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(Research Article)

Characterization by benthic macroinvertebrates and some environmental factors of streams in the East Cameroon region

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Abstract

Macrobenthic fauna have recently been widely used as bio-indicators for their ability to reflect the various disturbances in aquatic ecosystems. They have recently been used to assess the ecological health of streams in the East Cameroon region. This study aims to reveal the ecological health of four streams by studying the variations in the population of benthic macroinvertebrates collected in them. Sampling was done from December 2018 to December 2019 for a total of 13 months spread over four collection seasons. Kohonen's self-organising map (SOM) was performed for the various distribution patterns of the organisms collected. Discriminant factor analysis (DFA) was used to identify the parameters that characterise these patterns observed in the environment. Four groups of macrobenthic populations were observed. The distribution of benthic macroinvertebrates in these streams was spatial, temporal and discriminated by variable mineralization parameters and sediment grain size. The distribution of taxonomic richness is linked to the environmental conditions of the stations, which appear to be more or less stable, highlighting a stress gradient on the organisms. The station (Sen3), with unstable conditions, is the site of anthropic activities due to its proximity to residential areas, which are enriched in organic matter and, as a result, abound in pollutant-resistant species such as diptera (*Chironomus holomelas*, *Chironomus* sp1 and *Chironomus* sp2). The population of the other well differentiated groups is subject to light anthropogenic disturbance.

Keywords: Environmental factors; Physicochemical; bioécology; Benthic macroinvertebrates; Self-organizing map

1. Introduction

In the aquatic environment, benthic macroinvertebrates are among the groups of organisms most commonly used today as bioindicators (22; 21). Indeed, their sedentary nature, their specific richness and their relatively long life cycle make them the best continuous integrators of environmental conditions (33; 8). The study of their bioecology makes it possible to assess the impact of various environmental stresses and alterations to aquatic and riparian habitats on the dynamics of their populations (40). The lack of information on the variability of this fauna is a handicap in the development and implementation of policies for sustainable development and protection of the quality of aquatic ecosystems (40; 8).

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In Cameroon, a few studies have been conducted on the biodiversity of benthic macroinvertebrates in lotic environments. These include the work of BIRAM A NGON (3) in the streams of the Centre region, TCHAKOUNTE (38) in urban and forest streams of the Littoral region, KENGNE (24) in the West region, ENAH ACHUO (14) in the North West region, NWAHA (29) in the South-West region, NYAMSI (30) in the South, and MADOMGUIA (27) in the Far North. However, in the Eastern region, despite the work of YOGBA (44), the benthic macroinvertebrate community remains poorly known. The present work will improve the knowledge of benthic macroinvertebrates in this region and determine the ecological health status of some streams.

2. Material and methods

2.1. Study environment

This study was carried out in the East Cameroon region, whose capital is Bertoua, in particular in the commune of Abong-Mbang located between 3° 59′ North latitude and 13° 10′ East longitude. This commune covers an area of 11,250 km^2 is bounded to the north by the communes of Doumé and Angossas, to the south by the commune of Messamena, to the east by the commune of Mindourou and to the west by the commune of Atok (10). This area is irrigated by the Nyong River as well as many other streams. The relief of this region is part of the vast South Cameroonian plateau with an average altitude of 650m. It is rugged in places due to isolated hills or hill complexes, variable slopes and some rocks (10). The vegetation formation is low and medium altitude dense evergreen rainforest, consisting of secondary forests, forest fallows and *Chomolaena odorata* fallows (31). The climate is humid tropical, equatorial, with four well-marked and unevenly distributed seasons: a long rainy season (LRS) from March to June, a short rainy season (SRS) from September to October, a long dry season (LDS) from November to February and a minor dry season (SDS) from July to September. The average annual temperature is 23.6°C (10). The average annual rainfall is 1,700 mm. In this area, artisanal fishing and agriculture are practiced by the majority of the population. Other activities such as sand extraction from the streams and logging are also practiced.

Thus, two sub-watersheds were selected, namely the Abong-Doum sub-watershed with 2 streams (Séna and Anzié) and 6 sampling stations (Sen1, Sen2, Sen3, Anz1, Anz2, and Anz3), and the Djenassoume catchment with 2 streams (Chef and Djenassoume streams) and 6 sampling stations (Cdc1, Cdc2, Cdc3, Dje1, Dje2, and Dje3) (Figure 1).

