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Influence of granulometry on the distribution of benthic macro invertebrates in some streams of the Mvilla and Haut-Nyong watersheds in Cameroon

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Abstract

This study was conducted from November 2018 to October 2019 in 8 forested streams in the Haut-Nyong and Mvilla watersheds to determine the influence of substrates granulometry on benthic macroinvertebrates. The physicochemical analyses showed highly oxygenated, weakly mineralized and slightly acidic waters. The granulometric analyses reveal 9 categories of substrates depending on the scale of sand, sand+gravel or sand+mud. Sampling of benthic macroinvertebrates allowed the collection of 15058 organisms divided into 5 classes, 14 orders and 49 families. The results showed a taxonomic richness strongly influenced by the nature of the substrate. The combination of coarse sand + silt + dead leaves was more favored the development of benthic macroinvertebrates with 48 families. The taxonomic richness associated to the different index revealed good ecological quality of Sounou, Bengo'o and Lo'o rivers.

Keywords: Substrates; Benthic macroinvertebrates; Ecological quality; Diversity; Mvilla watershed; Haut-Nyong watershed

1. Introduction

The monitoring of organisms is carried out in shallow watercourses where biological communities such as benthic macroinvertebrates (MIBs) currently demonstrate the most remarkable efficiency and usefulness for a better ecodiagnosis of the quality of hydrosystems (Moisan and Pelletier, 2014). Because of their taxonomic richness, abundance, diversity, sedentary nature, varied life cycle, variable tolerance to pollution and habitat degradation, and flexibility related to their ecological requirements, MIBs are well suited to the study of the quality of hydrosystems. MIBs are well suited to assessing the quality of hydrosystems (Moisan *et al.*, 2010). Moreover, they incorporate numerous cumulative and synergistic short- and long-term effects of multiple physical, biological and chemical disturbances. African tropical and equatorial forests are under increasing anthropogenic pressure due to the excessive, uncontrolled destruction of many plant species for various purposes, including export for the production of wooden objects (Tchatchou *et al.*, 2015; Biram *et al.*, 2018). However, most forest aquatic ecosystems remain unaffected by natural or anthropogenic disturbances. Such environments still retain their more or less natural state and can therefore, be described as ecologically healthy rivers. This preservation of the natural state gives them the status of reference rivers (Biram 2019; Mboyé *et al.*, 2018). The quality of the benthic habitat is therefore becoming an essential element for a better understanding of the ecology of benthic macroinvertebrates with varying sensitivities to pollutants (Foto *et*

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al., 2012; Yogback *et al*., 2018). Participating in the transformation of organic matter by decomposing litter (Ben Moussa *et al*., 2014), benthic macroinvertebrates thus reflect the levels of water and habitat alterations (Usseglio-polatera & Beisel, 2002, Mboye 2019). Although the biotope hosting the benthic macrofauna is almost completely documented in several regions of the world (Europe, North America), it remains poorly documented in sub-Sahelian Africa, particularly in Cameroon. Depending on the granulometry, the sediments are characterized by a great diversity of microhabitats sheltering a benthic macrofauna whose diversity remains poorly elucidated. The aim of this study is to contribute to the knowledge of the structure of the benthic macroinvertebrate population in relation to the bottom substrates of some watersheds.

2. Material and methods

2.1. Description of the sampling area

The Mvilla Basin covers an area of about 47,191 km^2 and is located in the Southern Cameroon Region. It consists of the Southern Cameroon plateau, which is a vast erosion surface sloping towards the Congo Basin to the southeast. To the west, it ends abruptly with an escarpment dominating the coastal surface. Its average altitude is about 650 m. All these valleys are occupied by vast swamps, favored by very gentle slopes. In its greatest extent, the southern cameroonian plateau has the characteristic facies of equatorial forest peneplains. It appears as a series of hills separated by a succession of relatively wide and deep valleys, sometimes widened into marshy basins (Olivry 1986). The very dense hydrographic network is favored by abundant rainfall and impermeability of the crystalline bedrock. The climate is equatorial with 4 seasons including 2 dry and 2 rainy seasons, unevenly distributed (Servat *et al*., 1999). The temperature varies between 23 °C and 24 °C. The vegetation consists of dense forests. The soils are hydromorphic to the valleys and ferrallitic on altitudes.

Table 1 Some characteristics of the sampling stations of the streams of the Mvilla and Haut-Nyong watersheds

Watersheds	Streams	Stations Codes	GPS Coordinates			Human activities
			Latitude (°N)	Longitude (°E)	Altitude (m)	
Haut-Nyong	Andzié	And1	03° 58'14''	013°08'46''	670	None
		And2	03°58'19''	013°08'56''	667	Net fisching
		And3	03°58'38''	013°10'03''	657	None
	Sena	Sen1	03°58'43''	013°08'49''	675	
		Sen2	03°58'58''	013°08'47''	662	
		Sen3	03°06'59''	013°08'42''	657	Laundry
	Djénassoumé	Dje1	03° 57'33''	013° 06'43''	659	None
		Dje2	03° 57'39''	013°06'50''	649	Rouissage
		Dje3	03° 57'42''	013°06'83''	646	Net fisching
	CDC	CDC1	03°57'39''	013°06'58''	673	None
		CDC2	03°57'37''	013°06'35''	670	
		CDC3	03°06'57''	013°06'61''	668	
Mvilla	Bengo'o	Ben1	02°53'18''	011°09'28''	578	None
		Ben2	02°53'08''	011°09'24''	574	
		Ben3	02°53'03''	011°09'28''	569	Sand quarry
	Sounou	Sou1	02°52'36''	011°06'53''	581	None
		Sou2	02°52'41''	011°06'45''	576	
		Sou3	02°52'43''	011°06'41''	570	
	Lo'o	Lo'o1	02°53'48''	011°06'47''	594	
		Lo'o2	02°53'53''	011°06'53''	585	
		Lo'o3	02°53'59''	011°06'58''	579	
	Metyi	Met1	02°52'22''	011°09'19''	564	Net fisching
		Met2	02°52'50''	011°09'03''	560	None

With an area of 27,800 km² and an average altitude of 700 m (Bachelier *et al*., 1956), the Haut Nyong watershed is located in the East Cameroon region. It consists of hills interspersed with vast swampy areas containing flooded forests over more than 3 km (Olivry, 1986). Savannahs are predominant. The average temperature varies between 22 °C and 24 °C. The climate is guinean with a short dry season of 3 to 4 months (mid November to February). Four rivers were selected in the Mvilla watershed (Bengo'o, Sounou, Metyi and Lo'o) and four in the Haut-Nyong watershed (Djenassou, Andzié, Sena and the CDC). Thus, the sampling points were chosen according to their accessibility, their representativity, and their position relation to the source of pollution. Twenty-three stations were selected, 3 per stream, except the Metyi stream (2 stations).

