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Composition and Structure of Aquatic Macroinvertebrate Communities in Mining Areas Streams (Côte d'Ivoire, West Africa)

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Abstract

The existence of mining areas for decades could potentially affect aquatic environments and human health. This study allowed assessing the effects of mining activities on streams in three mining areas (Hiré, Lauzoua and Tortiya). Macroinvertebrates were collected on eight campaigns at eight stations using a hand-net, an Ekman grab and surber net. Environmental variables were recorded also. In this study the conductivity values were higher in the locality of Hiré. It was between 154.2 µS / cm (Tchindégri station) and 1753 µS / cm (Tributary Gbloh station). The highest temperature values were recorded in the stations of Tortiya locality (24 ^{o} C: Bou 2; 33.1 ^{o} C: Bou 1). A total of 184 taxa distributed among nine classes, 20 orders, 80 families and comprising 14 401 individuals were recorded. Insecta were the most diversified class in macroinvertebrate community (84% of taxa collected, eight orders and 59 families). Ecological indices (Shannon Weiner, rarefied richness, Pielou's evenness) were significantly low at Lauzoua (N'Téko station) and Hiré (Tributary Gbloh station) (Mann-Whitney test, P <0.05). Ecological indices showed no significant variation between the stations of the locality of Tortiya. The PCA had grouped the stations into four clusters. Conductivity, ammonium, phosphate, nitrites, and nitrates were significantly higher (Mann- Whitney test, P < 0.05) in cluster I (Tributary Gbloh station) Compared to other clusters. Eight taxa (*Limnius* sp., *Liberonautes chaperi*, *Gordius* sp., *Phyllogomphus* sp., *Orectogyrus* sp., *Bezzia* sp., *Adenophlebiodes*, *Parasedodes* sp.) were specific to Tchindégri station (Hiré) and six taxa (*Naucoris* sp., *Amphiops* sp., *Hydrobius* sp., *Pseudobagous longulus*, *Culicina*e and *Gomphus* sp.) were associated to the Bou 1 and Bou 2 stations (Tortiya).

Keywords: aquatic macroinvertebrates, composition, structure, mining activities, streams, Côte d' Ivoire

1. Introduction

Mining become widespread around the world due to the excessive price of certain metals and minerals. Metal prices are very high these days (World bank, 2019). In Côte d'Ivoire, gold and manganese are the two main minerals mined on an industrial scale (Fair Links, 2013). For example, four gold mining companies were created (Society of mining of Ity, Newcrest, Yaouré Mining and Tongon) since 2011 (Sodemi, 2012) as well as two manganese mining companies on an industrial scale (NABC and Boundoukou Manganese) (Koffi *et al.*, 2014).

Human activities around streams such as mining has the most negative environmental impact, although seen as a beneficial activity in terms of socio-economic fallout (Bridge, 2004; Yapi *et al*., 2014). Processing activities resulting from mining exploration and development degrade the natural environment by polluting soil and water with tailings (Paquet, 2012). Indeed, among the mining wastes on earth, sulphide mine tailings are the most important and likely to produce acid mine drainage (AMD) (Dold, 2014). The AMD is responsible for the acid metalification of water. Water contaminated with AMD can be toxic to aquatic organisms (Battaglia *et al*., 2005; Mc Tammany, 2007).

The integrity of aquatic ecosystems is now based on quantify existing biological communities, including aquatic macroinvertebrates, which are the most commonly used bioindicators (Clarke *et al.* 2002). Indeed, these organisms are present at different water strata (Sanogo *et al*., 2014). They are good bioindicators because of their sedentary lifestyle, long-life cycle, great diversity and variable tolerance to pollution and habitat degradation (Moretti and Callisto, 2005).

In many parts of the country, authorized and non-authorized mining are located, especially in Hiré, Lauzoua and Tortiya localities. Wastes from these mining activities can cover the surface of stream sediments, destroying habitat and reducing niches and nursery areas of aquatic macroinvertebrates (Jennings *et al.*, 2008). In Côte d'Ivoire several studies explored the impact of mining activities based on the chemical quality of water (Coulibaly *et al*., 2009; Keumean *et al*., 2013; Yapi *et al*., 2014). However, there is a lack of study in Côte d'Ivoire using a biological community, especially macroinvertebrates, in order to assess the impact of mining activities on the rivers near the mining sites. This study will fill informations gap that will constitute a baseline for further studies.

This study aimed to inventory aquatic macroinvertebrates, to determine their composition, their structure and impacts of mining activities on communities of macroinvertebrates collected in streams in mining areas in order to assess their ecological quality.

2. Materials and Methods

2.1 Environment Variables

At each sampling station and each campaign, nine physicochemical parameters were measured using a variety of instruments. Conductivity was determined using a multi-parameter HANNA HI98703. A turbidimeter HANNA (HI 98703) was used to measure the turbidity and Dissolved oxygen was measured with an oximeter type HANNA HI9146. The pH and temperature were determined with a pH meter type HANNA HI991001. Water was also collected with bottle of 1 L at each sampling station for nutrients (ammonium, nitrate, nitrite, and phosphate) analysis in the laboratory.

2.2 Study Areas and Sampling Stations

The study was conducted in three mining areas in Côte d'Ivoire: Tortiya in the north (diamond mining), Hiré (gold mining) and Lauzoua (manganese mining) in the south of the country. Three streams were sampled in Hiré (Tributary Gbloh, Gbloh, Tchindégri) and lauzoua (Tributary Dougodou, Dougodou, N'Téko). In the town of Tortiya, the Bou stream was sampled. These localities were chosen according mining activities. Sampling stations (Figure 1) were selected according their accessibility, the permanence of water at any time and the potential presence of the impacts of mining activities. In each stream one station has been defined, except the Bou stream where two stations (Bou 1 and Bou 2) have been defined. The characteristics of the stations are listed in Table 1.

