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Using physicochemicals variables and benthic macroinvertebrates for ecosystem health assessment of inland rivers of Togo

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ABSTRACT: Zio River catchment drains many cities that it receives waste, domestic and industrial effluents and its waters used to supply drinking water from downstream to upstream. Some schools use it in school canteens without treatment. Meanwhile, no study on tools of water resources management is done in this basin and whole of Togo. To fill this gap, the environmental variables and benthic macroinvertebrates assemblages were investigated to assess ecological integrity of the Zio River and its tributaries that varied in disturbance from upstream to downstream. Macroinvertebrates were sampled during four campaigns from 42 sites selected to correspond with different human activities in the catchment. The AFNOR methods were used for physicochemical analysis. Multivariate analyses (PCA) were applied to characterize sites typology and FCA for similarity between sites or taxa. The result showed that physicochemical variables of downstream sites, with the lower level of dissolved oxygen (0.6mgO2/L) and high contents of ion NH4 (5.6mg/L), KMn (30.7mgO2/L) and high Conductivity (10670µS/Cm) differ strongly form upstream sites. Downstream sites were characterized by presence of tolerant taxa such as Syrphidae and Hirudinae (Leeches), while Ephemeroptera, Plecoptera and Trichoptera dominated in upstream sites. Our result also revealed a significant correlation between biological indexes (EPT, Marg, RTFm) and some environmental variables such ion NH4, dissolved oxygen and ion Cl. Based on the results obtained, we recommend the use of both physicochemical variables and benthic macroinvertebrates to assess ecological status of rivers in Togo.

KEYWORDS: Zio River, Togo, physicochemical quality, biological index, macroinvertebrates, sensitivity.

1 INTRODUCTION

Water is a natural resource essential for human and life of any ecosystem. Maintaining water quality is a major concern for a society which must supply for increasingly important water needs [1]. Although we turn to groundwater for drinking water, surface water remains a very important resource for sustainable development. Rivers contribute to development by providing resources like food or energy (hydropower). These wetlands are often subject to a wide range of socio-economic activities such as agriculture, breeding, fisheries, aquaculture, mining (sand and gravel) and tourism [2], [3]. Despite the benefits and the services that they provide to humans, rivers are subject to strong negative impacts. Thus, water systems around the world are more or less modified by human activities [4]. In many parts of sub-Saharan Africa, wetlands are under high pressure due to land use and climate change although they are recognized as vital resources for food security and rural livelihoods [5]. The main gap to a good and sustainable management lies in to the lack of management tools. In many areas in the world invertebrates are used to characterize hydro-systems. In Togo and to larger extent in the whole of Africa, the use of benthic macroinvertebrate for assessment and monitoring of rivers or lakes is embryonic. The leading country in Africa, about benthic macro invertebrates use are South Africa, Ethiopia and Kenya [6], [7], [5], [8]. The Zio River is the only one perennial river feed Lake Togo in the south of Togo. It contributes greatly to irrigation. Its basin drains many cities, from which it receives waste, domestic and industrial effluents. Effect of those impacts on aquatic organisms need to be clarified. Despite these strong anthropogenic pressures, the water from Zio River is used for drinking water. Some schools use it in school canteens without treatment. Management of those ecosystems and risks related to human impact justify this study. Then, the main objective of this paper is to give bases for ecological assess of the Zio River. Specifically our aim is to analyze distribution and abundance of macroinvertebrate fauna of the Zio River in relation to the water quality. This will be the first steps to develop a multimetric index for Zio River assessment based on macroinvertebrates.

2 MATERIALS AND METHODS

2.1 STUDY AREA PRESENTATION

Zio River catchment drains a tapered area of about 3400 km². The catchment is oriented NNW-SSE and located between latitude 6°5’ and 7°18’N and longitude 0°15’ and 1°40’E (Figure 1). Zio River receives water from many tributaries from the abundantly watered Togo Mountains. At upstream, human activities in the basin is agriculture. After Alokoegbe dams (downstream) (figure 1), Zio River develops a wide flooding plain. The human activities are growing and diversifying from upstream to downstream. The main impact come from cities like the capital Lomé crossed by the river.

2.2 INVERTEBRATES SAMPLING

In the Rivers, 42 stations were selected from downstream to upstream according to three criteria: (1) sites accessibility, (2) distribution throughout the river catchment, and (3) the location about potential pollution sources. Four sampling campaigns were conducted according to the river hydrology. The first campaign was conducted from December 2012 to January 2013), this period corresponds to transition between high water flow and low water flow (dry season). The second campaign was conducted from March to April 2013, corresponding at low water flow (dry season) and third campaign in July 2013, corresponding to transition between low water flow and high water flow (Rainy Season). The last campaign was conducted from September to October 2013 and corresponds to high water flow (Rainy Season). Thus, each station was visited 4 times from December 2012 to October 2013. Macroinvertebrates were sampled according to AFNOR methods (NFT90-350) and taxa identification was done by using identification keys at Laboratory of Animal biology and Ecology of the University of Ouagadougou (Burkina Faso).

2.3 PHYSICOCHEMICAL ANALYSIS METHODS

In the field, parameters such as, pH, electrical conductivity (cond), temperature and dissolved oxygen (O2) was measured using HANNA portable multiparameters. Accuracy is ± 0.1 for pH, ± 0.5 mgO2/L for O2, and ± 1% for conductivity. For the other parameters, 1.5 L of water was sampled in a plastic bottle for further analysis in the laboratory. Major and minor ions was determined by volumetric analysis for HCO_3^- (± 3mg/L) and Cl^- (± 0.5 mg/L), and by molecular absorption spectrophotometry for NO_3^- , SO_4^{2-}, PO_4^{3-}, Mn^{2+}. All these parameters were measured in the Laboratory of water chemistry of the University of Lomé (Togo), with an accuracy ranking from 1 to 2%.

Table 1: Physicochemical analysis methods and equipements [9]

Parameters	Methods	Equipements
pH	Electrometric (NFT90-017)	pHmeter WTW
Suspended materials	Gravimetric (NFT 90-105)	Pressure pump
Dissolved Oxygen	Oximetry/volumetric (NF25813/ ISO5813)	Oximeter WTW
Color	Platinum-Cobalt (NFT90)	-
Transparency (Tran)	Secchi Method	Secchi disc
Conductivity (Cond)	Conductimetric (NFT90-111)	Conductimeter WTW
Ca^{2+}, Mg^{2+}	Complexometry (NFT90-003)	-
HCO_3^-	Volumetric (ISO 9963-I)	-
Oxidability to KMnO4	Acid and hot middle (Guerrée test)	-
Cl^-	Volumetric (NFT90-014)	-
Na^+, K^+	Spectrophotometry (NFT90-09, NFT90-020)	Spectrophotometer by flame
$NH4^+$, NO_3^-, NO_2^-, Fe SO_4^{2+} et Mn^{2+}, PO_4^{3-}	(NFT90-015, NFT90- 012, NFT90-013, NFT90-017, NFT90-009, NFT90-024, NFT90-023)	Molecular spectrophotometer (Digitron Elvi)

2.4 DATA ANALYSIS

Descriptive statistics were performed with Statistica 7.0 software to describe trends in the evolution and distribution of data. Principal components analysis (PCA) was used to assess sites typology or similarity according to physicochemical parameters [10], [11], [12]. Factorial Correspondence Analysis (FCA) was used to highlight affinity between taxa (at family level) and sites. PCA and FCA were performed with Xlstat software. A RDA was used to show correlation between taxa and physicochemical variables, it was done by using CANOCO for windows 4.0. Boxplot was used to show habitat used by each taxa compared to the available habitat for each measured parameter. These boxplot were performed under R software using R Studio interface.