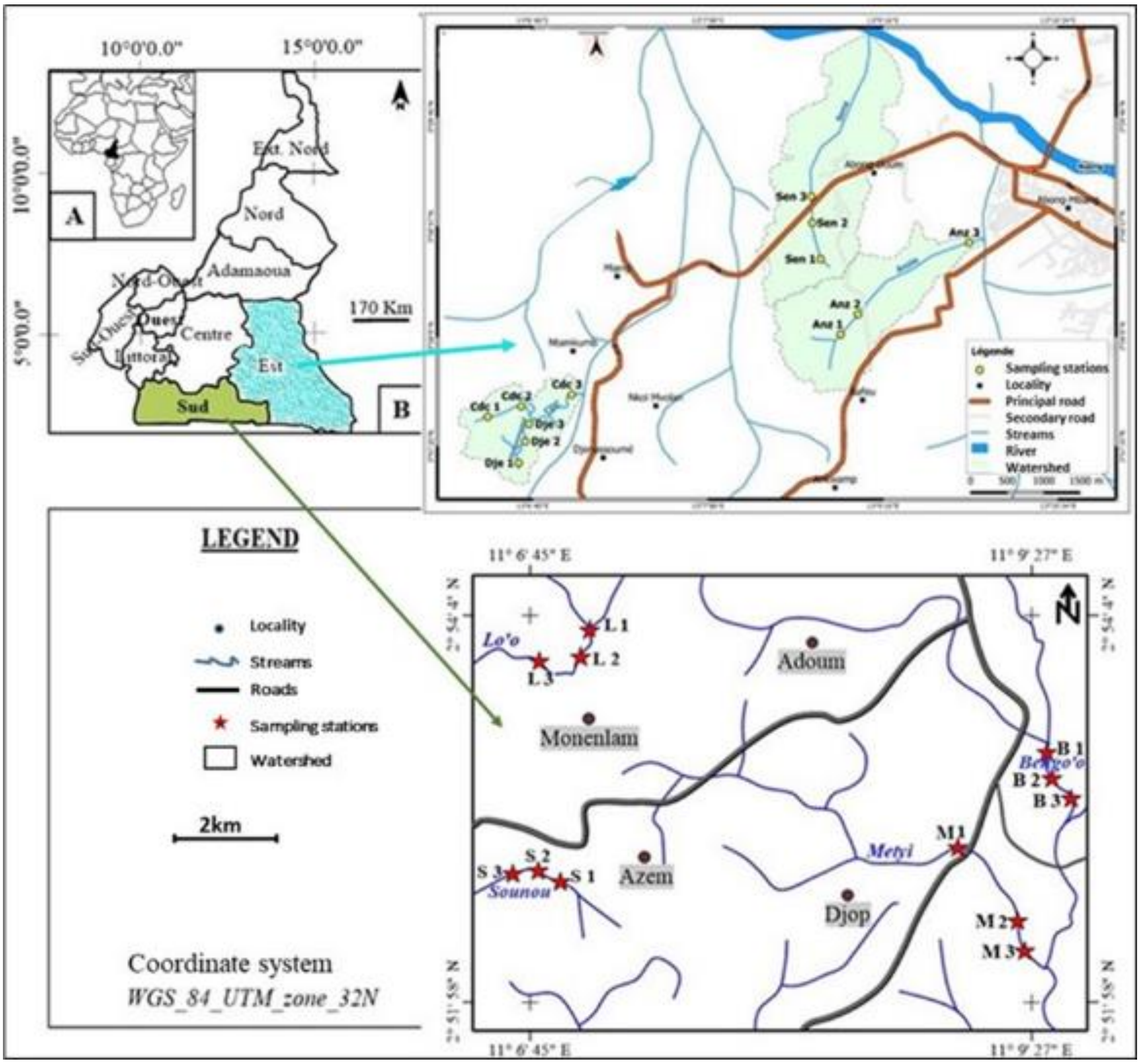


Figure 1 Map of the Haut-Nyong watersheds and the Mvilla showing the different stations

2.2. Physico-chemical parameters

Water samples for physico-chemical analyses were taken at a seasonal frequency, following the recommendations of APHA (1998) and Rodier *et al*. (1999) Temperature (°C), pH and dissolved oxygen saturation (%) were measured in situ using a HANNA HI 98130 portable multimeter and a HANNA HI 9147 portable oxymeter respectively. The results were given in °C, UC and % O_2 saturation respectively. In the laboratory, nitrate, orthophosphate, and oxidizability were determined colorimetrically using the HACH DR 2800 spectrophotometer, followed by dissolved CO_2 and oxidability by volumetry. The results were expressed in mg/L.

2.3. Granulometric analysis.

Substrate samples were taken in the dry season at each station at a depth of between 5 and 10 cm using an auger following the recommendations of Intès and Le Loeuff (1986). Colloidal particle size analysis was carried out in the laboratory where samples were sieved to separate silt from sand (Kamb *et al.*, 2015). The obtained samples were then put into the plastic zip bags, brought back to the MTL (Mineral treatment laboratory of the Geological and Mining Research Institute) and stored at room temperature. The samples were then dried and weighed before the sieving operations. The substrate bulk rate, which determines the amount of allochthonous material (g/kg substrate) in the streambed, was calculated and sediment characterization was carried out by particle size analysis, followed by sedimentometry. After the granulometric and sedimentometric analyses which gave the different proportions of gravel (Gr), sand (S), silt (L) and clay (A), the sum of clay and silt (A+L) was determined.

2.4. Benthic macroinvertebrates

The collection of benthic macroinvertebrates was carried out by season according to the multi-habitat approach (Stark *et al.*, 2001) which consists of carrying out in each station of approximately 100 m in length, a total of 20 net shots equivalent to 3m^2 of surface area, in different micro-habitats, using a haze consisting of a metal frame of 30 cm X 30 cm, mounted on a steel handle of 150 cm in length and fitted with a conical net of 500 µm mesh and 50 cm in depth. Each time, the contents of the net were washed over a sieve of 500 µm mesh opening and the specimens collected using a pair of fine tweezers and a hand-held magnifying glass. The collected organisms were preserved in referenced pillboxes containing 10% formalin. In the laboratory, the organisms were rinsed with running water, grouped according to their morphological similarity and observed using a binocular stereomicroscope, then identified using the keys of Tachet *et al*. (2010), Merritt *et al*. (2008) and Durand & Lévêque (1981).

2.5. Data analysis

The Shapiro test was used to verify the normality of the distributions, while the Kruskal-Wallis and Mann-Whitney tests were used to verify the significance of the differences in variances of abiotic parameters and taxonomic abundances in space and time using SPSS version 20.0 software. The hierarchical ascending classification (HAC) based on the Ward method and Euclidean distance as an aggregation criterion highlighted the actual assemblages of the stations on the output map (Park *et al.*, 2003). The population structure of MIBs was determined from taxonomic richness, relative abundance (Dajoz, 2000) as well as Shannon-Weaver diversity, Piélou equitability, Simpson diversity and EPT index.

The Shannon-Weaver index has the formula :

$$H' = -\sum_{i=1}^{S}(p_i \log_2 p_i)$$

H' = diversity index; S = number of taxa; Pi = proportion of taxon i in the sample. It is subdivided into three water quality classes: 2 ≤H for clean water ;

Pielou's (1966) equitability index, which measures the equi-representation of the taxa present (Amanieu & Lasserre, 1982; Dajoz, 2000) has the formula

$$E = \frac{H'}{\mathrm{Log}_2 S}$$

E = equitability; H = Shannon-Weaver diversity index and S = number of taxa

Correspondence Factor Analysis (CFA) was used to relate the nature of the substrate to taxonomic richness.

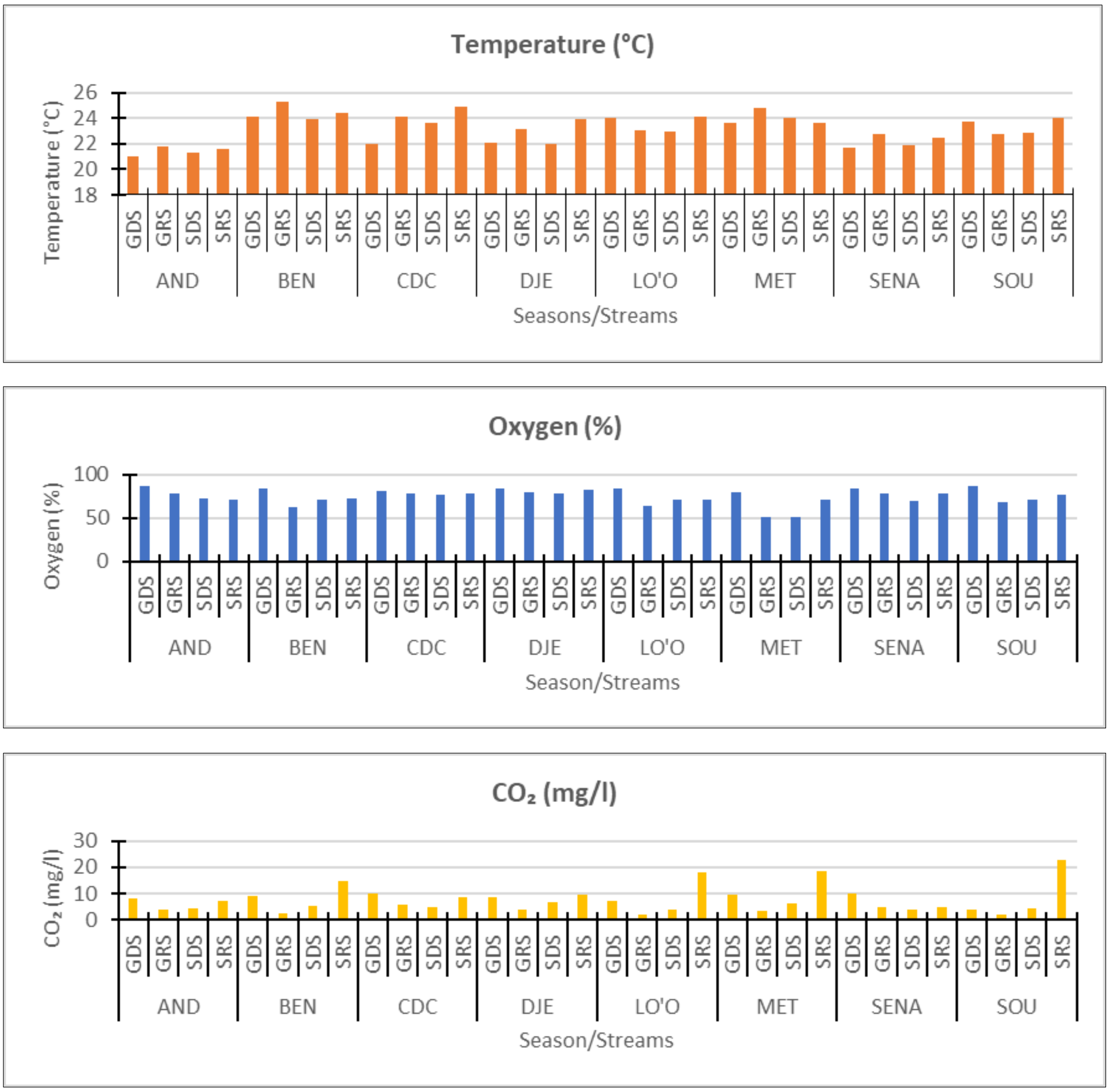
Principal Component Analysis (PCA) was used to establish the affinities between MIB abundances and environmental factors.