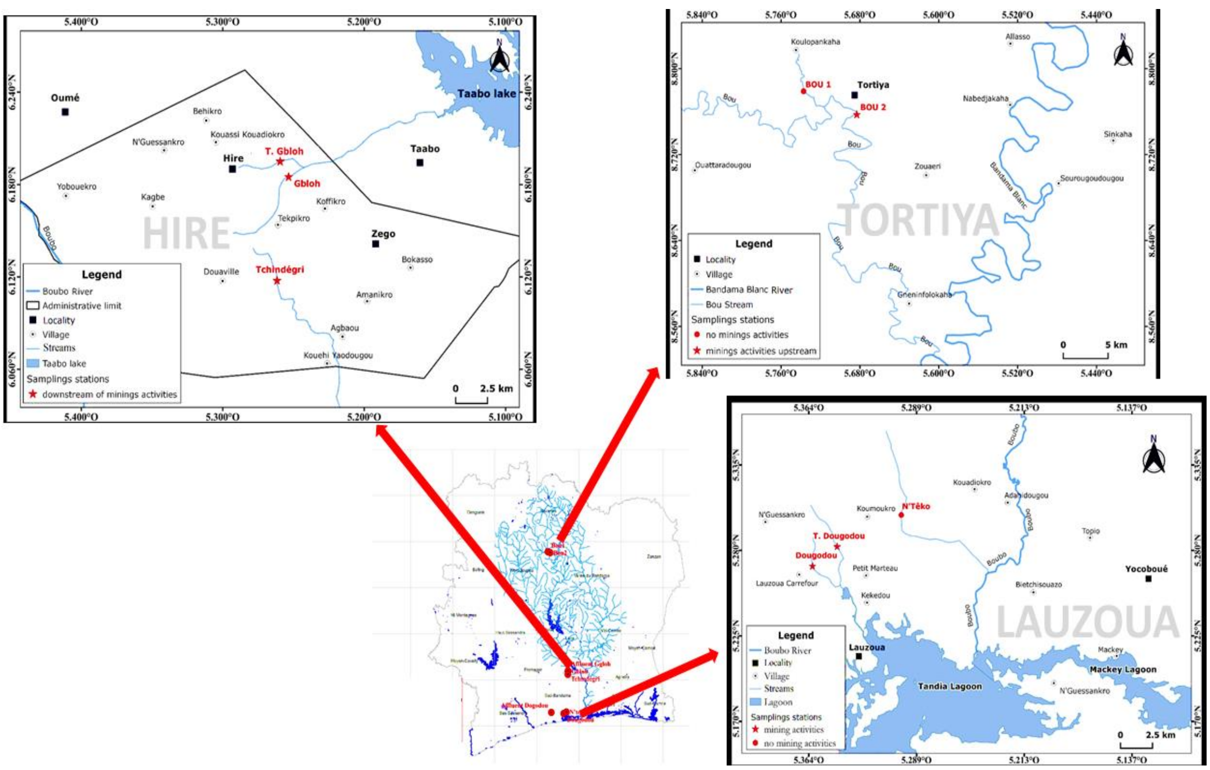


Figure 1. Maps of streams and sampling station

Table 1. Characteristics of sampling stations

LOCALITIES	TORTIYA		HIRE			LAUZOUA		
Streams	Bou		Gbloh	Tributary Gbloh	Tchindegri	Dougodou	Tributary Dougodou	N'Teko
Stations	Bou 1	Bou 2	Gbloh	Tributary Gbloh	Tchindegri	Dougodou	Tributary Dougodou	N'teko
Codes	B1	B2	G	TG	Tg	D	TD	NT
Latitude	200619	387252	250551	249927	200615	238101	240225	245176
Longitude	970058	595637	684486	685437	970060	582993	584411	546616
Altitude (m)	300	343	191	168	189	4	1	4
Land occupation and mining activities	Mahogany plantation, food, fishing, no mining activity	Fishing, washing cars and beef, abandoned diamond mining and artisanal mining	Teak, food and cocoa plantations, artisanal and industrial gold mining	Gold mining company	Cocoa plantations and abandoned gold mining	Cocoa plantations, village, manganese mining	Manganese mining, food and cocoa plantations, village,	Cocoa plantations, no mining activity
Average width (m)	30	35	3	2,5	5	6	4	8
Deep width (m)	3,5	4	0,9	1,5	1,1	4,5	4	5
Canopy (%)	0	0	90	5	20	50	5	80
Substrate	dominated by compact clay and mud	dominated by compact clay and gravel	dominated by sand	dominated by clay	mostly muddy and sandy	mostly sandy	dominated by compact clay and mud	mostly compact clay

2.3 Macroinvertebrate Sampling and Identification

Macroinvertebrates were collected during eight campaigns (from November 2017 to January 2019) at each sampling station. Three gears were used to sample aquatic macroinvertebrates: Hand net (250 µm mesh, 50 cm length), Surber net (25 x 20 cm) and an Ekman grab (0.115 m^2). The samples were sieved in the field through a 1mm mesh sieve, and the material retained on the mesh was immediately fixed in 70% alcohol. In the laboratory, macroinvertebrates were identified to the lowest possible taxonomic level using a stereomicroscope Olympus SZ (40× magnification) and a series of identification keys (Monod, 1966; Dégoux *et al*., 1981; Day *et al.*, 2001; Day *et al.,* 2003; De Moor *et al*., 2003a; De Moor *et al*., 2003b; Stals & De Moor, 2007 & Tachet *et al*., 2010).

2.4 Data Analysis

Aquatic macroinvertebrates structure was described through taxonomic composition, rarefied richness, Shannon-Weiner index, Pielou’s Evenness index, frequency of occurrence and Trichoptera, Plecoptera and Ephemeroptera index (EPT). Taxa richness was rarefied to eliminate any bias related to differences in abundances between samples (Heck *et al*., 1975; Edia *et al*., 2016). Calculations were performed using the lowest abundance (11 individuals for this study) found in all stations as the target number of individuals (Oksanen *et al.,* 2013). Trichoptera, Plecoptera and Ephemeroptera index (EPT) was also determined at all stations with the aim of determining the impact of mining activities on the water quality of the studied stations.This index represents the relative abundance of these three groups among macroinvertebrates collected at all the stations.

The Frequency of occurrence (FO) was calculated at all sampling station. FO is the percentage of samples in which each taxon occurred. It was calculated according to Dajoz (2000) to gives some information on the number of taxa frequently met in each station without any indication on their quantitative importance (Lauzanne, 1976; Hyslop, 1980).

In order to assess the structure of macroinvertebrate communities, in each mining area, between-stations variations of abovementionned indices were determined using Kruskal- Wallis and Mann-Whitney tests.

Principal Component Analysis (PCA) using the euclidean distance was performed to ordinates sampling stations according to environmental variables. A Hierarchical Classification Analysis (CAH) was performed on PCA axes in order to cluster sampling stations with similar environmental conditions. This analysis was carried out using the Factomine R and factoextra packages.

Variations of physico-chemical parameters and diversity indices (rarefied richness and Shannon-Weiner index) between clusters were assessed using Kruskal-Wallis and Mann- Whitney tests in order to characterize each group of stations. Before performing the comparison test, the normality of data was checked by Shapiro test.

Characteristic taxa of each group were determined through Indicator Value Method (Indval) (Dufrêne & Legendre, 1997). This method matches information on species abundance and frequency of occurrence among groups. A Monte Carlo permutation test was employed to test significant associations of taxa and group of sites ($p < 0.05$). The indicspecies package was used to perform this analysis. Data analyses were performed using R software version 3.6.3.

3. Results

3.1 Environmental Variables

Variations of temperature, conductivity, turbidity, pH, dissolved oxygen, nitrate, nitrite, phosphate and ammonium between stations are summarized in Table 2. Temperature, pH and dissolved oxygen did not vary significantly between stations in the three localities (Kuskal-Wallis and Mann- Whitney tests, $p > 0.05$). The highest and lowest values of temperature were observed in Tortiya locality respectively in Bou 2 station (24 ℃) and Bou 1 station (33.1). The pH varied from 6.15 (N'Téko station, Lauzoua) to 8.69 (Tributary Gbloh station, Hiré). Dissolveld oxygen values oscillated between 1.76 mg / L (Tributary Dougodou station, Lauzoua) and 12.71 mg / L (Tributary Gbloh station, Hiré). Conductivity and turbidity did not vary significantly between the stations of Tortiya (Mann Whitney test $p > 0.05$). However, these parameters were statistically higher (Mann- Whitney test, $p < 0.05$) respectively in Tributary Gbloh and Gbloh stations, in the locality of Hiré. Turbidity was significantly higher in Tributary Dougodou station, in Lauzoua locality. Concerning nutrients, excepted in Hiré locality, nitrate, nitrite, phosphate and ammonium did not varied significantly between stations in studied localities (Kruskal-Wallis and Mann- Whitney tests, $p > 0.05$).