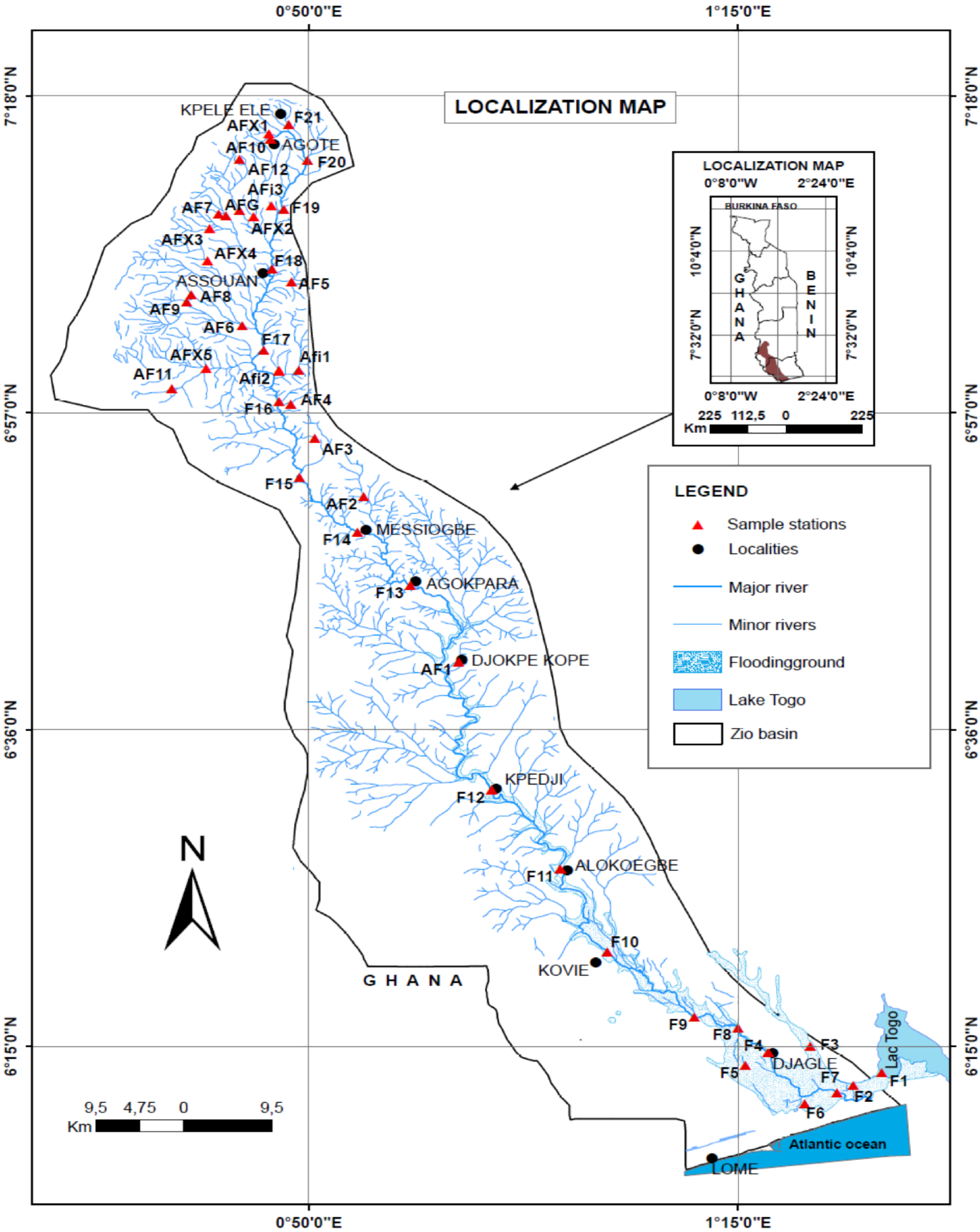

Figure 1: sites and study area situation map

3 RESULTS

3.1 PHYSICOCHEMICAL OR ENVIRONMENTAL CHARACTERISTICS

Table 3 shows mean values of physicochemical variables according to sites; a descriptive summary of these variables is given in the last row of the table. pH varied from 6.26 to 7.91, indicating that the water from Zio River is almost neutral. Conductivity values ranged from 25.3 to 10670µS/cm. The sites F1 and F2, near Lake Togo and Atlantic Ocean (fig.1) show the highest conductivity values, suggesting intrusion of sea water during lower water flow and/or pollution. Na^+, K^+, Cl^- exhibited a similar distribution to conductivity. They show a significant correlation with conductivity (fig.2 and table 7). Dissolved Oxygen indicates oversaturated water with values superior to 7 mgO2/L in about 75% of sites. NO_3^- contents like other measured nutrients are relatively low, with values 5 to 20 times smaller than WHO threshold value (50 mg/L). Meanwhile NH_4^+ ion show higher values in some downstream sites with maximum value 2 to 3 times higher than WHO threshold value (1.5mg/L) for site F6. Ion HCO_3^- is a dominant anion in whole Zio river water except for sites F1 and F2. Total Iron contents are usually higher than those of Mn^{2+} (2.5 mg/L as maximum value) with a maximum value of 2.3 mg/L during transition from high water to low water and maximum values between 5 and 8 mg/L for the other sampling periods.

3.2 SITES TYPOLOGY ACCORDING TO PHYSICOCHEMICAL CHARACTERISTICS

Results of the PCA performed on the matrix of physicochemical parameters are showed in figures 2 and 3. The first axis (A1) explains 41.01% and 37.33% of the variance respectively for the dry season and rainy season samples. In both seasons O2, Tran, KMn, NH_4^+, MES and Color are the most contributing variables, significantly correlated (± 0.6 to ± 0.94) to the first axis. The main contributors for the second axis are Conductivity, Cl^-, Na^+ and K^+. Distribution pattern of variables in the PCA (fig.2A and fig.2B) allow distinguishing three groups of variables: group1, characterized by anthropogenic pollution descriptors (NH4, MES, Color, KMn, PO4, NO3, SO4), group 2, characterized by O2 and Tran and the group 3 characterized by major ions, indicators of mineralization (Cl, Na, Ca, Mg, HCO3 and Conductivity). Group 1 and 3 are opposed to group 2 following A1. Then, axis A1 can be seen as "the gradient of anthropogenic impacts". Projection of sites shows also that sites can be divided into three groups: the upstream sites (N1), the downstream and/or impacted sites (N2) and the other sites (N3) which seem to be influenced by geology. The axis A2 corresponds to salinization and sites F1, F2 and F3 are most affected by this salinization process. These sites are located in the extreme southeast of the catchment near to Lake Togo (Figure 1).