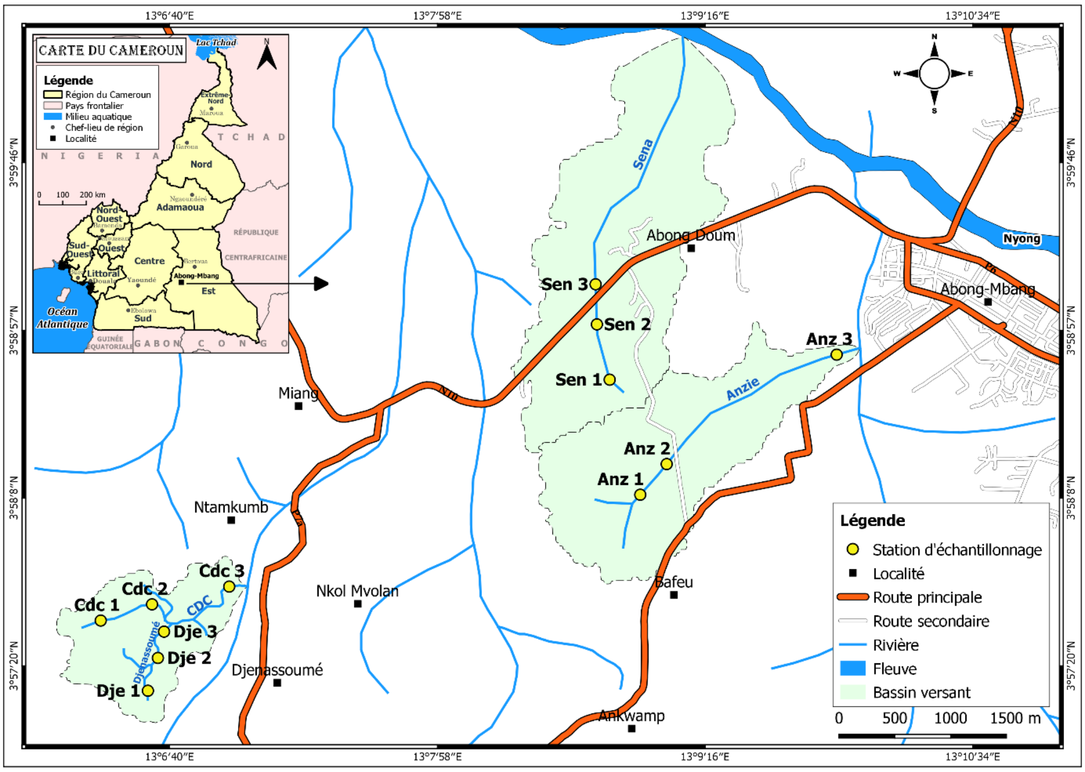


Figure 1 Hydrographic map of the stream catchment area with location of sampling stations (Source: INC, data extracted from topographic base 1/200000; 2020, modified)

2.2. Benthic macroinvertebrate sampling, particle size distribution and physicochemistry

Sampling of benthic macroinvertebrates and physicochemistry was carried out from December 2018 to December 2019. Following a monthly frequency.

The benthic macroinvertebrate collection was done following the multihabitat approach (36), using a square-shaped trouble net with 30 cm sides, fitted with a conical net of 400 µm mesh opening and 50 cm depth. Thus, at each station, about 20 dip net strokes were made over an area of about 3 m2 in total according to the different microhabitats. The load retained by the net was transferred to a white cloth where the macroinvertebrates were collected using a pair of fine tweezers introduced into pillboxes containing 10% formalin. In the laboratory, the benthic macroinvertebrate samples are rinsed with tap water to remove the formalin. The organisms collected at each station were preserved in pillboxes containing 70° alcohol, then counted and identified under a WILD M5 binocular loupe, using the identification keys and works of Day et al. (11), Tachet et al. (37), Stals and De Moor (35), up to the species level if possible.

For the particle size data, samples were taken from the sediments between 2 and 5 cm depth using 10 cm long and 5 cm diameter PCV tubes at each station. The samples obtained were then placed in plastic zip bags (23), taken to the LTM (Laboratoire de traitement des minerais de l'Institut de Recherches Géologique et Minière) and stored at room temperature.

The physicochemical analyses were carried out both in the field and in the laboratory following the recommendations of APHA (2) and Rodier et al. (34). For the laboratory analyses, the water samples were collected in 250 and 1000 ml double-capped polyethylene bottles and brought back to the laboratory in a refrigerated chamber.

2.3. Data processing

The Kruskal-Wallis and Mann-Whitney tests were used to compare the taxonomic richness of the stations and the different groups formed by the SOM. PAST 3.0 software was used.

The macrobenthic settlement data were analysed using self-organising maps (SOM) or Kohonen maps (25). This classification technique is able to identify similar groups in a simplified way from complex databases (26). This method was used to order the samples according to species assemblages. Once the map is obtained, a hierarchical clustering analysis (HCA) algorithm based on the Ward method as an aggregation criterion and the Euclidean distance is then used to highlight real object assemblages on the map (32). These clusters are based on the similarities between the samples projected into the cells of the SOM map. The analysis was performed with the SOM toolbox interface (version 2) for MATLAB 2016. Discriminant factor analysis (DFA) performed on XLSTAT 2021 was applied to identify the abiotic variables that best discriminate the groups predefined by the typology obtained from the SOM. Then, the significance of the AFD is tested by the Monte Carlo permutation test (999 permutations). It also provided the prediction percentage of the selected station groups.

3. Results

The average values of the physicochemical and granulometric variables are presented in Table 1. The water temperature fluctuated from 23.98 °C (Cdc2) to 21.47 °C (Anz1), the pH from 6.61 UC (Anz1) and 4.92 UC (Sen1). Dissolved oxygen varies from 73.72 % (Dje1) and 60.24 % (Anz3). CO2 fluctuated from 9.29 mg/L (Cdc3) and 4.65 mg/L (Sen1). Nitrogen and phosphate compounds show very low levels overall. The high values are only observed at the Sen3 station. The colour varies between 187.08 Pt-Co (Anz3) and 92.46 Pt-Co (Sen1), the suspended solids (SS) vary between 41.46 mg/L (Cdc3) and 35.08 mg/L (Sen3) and the turbidity fluctuates between 28.08 NTU (Cdc3) and 21 NTU (Cdc1). Electrical conductivity and alkalinity ranged from 23.08 µS/cm (Dje1) to 19.23 µS/cm (Anz2 and Sen1) and 3.46 mg/L (Cdc3) to 2.02 mg/L (Sen1) respectively. Oxidability fluctuated from 1.22 mg/L (Dje1) to 0.82 mg/L (Cdc3 and Sen1). The depth fluctuates between 0.6357 m (Anz3) and 0.045 m (Sen3). The width of the bed varies between 4.50 m (Sen2) and 0.70 m (Anz1) and the flow velocity of the water varies from 0.24 m/s (Cdc1) to 0.02 m/s (Anz3). From this work four types of substrates were characterised during the study period. The substrate is fine gravel (station Sen3), coarse sand (Dje2 and Anz1), fine sand (Cdc1, Cdc2, Cdc3, Dje1, Dje3, Anz3, Sen1 and Sen2) and silt (Anz2).