Hierarchical clustering analysis (HCA) was used to group stations according to their abiotic and biotic similarities.

3. Results

3.1. Abiotic parameters

During the study period, water temperature varied from 21.05 °C in Andzie stream (GDS) to 25.25 °C in Bengo'o stream (GRS) with a mean value of 23.17 °C ± 1.13 °C (Figure 2A). The different variations were significant from one stream and one season to another ($p < 0.05$). The minimum tenor of dissolved oxygen saturation (Figure 2C) was obtained in GRS with 50.55% in the Metyi stream while the maximum value was observed in GDS with 86.55% in the Andzie stream the mean value being 74.69% ± 8.66% (Figure 2B). The variations were significant from one season to another ($p < 0.05$). The profile of dissolved carbon dioxide (CO_2) showed values ranging from 2.053 mg/L in Lo'o and Sounou streams during GRS to 18.48 mg/L in Metyi stream during SRS with an average of 7.53 mg/L ± 4.96 mg/L (Figure 2C). However, the difference was significant from one stream to another ($p < 0.05$). The pH values ranged from 3.93 U.C in Djenassoume stream (SDS) to 6.48 U.C in Bengo'o stream (GRS) (Figure 2B), with a mean value of 5.24 U.C ± 0.61 U.C (Figure 2D). No significant differences were observed from station and one season to another spatially and temporally ($p > 0.05$). The profile of Nitrate levels showed the maximum value at GDS in the MET stream (2.27 mg/L) and the minimum value obtained at GRS in the SENA stream (0.40 mg/L) with a mean value of 1.39 mg/L ± 0.59 mg/L (Figure 2E). There is was significant difference between the values from one stream and one season to another ($p < 0.05$). With regard to the Oxidability content, the values fluctuated between 0.29 mg/L at BEN during GRS and 2.47 mg/L at MET during SRS, with a mean value of 1.02 ± 0.66 mg/L (Figure 2F). The Kruskal Wallis test showed a significant difference from one season to another ($p < 0.05$).



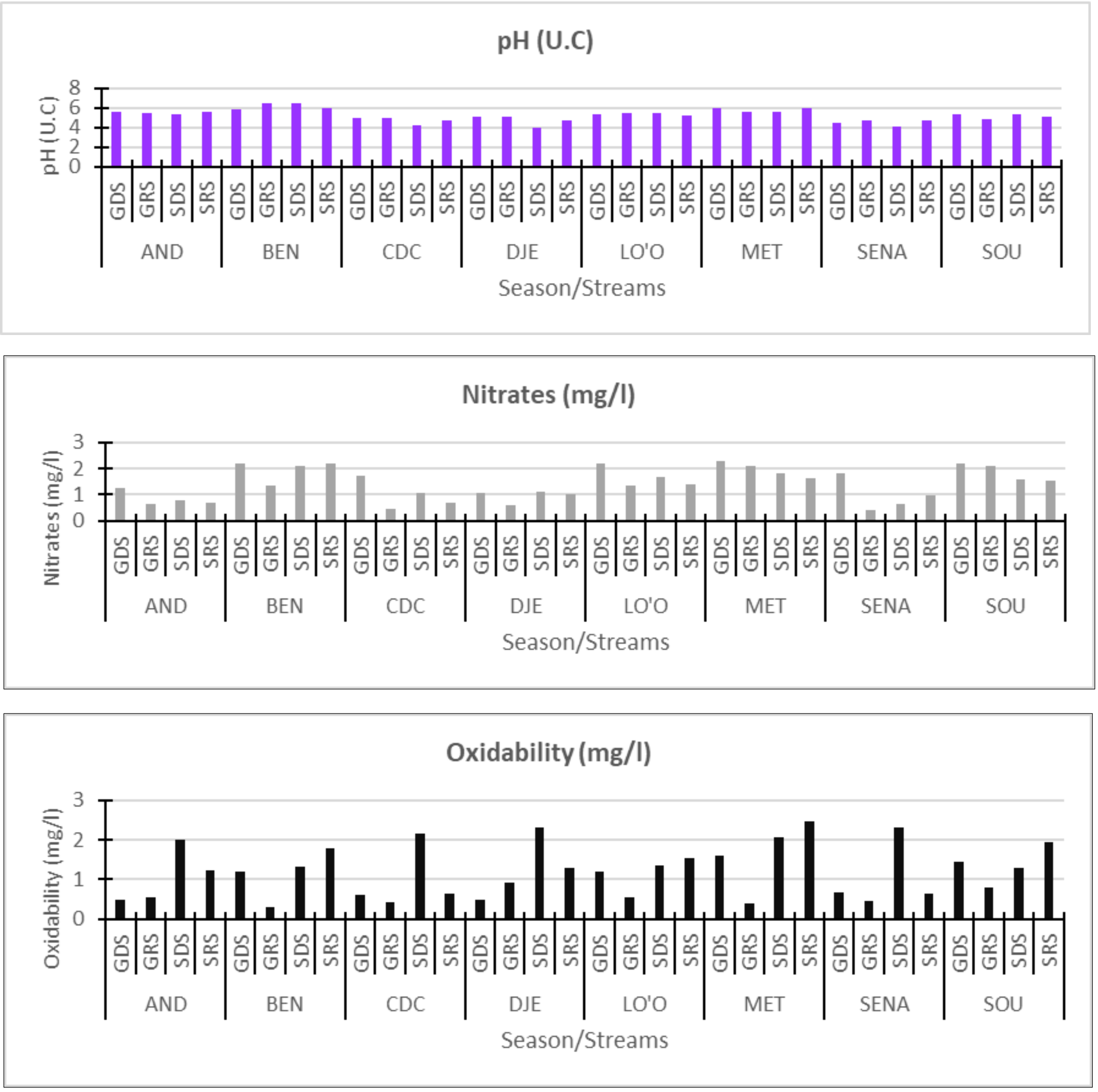


Figure 2 Spatial variation of temperature (A), dissolved oxygen (B), CO2 (C), pH (D), Nitrates (E), and Phosphates (F). Code of streams Andzié (AND) ; CDC (CDC) ; Djénassoumé (DJE) ; SENA (SEN) ; Bengo'o (BEN) ; Sounou (SOU) ; Lo'o (LO'O) ; Metyi (MET). GDS: Great Dry Season; GRS: Great Rains Season; SDS: Small Dry Season; SRS: Small Rain Season

3.2. Granulometry

The granulometric characterization of the substrate sampled at the stations made it possible to determine two proportions of particle sizes in all watersheds of the Haut-Nyong and Mvilla watershed. This is indeed fine gravel, coarse sand. For this purpose, stations CDC 1, CDC 2, CDC 3, DJE 1, DJE 2, DJE 3, AND 1, AND 2, AND 3, SEN 1 et SEN 2 BEN 1, BEN 2, BEN 3, SOU 1, SOU 2, SOU 3, LO'O 1 and LO'O 2 are essentially dominated by coarse sand, while the stations MET 1, MET 2 et SEN 3 are dominated by fine gravel (Table 2).