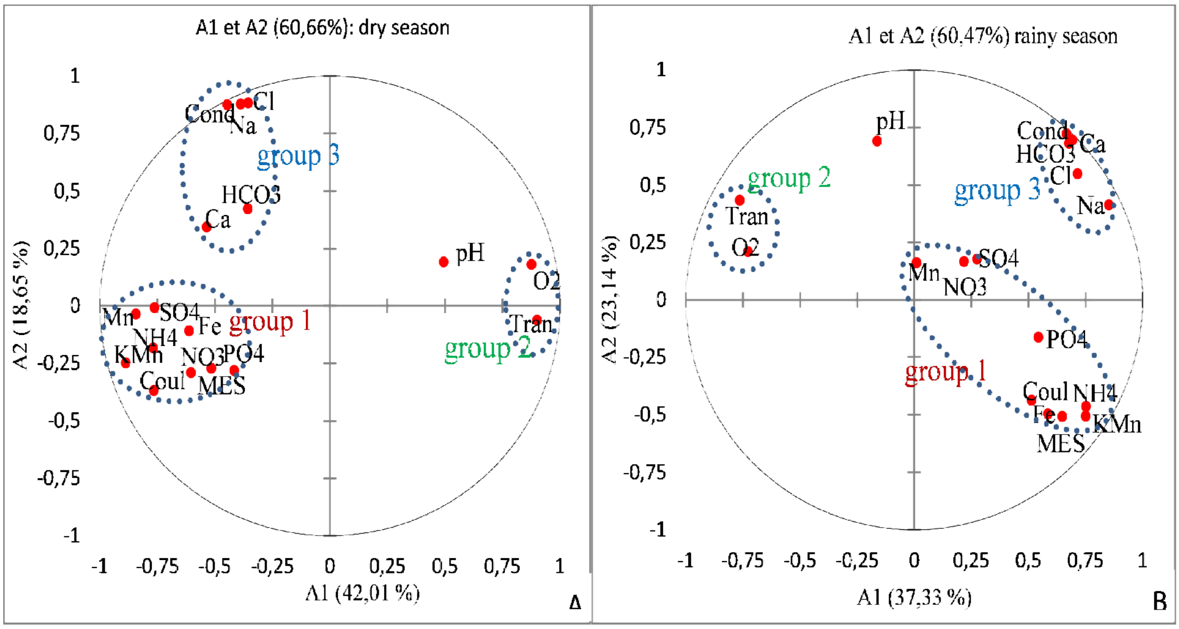

Figure 2: Principal Components Analysis of physicochemical variables for the dry season (A) and the rainy season (B)

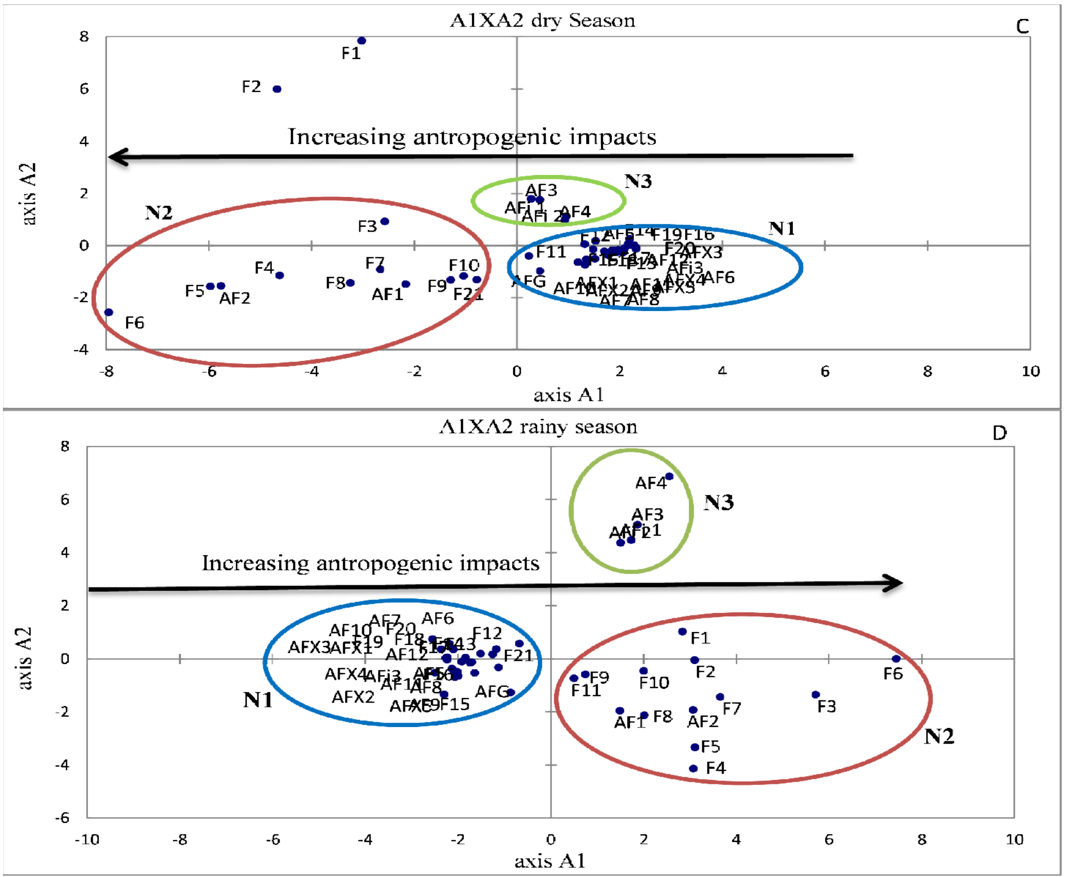

Figure 3: Scatter plot showing sites distribution from the PCA

Table 2: Correlation of measured variables with Axis A1 and A2 for dry and rainy season

	dry season		rainy season	
	A1	A2	A1	A2
pH	0,495	0,191	-0,163	**0,692**
Cond	-0,446	**0,874**	**0,668**	**0,723**
O2	**0,878**	0,181	**-0,728**	0,21
Tran	**0,901**	-0,063	**-0,764**	0,434
MES	**-0,603**	-0,292	**0,649**	**-0,507**
Coul	**-0,765**	-0,37	**0,515**	-0,438
KMn	**-0,887**	-0,25	**0,751**	**-0,506**
HCO3	**-0,357**	0,423	**0,692**	**0,695**
Ca	**-0,535**	0,344	**0,678**	**0,682**
NO3	**-0,516**	-0,273	0,219	0,167
NH4	**-0,767**	-0,184	**0,753**	-0,463
PO4	-0,415	-0,283	**0,544**	-0,163
SO4	**-0,761**	-0,008	0,011	0,163
Cl	-0,356	**0,882**	**0,586**	-0,497
Na	-0,388	**0,878**	0,276	0,177
Mn	**-0,842**	-0,036	**0,717**	**0,549**
Fe	**-0,612**	-0,109	**0,853**	0,414
Eigen value	7,142	3,17	6,346	3,933
% of total Variance	42,009	18,648	37,33	23,138
cumulative %	42,009	60,657	37,33	60,468

Table 3: Mean values of physicochemical variables according to sites

Cond: conductivity (µS/Cm); O2: Dissolved Oxygen (mgO2/L), Tran: Transparency (%), MES: Suspended materials (mg/L), Cou: color (mgPt/L), KMn: Oxydability to KMnO4 (mgO2/L) all ions contents in mg/L, Aver: mean; Min: Minimum; max: Maximum; Medi: Median; 25cen: 25percentile; 75cen:75percentile.