Table 2. Environmental variables measured sampling stations in three mining areas (Côte d'Ivoire), T= temperature; CND= conductivity; Turb= turbidity; DO= dissolved oxygen, $Phos^-$ = phosphate; Amo= ammonium)

Localities	Stations	Values	T (℃)	CND (µS/cm)	pH	DO (mg/L)	Turb (NTU)	Nitrate (mg/L)	Nitrite (mg/L)	Amo (mg/L)	Phos (mg/L)
Tortiya	B 1	Min	25.3	108.1	6.31	2.62	16.5	2.2	0.009	0.08	0.04
		Med	30.5	150	6.82	4.84	56.73	4.25	0.017	0.415	0.215
		Max	33.1	199.3	7.22	8.58	170.67	22.4	0.055	6.15	3.64
	B 2	Min	24	65.9	6.52	2.4	4.3	3	0.015	0.1	0.03
		Med	28.2	107.3	6.68	4.71	22.21	5.05	0.02	1.185	0.303
		Max	30.3	412	7.45	12.5	308.67	41.6	0.154	5.65	1.93
Lauzoua	D	Min	25.7	106.6	6.33	2.02	8.39	2.4	0.012	0.03	0.11
		Med	26.9	176.6	6.84	4.31	10.55	6.85	0.02	0.42	0.22
		Max	32.1	375	8.17	8.65	24.73	36.2	0.175	0.78	0.93
	TD	Min	25.3	101.5	6.23	1.76	19.4	1.2	0.014	0.038	0.03
		Med	27.2	192.1	6.93	4.2	39.35	3.5	0.031	0.54	0.295
		Max	28.4	452	7.64	8.8	225.67	31.4	0.072	0.79	2.61
	NT	Min	24.1	141.7	6.15	2.38	9.64	4.1	0.017	0.29	0.13
		Med	25.9	211.6	6.85	3.5	23.07	8.1	0.031	0.44	0.46

		Max	26.5	225.1	7.33	8.19	88.73	22.5	0.091	0.82	4.3
Hiré	G	Min	25.4	316	6.65	2.37	28.43	2.4	0.008	0.05	0.12
		Med	26.4	579.8	6.92	5.71	101.28	3.8	0.025	0.745	0.74
		Max	28	946	7.69	9.74	710.33	8.2	0.087	0.97	2.01
	TG	Min	25	1162	6.54	6.71	102.3	34.1	0.205	2.05	0.97
		Med	27.5	1286	7.16	7.95	134.5	47.95	0.328	3.19	1.75
		Max	29.7	1753	8.69	8.47	189.3	59.6	0.512	4.88	2.77
	Tg	Min	24.4	154.2	6.36	6.57	42	27.4	0.1	0.11	0.2
		Med	26.15	194.2	7.13	8.26	73.89	40.35	0.117	0.251	1.24
		Max	29.9	241.3	7.24	12.71	120.33	50.3	0.19	0.59	1.84

3.2 Taxonomic Richness and Composition

Table 3 shows macroinvertebrate composition of studied streams in three mining areas. A total of 176 different taxa (genus and species) belonging to nine classes (Insecta, Gastropoda, Malacostraceae, Acheata, Oligochaeta, Arachnids, Gordiaceae, Nematoda and Bivalves), 20 orders and 75 families comprising 14 401 individuals were collected. Taxonomic richness was dominated by insects (84.78%) divided in eight orders: Coleoptera, Diptera, Ephemeroptera, Hemiptera, Lepidoptera, Odonates, Plecoptera and Trichoptera and 57 families.

A total of 104 different taxa belonging to eight classes (Acheata, Arachnids, Bivalves, Gastropoda, Gordiaceae, Insecta, Malacostraceae, Oligochaeta,), 15 orders and 48 families comprising 3,355 individuals were collected in the locality of Tortiya.

In Lauzoua locality, a total of 142 different taxa belonging to nine classes (Acheata, Arachnids, Bivalves, Gastropoda, Gordiaceae, Insecta, Malacostraceae, Nematoda and Oligochaeta), 19 orders and 65 families comprising 6 630 individuals were collected.

In Hiré, 133 taxa belonging to eight classes (Acheata, Arachnids, Bivalves, Gastropoda, Gordiaceae, Insecta, Malacostraceae, Oligochaeta,), 17 orders and 63 families comprising 4,416 individuals were collected.

Taxonomic richness was dominated by insects in all localities (87: Tortiya, 123: Lauzoua, Hiré = 112). The main orders of insects encountered in these localities were: Diptera (Tortiya=36.13%; Lauzoua = 33.68% and Hiré = 29.43%); Odonata (Tortiya = 20.74%; Lauzoua = 16.07% and Hiré = 21.09%), Coleoptera (Tortiya = 15, 45%, Lauzoua = 13.31% and Hiré = 16.02%). This class was most abundant in Lauzoua (48.62%) and Tortiya (80.59%). However, macroinvertabrates community was numerically dominated by Gastropods in Hiré (61.50%). In all the stations, rare taxa were the most abundant except in Lauzoua where they were in very low proportion (6.67%, N'Téko station). The highest percentage (25.64%) of very frequent taxa was found in Tortiya (Bou 2 station) and the lowest (12.50%) in Hiré (Tributary Gbloh station). Frequent taxa were abundant in Lauzoua precisely in N'Téko station (71.11%). Their lowest proportion (20.73%) was found in Hiré (Tchindégri station).

Table 3. Taxonomic list and occurencies of macroinvertebrates collected; *** (Very frequent taxa), **(Frequent taxa), *(Rare taxa)

Stations codes (D: Dougodou, TD: Tributary Dougodou, NT: N'Teko, G: Gbloh, TG: Tributary Gbloh, Tg: Tchindégri, B1: Bou1, B2: Bou2)