The granulometry of the substrate coupled with the different micro-habitats comparing the beds of the 8 rivers were counted and classified into 9 main categories (Table 3) made up of combinations of mud, coarse sand, macrophytes, pebbles, dead leaves and fine gravel. Mud combined with coarse sand and dead leaves constituted the main part of the substrates in the CDC, SENA, Djenassoumé, Sounou and Lo'o streams. In the Andzié stream, the substrate was made up of mud, coarse sand, dead leaves and macrophytes. In the Bengo'o stream, the substrate was comprised of silt associated with coarse sand and macrophytes. The Correspondence factor analysis (CFA) showed that these 9 categories of substrates can be reorganized into three main groups according to the importance of fine gravel, sand or silt (Figure 5).

Table 2 Granulometric characterization of stations in the Haut-Nyong and Mvilla watersheds

Watersheds	Streams	Stations Codes	Granulometry (%)			Nature of substrate
			Fine gravel	Coarse sand	Fine Sand	
Haut-Nyong	CDC	CDC 1	10%	90%	0%	Coarse sand
		CDC 2	30%	69%	2%	
		CDC 3	42%	57%	2%	
	Djénassoumé	DJE 1	10%	89%	2%	
		DJE 2	47%	50%	3%	
		DJE 3	20%	78%	2%	
	Andzié	AND 1	38%	59%	4%	
		AND 2	3%	92%	5%	
		AND 3	22%	77%	1%	
	Sena	SEN 1	7%	92%	0%	
		SEN 2	25%	73%	2%	
		SEN 3	76%	23%	1%	Fine gravel
Mvilla	Bengo'o	BEN 1	13%	82%	5%	Coarse sand
		BEN 2	4%	92%	4%	
		BEN 3	5%	91%	4%	
	Sounou	SOU 1	16%	83%	1%	
		SOU 2	27%	71%	1%	
		SOU 3	18%	81%	1%	
	Lo'o	LO'O 1	48%	50%	2%	
		LO'O 2	36%	62%	2%	
		LO'O 3	57%	41%	2%	
	Metyi	MET 1	59%	40%	2%	Fine gravel
		MET 2	88%	11%	1%	

Stations Codes : CDC 1, CDC 2, CDC 3, DJE 1, DJE 2, DJE 3, AND 1, AND 2, AND 3, SEN 1, SEN 2, SEN 3, BEN 1, BEN 2, BEN 3, SOU 1, SOU 2, SOU 3, LO'O 1, LO'O 2, LO'O 3, MET 1, MET 2

Table 3 Abundance of benthic macroinvertebrates according to the nature of substrate in the stations studied

Substrate	Fg+R	Cs+Dl	Cs+Ma	M+Cs	M+Cs+Dl	M+Cs+Dl+Ma	M+Cs+Fg	M+Cs+Fg+Dl	M+Cs+Ma
Stations Families	SEN3	DJE1, DJE2	AND3	BEN1	CDC1,CDC2,CDC3,DJE3,SEN1,SEN2, SOU1,SOU2,SOU3,LOO1,LOO2,LOO3	AND1, AND2	MET2	MET1	BEN2,BEN3
Aeshnidae					13		2	2	7
Atyidae		28	5	18	1807	55	37	21	39
Belostomatidae		64		31	246	19	23	15	32
Baetidae				1	13		15	4	13
Blaberidae		245	125	119	2837	611	99	79	249
Caenidae				1	4		2	2	7
Calopterygidae					70		1		
Ceratopogonidae					3				
Chironomidae	6	15		4	154		1		
Coenagrionidae		5	1	8	35	2	24	6	12
Corduliidae		2			14	4			
Dixidae					5				2
Dryopidae					24				5
Dytiscidae	20	26	62	24	222	53	40	32	43
Ecnomidae					6				
Elmidae		7	11	3	32	61	9	4	1
Ephemerellidae		6			49		9		9
Gerridae	16	3	14	17	191	26	15		36
Gomphidae	20	47	6	10	230	41	3		22

Gyrinidae	11	67	60	229	700	140	51	55	234
Hydrometridae	15	3	44	1	99	7		3	7
Heptageniidae				6	50		2	1	30
Hydraenidae				2	17		12	4	17
Hydrophilidae	16	28	39	30	177	51	11	24	18
Hydroptilidae		2			23	12			
Hydropsychidae				5	87		18		6
Leptophlebiidae		7		2	431	10	4	1	3
Libellulidae		52	10	25	220	3	18	20	30
Lumbricidae		2			13	4	2		2
Macromiidae		7			15	3			
Naucoridae	7	16	7	10	50	34	2	8	6
Neoperlidae					10		42		45
Nepidae	36	43	4	8	297	38	2	7	15
Noteridae	26	32	21	5	91	26	2	3	5
Notonectidae	10	5	17	10	83	4	2	12	11
Perlidae		2			19				
Palaemonidae		1		13	207	16	33	10	20
Phryganeidae					5				2
Psilidae		21	8		63	22			
Sphaeriidae	17	193	64		200	24			
Planorbidae				1	7			3	5
Potamidae		7	4		120	2	6		8
Ptychopteridae					6			1	4
Scatophagidae					7				2

Sciomyzidae					7				
Scirtidae				1	7			3	13
Thiaridae						8	32		23
Unionidae				1	28			3	21
Veliidae	23	15	12	7	369	113	65	18	97

Legend: Cs: Coarse sand; Dl: Dead leaves; Fg: Fine gravel; M: Mud; Ma: Macrophytes; R: Rock

Table 4 Abundance of benthic macroinvertebrates families in the stations studied

Stations / Families	**CDC 1**	**CDC 2**	**CDC 3**	**DJE 1**	**DJE 2**	**DJE 3**	**AND 1**	**AND 2**	**AND 3**	**SEN 1**	**SEN 2**	**SEN 3**	**MET 1**	**MET 2**	**BEN 1**	**BEN 2**	**BEN 3**	**SOU 1**	**SOU 2**	**SOU 3**	**LOO 1**	**LOO 2**	**LOO 3**
Aeshnidae	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	5	2	1	0	1	0	4	7
Atyidae	40	9	13	28	0	30	14	41	5	7	20	0	21	37	18	20	19	381	658	277	135	189	48
Belostomatidae	9	21	0	26	38	19	19	0	0	7	0	0	15	23	31	15	17	27	48	18	21	47	29
Baetidae	0	0	0	0	0	0	0	0	0	0	0	0	4	15	1	5	8	1	2	4	2	0	4
Blaberidae	201	132	209	145	100	208	348	263	125	186	250	0	79	99	119	135	114	409	370	248	194	194	236
Caenidae	0	0	0	0	0	0	0	0	0	0	0	0	2	2	1	5	2	0	1	2	1	0	0
Calopterygidae	0	0	0	0	0	7	0	0	0	10	12	0	0	1	0	0	0	9	7	10	5	4	6
Ceratopogonidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0
Chironomidae	7	0	121	8	7	0	0	0	0	25	0	6	0	1	4	0	0	1	0	0	0	0	0
Corduliidae	0	0	13	0	1	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coenagrionidae	0	7	6	0	5	2	1	1	1	2	0	0	6	11	2	6	6	10	6	5	3	8	5
Dixidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	3	1	1	0	0
Dryopidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	1	4	4	0	5	10
Dytiscidae	74	31	0	17	9	4	42	11	62	39	2	20	32	40	24	25	18	5	14	12	20	7	14
Ecnomidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	2