Sites	T°C	pH	Cond	O2	Tran	MES	Coul	KMn	HCO3	Ca	Mg	NO2	NO3	NH4	PO4	Mn	Fe	SO4	Cl	Na	K
F1	26,58	7,10	2936,25	6,28	22,50	158,25	13,75	6,55	190,63	21,50	8,94	0,03	1,85	0,10	0,03	0,16	1,62	3,71	735,75	507,18	21,25
F2	26,95	6,71	2479,25	4,85	21,75	145,50	15	11,50	169,88	22,10	8,64	0,05	1,61	0,54	0,03	0,61	1,72	4,53	555,48	436,88	17,30
F3	26,93	6,66	700,20	3,70	21,50	200	42,50	13,20	235,31	27,50	12,84	0,04	1,22	0,61	0,06	0,04	3,31	2,44	152,11	140,45	12,30
F4	27,25	6,48	223,75	3,98	32,50	209	48,75	11,38	103,50	13,80	5,88	0,09	0,90	0,54	0,06	0,68	5,02	5,98	21,05	20,38	3,75
F5	27,10	6,70	360,40	2,23	25,01	224	56,25	23,18	121,48	17,50	6,60	0,18	1,25	0,88	0,04	0,51	1,95	6,88	21,78	28,38	5,78
F6	27,30	6,54	541,25	1,83	21,25	156,50	53,75	26	246,28	38,40	17,46	0,26	2,23	2,22	0,15	0,69	1,82	8,66	37,79	55,35	9,90
F7	27,55	6,64	329,50	3,85	41,25	151,50	18,75	16,95	140,48	14,80	8,24	0,07	1,55	0,53	0,07	0,13	2,85	5,90	15,75	36,25	3,43
F8	27,78	6,99	190,90	6,35	29,01	226	66,25	13,28	93,75	12,50	8	0,03	1,38	0,22	0,03	0,63	1,69	4,27	17,56	15,38	3,58
F9	27,05	7,01	148,15	6,90	48,75	125	20	9,40	85,05	9,60	8,64	0,03	1,01	0,10	0,13	0,04	1,52	4,60	13,78	15	4,30
F10	27,01	7,14	154,70	7,83	30,01	99	21,25	10,15	104,63	9,40	7,68	0,04	3	0,09	0,14	0,03	1,13	5,30	16,62	30,25	3,83
F11	27,30	7,30	101,38	8,70	56,25	77,25	12,50	9,35	84,75	8	5,52	0,04	2,01	0,15	0,09	0,02	1,59	6,14	9,63	20,10	5,15
F12	27,35	7,34	103,60	9,05	68,75	53,25	11,25	5,13	83,03	9,80	5,58	0,03	3	0,03	0,06	0,04	1,06	3,25	7,05	13,13	3,65
F13	27,45	7,26	101,08	10,90	77,50	79,50	15	3,70	71,33	10,40	4,56	0,03	1,21	0,04	0,03	0,03	0,99	5,57	6,03	7,93	2,05
F14	27,50	7,58	85,08	10,15	87,50	89,50	12,50	3,40	69,48	6,50	8,64	0,04	1,01	0,04	0,03	0,03	1,04	4,54	5,13	6,35	2,33
F15	25,48	7,24	87,18	8,93	82,50	119	16,25	4,75	59,48	7,80	3,96	0,06	1	0,07	0,02	0,04	1,42	4,04	4,25	5,63	2,18
F16	26,58	7,24	66,35	9,70	76,25	51,75	13,75	3,98	44,50	5,80	3,24	0,02	1,05	0,03	0,03	0,04	1	1,97	4,13	4,95	1,75
F17	26,75	7,33	69,23	11,55	85,01	53,25	36,25	3,33	45,75	6	3,12	0,15	1,18	0,03	0,02	0,04	1,15	2,79	3,38	5	1,63
F18	26,50	7,12	71,13	10,90	97,50	57	20	2,83	52,90	7,28	3,88	0,06	0,91	0,03	0,02	0,03	1,36	2,22	4,15	4,75	1,85
F19	26,98	7,27	88,03	9,70	97,50	49	17,50	3,35	70,18	8,80	4,68	0,04	0,72	0,02	0,03	0,04	0,57	2	3,40	5,33	2,45
F20	26,35	7,23	76,93	10,08	100	92,25	15	3,10	52,90	8,80	2,16	0,05	0,53	0,02	0,02	0,04	0,45	1,75	3,65	5	1,78
F21	27,30	7,05	151,18	7,20	100	51,50	36,25	12,18	70,45	9,90	4,80	0,13	0,98	0,12	0,07	0,15	1,46	2,16	9,01	10,38	4,88
AF1	27,10	7,04	102,38	3,10	22,50	215	45	15,13	77,08	10	3	0,12	0,84	0,27	0,03	0,10	0,45	2,60	8,45	21,50	4,58
AF2	27,73	7,17	558,08	2,58	25,50	184	33,75	21,38	135,50	18,30	7,02	0,20	1,67	0,79	0,04	0,73	2,20	7,41	11,58	24,00	6,28
AF3	25,75	7,40	822,33	6,70	100	46,25	10	1,83	460,05	39,20	58,20	0,04	1,51	0,04	0,07	0,08	0,49	0,77	37,65	49,75	1,65
AF4	26,48	7,63	703,80	7,30	100	49,25	11,25	1,75	365,73	39,40	44,42	0,03	1,40	0,04	0,04	0,18	0,62	4,23	31,04	49,25	1,80
AF5	27,08	7,05	51,13	7,80	100	76	13,75	2,78	40,90	6	3,72	0,03	0,90	0,03	0,09	0,12	0,77	2,63	3,38	5,35	1,25
AF6	27,33	7,47	73,98	6,98	100	55,75	15	2,03	38,33	6,20	2,78	0,03	0,95	0,09	0,03	0,09	0,80	1,47	4,56	3,58	1
AF7	27,01	7,43	65,38	7,45	100	48,25	15	1,33	25,65	3,40	2,04	0,04	0,97	0,05	0,03	0,05	0,70	1,46	5,73	3,55	1,38
AF8	26,90	7,23	61,58	7,20	100	95,25	13,75	2,50	28,03	4	2,16	0,04	0,94	0,06	0,04	0,09	0,48	0,94	6,33	3,28	0,83
AF9	26,45	7,25	52,03	7,63	100	94	16,25	2,53	29,83	3,88	2,68	0,06	0,73	0,06	0,02	0,16	0,39	1,68	4,83	2,63	0,90
AF10	28,01	7,40	56,85	7,35	98,75	61	8,75	1,55	29,10	4,15	1,99	0,01	0,99	0,04	0,03	0,03	0,45	2,59	7,13	5,23	1,70
AF11	28,01	6,87	25,88	9,50	100	122,50	11,25	1,95	21,96	3,20	1,56	0,04	1,08	0,02	0,02	0,04	0,31	3,25	4,30	4,58	1,15
AF12	27,20	7,28	54,75	7,95	100	48	11,25	1,45	35,58	4,60	2,28	0,04	1,33	0,20	0,03	0,03	0,48	1,95	4,73	4,20	1,10
AFG	26,90	7,12	36,88	7,53	97,50	137,75	18,75	9	22,89	4	1,74	0,02	1,65	0,11	0,06	0,06	0,51	6,48	4,75	3,90	1,20
AFi 1	27,35	7,66	614,25	7,55	100	115,50	15	2,73	329,36	44,92	32,76	0,02	0,91	0,11	0,04	0,08	0,33	4,77	39,65	36,38	4,60
AFi 2	27,73	7,51	531,90	7,50	100	95,50	13,75	2,30	337,02	39	33,94	0,03	1,11	0,05	0,03	0,03	0,30	2,37	37,29	39,83	5,10
AFi3	27,55	7,13	53,13	7,58	100	156,25	15	2,63	38,46	5	2,28	0,03	0,48	0,07	0,03	0,08	0,57	3,34	3,63	5,30	1,60
AFX1	27,90	6,99	47,35	7,05	100	132,50	17,50	2,48	29,69	4,85	1,20	0,04	0,92	0,04	0,03	0,07	1,05	0,44	2,88	3,78	0,95
AFX2	27,25	6,85	44,18	7,75	100	110,50	12,50	2,58	26,70	3,30	1,38	0,02	0,88	0,10	0,01	0,12	1,26	1,01	2,40	4,15	0,83
AFX3	27,85	6,63	39,53	7,10	100	70,50	13,75	2,50	27,38	3,30	1,80	0,05	0,69	0,03	0,03	0,13	0,77	2,62	3,25	4,65	0,95
AFX4	27,80	6,60	77,90	7,56	100	72,50	13,75	3,60	39,58	4,60	1,62	0,06	1,08	0,05	0,03	0,16	0,26	1,39	5,23	6,60	2,28
AFX5	27,25	6,33	44,60	8,68	100	49,25	15	3,63	23,38	4,30	1,50	0,03	0,56	0,07	0,03	0,06	0,46	1,20	3,33	2,55	0,95
Aver	27,13	7,09	313,89	7,25	75,39	107,23	21,49	6,77	103,76	12,66	8,41	0,06	1,22	0,21	0,04	0,15	1,15	3,41	44,75	39,48	3,74
Mini	20,00	6,26	25,30	0,60	7,00	12,00	5,00	0,40	18,30	2,40	0,48	0,01	0,11	0,01	0,01	0,01	0,01	0,05	0,50	1,60	0,30
Maxi	29,60	7,91	10670,00	14,60	100,00	325,00	100,00	32,50	580,00	64,00	76,40	0,50	7,80	5,60	0,36	2,57	7,77	14,00	2803,08	1860,00	71,00
Medi	27,40	7,14	97,35	7,40	100,00	80,00	15,00	3,60	67,10	8,00	4,16	0,04	0,96	0,05	0,03	0,05	0,84	2,24	7,00	7,15	2,00
25cen	26,55	6,77	50,25	6,40	42,50	53,00	10,00	2,10	30,55	4,80	2,40	0,02	0,73	0,03	0,02	0,03	0,40	0,84	3,50	4,25	1,20
75cen	27,70	7,40	214,80	8,40	100,00	142,50	25,00	9,60	113,55	14,80	7,20	0,05	1,38	0,22	0,05	0,10	1,30	5,25	15,51	26,50	3,95

