Trichoptera-Odonata (%ETO), the ETO density/Chironomidae density ratio and the ETO taxonomic richness (S.ETO) were very low in station K2 (Table 3).

Relationships between environmental variables and benthic macro-invertebrates

The values of Hilsenhoff biotic index (HBI) are respectively 7.44, 7.52 and 6.38 for stations K1, K2 and K3. This result revealed that the water quality ranged from rather poor (station K3) to very poor (stationK1 and K2), indicating a very high organic pollution of the Kondi stream.

Table 4. Values of Spearman correlation coefficients between physico-chemical parameters and benthic macro-invertebrates metrics.

Variables	Macroinvertebrates metrics							
	Lym	Chir	Psy	Syr	Cord	Dyt	ETO/Chir	S.ETO
SS	-0.004	-0.368*	0.181	0.383*	-0.269	0.165	-0.370*	-0.465*
Turbidity	0.463*	-0.048	0.021	0.064	-0.510*	-0.037	-0.149	-0.385*
Color	0.159	-0.360*	0.077	0.168	-0.432*	0.290	-0.327*	-0.578*
Temperature	-0.337*	-0.115	0.233	-0.122	0.295	0.037	0.028	0.088
EC	0.134	-0.392*	-0.001	0.174	-0.246	0.029	-0.142	-0.287
NH_4^+	-0.114	-0.194	0.004	0.008	-0.364*	0.205	-0.137	-0.255
NO_2^-	-0.307*	0.108	-0.125	-0.206	0.419*	-0.346*	0.005	0.292
PO_4^{3-}	-0.078	-0.243	0.323*	0.133	-0.199	0.422*	-0.128	-0.331*
DO	0.014	0.372*	-0.117	-0.166	0.144	-0.138	0.226	0.351*
Calcic hardness	-0.082	-0.242	-0.027	0.172	-0.082	-0.051	-0.420*	-0.234
Oxydability	-0.003	-0.286	-0.093	0.134	-0.232	0.165	-0.374*	-0.314*
Zn	0.022	0.168	0.346*	0.054	0.121	0.247	0.339*	0.105
Mn	-0.058	0.076	0.337*	0.031	0.145	0.048	0.241	0.015
Fe	0.063	0.073	0.068	0.359*	-0.121	0.128	0.048	-0.138

Only values bearing stars are significant correlations; correlation is significant at the level $P < 0.05$. Lym: Lymnaeidae; Chir: Chironomidae; Psy: Psychodidae; Syr: Syrphidae; Cord: Cordulegasteridae; Dyt: Dytiscidae; (S.ETO): Ephemeroptera-Trichoptera-Odonata taxa richness; (ETO/Chir): Ephemeroptera-Trichoptera-Odonata density/Chironomidae density ratio.

The Spearman's correlation analysis permitted to put in evidence, certain relationships between water quality and aquatic invertebrates community structure metrics (Table 4). The Lymnaeidae abundance was positively and significantly correlated with turbidity. Also, abundance of the family Psychodidae appeared to have significantly positive associations with orthophosphates, Zn and Mn. The family Dytiscidae was positively correlated to orthophosphates; and negatively related to nitrates. Positive and significant associations were found between Syrphidae and SS, and Fe. Concerning benthic macroinvertebrates metrics, the ETO/Chir ratio was negatively and significantly correlated with turbidity, water color, oxydability, and calcic hardness. As far as, taxonomic richness of ETO showed negative correlations with parameters indicating organic pollution such as turbidity, orthophosphates and oxydability; and significantly positive association with dissolved oxygen.