Elmidae	0	0	4	0	7	0	43	18	11	0	14	0	4	9	3	0	1	4	2	2	1	0	5
Ephemerellidae	0	0	0	6	0	6	0	0	0	0	0	0	0	9	0	5	4	4	6	10	2	7	14
Gerridae	13	16	7	1	2	13	26	0	16	25	32	16	28	13	17	20	16	9	7	18	8	4	11
Gomphidae	37	37	0	21	26	16	32	8	6	0	27	20	4	3	10	11	9	29	16	17	10	18	22
Gyrinidae	90	48	28	31	36	54	70	70	60	49	8	11	55	51	229	166	68	69	77	49	45	128	55
Hydrometridae	36	11	0	0	3	1	0	7	44	0	21	15	3	0	1	4	3	2	1	8	4	9	6
Heptageniidae	0	0	0	0	0	0	0	0	0	0	0	0	1	2	6	11	19	7	0	11	10	7	15
Hydraenidae	0	0	0	0	0	0	0	0	0	0	0	0	4	12	2	4	13	6	0	4	5	0	2
Hydrophilidae	29	18	5	13	15	0	32	19	39	21	21	16	24	11	30	6	12	9	9	17	10	13	25
Hydroptilidae	6	9	0	0	2	8	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropsychidae	0	0	0	0	0	0	0	0	0	0	0	0	0	18	5	3	3	20	9	6	2	25	25
Leptophlebiidae	14	10	0	3	4	0	6	4	0	3	7	0	1	4	2	2	1	165	53	30	52	57	40
Libellulidae	15	2	5	25	34	5	3	0	7	0	9	0	20	17	25	11	18	25	39	36	29	27	26
Lumbricidae	0	4	0	1	1	1	0	4	0	3	1	0	0	2	0	1	1	3	0	0	1	0	0
Macromiidae	0	4	0	0	7	3	3	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0
Naucoridae	9	3	0	8	8	9	16	18	7	2	9	7	8	2	10	1	5	4	4	5	2	1	2
Neoperlidae	0	0	0	0	0	0	0	0	0	0	0	0	0	42	0	28	17	0	0	4	5	0	1
Nepidae	30	74	0	21	22	18	29	9	4	26	37	36	7	2	8	8	7	10	15	19	19	30	19
Noteridae	34	6	1	4	28	16	11	15	21	14	4	26	3	2	5	0	5	4	6	2	2	1	1
Notonectidae	0	14	0	5	0	2	0	4	17	13	8	10	12	2	10	7	4	2	11	7	6	20	0
Perlidae	11	2	0	1	1	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0
Palaemonidae	12	4	4	0	1	0	0	16	0	12	0	0	10	33	13	6	14	26	21	24	56	31	17
Phryganeidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	2	0	0	2
Psilidae	8	22	0	21	0	0	14	8	8	13	16	0	0	0	0	0	0	0	0	0	2	1	1
Sphaeriidae	0	4	0	78	115	100	24	0	64	65	31	17	0	0	0	0	0	0	0	0	0	0	0

Planorbidae	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	1	4	0	2	1	0	0	4
Potamidae	1	1	0	2	5	0	0	2	4	0	0	0	0	6	0	5	3	43	33	11	8	17	6
Ptychopteridae	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	4	1	0	0	0	0	5
Scatophagidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	1	0	2	2
Sciomyzidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	4
Scirtidae	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	5	8	0	2	0	1	0	4
Thiaridae	0	0	0	0	0	0	0	8	0	0	0	0	0	32	0	21	2	0	0	0	0	0	0
Unionidae	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	21	0	0	15	3	0	7	3
Veliidae	25	13	11	5	10	71	4	109	12	17	39	23	18	65	7	70	27	44	47	51	10	20	21
Total	701	502	427	470	487	595	753	635	513	547	574	223	373	568	586	634	464	1332	1493	921	676	885	699

Stations Codes : CDC 1, CDC 2, CDC 3, DJE 1, DJE 2, DJE 3, AND 1, AND 2, AND 3, SEN 1, SEN 2, SEN 3, BEN 1, BEN 2, BEN 3, SOU 1, SOU 2, SOU 3, LO'O 1, LO'O 2, LO'O 3, MET 1, MET 2

3.3. Benthic macroinvertebrates (MIBs)

The taxonomic richness and abundance related to in the 15058 benthic macroinvertebrates collected belonged to 5 classes, 14 orders (Blattaria, Hemiptera, Odonata, Coleoptera, Diptera, Clitellatea, Trichoptera, Ephemerella, Plecoptera, Decapoda, Mesogasteropoda, Unionida, Veneroida, and Caenogasteropoda) and 49 families (Tables 3 and 4). Insects were the most abundant with a relative abundance of 79%, followed by Malacostraca (16%), Bivalva (4%) and Gastropoda (1%) (Figure 6). In the CDC stream the orders Blattaria (33.3%), Coleoptera (22.6%), Heteroptera (17.9%), Diptera (9.7%), Odonata (7.7%), Decapoda (5.2%) were predominant. In the Djenassoume stream, Blattaria (29.2%), Veneroida (18.9%), Heteroptera (18.2%), Odonata (9.9%) dominated the fauna. The Andzie stream was distinguished by the emergence of Blattaria (38.7%), Coleoptera (27.6%), Heteroptera (17.9%), and the Sena stream by Blattaria (32.4%), Heteroptera (25.5%), Coleoptera (18.2%) and Veneroida (8.4%). The Metyi stream showed the dominance of Coleoptera (22.6%), Heteroptera (21.0%), Blattaria (18.9%) and Decapoda (11.4%). In the Bengo'o stream, Coleoptera (37.4%) was predominant followed by Blattaria (21.9%) and Heteroptera (17.1%). The Sounou river was distinguished by the supremacy of Decapoda (39.3%) followed by Blattaria (27.4%), Heteroptera (9.5%) and Coleoptera (8.1%). Then come Lo'o river characterized by the dominance of Blattaria (27.6%), Decapoda (22.4%), Coleoptera (15.7%), Heteroptera (12.8%), Ephemeroptera (9.3%) and Odonata (7.7%) (Tableau 5).

Table 5 Relative abundance of benthic macroinvertebrate orders in the rivers studied

Streams / Order	CDC	Djenassoume	Andzie	SENA	Metyi	Bengo’o	Sounou	Lo’o
Blattaria	33.3%	29.2%	38.7%	32.4%	18.9%	21.9%	27.4%	27.6%
Diptera	9.7%	2.3%	1.6%	4.5%	0.2%	0.7%	0.3%	0.9%
Coleoptera	2.6%	15.1%	27.6%	18.2%	26.6%	37.4%	8.1%	15.5%
Heteroptera	17.9%	18.2%	17.9%	25.5%	21.0%	17.1%	9.5%	12.8%
Odonata	7.7%	9.9%	3.5%	6.5%	7.0%	6.2%	5.6%	7.7%
Ephemeroptera	1.5%	1.2%	0.5%	0.7%	4.3%	4.3%	7.9%	9.3%
Plecoptera	0.8%	0.1%	0.0%	0.4%	4.5%	2.7%	0.1%	0.3%
Tricoptera	0.9%	0.6%	0.6%	0.0%	1.9%	0.8%	1.0%	2.6%
Decapoda	5.2%	4.3%	4.3%	2.9%	11.4%	5.8%	39.3%	22.4%
Mesogasteropoda	0.0%	0.0%	0.0%	0.0%	0.3%	0.4%	0.1%	0.2%
Unionida	0.0%	0.0%	0.0%	0.0%	0.3%	1.3%	0.5%	0.4%
Veneroida	0.2%	18.9%	4.6%	8.4%	0.0%	0.0%	0.0%	0.0%
Caenogastropoda	0.0%	0.0%	0.4%	0.0%	3.4%	0.0%	0.0%	0.0%
Clitellata	0.2%	0.2%	0.2%	0.3%	0.2%	0.1%	0.1%	0.0%

3.4. Data analysis

The principal component analysis (Figure 3) led to a distribution of taxa around axes 1 and 2. The latter explain 77.78% of the variability observed, 47.61% of which is explained by axis 1 and 30.17% by axis 2. The benthic macroinvertebrates are distributed in three main groups. The first group was composed of Blaberidae, Atyidae, Potamidae, Belostomatidae, Ceratopogonidae, Ephemerillidae, Palaemonidae, Hydropsychidae, Ecnomidae found at the stations LO’O 1, LO’O 2, LO’O 3, SOU 1, SOU 2 and SOU 2 characterized by a good water oxygenation and low nitrogen content. The second group consists of Thiaridae, Neoperlidae, Scirtidae, Gyrinidae, Veliidae, Hydraenidae, Beatidae, Planorbidae, Aeshnidae, Unionidae colonizing the stations BEN 1, BEN 2, BEN 3, MET 1 and MET 2 characterized by waters rich in nitrogenous matter and slightly acidic. The third group of Naucoridae, Lumbricidae, Gomphidae, Spercheidae, Cordulidae, Chironomidae, Dytiscidae, Hydrophilidae, Noteridae, Hydrophilidae, Hydrometridae, Elmidae found at the streams CDC, Andzié, Djénassoumé and SENA characterized by waters rich in organic matter.