				LAUZOUA				**HIRE**		**TORTIYA**	
CLASS	ORDER	FAMILIES	TAXA	D	T D	NT	G	TG	Tg	B1	B2
Acheata	Pharyngodelliformes	Erpobdeliidae	*Dina* sp.		x						
	Rhynchobdelliformes	Glossiphoniidae	*Glossiphonia* sp.	x	xx			x			x
			Haementeria sp.		x						x
			Helobdella sp.	xxx	xxx	xxx	x	xx	xx	x	x
Oligocheata	ind	ind	*Oligochètes*	xxx	xx	xx	x	x	xx		xx
Bivalves	Sphaeriida	Sphaeriidae	*Pisidium* sp.	**x**			**x**			**x**	
	Unionoida	Corbuliidae	*Corbula gibba*	xxx	xxx		xxx		x		
	Unionoida	Unionidae	*Pseudanodonta* sp.							x	
Gastropoda	Basommatophora	Lymnaeidae	Lymnaea natalensis	xx	xxx	xx	xxx	xxx		xxx	xxx
		Physidae	*Physa marmorata*	xx	x	xx	xxx	xxx		xx	xx
		Planorbidae	*Biomphalaria pfeifferi*	xxx	xxx	xx	xxx	xxx	xx	xxx	xx
			Bulinus forskalii	x	xx	xx	xx		x	xxx	xx
			Bulinus globosus	xx	x		x		x	xxx	x
			Bulinus troncatus	xx	xxx		xx		x	xxx	xx
			Indoplanobis exustus	xxx	xxx	xx	xx	xxx	x	xxx	xxx
Gastropoda	Heterostropha	Pyramidellidae	*Megastomia conspicua*						x		
	Mesogastropoda	Ampullariidae	*Lanites varicus*	xx	xx	xxx	x		xx	xx	xxx
			Pila africana	xx	xxx	xx		xx	x		x
		Bithyniidae	*Bythinella* sp.				x				
			Gabiella africana	x	xxx	xxx	x	xx			
		Thiaridae	*Melanoides tuberculata*	xxx	xxx	xxx	xxx	xxx	xxx	x	xx
Gordiaces	Gordea	Gordiidae	*Gordius* sp.	xx	xx	xx	xx		x	x	
Nematode	Hoplonemertea	Tetrastemmatidae	*Prostoma* sp.		x						
	Mermithida	Mermithidae	*Mermithidae*	x	x						
Arachnids	Trombidiformes	Hydrachnidae	*Hydrachnella* sp.	xxx	xxx	xx	xxx	xx	xxx	xxx	xxx
Insecta	Coleoptera	Dytiscidae	***Dytiscus* sp.**		**x**	**xx**				**xx**	**x**
			Hydaticus sp.	xx	xx	xxx	xx	x		xx	xxx
			Hydrocoptus sp.		x		x			xx	xx
			Hydrovatus sp.	xx	x					xx	
			Hyphydrus sp.	x	x		xx				xx
			Laccophilus sp.	xxx	xxx		xx		x	xx	xxx
			Neptosternus sp.	xx	xx						
		Elmidae	*Dupophilus* sp.		x						
			Esolus sp.	x	x				x		x
			Leptelmis sp.	x			x				
			Limnius sp.	xxx	xxx		xx	xx	xxx	x	xx
			Macronychus sp.	x		x					

Table 3 continued

				LAUZOUA				HIRE		TORTIYA	
CLASS	ORDER	FAMILIES	TAXA	D	A D	NT	G	AG	Tg	B1	B2
Insecta	Coleoptera	Elmidae	*Peloriolus* sp							x	
			Potamodytes sp.		xx				x	x	
			Potamophilus sp.						x		
			Pseudancryonyx sp.				x				
			Riolus sp.	xx	xx						
		Gyrinidae	*Dineutus* sp.		xx		xx				
			Gyrinus sp.	x						x	
			Orectogyrus sp.	x	xx		x		x		
		Halipidae	*Halipus* sp.	x	x		x		x		
			Peltodytes sp.	x	xx						
		Hebdidae	*Hebdidae*		x						
			Helodidae				x				
		Hydraneidae	*Hydraena* sp.		x				x	x	xx
			Limnebius sp.	x						x	
			Mesoceriaton sp .						x		x
		Hydrophilidae	*Amphiops* sp.	xx	xx	xx	xxx		x	xxx	xxx
			Berosus sp.		x	xx	x			xx	
			Enochrus sp.	x	x		x		x	x	x
			Hydrobiinae		x	xx	xx	xx		xx	xx
			Hydrobius sp.		x			x		x	x
			Hydrochara sp.				x	xx		xxx	
			Polyphaga sp.	xx	xx		x				
Insecta	Coleoptera	Hydroscaphidae	*Hydroscapha* sp.								x
		Noteridae	*Noterus* sp.								x
		Scirtidae	*Cyphon* sp.							x	
			Helodes sp.						xx	x	
		Athericidae	*Atherix* sp.	x					x		
		Blephariceridae	*Clogmia* sp.	x							
	Diptera	Ceratopogonidae	*Atrichopogon* sp.		x		x		x	x	
			Bezzia sp.	xx	xx		xx		xxx	xx	x
			Culicoides sp.		x					x	x
		Charboridae	*Chaoborus* sp.						x	x	
		Chironomidae	*Ablabesmyia* sp.	xx	xxx		xx		xx	xxx	xx
			Chironomus sp.	xxx	xxx	xx	xx	x	x	xx	xx
			Cladotanytarsus sp.					x			
			Clinotanypus sp.	xx	xx				x		
			Cricotopus sp.							x	
			Cryptochironomus sp.	xxx	xx	xx	xx	xx	xxx	xxx	xxx
			Nilodorum sp.	xx	xx	xxx	xx		xxx	xx	xx
			Ortocladius sp.							x	
			Polypedilium sp.		xxx		xx	x	xx	xx	xx
			Procladius sp.	x			x			x	

Table 3 continued

				LAUZOUA			HIRE			TORTIYA	
CLASS	ORDER	FAMILIES	TAXA	D	A D	NT	G	AG	Tg	B1	B2
Insecta	Diptera	Chironomidae	*Stictochironomus* sp.	xxx	xxx		xxx	xx	xxx	xxx	xxx
			Tanypus sp.	xx					x		x
			Tanytarsus sp.	x							
			Xenochironomus sp.					x			x
		Culicidae	*Aedes* sp.					x		x	
			Anopheles sp.	x	xx		x			xx	x
			Culex sp.		xx		xx	x		xx	xx
			Culicinae	x	xx					xx	xx
		Dixidae	*Dixa* sp.						x		x
		Empididae	*Trichoclinocera* sp.	x			x				
		Muscidae	*Dolichopodid* sp.						x		
			Ephydrid sp	x							
		Psychodidae	*Psychodidae*		x		x		x		
		Simulidae	*Simulium* sp.	x	x				xx		
		Stratiomyidae	*Brachycera* sp.		x		x	x		x	x
		Syrphidae	*Eristales* sp.	x	x				x	x	
		Tabanidae	*Tabanus* sp.		x		x		x	x	x
		Thaumaleidae	*Thaumalea* sp.						x	x	x
		Tipulidae	*Limonia tipulipes*	x			x	x			x
	Ephemeroptera	Baetidae	*Baetis* sp.	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
			Cloeon sp.	xx	xx		xx		x	xx	xxx

Table 3 continued

				LAUZOUA			HIRE			TORTIYA	
CLASS	ORDER	FAMILIES	TAXA	D	A D	NT	G	AG	Tg	B1	B2
Insecta	Ephemeroptera	Baetidae	*Pseudocleon* sp.	x							
		Caenidae	*Caenis* sp.	xx	xxx	xx	xxx		xx	xx	xxx
		Heptageniidae	*Afronurus* sp.						x		
			Electrogena sp.		x		x				
		Leptophlebiidae	*Adenophlebiodes*	x					xx		
			Choroterpes sp.	x			x				
	Hemiptera	Belostomatidae	*Diplonychus* sp.	xxx	xxx	xx	xxx	x	x	xxx	xxx
			Limnogeton sp.	x	xxx			x			
		Gerridae	*Eurymetra* sp.	x	x		xx	x	xx	x	xx
			Gerris sp.								x
			Lymnogonus sp.	x	xx		xx	x	xx	xx	xx
			Rhagadotarsus sp.	x				x			
			Rhagovelia sp.	xx	xx		x	x	x	x	x
		Hydrometridae	*Hydrometra* sp.					xx		x	
		Mesoveliidae	*Mesovelia* sp.	xxx	xx	xx	xx	x	xx	xx	xx
		Naucoridae	*Naucoris* sp.	x	x	x	x	x	x	x	x
			Neomacrocoris sp.				xx	xx		xxx	xxx
		Nepidae	*Laccotrepes* sp.	x	xx		x	x		x	
		Notonectidae	*Anisops* sp.	x	xx	xx		xx	x	xx	xx
			Enithares sp.	x	x		x			x	xx
			Notonecta sp.	xx	x	xx	xx			xxx	