3.3 MACROINVERTEBRATE COMMUNITY OF THE ZIO RIVER

The Table 4 shows an overview of the macroinvertebrates community in the Zio River catchment. Numbers of families and total abundance are showed for each benthic macroinvertabre order. Insects are the most abundant and diversified class, recording 49 families. Gastropoda is the second group in term of diversity and abundance. Excepted crustaceans, about 90% of arthropod were collect at larval stage. Table 5 shows families list, abbreviations of family names and abundance of each family.

Table 4: Overview of the benthic macroinvertebrates community in the Zio River

Kingdom	Class	Order	family Number	Abundance
Arthropoda	Insects	Hemiptera	9	2698
		Coleoptera	5	2073
		Odonata	8	1634
		Diptera	11	3032
		Ephemeroptera	8	2087
		Trichoptera	6	659
		Lepidoptera	1	97
		Plecoptera	1	239
	Crustaceans		3	925
	Arachnida		1	115
Mollusca	Gastropoda		6	5224
	Bivalvia		4	330
Annelida	Oligocheata		2	797
	Hirudinae		1	34

Table 5: Families lists, Abbreviations of family names and abundances of families

Families	abbreviations	Abundance	Families	abbreviations	Abundance
Thiaridae	Thi	4230	Culicidae	Cul	199
Pilidae	Pil	163	Ceratopogonidae	Cer	63
Neritidae	Ner	47	Dixidae	Dix	42
Lymnaeidae	Lym	48	Tipulidae	Tipu	22
Bulinidae	Bul	137	Syrphidae	Syr	79
Planorbidae	Pla	599	Simuliidae	Sim	89
Sphaeridae	Sph	128	Athericidae	Ath	226
Unionidae	Uni	94	Psychodidae	Psy	115
Iridinidae	Iri	44	Tabanidae	Tab	122
Mutelidae	Mut	64	Ephydridae	Efi	41
Veliidae	Vel	272	Pyralidae	Pyr	97
Corixidae	Cor	391	Baetidae	Bae	898
Pleidae	Ple	134	Caenidae	Cae	141
Belostomidae	Bel	462	Heptagniidae	Hep	178
Nepidae	Nep	327	Polymitarcyidae	Plm	32
Notonectidae	Not	448	Tricorythidae	Tri	167
Hydrometridae	Hdr	105	Oligoneuridae	Oli	449
Naucoridae	Nau	273	Leptophlebiidae	Lep	178
Geriidae	Ger	286	Ephemeridae	Eph	44
Coenagriinidae	Coe	294	Perlidae	Per	239
Chlorocyphidae	Chl	164	Leptoceridae	Lpt	197
Calopterygidae	Cal	139	Hydropsychidae	Hps	221
Lestidae	Les	52	Ecnomidae	Ecn	108
Gomphidae	Gom	293	Hydroptilidae	Hdp	73
Libellulidae	Lib	342	Polycentropodidae	Plc	37
Corduliidae	Cor	274	Philopotamidae	Phi	23
Aeschnidae	Aes	76	Atyidae	Aty	302
Elmidae	Elm	339	Palaemonidae	Pal	305
Hydrophilidae	Hdp	230	Potamidae	Pot	318
Dytiscidae	Dyt	978	Hydrachnidae	Hyd	115
Gyrinidae	Gyr	452	Tubificidae	Tub	374
Haliplidae	Hal	74	Naididae	Nai	423
chironomidae	Chi	2034	Hirudinidae	Hir	34

3.4 SPATIAL DISTRIBUTION OF BENTHIC MACROINVERTEBRATES

A Correspondence Analysis (CA) was performed on presence-absence data of the four campaigns (fig.4). This analyzes allow us to classified sites according to taxa. According to the first axis (A1) that contributes to 46.56% of variance, sites can be divided into three groups which characterized by a group of taxa. The table 6 below shows the characteristics of the three groups. According to this result the first axis can be seen as the “water quality or sites degradation gradient”; going from least impacted sites to impacted ones. Least impacted sites are associated to intolerant/sensitive species while the impacted ones are associated to tolerant species.