Discussion

The very good oxygenation of the Kondi's water at the level of station K1 is surely due to his location in a marshy zone crammed by macrophytes. The high photosynthetic activity in marshy area may lead to the enrichment of the aquatic media in oxygen (Devidal *et al.,* 2007). Furthermore, the presence of rapid flow rate and curved flow of water in the upper part of the stream lead to disturbance and recirculation of water, favoring its reoxygenation at the water/air interface. The important decrease of oxygen content at the level of station K2 could be attributed to the activities of microorganisms involved in the mineralization process of the important quantity of organic matter unloaded in the Kondi stream; knowing that this process consume oxygen. Indeed, in addition to domestic wastewaters and solid wastes which are the primary pollution sources, rough effluent of the SABC brewery and municipal wastes from PK8 market enriched in organic matters are discharged upstream of station K2. Physico-chemical analyses which showed high values of oxydability, ammonium, orthophosphates and electrical conductivity testified this anthropogenic organic pollution. Kengni *et al.* (2012) showed that streams water qualities of Mgoua watershed in Douala city are substantially impaired due to industrial pollution. The slightly betterment of the water quality at the level of station K3 located at about 1.5 km downstream of a marshy zone could be attributed to the self-purification process of marsh systems (Bravard *et al.*, 2000). The low heavy metal concentrations (Cu, Mn, Fe, and Zn) did not make it possible to detect a metal pollution in the Kondi stream. According to Rodier *et al.* (2009), the contents of Cu, Mn, Fe and Zn registered in the Kondi stream are consistent with unimpaired surface water.