Table 3 continued

				LAUZOUA			HIRE			TORTIYA	
CLASS	ORDER	FAMILIES	TAXA	D	A D	NT	G	AG	Tg	B1	B2
Insecta	Hemiptera	Pentatomidae	*Podisus* sp.	x			x				
		Ranatridae	*Ranatra* sp.	x			x				
		Veliidae	*Microvelia* sp.	xx	xx		xx			x	xxx
	Lepidoptera	Pyralidae	*Elophila* sp.	xx	xx	xxx	x	xx		xx	xx
	Odonata	Calopterygidae	*Phaon* sp.		x	xx			x		
			Sapho bicolor	x							
		Chlorocyphidae	*Chlorocypha* sp.	xx			xx		x	x	
		Coenagrionidae	*Ceriagrion* sp.	xx	x		xx	xx	x	xx	xxx
			Coenagrion sp.	x		xx	xx		xx		
			Erythromma sp.		x						
			Pseudagrion sp.	xxx	xxx	x	xxx	xxx	xxx	xxx	xxx
		Corduliidae	*Cordulia* sp.	xx	xx	xx	xx	x	x	xx	xxx
	Odonata	Gomphidae	*Gomphus* sp.	x						xx	xx
			Ictinogomphus sp.	xx	x			x			x
			Paragomphus sp.	xx	xx		x	x		x	
			Phyllogomphus sp.	x	xx		x	x	xxx		
		Libellulidae	*Bradinopyga* sp.	xxx	xxx	xx	xx	x		xxx	xxx
			Chalcostephia sp.					x		x	
			Diplacodes sp.	x							
			Libellula sp.						x		
			Oplogastra sp.	xx	xxx	xx		x	x		x

Table 3 continued

				LAUZOUA			HIRE			TORTIYA	
CLASS	ORDER	FAMILIES	TAXA	D	A D	NT	G	AG	Tg	B1	B2
Insecta	Odonata	Libellulidae	*Sympertum* sp.								x
			Trithemis sp.		x		x	x			x
			Urothemis sp.		x			x		x	
			Zygonix sp.		x		x				
		Macromiidae	*Phyllomacronia* sp.	xx	xxx	xx	x		x	xxx	xx
	Plecoptera	Perlidae	*Neoperla* sp.	x	x		x			x	
	Trichoptera	Ecnomidae	*Ecnomus* sp.		xx						
		Goeridae	*Lithax* sp.		x						
		Glossomatidae	*Glossosoma*	x							
		Hydropsychidae	*Aethaloptera* sp.						x		
			Amphipsyche sp.	x	xx		x	x	xx		
			Cheumatopsyche sp.	xx	xxx	xxx	xx	xx	xxx	x	x
		Hydropsychidae	*Chimara* sp.	xx	x		xx				
			Hydropsyche sp.	xx	xx	xx	xx			x	x
			Polymorphanisus sp.	xxx	xxx	xx	x		x		
			Protomacronema		x						
		Hydroptilidae	*Hydroptila* sp.	x							
			Orthotrichia sp.	x							
		Leptoceridae	*Athripsodes* sp.		x						
			Ceraclea sp.	xx	xx		x	x			
			Leptocerus sp.						x		

Table 3 continued

					LAUZOUA			HIRE		TORTIYA	
CLASS	ORDER	FAMILIES	TAXA	D	A D	NT	G	AG	Tg	B1	B2
Insecta	Trichoptera	Leptoceridae	*Parasetodes* sp.	x		xx	x		xx		
			Setodes sp.	xxx	xx						
			Trianodes sp.		x				x	x	
			Trichosetodes sp.						x		
		Polycentropodidae	*Polycentropus* sp.		x						
Malacostracea	Decapoda	Atyidae	*Caridina africana*	xxx	xxx	xxx	xxx	x	xxx	xx	x
			Caridinopsis						x		
		Desmocarididae	*Desmocaris trispinosa*	x			x				
		Palaemonidae	*Macrobrachium Thysi*			xx					
			Macrobrachium Vollenhovenii	x		xx			x		
		Potamonautidae	*Liberonautes chaperi*		x	xx			xxx		
			Potamon sp.		xx		xx		x		
			Potamonautes sp.						x		
Taxonomic richness				107	111	46	91	55	81	86	76

3.3 Macroinvertebrate Structure

Figure 2 shows variations of diversities indices between stations. The rarefied richness in Lauzoua was ranged between 2.96 (N'Téko station) and 8.34 (Dougodou station). This index was significantly higher in Dougodou station (Mann- Whitney test $p < 0.05$). In Hiré, rarified richness was between 2.34 (Gbloh station) and 7.23 (Tchindégri station). This index was significantly lower at Gbloh station (Mann- Whitney test $p < 0.05$). Concerning Tortiya, this index oscillated between 3.37 and 8.75 (Bou 2 station).