The Hierarchical Ascending Classification (Figure 2) was carried out to group the sampling stations according to the physicochemical quality of the water and the granulometric quality of the substrate. This resulted in 3 groups of stations. Group I consists only of the Sen3 station located in a highly urbanised area and downstream of the outlet of the Séna watercourse, group II includes the Cdc1, Dje1, Anz2, Sen1 and Sen2 stations. Group III includes stations Anz1, Dje2, Anz3, Cdc3, Cdc2 and Dje3. These last two groups are located in forested areas far from human activities. The Kruskal-

Wallis test carried out on the physicochemical data resulting from the groups formed by the AHC shows a significant difference between groups I, II and III.

Table 1 Average values of physicochemical parameters and stream substrate during the study period

Variables / Stations	Cdc1	Cdc2	Cdc3	Dje1	Dje2	Dje3	Anz1	Anz2	Anz3	Sen1	Sen2	Sen3
T (°C)	23.49	23.98	23.66	22.64	22.76	23.46	21.47	21.51	21.82	22.17	22.15	22.28
O2 (%)	73.30	70.64	68.70	73.72	71.79	71.80	70.90	72.60	60.24	71.75	67.97	67.48
CO2(mg/L)	6.18	6.26	9.29	6.40	6.61	8.64	5.59	5.93	6.54	4.65	5.70	8.50
Color (Pt-Co)	108.62	164.15	191.38	164.85	156.00	178.08	92.46	132.46	187.08	93.85	111.15	141.77
MES(mg/L)	38.54	38.77	41.46	38.69	38.62	38.69	37.77	44.23	39.08	35.54	35.93	35.08
Cond(µS/cm)	22.31	20.77	21.54	23.08	20.77	21.54	21.54	19.23	20.77	19.23	20.00	20.00
Alcalinity (mg/L)	2.23	2.31	3.46	2.23	2.62	2.23	2.08	2.46	2.23	2.02	2.17	1.77
Ph (UC)	4.96	5.01	4.93	5.15	4.97	4.91	6.61	5.66	5.16	4.92	4.96	4.99
Turbidity (NTU)	21.00	26.23	28.08	26.00	24.80	25.91	22.03	26.85	25.29	21.31	23.08	25.92
$PO_4{}^3$ (mg/L)	0.26	0.66	0.28	0.63	0.48	0.22	0.59	0.51	0.64	0.32	0.43	0.79
NO_3 (mg/L)	0.84	0.87	0.86	0.76	0.68	0.78	0.73	0.75	0.80	0.81	0.85	0.89
NH_4 (mg/L)	0.85	1.62	0.81	0.55	0.58	0.52	0.33	0.58	0.71	0.41	0.56	0.92
Oxydability (mg/L)	1.15	0.90	0.80	1.22	0.90	1.26	0.88	0.91	0,99	0,80	0,98	0,94
Bed width (cm)	2,10	1,70	1,80	2,30	1,15	2,10	0,70	1,00	1,50	1,30	4,50	3,10
Bed depth (m)	4,66	39,41	48,16	22,33	28,92	46,83	22,08	16,70	63,57	36,42	54,99	4,50
Flow velocity (m/s)	0.24	0.22	0.17	0.08	0.03	0.04	0.05	0.05	0.02	0.08	0.10	0.07
Fine gravel	10.17	29.60	28.90	9.62	46.51	19.57	39.17	2.64	21.56	7.46	24.68	76.00
Coarse sand	6.95	3.50	3.02	3.57	12.88	5.48	10.77	0.95	2.25	1.81	4.42	1.40
Fine sand	82.70	65.20	65.90	85.18	37.53	72.78	46.60	81.71	74.80	90.22	69.15	21.60
Limon	0.18	1.70	2.18	1.63	3.08	2.17	3.46	14.70	1.39	0.51	1.75	1.00

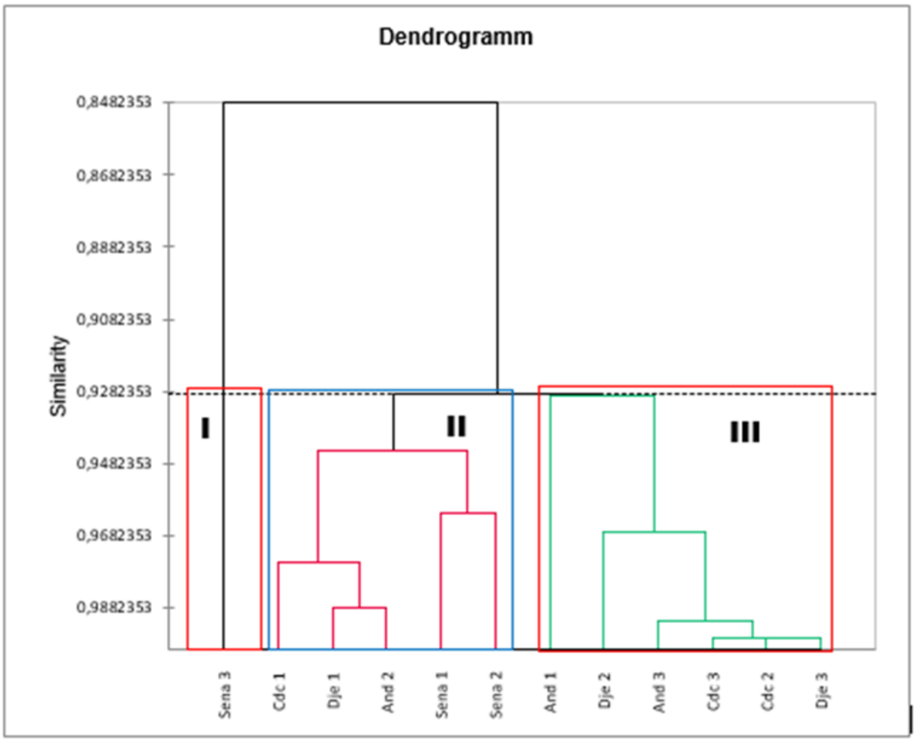


Figure 2 Dendrogram of the stations based on physicochemical, granulometric and hydromorphological variables during the study period

3.1. Abundance and taxonomic richness

A total of 56 taxa of benthic macroinvertebrates were collected, 54 of which were identified to genus and/or species level and 2 to family level, for a total abundance of 12558 individuals. These taxa are divided into 3 phyla (Arthropods, Molluscs and Annelids), 5 Classes (Crustacea, Insects, Bivalves, Gastropods and Oligochaetes), 12 orders and 33 families. Arthropods are the most diverse with 2 classes, 9 orders, 29 families and 52 genera and species (either 92.85% of taxonomic richness). They are followed by the Molluscs with 2 classes, 2 orders, 3 families and 3 genera and families. The Annelids contain only one class, one order, one family and one genus and species.