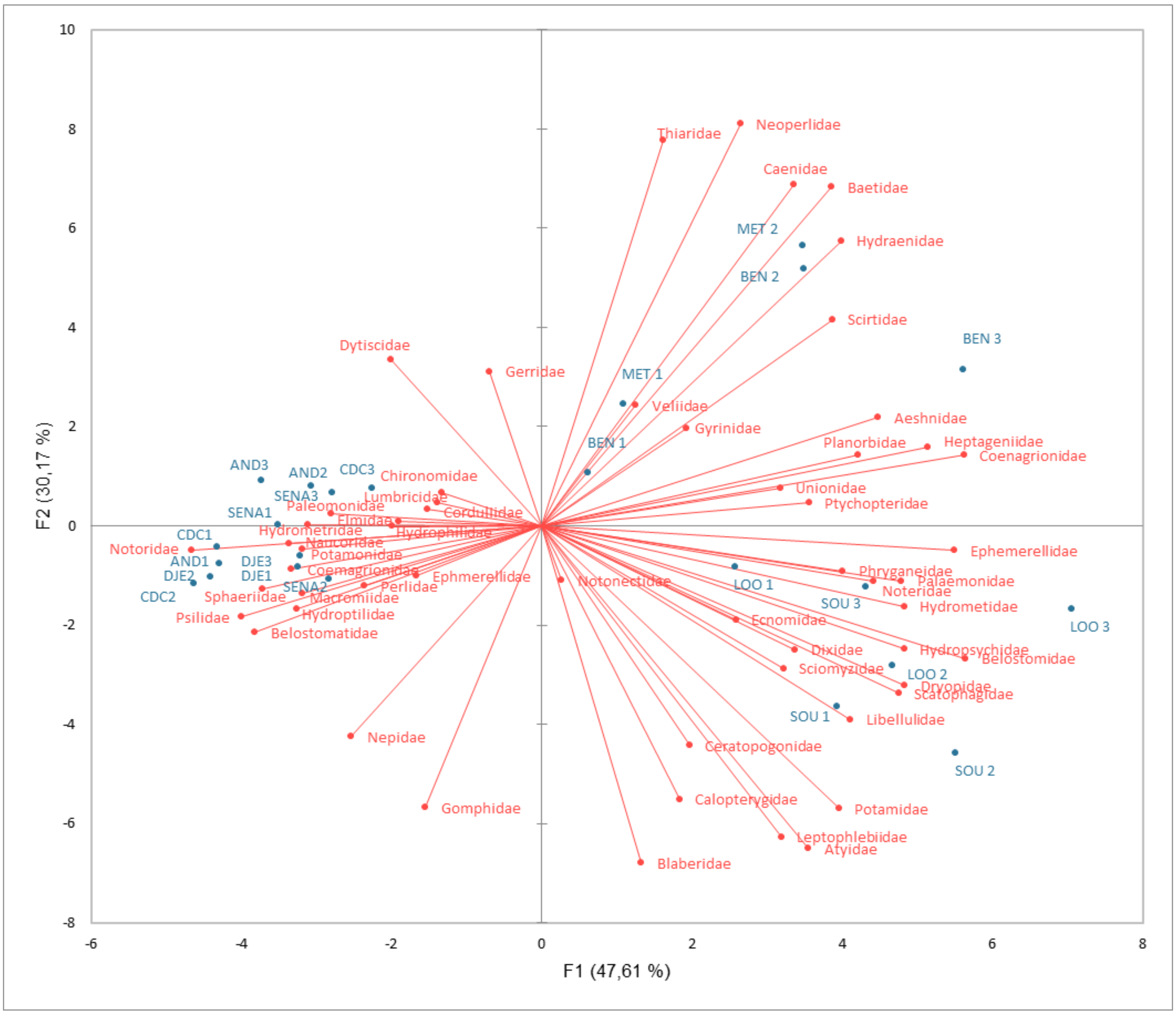


Figure 3 Principal component analysis of MIB families and stations

Regarding the distribution of benthic macroinvertebrates according to the substrates, 10 orders were considered, including Blattaria (29%), Coleoptera (19%), Decapoda (16%), Heteroptera (16%), Odonata (7%), Ephemeroptera (5%), Veneroida (3%), Diptera (2%), Plecoptera (1%), Trichoptera (1%), Caenogastropoda (0.4%), Clitellata (0.2%), Unionida (0.4%), Mesogasteropoda (0.1%) (Figure 4).

With regard to Correspondence factor analysis (CFA) (Figure 5), in substrates (Fg+R) containing fine gravel and pebbles, 13 families of benthic macroinvertebrates were collected. The most predominant are Nepidae, Dytiscidae, Gomphidae and Noteridae colonizing station SEN3 characterized by polluted water (Figure 5). The In substrates (Cs+Dl) consisting of coarse sand and dead leaves, 29 families were recorded. The most predominant are Blaberidae, Sphaeriidae, Gyrinidae and Belostomatidae found at the stations DJE1, DJE2 characterized by low acid waters (Figure 5). In the substrates (Cs+Ma) comprising coarse sand and macrophytes, 19 families were counted. The most predominant are Blaberidae, found at the stations AND3 characterized by water with low dissolved carbon dioxide content (Figure 5). In substrates (M+Cs) made up of mud and coarse sand, 28 families were obtained. The most predominant are Gyrinidae and Blaberidae found at the station BEN1 characterized by slightly alkaline water (Figure 5). In the substrates (M+Cs+Dl) containing mud, coarse sand and dead leaves, 48 families were counted. Families such as the Blaberidae, Atyidae, Gyrinidae, Leptophlebiidae and Veliidae were dominant at the stations CDC1, CDC2, CDC3, DJE3, SEN1, SEN2, SOU1, SOU2, SOU3, LOO1, LOO2 and LOO3 characterized by water good oxygenated, low acid and low organic matter. In substrates (M+Cs+Dl+Ma) comprising mud, coarse sand, dead leaves and macrophytes, 27 families were collected. The most predominant are Blaberidae, Gyrinidae and Veliidae found at the stations AND1 and AND2 characterized by waters with low nitrogen content (Figure 5). In the substrates (M+Cs+Fg) containing mud, coarse sand and fine gravel, 31 families were counted and in substrates (M+Cs+Fg+Dl) composed of mud, coarse sand, fine gravel and dead leaves 26, families were counted. The most predominant are Dytiscidae, Gyrinidae and Veliidae present at the stations MET and MET2 with waters rich in organic matter. At last, in substrates (M+Cs+Ma) comprising mud, coarse sand, fine gravel and dead leaves, 38 families were obtained. The most predominant are Blaberidae, Gyrinidae and Veliidae found at the station BEN2 and BEN3 characterized by good oxygenated and low acid water (Figure 5) results showed that the substrate (M+Cs+Dl) containing mud, coarse sand and dead leaves presented the highest taxonomic richness and diversification of MIBs (Figure 5).

The hierarchical ascending classification (Figure 6) permitted to evaluate the dissimilarity between the stations and the taxa of benthic macroinvertebrates showing that these stations can be divided into two groups (Figure 6). Group I included stations CD1, CD2, CD3, DJE1, DJE2, DJE3, AND1, AND2, AND3, SEN1, SEN2, SEN3, MET1, MET2, BEN1, BEN2, BEN3 and LOO3, and group II led to stations SOU1, SOU2, SOU3, LOO1 and LOO2, with a substrate including mud, coarse sand and dead leaves.