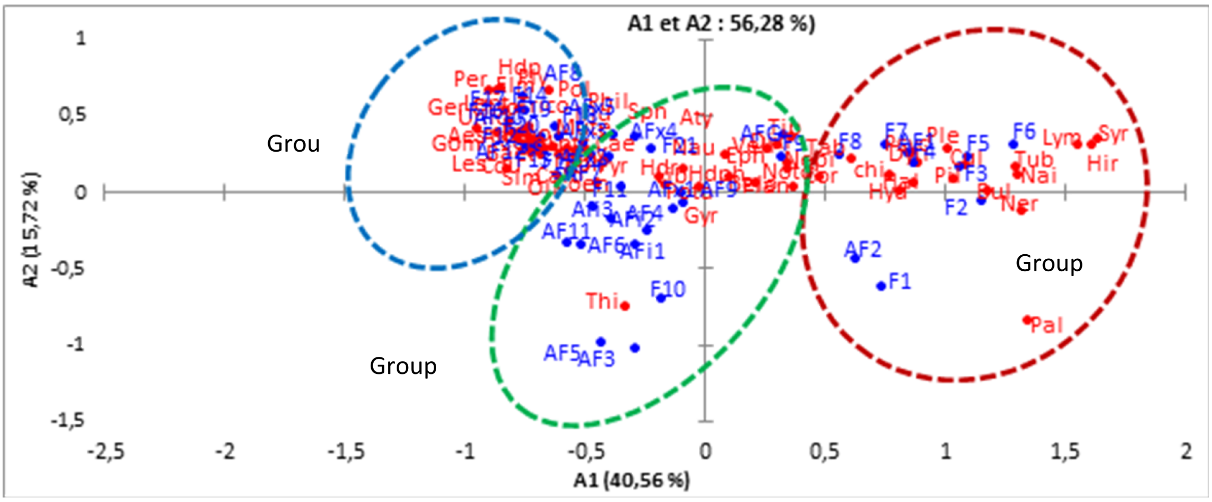

Figure 4: Correspondence Analysis (FCA)

Table 6: Characteristics of the three groups of site following the FAC

	Group 1	Group 2	Group 3
Sites	F1 to F8, AF1 and AF2	F9, F10, F11, AF3, AF4, AFi1, AFi2, AFi3, AFG, F21, AF5, AF11, AF9, AFX1 to AFX5	F12 to F20, AF10, AF12, AF8, AF6, AF7
Characteristics of sites	Downstream sites Important human impacts Degraded water quality	Mean Course sites and upstream sites Moderate human impacts, Acceptable water Quality	Upstream sites Very few human impacts Good water quality
Indicator taxa	Syrphidae, Hirudinae, Naididae, Tubificidae, Lymnaeidae, Chironomidae	Gyrinidae, Geriidae, Naucoridae, Baetidae Hydrometridae, Coenagriidae, Libellulidae	Ephemeroptera, Trichoptera, Plecoptera and Odonata
Indicator taxa Sensitivity	Tolerant taxa	Moderate Tolerant taxa	Sensitive taxa

3.5 Correlation between fauna and water physicochemical quality

A ReDundancy Analysis (a canonical analysis) was performed using the matrix of abundance (at Orders level) and the matrix of the physicochemical parameters. This ReDundancy Analysis (RDA) aims to highlight the relationship between physicochemical parameters and the relative abundances of orders. According to figure 5, Ephemeroptera, Plecoptera, Trichoptera, Odonata and Bivalves showed strong correlation with dissolved oxygen and transparency and oppose to Diptera, Oligochaeta, Leeches and pulmonates molluscs which are strongly correlated with NH_4, SO_4, KMn, MES and the Water Color.

The correlation matrix in Table 7 shows the values of Spearman correlation between some selected variables, including physicochemical variables and some community index such as Margalef, Shannon, Simpson, EPT and the number of families. There is significant positive correlation ($r > 0.5$; $p < 0.01$) between dissolved oxygen and all biological indexes. Transparency is significantly correlated to the number of families, Margelef and EPT Index. On the other hand, these biological indexes show a negative correlation ($r < -0.5$; $p < 0.01$) with NH_4. Margalef and EPT index are also negatively correlation to KMn, Color, Na and Cl. It is the same case between the number of families, the EPT index and Na, Cl ions. Then, dissolved oxygen and transparency can be use as positive indicator of water quality while NH_4, Color and KMn can be used as indicators of anthropogenic pressure (or pollution).

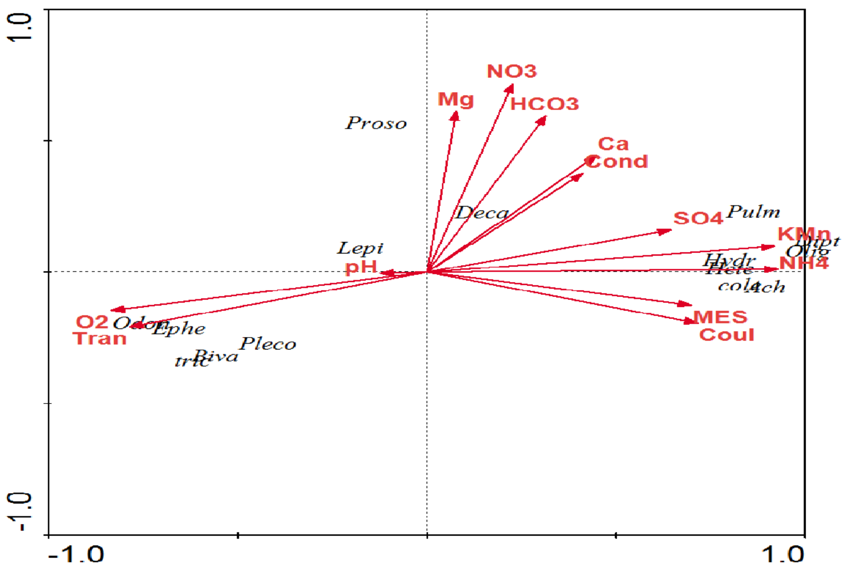

Figure 5: Biplot showing the results of the ReDundancy Analysis (RDA)

Table 7: correlation matrix of physicochemical parameters and biological indexes

RTFm: number of family, Shan: Shannon index, Simp: Simpson index, Marg: Margalef index, EPT: number of Ephemeroptera, plecoptera and Trichoptera familyies.

	Cond	O2	Tran	MES	Coul	KMn	NH4	SO4	Cl	Na	RTFm	Shan	Simp	Marg	EPT
Cond	**1**	**-0,513**	**-0,797**	**0,507**	**0,618**	**0,776**	**0,633**	0,448	**0,669**	**0,884**	-0,437	-0,380	-0,263	**-0,540**	**-0,742**
O2		**1**	**0,580**	-0,382	-0,384	**-0,595**	**-0,745**	-0,306	**-0,575**	**-0,492**	**0,525**	**0,552**	**0,504**	**0,601**	**0,655**
Tran			**1**	-0,478	**-0,618**	**-0,800**	**-0,717**	-0,437	**-0,704**	**-0,868**	**0,504**	0,447	0,329	**0,596**	**0,740**
MES				**1**	**0,705**	**0,706**	0,497	0,140	0,356	**0,528**	-0,406	-0,392	-0,301	-0,439	**-0,557**
Coul					**1**	**0,703**	**0,570**	0,237	**0,516**	**0,645**	**-0,556**	-0,462	-0,323	**-0,605**	**-0,717**
KMn						**1**	**0,660**	0,421	**0,576**	**0,807**	-0,431	-0,376	**-0,269**	**-0,540**	**-0,696**
NH4							**1**	0,284	**0,649**	**0,662**	**-0,680**	**-0,641**	-0,495	**-0,742**	**-0,804**
SO4								**1**	0,475	0,438	-0,113	-0,054	-0,010	-0,172	-0,282
Cl									**1**	**0,702**	**-0,622**	-0,477	-0,309	**-0,666**	**-0,756**
Na										**1**	**-0,518**	-0,438	-0,305	**-0,604**	**-0,764**
RTFm											**1**	**0,825**	**0,618**	**0,972**	**0,837**
Shan												**1**	**0,939**	**0,874**	**0,740**
Simp													**1**	**0,690**	**0,572**
Marg														**1**	**0,880**
EPT															**1**

3.6 HABITATS USED BY THE INDICATOR TAXA

The figure 6 show the “habitats” used by each taxa. The first boxplot in each graph indicate the available habitat, the distribution of the values for a selected parameter and showing its minimum, maximum, quartiles and median.