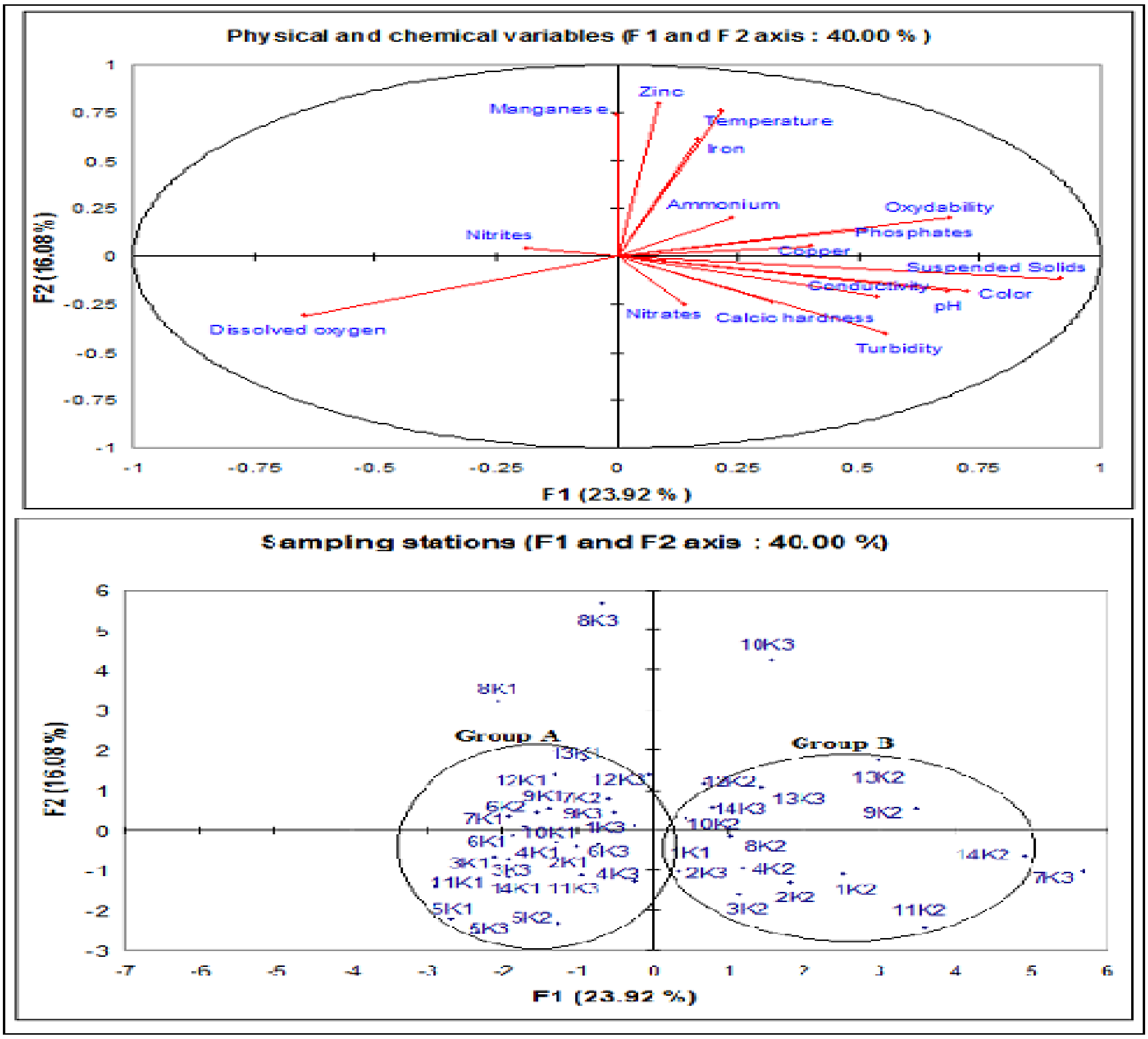

Fig. 2. Principal Component Analysis based on physico-chemical parameters, showing correlation circle (A) and gathering of samples (B); K1, K2 and K3 stand for sampling stations, while the numbers 1, 2, ….,14 represent sampling months (April 2011 to May 2012).

Regarding benthic macro-invertebrates, the low taxonomic richness (28 families) obtained in the Kondi stream compared with those observed in some suburban forested streams of Cameroon (Foto Menbohan *et al.*, 2010; Nyamsi Tchatcho *et al.*, 2014; Tchakonté *et al.*, 2015) revealed the highly polluted state of the Kondi stream. Zhang *et al.* (2013), Colas *et al.* (2014) and Wang *et al.* (2014) showed that taxonomic richness of benthic macro-invertebrates, particularly insect taxa could be used as good descriptors and indicators of anthropogenic disturbances in lotic aquatic systems. Whereas just 17 families of aquatic insects were identified in this study, respectively 55, 37 and 36 families of aquatic insects were announced in a suburban stream in Cameroon by Foto Menbohan *et al.* (2010 and 2013) and Tchakonté *et al.* (2015). The low taxonomic richness of aquatic insect in Kondi stream is a consequence of the profound deterioration of his ecological condition. Almost all sensitive taxa of aquatic insects were absent in Kondi stream. The presence of only one family of sensitive taxa (Ephemeroptera-Ameletidae) highlights that species richness and distribution of benthic macro-invertebrates in Douala watershed are highly and negatively influence by polluted status of its urban streams due to anthropogenic activities which cause the extinction of the sensitive taxa. In a study carried out in United States, Carliste *et al.* (2007) underlined that the group of Ephemeroptera-Trichoptera-Plecoptera is among the most sensitive taxa of invertebrate assemblages to environmental pollution, and therefore, their species richness decreases dramatically with urbanization of river basins.