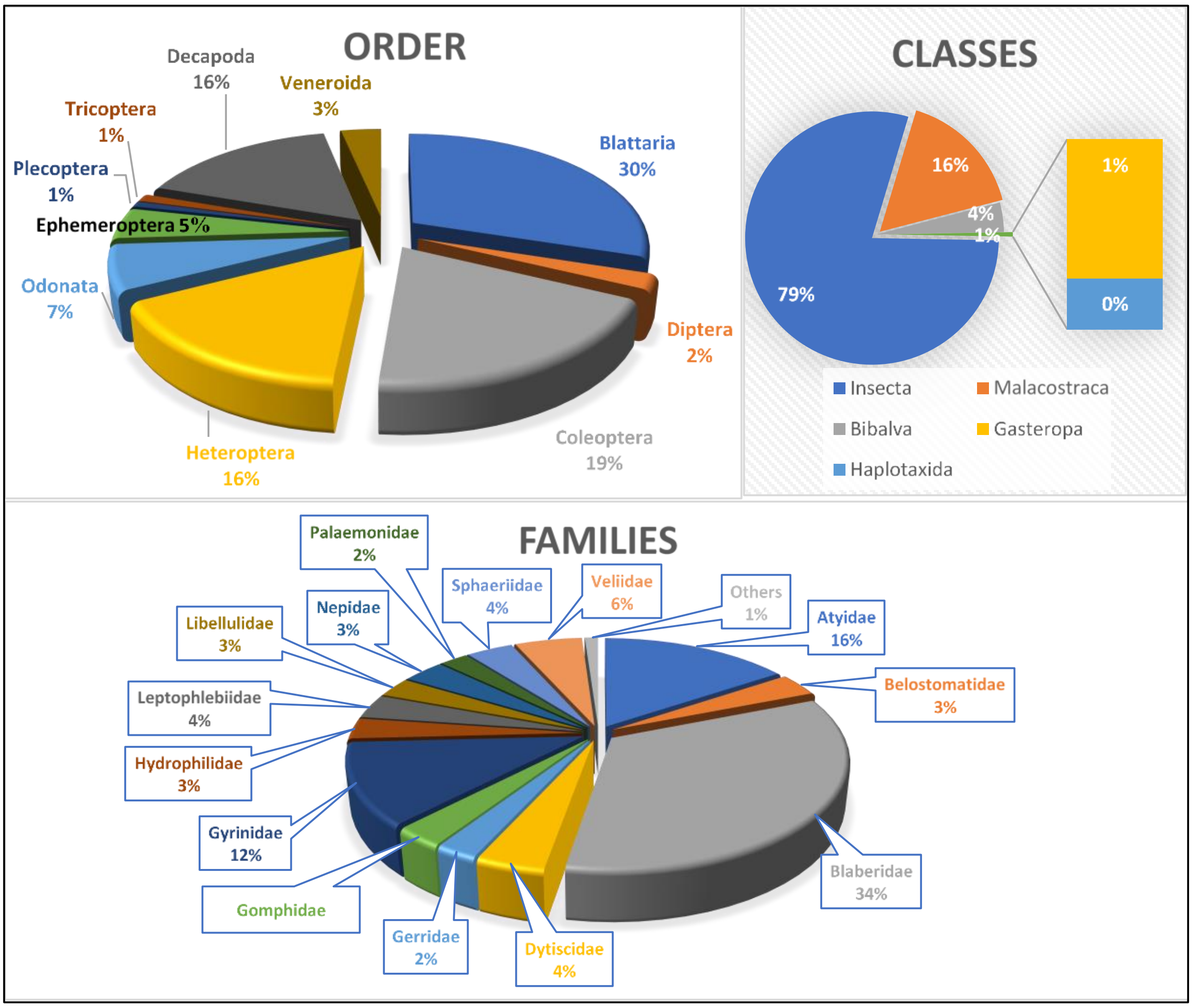


Figure 4 Relative abundance of MIBs in all studied watersheds

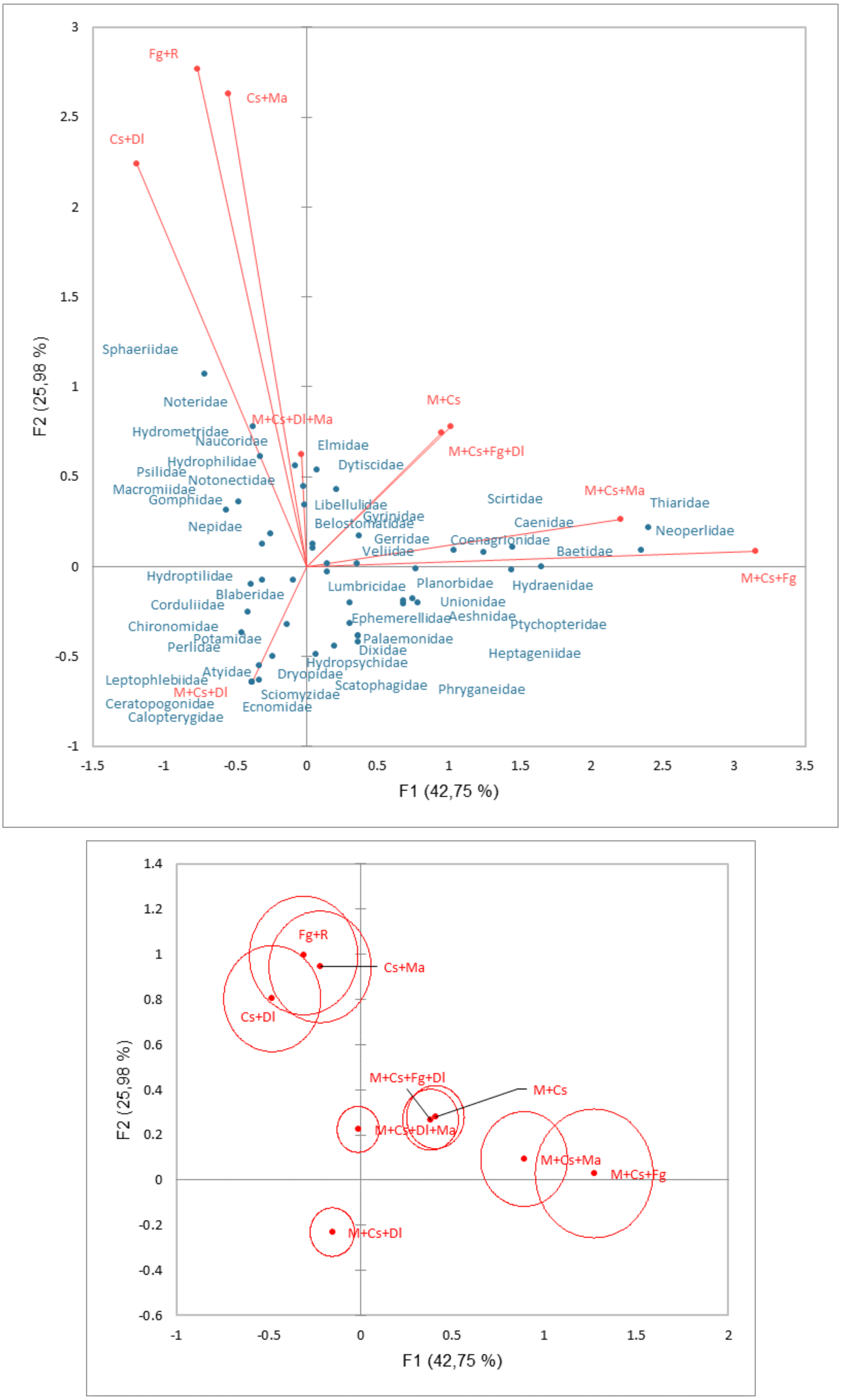


Figure 5 Correspondence Factor Analysis on MIBs and different substrates

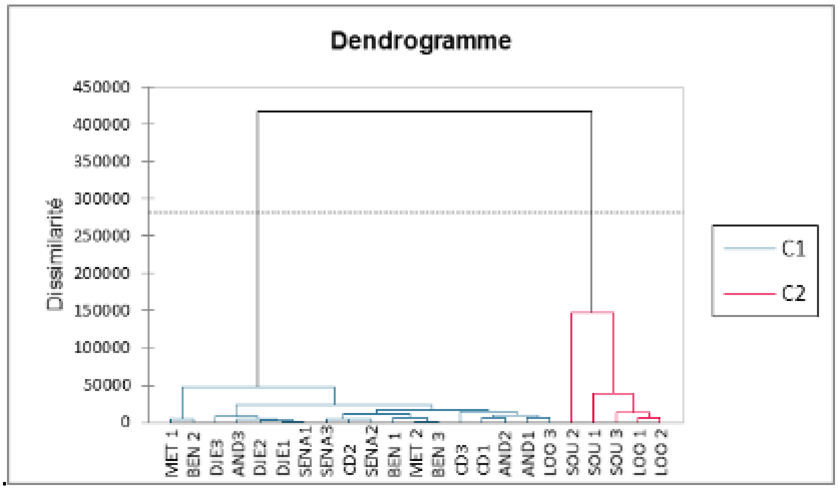


Figure 6 Hierarchical Ascending classification of stations according to MIBs

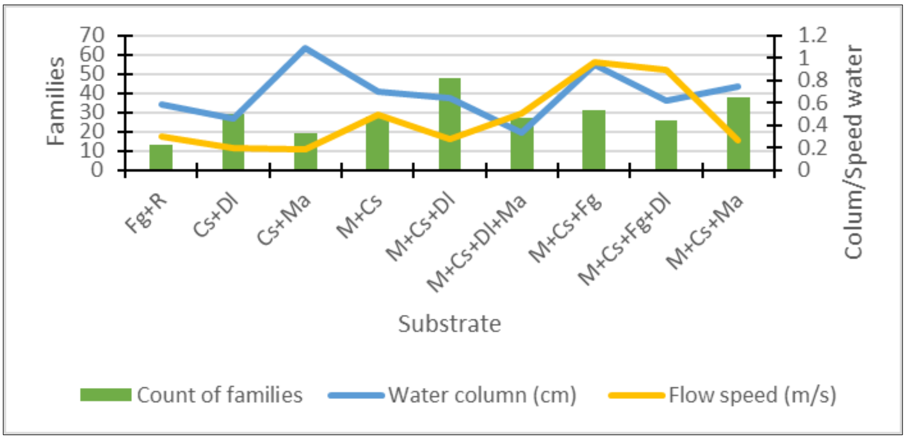


Figure 7 Distribution of families according to hydrological parameters in each biotope studied

3.5. Diversity index

The value of the Shannon and Weaver diversity index varied between 2.97 at station CDC3 and 5.05 at station LOO3 for a mean value of 4.10±0.39. The Simpson's diversity index ranged from 0.71 at station SOU2 to 0.95 at stations CDC1, BEN1, and LOO3 for a mean value of 0.89±0.04. As for the Pielou equitability Index, it varied between 0.54 at station SOU2 and 0.89 at stations CDC1 and SENA3 for a mean value of 0.77±0.07 (Figure 8).

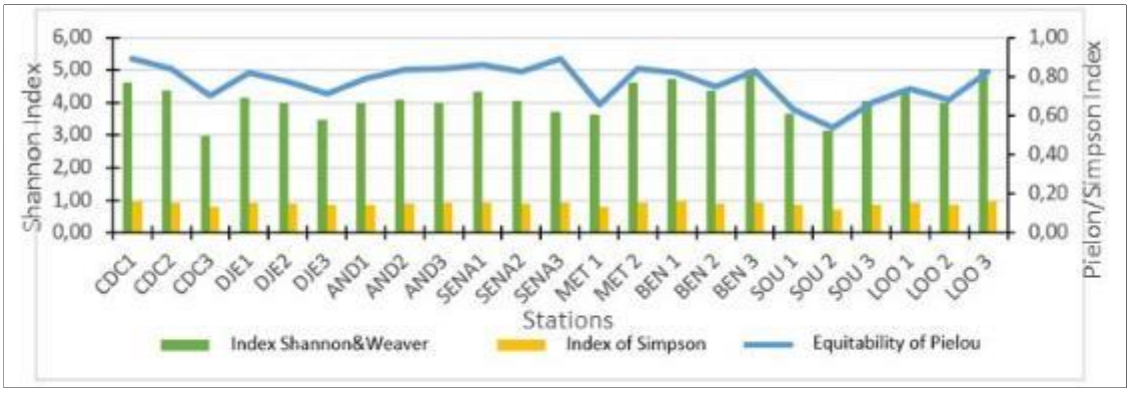


Figure 8 Spatial values of diversity indices at each studied station

4. Discussion

In the hydrosystems studied, 9 types of substrates were collected, which can be reorganized into 3 categories according to the importance mud, sand or gravel. This result corroborates the observations of Kamb *et al*. (2015) who showed that habitat quality is a defining feature of the environment with respect to the nature, abundance and population structure of benthic macroinvertebrates. However, our results also showed that the distribution of organisms in headwater streams is strongly influenced by current velocity and depth (Mboye *et al*., 2018). This study also showed a predominance of benthic macroinvertebrates on substrates dominated by sand, mud and dead leaves, at shallow depths and average current speed. This substrate characterized by sand, mud and dead leaves, is subservient to families such as the Blaberidae, Atyidae, Gyrinidae, Leptophlebiidae and Veliidae reflect a very good water ecological quality.

As for the physico-chemical parameters, the values of oxygen, temperature, and nitrogenous elements showed satisfactory levels favourable to the development of a large, rich and diversified community of benthic macroinvertebrates. In addition, the influence of the nature of the substrate on the distribution of organisms was established and agrees with the observations of Ward (1992), Jowett (1993), De Crespin & Usseglio-Polatera (2002). In this regard, Mboye *et al*. (2018), AQUA & GAS (2016), UNESCO (1996) point out that the distribution of benthic macroinvertebrates taxa is strongly influenced by the size of the substrate particles.