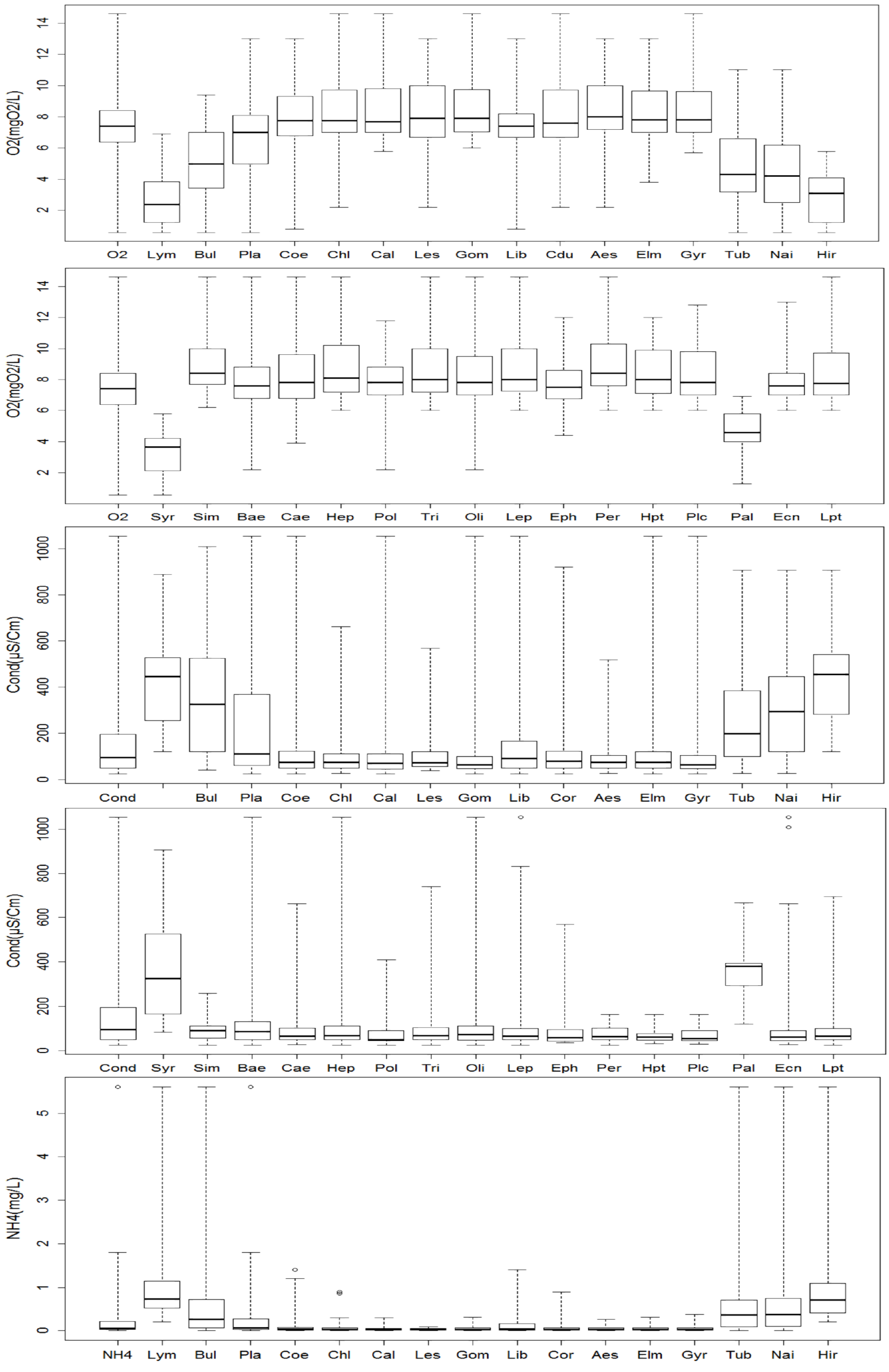

Figure 6a: Habitat used by the indicators taxa following Dissolved Oxygen (O2), Conductivity (Cond) and NH4 ion content.