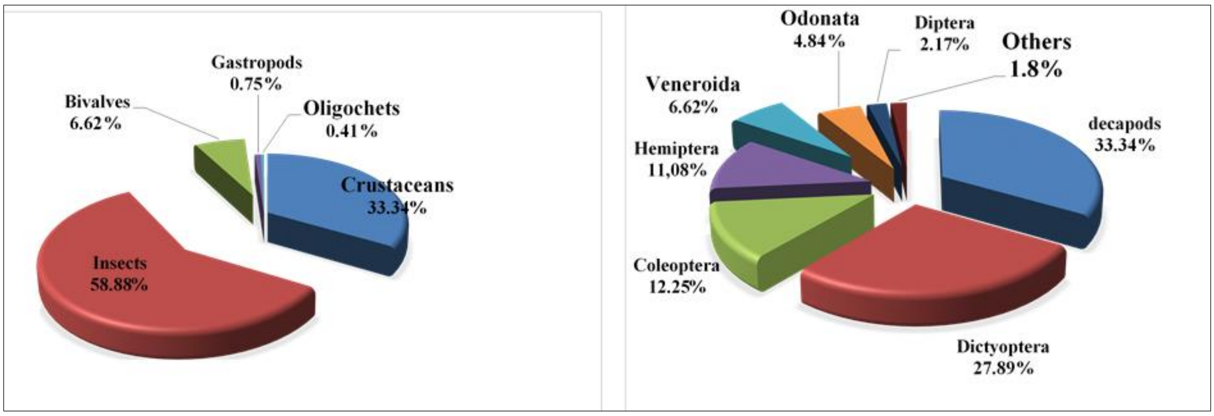


Figure 3 Relative abundance of classes (A) and orders (B) of benthic macroinvertebrates in streams surveyed during the study period

The Insects class is the best represented with 8 orders, 22 families and 49 genera (either 58.87% taxonomic richness) (Figure 3A). The Crustacea class has 1 order, 3 families and 3 species, either 33.34% of taxonomic richness. The classes of Bivalves, Gastropods and Oligochaetes have 1, 1, 2 orders and 1 family each respectively.

Of the 8 orders of Insects, the Dictyoptera is the least diverse (1 family), but the most abundant with 28 % of relative abundance. This order is followed by Coleoptera, Hemiptera, Odonata, Diptera, Ephemeroptera, Trichoptera and Plecoptera with relative abundances ranging from 12 % to 2 %. The order Coleoptera is the most diverse with 15 genera (20.80 % taxonomic richness), followed by Odonata with 13 taxa (8.2 % taxonomic richness) and Hemiptera with 12 taxa (18.8 % taxonomic richness).

Overall, the order Decapoda is the most represented, with 33.34% relative abundance, followed by Dictyoptera (27.89 %), Coleoptera (12.24 %), Hemiptera (11.08 %), Veronida (6. 61 %), Odonata (4.84 %), Diptera (2.16 %) (Figure 3B), the others (Mesogasteroptera, Lombricidae, Ephemeroptera, Trichoptera and Plecoptera) totalled 1.78 % relative abundance.

3.2. Spatio-temporal variation in taxon richness

Temporally, the minimum taxon richness was observed in April 2019 (27 taxa) and the maximum in January 2019 (38 taxa) (Figure: 4a). Spatially, taxon richness varied from 9 taxa (Sen3 station) to 41 taxa (Sen2 station) (Figure: 4b). Seasonally, the variation in richness fluctuated from 35 taxa in the short dry season to 40 taxa in the short rainy season (Figure: 4c), and 39 taxa in the long rainy season to 55 taxa in the long dry season. The Kruskal-Wallis significance test ($p<0.05$) shows significant differences in taxon richness between stations, months and short seasons.