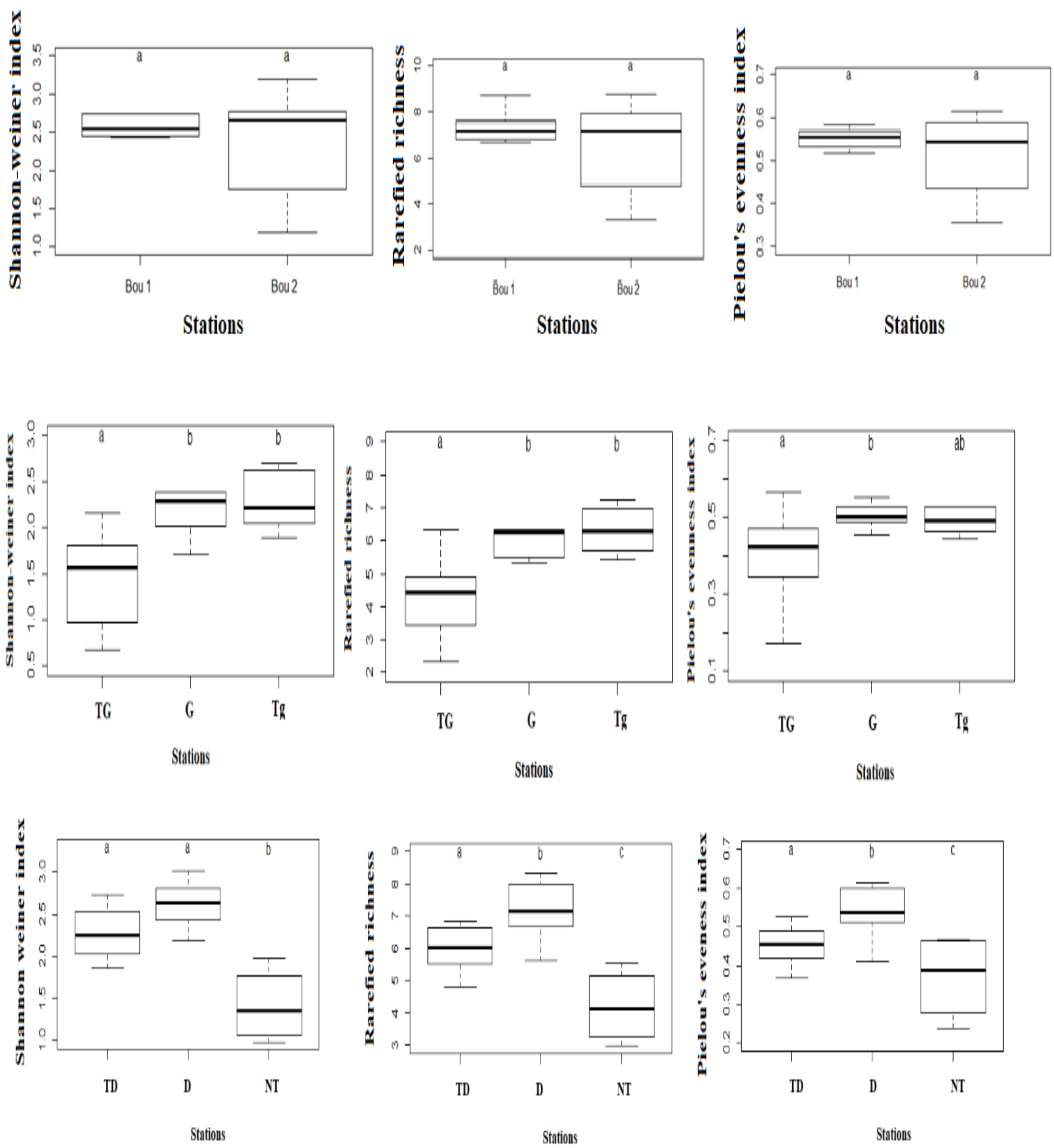


Figure 2. Boxplots showing differences in diversity indices (rarefied richness, Shannon Weiner, Pielou's evenness index) between sampling stations in three mining areas in Côte d'Ivoire. Different letters (a,b,c) on Boxplots denote significant differences between them (Mann- Whitney test, P< 0.05). B1- B2= TORTIYA, TD-NT= LAUZOUA, TG-Tg= HIRE

Shannon-Weiner index observed in Lauzoua, varied between 0.98 (N'Téko station) and 3.02 (Dougodou station). This index was significantly higher in Dougodou station (Mann- Whitney test p < 0. 05). In Hiré, it was located between 0.68 (Tributary Gbloh station) and 2.69 (Tchindégri station). Shannon-Weiner index was significantly lower in Tributary Gbloh station (Mann- Whitney test p < 0. 05). Regarding Tortiya, this index was ranged between 1.19 (Bou 2 station) and 3.3 (Bou 1 station).

The Pielou's Evenness Index in Lauzoua varied from 0.24 (N'Téko station) to 0.61 (Dougodou station). This index was significantly lower in N'Téko station (Mann- Whitney test p < 0. 05). In Hiré, this index oscillated between 0.17 and 0.56 (Tributary Gbloh station) and was significantly lower in Tributary Gbloh station (Mann-Whitney test p < 0. 05). In Tortiya, this parameter varied from 0.36 to 0.62 (Bou 2 station).

In Lauzoua, EPT percentage varied between 4.50% (N'Têko station) and 18.92% (Tributary Dougodou station). In the locality of Tortiya, the value of ETP index was 13% at the two stations (Bou 1 and Bou 2). Relative abundance of EPT was less than 6% in Hiré at all stations.

3.4 Abiotic and Taxonomic Differentiations of Sampling Stations

Principal component analysis (PCA) has established the abiotic typology of the stations studied (Figure 3). The first two axes expressed 52.4% of the total variance, 39.5% for axis 1 and 12.9% for axis 2 (Figure 3A). The correlation circle (Figure 3B) revealed that all of the physico-chemical parameters were negatively correlated to axis 1 excepted the temperature which was positively correlated to axis 2. The factor map (Figure 3C) distinguishes four groups of stations (Figure 3D).

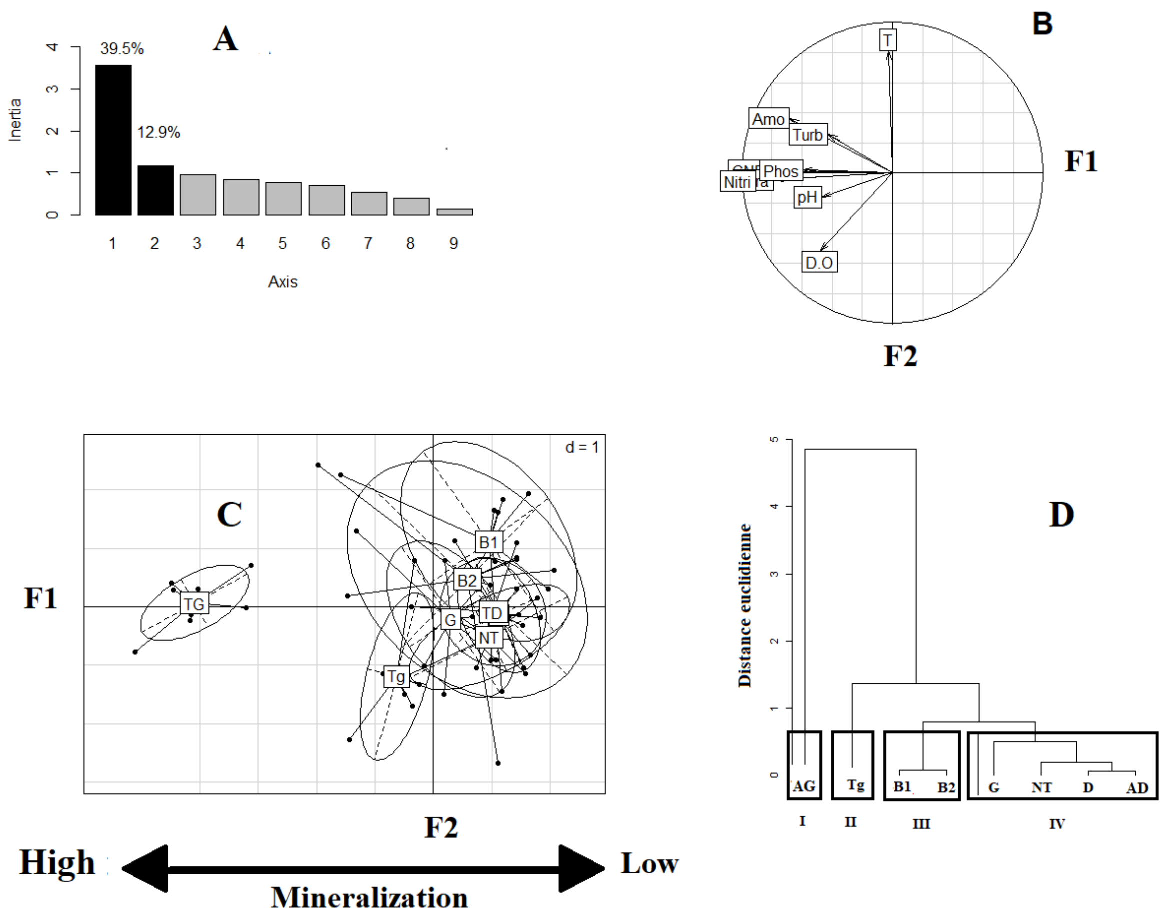


Figure 3. Ordination of physicochemical parameters of the stations studied from a Principal Component Analysis: TG to Tg = Stations codes; A = histogram of eigen values; B = circle of correlation; C = factoriel map; D= Hierarchical classification, from a Principal Component Analysis : I, II, III and IV = clusters. Amo = Ammonium; DO = Dissolved oxygen; Turb= Turbidity, Phos= Phosphate, CND= Conductivity.