The taxonomic richness observed in the two catchments as a whole showed that the 8 streams host a rich and diverse fauna, with the CDC stream counting 28 families, Djenassoume (30 families), Andzie (27 families), Sena (26 families), Metyi (36 families), Bengo'o (39 families), Sounou (41 families), Lo'o (41 families), values higher than those obtained in Kinshasa, in Gombe (16 families), Kinkusa (16 families) and Mangengenge (24 families) streams by Kamb *et al*., (2015). However, the cumulative taxonomic richness of 49 families is lower than that obtained by (Mboye *et al*., 2018) in the Maboumié watershed in Gabon (90 families). The organisms collected in all 23 stations reveal the predominance of Blaberidae with 29% of relative abundance followed by Atyidae (13%). These results are contrary to those of (Mboye *et al*., 2018). The distribution of taxa on all 9 types of substrates shows the supremacy of the order Blattaria with 30% of relative abundance followed by Coleoptera (19%), Decapoda and Heteroptera with respectively 16% of relative abundance.

These results are different from those of Tchakonté *et al*. (2014). Overall, the insect class predominates with 79% of relative abundance followed by Malacostraca (16%). These values are higher than those of Kamb *et al*. (2015) in Congo (75% of relative abundance). Diomande *et al*. (2009) and Foto *et al*. (2010) also showed a predominance of insects in the Agnebi and Nga rivers respectively.

In all the streams, the EPT group was observed except Andzié stream which hosted only Ephemeroptera. The Bengo'o, Sounou, Lo'o and CDC streams had relative EPT abundances above 9%, reflecting the good ecological quality of the water. These observations are similar to the results of Biram *et al*. (2018) and Mboye *et al*. (2018). Our observations corroborate those of Alhou *et al*. (2009).

5. Conclusion

This study allowed us to make an inventory of the benthic macroinvertebrate population in the Mvilla and Haut-Nyong catchment areas in relation to their respective habitats. Thus, in the 8 rivers studied, 9 types of substrates were observed, resulting from combinations of mud, sand, gravel, dead leaves and macrophytes. Of all these results, the substrate composed of mud, coarse sand and dead leaves (M+Cs+Dl) was the most biogenic as it harbored the richest and most diverse fauna. The insect class predominates with 79% of relative abundance followed by Malacostraca (16%). The taxonomic richness coupled with the univariate and multivariate analyses indicate that the Sounou, Bengo'o and Lo'o streams are of good ecological quality.

Compliance with ethical standards

Acknowledgments

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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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