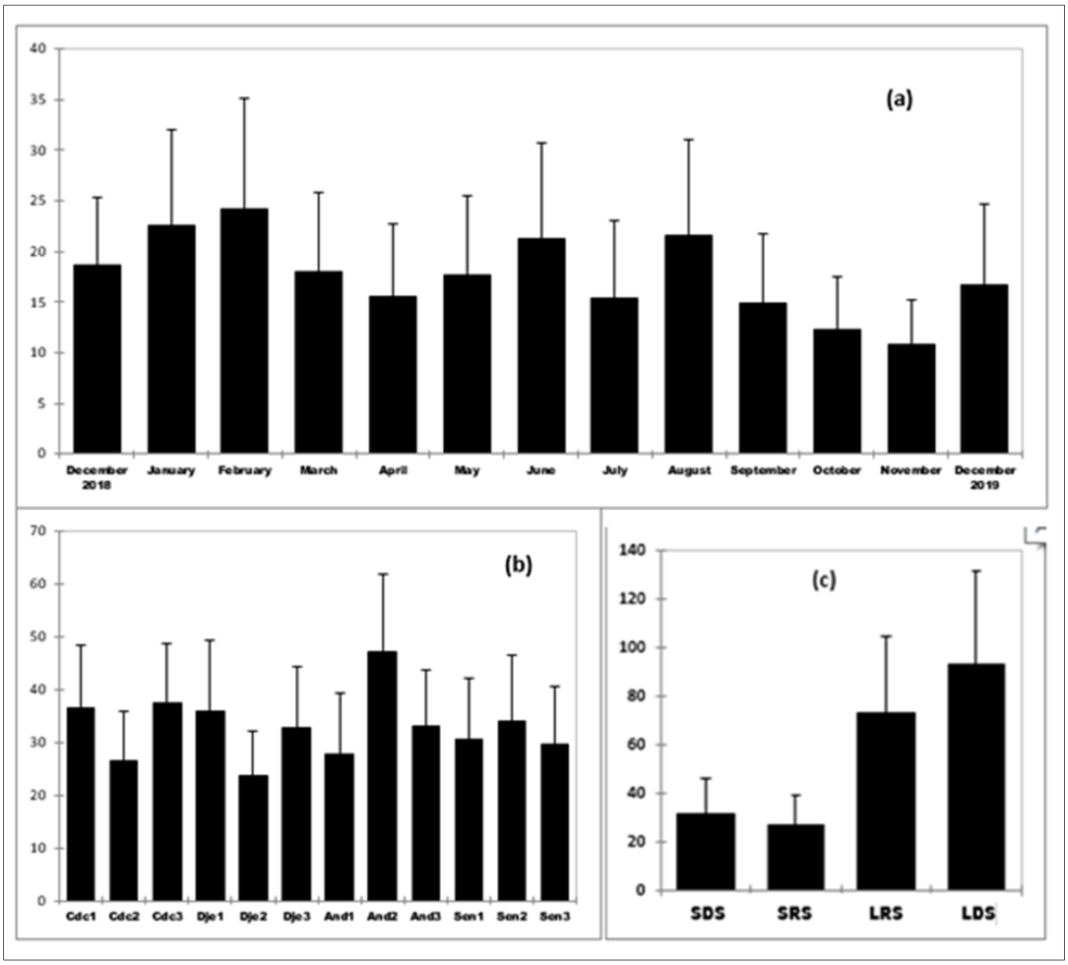


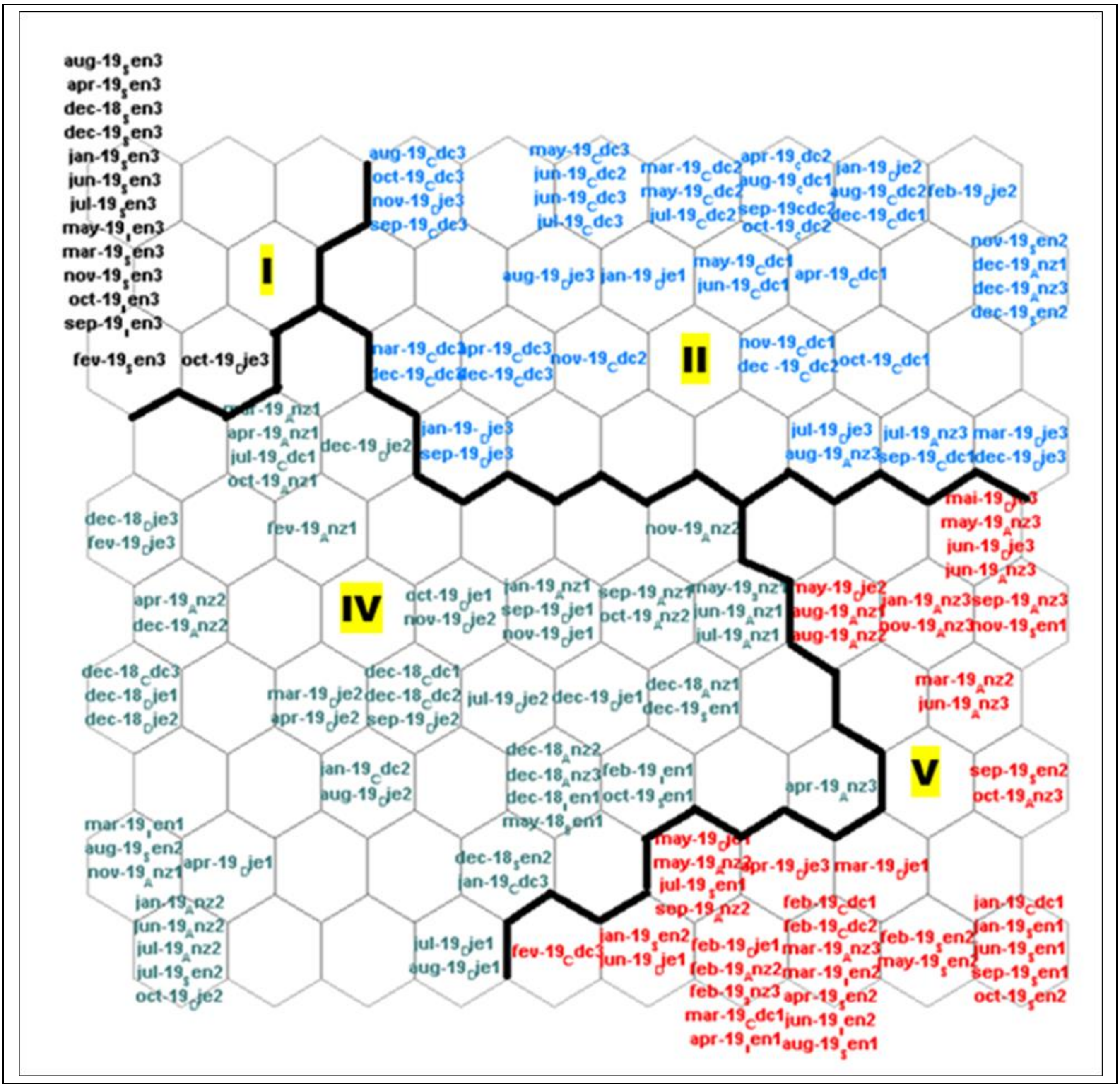
Figure 4 Temporal (a), spatial (b) and seasonal (c) variations in the taxonomic richness of benthic macroinvertebrates during the study period

3.3. Benthic population structure of the studied streams

The study carried out using the presence-absence matrix made it possible to group the 156 samples (12 stations × 13 surveys) taking into account the abundance of taxa at each station and each survey. Processing of this matrix by Self-Organizing Maps (SOM) on the basis of the minimum values of topographic and quantification error (Table 2) resulted in a map of 100 cells (10 rows × 10 columns) on which the 156 samples are projected. The map chosen for this biotyping approach is the one with bold numbers.