Shannon Weiner index in cluster I ranged from 0.67 to 2.15. Concerning cluster II, this index was between 1.89 and 2.68. Shannon Weiner index of Group III was ranged between 2.48 and 2.74. The Shannon Weiner index of group IV ranged from 1.16 to 3.02.

Rarefied richness of group I ranged from 2.34 to 6.33. Rarefied richness index of Group II was between 5.41 and 7.23. Rarefied richness of Group III was ranged between 6.71 and 8.7. Rarefied richness of group IV ranged from 3.02 to 8.34. Rarefied richness and Shannon Weiner's index were significantly lower in cluster I (Mann Whitney test, P < 0.05) (Figure 4).

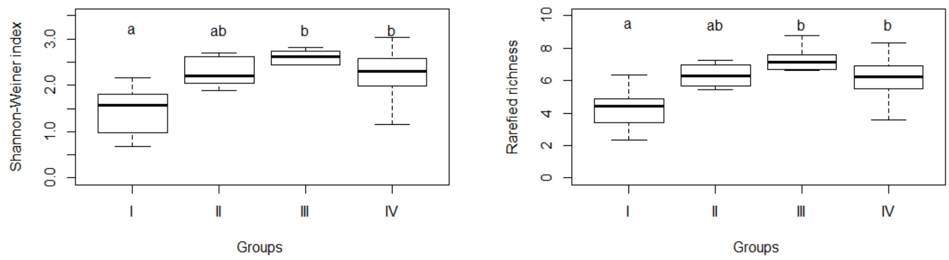
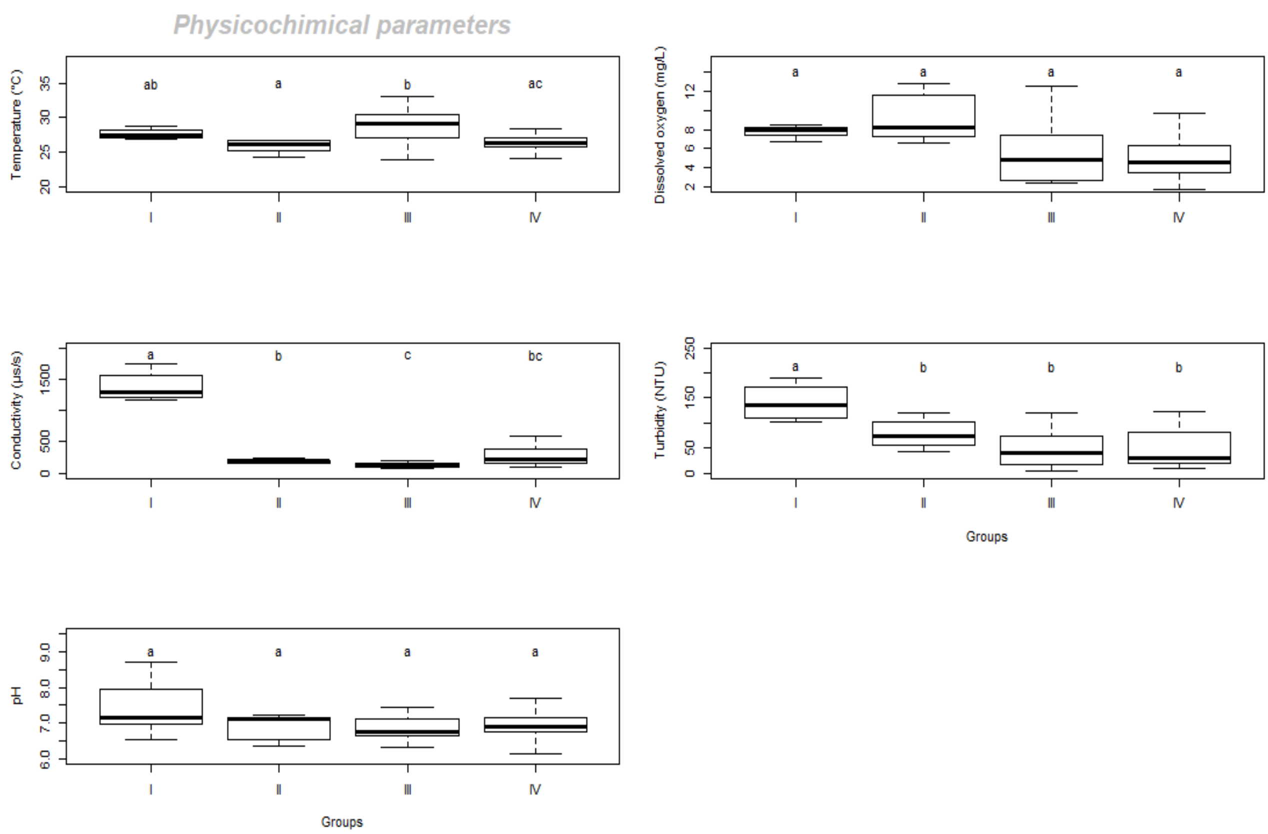


Figure 4. Rarefied richness and Shannon Weiner index of the four clusters obtained after the Hierarchical Classification Analysis. Different letters (a, b) on Boxplots denote significant differences between them (Mann-Whitney test, P < 0.05).

Cluster I consisted of samples from Tributary Gbloh station. It was characterized by higher values (Mann-Whitney test p < 0. 05) of conductivity (1214.5 – 1753), ammonium (2 - 4.8 mg/L), phosphate, nitrites and nitrates than those obtained in other clusters. Clusters I and II (samples of Tchindégri station) were characterized by higher values (Mann- Whitney test p < 0. 05) of phosphate, nitritres and nitrates comparatively of clusters III and IV. Concerning cluster III, it consisted of samples from stations Bou 1 and Bou 2. This group was characterized by higher values of temperature (24 - 33.1^{o} C) compared to the clusters II and IV (Figure 5). Stations of Group IV were characterized by low mineralization.