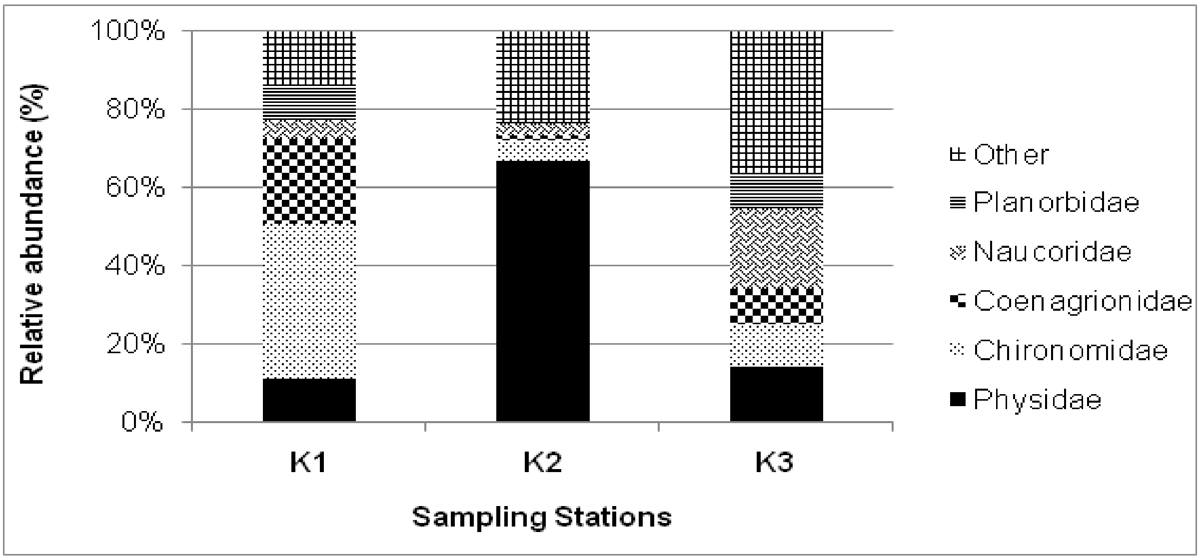

Fig. 3. Variation of the mean relative abundance (%) of the main benthic macro-invertebrates families at each sampling stations of the Kondi stream during the study period.

Contrary to suburban streams where the sensitive groups of Arthropods (Ephemeroptera-Trichoptera-Plecoptera) are dominant (Foto Menbohan *et al.*, 2010; Wang *et al.*, 2012; Nyamsi Tchatcho *et al.*, 2014; Tchakonté *et al.*, 2015), in Kondi stream, Chironomidae (21.70%) and Physidae (24.05%) are the prominent families. The proliferation of these resistant taxa in Kondi stream is concomitant with his enrichment in organic matter. Thereupon, Mouthon (2001) and Armitage *et al.* (1994) revealed the preeminence of the families Physidae and Chironomidae in organic polluted rivers. Indeed, Chironomidae are known as 'blood worms' because they are bright red, due to the presence of hemoglobin in their body fluids that enables them to respire at low oxygen concentrations and live in hypoxic or occasional anoxic bottom mud (Armitage *et al.*, 1994). Similarly, Physidae have a rudimentary lung that allows them to breathe atmospheric air and therefore to live in hypoxic aquatic environments (Mouthon, 2001).

Physico-chemical variables, diversity index and other macro-invertebrates metrics revealed that the Kondi stream is highly polluted, especially at the level of station K2. Indeed, the substantial decrease of benthic macro-invertebrates, taxonomic richness and abundances in station K2 is surely due the rough effluent of the SABC brewery discharged upstream of this station. Fagrouch *et al.* (2011) also showed a decrease in macro-invertebrates diversity in Oued Za River due to urban effluent from Taourirt city. In station K3 located downstream of a marshy zone, the slightly improvement of the water quality would have favored the increase of the diversity and a fairly good distribution of macro-invertebrates individuals. Moreover, the Hilsenhoff biotic index showed a moderate organic pollution of water at station K3, compare to stations K1 and K2 where the organic pollution level is very high. Similar results are obtained with the Shannon-Weaver and Evenness diversity indices where the highest values were recorded in station K3, highlighting a betterment ecological condition in this station. Comparable results were documented by Foto Menbohan *et al.* (2011), where the authors demonstrated that there is an improvement in water qualities and aquatic community diversities downstream of marshy area in Biyémé stream.

Conclusion

In this study, diversity indices and other benthic macro-invertebrates metrics used to describe the community structure permitted to put in evidence the impairment of the ecological integrity of the Kondi stream in urban township of Douala. However, the deterioration of this urban waterway is more pronounced in the middle part of the stream which is subjected to the impact of the Cameroon SABC brewery effluent; there is a significant decrease of the benthic macro-invertebrates biodiversity at this level, characterized by the disappearance of many sensitive taxa. Therefore, there is an urgent need for the evaluation of treatment facilities of municipal and industrial wastewaters and solid wastes so as to assess the status and control water pollution in Douala township.

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