Table 2 Tested matrix model of quantification error and topography error for the development of the Kohonen map (in bold, the selected map)

Map size	Quantization error	Topography error
72 (9 × 8)	1.069	0.013
80 (10 × 8)	1.054	0.006
90 (10 × 9)	1.051	0.006
100 (10 × 10)	1.031	0.000



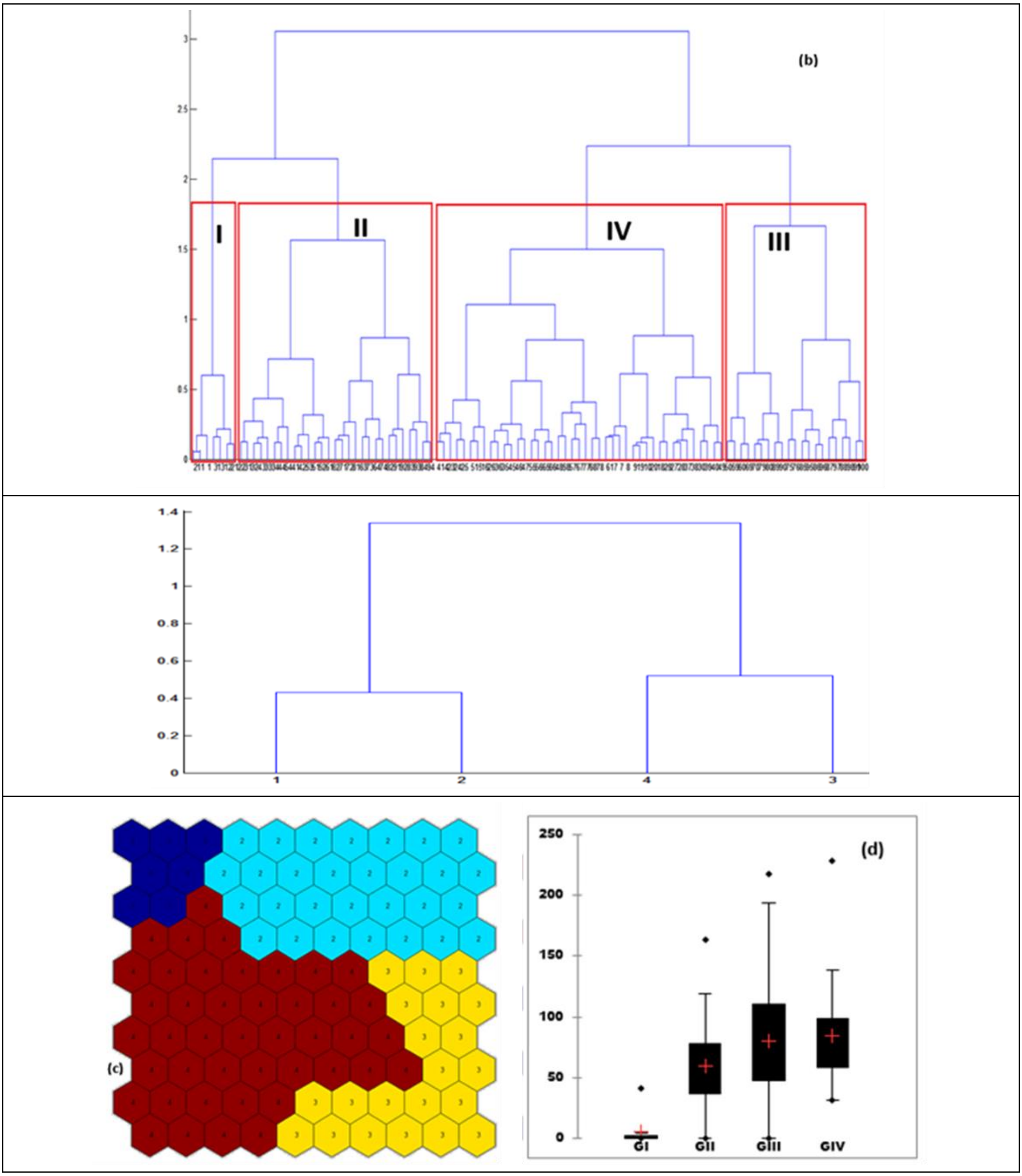


Figure 5 Distribution of samples (a), hierarchical classification of map cells (b), Kohonen's self-organising map (c) and taxonomic richness of the different groups (d) in the study area, hierarchical classification of groups (e). 1 to 10 correspond to the map cell numbers; the Roman numerals (I to IV) represent the groups formed and retained

Next, a hierarchical classification was carried out on the basis of the 100 cells obtained. These cells are grouped by taxonomic affinity according to Ward's method and the Euclidean distance allowed to distinguish 4 groups of samples (Figure 4b).

The graphical representation of the overall distribution of the 156 samples by the SOM is defined in Figure 5a below. The hierarchy of taxonomic richness obtained in the different groups identified by the SOM is illustrated in Figures 4c and 4e. Group I, located above the left end of the map, is essentially made up of 14 samples encompassing 7 cells belonging mainly to the Sen3 station located in an urban area. Group II, being on the upper right part of the map and extends over 44 samples of which 10 belong to stations Cdc2 and Cdc3, 8 to station Cdc1, 7 to station Dje3, 3 to station Anz1, 2 to stations Sen2 and Dje2 and 1 to stations Dje1 and Anz1. Group III, located at the lower right-hand corner, consists of 43 samples, 8 of which belong to stations Sen2 and Cdc1, 7 to station Sen1, 5 to station Anz2, 4 to station Dje1, 3 to stations Cdc1 and Dje3, 2 to station Dje2 and 1 sample to stations Anz1, Cdc2 and Cdc3. Group IV is composed of 47 samples of which, 10 belonging to station Anz1, 8 to station Anz2, 7 to station Dje1, 6 to station Dje2, 5 to station Sen1, then 3 to 2 to stations Sen2, Dje3, Anz3, Cdc1 and Cdc3 have respectively 3 and 2 samples. These groups show no significant difference between them ($p > 0.01$).