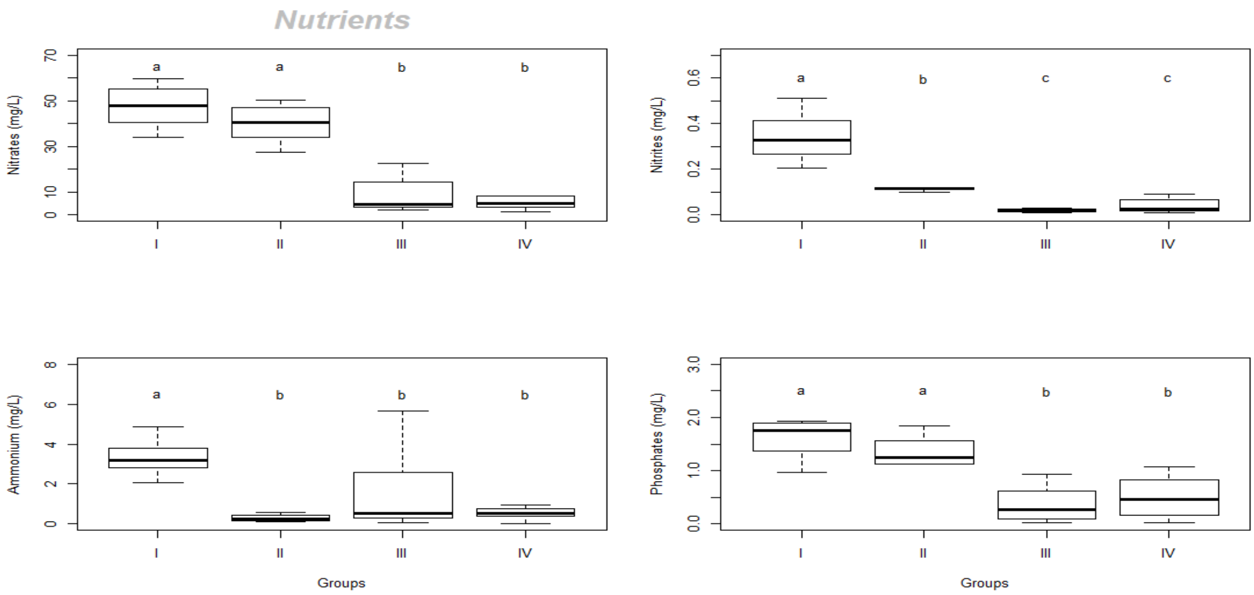


Figure 5. Boxplots showing differences in physicochemical parameters and nutrients concentrations between clusters (I–IV). Different letters (a, b, c) on Boxplots denote significant differences between them (Mann-Whitney test, $P < 0.05$).

Indval method revealed that eight taxa (*Limnius* sp., *Liberonautes chaperi*, *Gordius* sp., *Phyllogomphus* sp., *Orectogyrus* sp., *Bezzia* sp., *Adenophlebiodes*, *Parasedodes* sp.) were specific to the station Tchindégri (Hiré) and six taxa (*Naucoris* sp., *Amphiops* sp., *Hydrobius* sp., *Pseudobagous longulus*, *Culicina*e and *Gomphus* sp.) were associated at stations in the locality of Tortiya.

4. Discussion

During this study, the highest values of temperature were recorded in the stations of Tortiya locality. This could be due to the absence of canopy at these sampling stations. Indeed, any surface of water not covered is subject to a very important sunning thus favoring the increase of the temperature of the water.

The higher values of conductivity (1162 to 1753 µS / cm) registered in Tributary Gbloh station (Hiré) could be linked to the fact that this station was in an area subject to a permanent supply of effluent favoring the dissolution of the metals present in the rocks and sediments. These results corroborate those of Yapi *et al.* (2014) in this same locality.

Turbidity was higher in Tributay Gbloh station (102.3 to 189.3 NTU: Hiré). This situation could be explained by the location of this stream in downstream which receive particles from upstream areas where mining activities are practiced. These results corroborate those of Bamba *et al.* (2013) on the impact of mining on rivers which can destabilize the banks and lead to a massive sediment supply which can locally disturb the balance of the rivers and increase the turbidity of the water.

The abiotic typology of the stations by the PCA revealed that the Triblutary Gbloh station (cluster I) is distinguished from the other stations by high values of the mineralization parameters (conductivity, ammonium, nitrate, nitrite, phosphate). This high mineralization observed in this station could be explained by the drainage of agricultural products in this watercourse. Indeed, according to Brugneaux *et al.* (2004) and Troeh *et al.* (2004), by the action of rain that drains cultivated land, surface waters receive increased nutrient inputs.

The Indval method revealed that among the indicator taxa of Tchnidégri station, there were two polluo-sensitive organisms: *Adenophlebiodes* (Ephemeroptera, tolerance level = 2), *Parasetodes sp*. (Trichoptera, tolerance level = 4) recognized as good bio-indicators of watercourses because of their sensitivity to oxygen depletion (Hynes, 1957). We can therefore deduce that the waters of this station have a acceptable ecological quality.

A total of 184 aquatic macroinvertebrate taxa were collected and insects accounted for 84% of the taxa collected. Insects were the most abundant group among the macroinvertebrates collected in this study. Insects abundance could be explained by their omnipresence, which is due to their capacity for resilience. In several studies insects were most abundant (Diomandé *et al*., 2009; Akindele & Liadi, 2014).

In Hiré, the lowest rarefied richness (2.34) was obtained at Gbloh station. This station had the lowest values of Shannon Weiner index (0.68) and Pielou's eveness (0.17) index. These results obtained could indicate that this station was the most impacted by gold mining, which would have an impact on aquatic macroinvertebrate assemblages. According to Rosenberg & Resh (1993), human perturbations change community structure in watercourses because species are adapted to certain environmental conditions. The low diversity in this station may reflect the response of benthic macroinvertebrates to the toxicity in this station. This could be attributed to the loss of habitat diversity due to the reduction of ecological niches. The highest values of the Shannon Weiner index were obtained in Lauzoua and Tortiya respectively at Dougodou (3.02) and Bou 1 (3.2) stations. These results show that the aquatic macroinvertebrates of these stations were most diversified which could reflect good water quality at these stations.

EPT taxa are sensitive macroinvertebrates. They are met usually in water of good quality. This group were present at all stations with different proportions. These organisms were mainly composed of Baetidae (*Baetis* sp, Ephemeroptera) and Hydropsychidae (*Hydropsyche* sp., Trichoptera). These organisms are sensitive to metal pollution (Malmquist & Hoffsten, 1999) but can recolonized rapidly disturbed stations (Kiffney & Clements, 1994). The Tributary Gbloh station was the most affected by gold mining in Hiré with an EPT proportion of 4.91%. In Lauzoua, N'Téko station recorded the lowest proportion (4.50%) of EPT. However, there was no mining activity at this station. The low proportion of EPT at this station may be due to other human activities. In Tortiya locality, EPT proportions were relatively higher: 13.62% in Bou 1 and 12.30% in Bou 2. Diamond mining has little impact on station water quality. These proportions obtained could be explained by the fact that no metal is used in diamond mining. One of the limitations of this study is the number of sampling points chosen which should have been several on each station instead of choosing only one sampling point. However, the results show plausible consequences of mining on the quality of rivers, therefore alert the authorities to provide guidance on the consumption of drinking water by populations near these sites.

5. Conclusion

This study allowed to collect macroinvertebrates from three mining areas. Gold and manganiferous mining had an impact on macroinvertebrate communities. However, this impact was more significant in the streams near mining operation. Comparing to the latter two mining sites, diamond mining causes least disturbances to macroinvertebrate communities. Therefore, gold and manganiferous mining have most impact on the ecological quality of the studied rivers. Based on findings, actions must be conducted in these mining areas in order to stop the impact of the tailings on the pollution of waters surrounding residential areas.

Acknowledgement

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