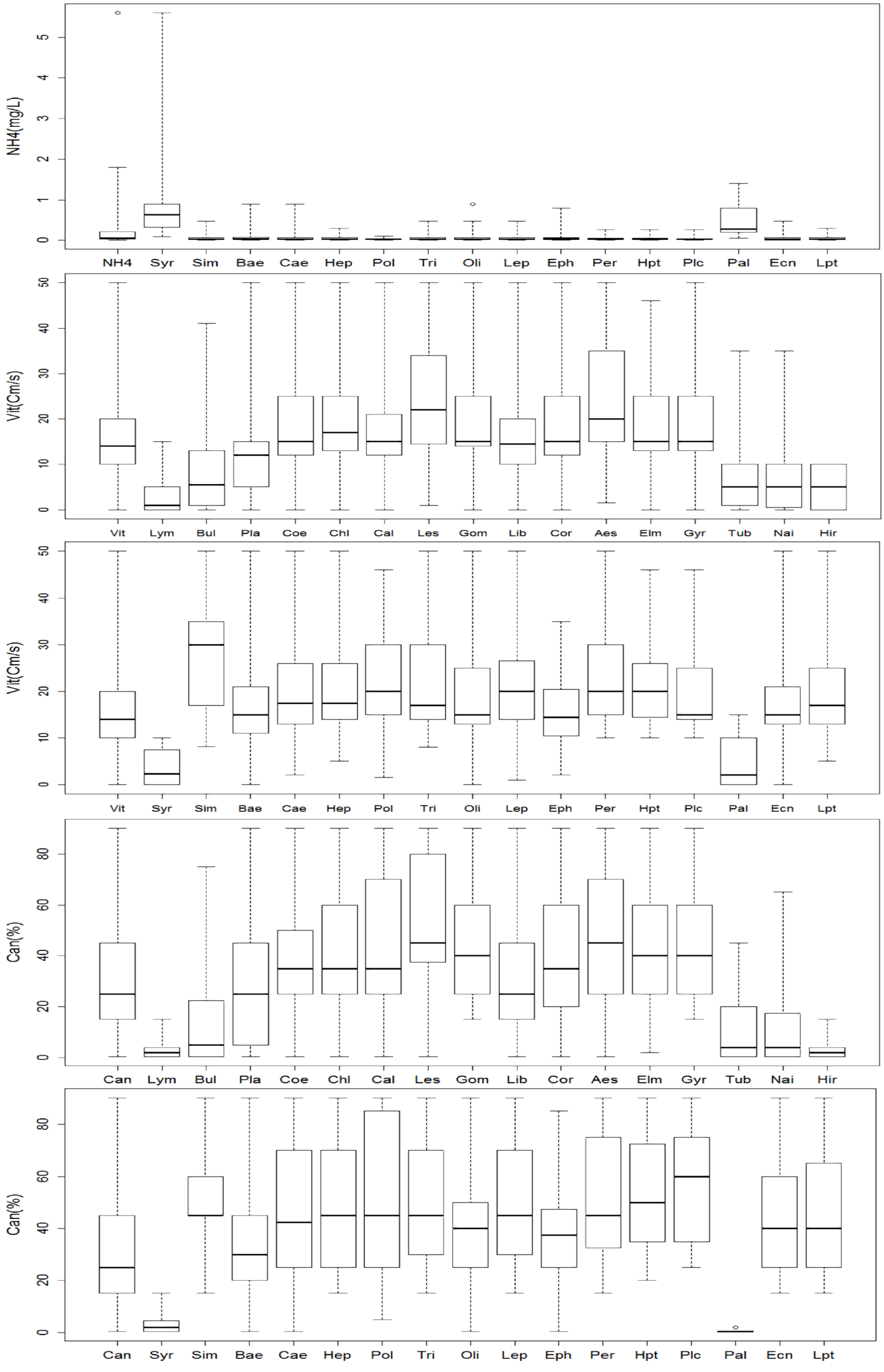

Figure 6b: Habitat used by the indicators taxa Following NH4 ion content, water speed (vit) and vegetation cover (can)

4 DISCUSSION

4.1 WATER PHYSICOCHEMICAL QUALITY

pH is an important factor that determines the suitability of water for various purposes [13].The observed values show a relative agreement with pH values of surface water which lie within the range of 6.5 to 8.5 [14],[15]. For most natural waters, the accepted range of pH is 6.0-8.5 pH units. The pH values from all sites were within the accepted pH range which provides adequate protection for aquatic life according to [15]. Highest conductivity values recorded in downstream suggest pollution of these sites from human activities and/or intrusion of sea water (sites F1, F2 and F3) during lower water flow. Indeed downstream received lot of effluents from activities above-mentioned. Na^+ and Cl^- contents distribution and their correlation with conductivity (fig.2 and table 5) seem to confirm this intrusion or pollution. The Na/Cl ≤ 1 in some downstream sites suggesting human impact and/or sea water intrusion. Na/Cl ≥ 1 in upstream sites suggest geological influence of Na content in waters of these sites [16]. This result show a relative agreement with [15] who related that naturally Na^+ may come from rock-water interactions as it is one of the most abundant ion found in the earth crust. Lower values of transparency and dissolved oxygen and higher values of NH4 ion are recorded in some downstream sites such as the site F6. The higher values of transparency and dissolved oxygen and lower values of NH4 ion are obtained at upstream sites. This is agree to anthropogenic impact gradient generate by PCA (fig.3). These results also show agreement with [17] and [18] who classify NH_4^+ ion as anthropogenic pollution descriptors or [15], [19], [11] who related that Dissolved oxygen is an hydrosystem health index or water quality indicator. [17] and [18] obtained higher values of NH_4^+ and lower values of dissolved oxygen in impaired sites respectively in groundwater of Meskiana (Algeria) and in Nokoué Lake water (Benin) and show by PCA analysis that ion NH4 content opposite to Dissolved oxygen content. According to PCA results, in rainy season, NO_3^- and SO_4^{2-} ions dissociated themselves from axis A1 and A2 (table 2 and fig. 2). Their contents may be affected by the rain-leaching of surface salts of farmlands in the rainy season.

4.2 DISTRIBUTION OF TAXA ACCORDING TO SITES QUALITY

Downstream sites with anthropogenic impacts and degraded water quality, recorded mainly Syrphidae, Hirudinae, Naididae, Tubificidae, Lymnaeidae, and Chironomidae. These taxa are indicators of impaired sites or indicators of bad water quality. This result show some agreement with [20] who related that more tolerant taxa such as some oligocheata, gastropoda and diptera tended to be associated with samples taken at the impaired sites in temporary streams. According to [21] and [22], Diptera larval (Chironomus, Syrphidae) and Oligocheata (Naididae and Tubificidae) are taxa which characterize polluted biotope receiving a very high organic discharges. Upstream sites with a good water quality recorded mainly families of Ephemeroptera, Trichoptera, Plecoptera and a lot of Odonata families. These taxa characterized unimpaired sites or good water quality. Indeed, Ephemeroptera, Trichoptera and Odonata possess some sensitivity to human disturbance [23], [24]. They reflect the diversity of aquatic organisms and are related to the health of aquatic ecosystems [25]. According to our results taxa above-mentioned can be used for bioassessment of freshwater. According to some authors such as [26], Ephemeroptera is an order of aquatic insects commonly used in bioassessment and biomonitoring of freshwater ecosystems all over the world. Trichoptera is recommended for detecting short-term impacts [27]. Odonata are relatively sensitive to pollution and can be used as a good indicator of water quality ; however there is some variation in tolerance to pollution of the taxa belonging to this group [5]. The larval odonata community has been successfully used as an indicator of habitat and water quality in both lentic and lotic systems [28].

4.3 TAXA SENSITIVITY AND CORRELATION WITH ENVIRONMENTAL PARAMETERS

The ReDundancy Analysis (RDA) and Relationship between taxa or biological indexes and environmental quality highlight characters of macroinvertebrates as bioindicators. This relationship According to our results figure 5, table 7) show an agreement with [26], [29] who related that Ephemeroptera are often the most abundant insects encountered in sites with a sufficiently high dissolved oxygen concentration. In the same way some studies have demonstrated that the relative abundance of tolerant taxa such as Chironomidae increases with increasing disturbance [30]. The taxa pattern according to physicochemical parameters highlight two main groups of taxa: sensitive taxa and tolerant taxa (fig.6). According to NH4 distribution, extremes contents characterize the preferable habitats of tolerant taxa indicating that NH4 is an excellent pollution indicator [18]. For water flow and vegetation cover, taxa seem to present no preferable habitat, however Syrphidae, Palaemonidae and Lymnaeidae were mainly collect in sites with low water flow while Simulidae were present in sites with a relative high water flow. It means that many taxa are not influenced by these environmental variables. Figure 6 show that macroinvertebrates sensitivity can be variable in the same order according to each family sensitivity. Low taxonomic level such as orders or class may provide general information while high level like family, genus and species express specific sensitivity. Thus, [31] suggested that chironomidae are a very diverse group that includes species with different pollution sensitivities, and must be identified to genus or species level in order to use them as water quality indicators. Family richness of Ephemeroptera, Odonata and Trichoptera (EPT) is positively correlated with dissolved oxygen. These orders are known to contain many taxa that are sensitive to changes in water quality and require a moderate to high concentration of dissolved oxygen [32], [33].

5 CONCLUSION

There is two groups of sites according to water physicochemical quality: downstream sites and upstream sites. Downstream sites are characterized by high contents in majors ions and nutrients and also by low level of dissolved oxygen and transparency. Upstream sites are characterized by high level of dissolved oxygen and transparency. After confrontation of the abiotic (physicochemical) and biotic data (Taxa abundance), three groups of site are finally distinguishable: (1) least impacted sites, mainly upstream sites characterized by sensitive taxa, (2) moderate sites and (3) impacted sites located downstream and characterized by tolerant taxa. The results obtained in this work support the knowledge that the macroinvertebrates are a suitable tool for water quality assessment and management of water resources in Zio River catchment.

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