3.4. Discriminating parameters

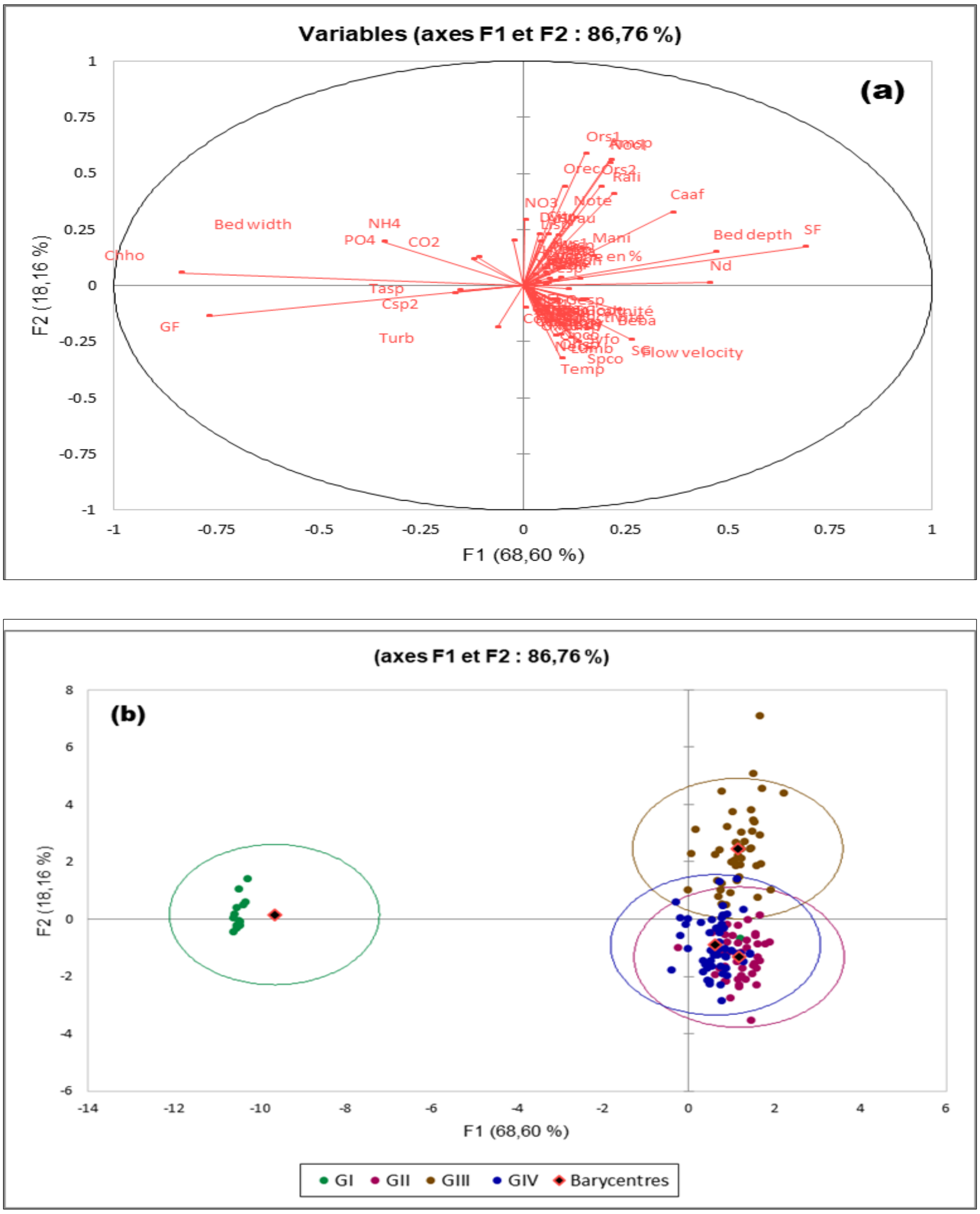


Figure 6 Representation of the factorial discriminant analysis by correspondence (a) distributions of the discriminant parameters and (b) distribution of the different groups formed by the SOM test (b) during the study period

Figures 5 show the different factors that discriminate the groups formed by the Kohonen SOM test. Group I, located on the negative side of the F1 axis, is characterised by high values of physicochemical parameters such as ammonia nitrogen, orthophosphate, turbidity, fine gravel substrate and a fauna rich in Diptera (Chironomidae) among others. Group III, located on the positive side of the F1 axis, is distinguished from the others by a predominantly silty and sandy substrate (fine and coarse sand), relatively high water depth values, low nitrate levels and a fauna rich in crustaceans. Groups II and IV are both negative in relation to the F2 axis and are distinguished by high flow velocity, relatively low temperature values and high dissolved oxygen values, medium alkalinity values and a sandy substrate (coarse sand).

4. Discussion

4.1. Environmental variables

The low water temperatures observed overall are due to the presence of the canopy, which is almost entirely present in almost all the stations, forming a barrier that reduces the penetration of solar radiation into the water column. These observations are in agreement with those of Vannote et al. (41) who emphasise that in rivers located in forest areas, the water temperature is very low and varies little. These results are similar to those obtained in the Matourou stream by Yogback et al. (43); in the Nga and Abouda by Foto Menbohan *et al.* (16, 18); in the Nsape by Tchakonte *et al.* (38), in the Nga, Fam, Nkomou by (Biram à Ngon *et al.* (4) and in the Ndongo by Foto Menbohan *et* al.(19).

The pH values are relatively low and tend towards acidity reflecting the ferralitic nature of the soil. Indeed, Nola *et al*. (28), point out that the pH of water is closely related to the nature of the soil in its catchment. In addition, the penetration of atmospheric carbon dioxide into the water, coupled with the metabolic activity of animal organisms present in the streams, contribute to the conversion of carbonates into bicarbonates, promoting the acidification of the environment (1). Our results are similar to those of Foto Menbohan *et al.* (17) and Tchakonté *et al.* (38) obtained in forest streams.

The percentage of oxygen saturation shows satisfactory values bringing the average value to 75.3%. This good saturation of the water could be attributable to the low heating of the water, coupled with the high photosynthetic activity, natural ventilation and the presence of riffles and meanders that create conditions of turbulence and recirculation of water, leading to reoxygenation at the water/air interface (12; 15). These values are similar to those obtained by Biram à Ngon (4), Tchakonté et al. (38), Foto Menbohan *et al.* (16, 17, 18 and 19) in forest streams.

The mineral elements nitrogen (NH_4^+ and NO_3^-) and phosphate (PO_4^{3-}) show low values in all sub-catchments, reflecting the low level of mineralization of waters, their good oxygenation and the low anthropization of sub-catchments. These results are similar to those of Foto Menbohan *et al.* (16) and Tchakonté *et al.* (38) obtained in some forest streams. The high values observed at the Sen3 station would be due to related anthropogenic activities.

As for the hydrological parameters, the maximum values of wetted bed width, depth and water flow velocity recorded during the rainy season in all the stations would be related to rainwater inflow. Our results are similar to those of Camara (6) who also reports that the maximum values of these hydrological variables are observed in the rainy season in the Banco River in Côte d'Ivoire.

The Discriminant Factor Analysis (DFA) shows that low water temperatures, good oxygenation and low mineralization of the waters and a sandy substrate littered with dead leaves and woody debris constitute the set of environmental conditions conducive to the installation of a high diversity of benthic macroinvertebrates. The opposite of all these conditions as observed at the Sen3 station leads to a sharp drop in taxonomic richness and an imbalance in macroinvertebrate populations. In this regard, *Colas et al.* (9) point out that aquatic organisms integrate various types and degrees of environmental disturbances that occur on a variety of spatio-temporal scales; their structure provides a much more accurate picture of the integrity of the hydrosystem (5).

The biotypology carried out by the SOM shows a distribution which reveals two categories of samples at the first level of the classification, where the anthropic effect is more marked, with samples with very low taxonomic richness (group I) and samples which are rich in taxa (groups II, III and IV). At the second level of the classification, the structure of the macrobenthic communities of the streams studied is more influenced by environmental parameters, highlighting a gradient of stress on the organisms, with a well-differentiated fauna in the groups subjected to disturbance. Thus, the samples of group I, which are almost essentially from the station located in the lower reaches of the Séna stream, showed a similar taxonomic composition with no significant differences ($p > 0.05$). A synoptic analysis of the quantitative data shows that the lowest relative abundances are observed in group I. Moreover, this group is mainly and in large quantities full of Pollutant-resistant taxa such as the dipterans Chironomus holomelas, Chironomus sp1 and Chironomus sp2 (40; 20). This station, located in an urban area and therefore subject to strong anthropic pressure, is strongly dominated by the species *Chironomus holomelas*. In fact, the modification of the sedimentary base by bio-deposits resulting from various anthropic activities disturbs the benthic communities and the distribution of species (7; 33). However, the presence of the species *Chironomus holomelas*, *Chironomus* sp1 and *Chironomus* Sp2 indicates a stressed environment as a result of a high concentration of nutrients.

Group II is globally composed of polluo-sensitive taxa which are typical of environments with a sandy substrate such as the crustaceans Caridina africana (872 individuals) and Macrobrachium niloticus (35 individuals), the bivalves Sphaerium corneum (677 individuals) and the insects: Dictyoptera (974 individuals) (40; 20). All these groups prefer water saturated with dissolved oxygen, relatively high water flow velocities, relatively low temperature and a sandy substrate. This result is in line with the physicochemical analyses which show that the stations located in the forest areas are relatively unmanaged waters suitable for the installation and development of a wide variety of benthic macroinvertebrate taxa. In addition, the presence of low quantities of *Chironomus holomelas*, *Chironomus* sp1 and *Chironomus* Sp2 species would reflect the beginning of a disturbance of the physicochemical quality of these waterways (33; 39).

Group III and IV with respective total abundances of 4374 and 4647 present at the same time the greatest taxonomic richness which seems to be based on the origin of the majority of these samples which all come from the Crenon and Rhitron. The faunistic similarity that seems to link these stations would be due to a little anthropised environment located in the middle of the forest favourable to the growth and multiplication of polluo-sensitive taxa such as crustaceans (*Caridina africana*), insects (*Rhagovelia reitteri*), Blaberidae, followed by some polluo-tolerant taxa such as insects (*Noterus clavicornis, Ranatra linearis*) and bivalves (*Sphaerium corneum*) These results reflect a certain balance in the taxonomic composition of the macrofauna of this region (13). However, the emerging anthropisation due to sand mining and creel fishing in the dry season in these rivers is causing a reduction in pollutant-sensitive taxa, particularly EPT.

5. Conclusion

For the analysis of stream water quality, benthic macroinvertebrates offer a multitude of possibilities. They can be used to quickly target a problem area, to evaluate the effectiveness of a development, or to measure the impacts of a large-scale project in a quantitative and precise manner. Benthic macroinvertebrates are also used to estimate the impact of different agro-pastoral practices on the aquatic environment as well as to assess pollution from runoff water, which contains a host of nutrients from the leaching of soils in anthropogenic areas.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this document.

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