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Relationship between Macroinvertebrates and Physico-Chemical Parameters to Access Water Quality of the Affon River in Bénin

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Abstract

The Affon River is one of the important rivers of the Ouémé River whose benthic diversity remained unknown. The present study aims to make the relationship between macroinvertebrates and physico-chemical parameters to access water quality of the Affon River. The measurement of physico-chemical parameters (temperature, pH, conductivity, transparency, depth and TDS, dissolved oxygen, ammonium, nitrite and phosphate) and the sampling of macroinvertebrates using a Surber net were carried out during floods in eight stations. A principal component analysis (PCA) and canonical correspondence analysis (CCA) were used. The indices of Shannon, Piélou, Simpson, Hilsenhoff, EPT and EPT/Chironomidae were used to assess the level of water pollution. The study identified 9755 macroinvertebrates divided into 4 classes, 14 orders and 49 families. Pollution-sensitive families (14 families) that are organic pollution indicators, as well as pollution-tolerant families (Chironomidae, Limnaeidae, Bithynidae, Physidae) were captured. Chironomidae were the most predominant and abundant family (FO = 100%). The predominance of Chironomidae coupled with the rarity of the Ephemeroptera, Trichoptera and Plecoptera would reflect the poor quality of the Affon River waters. The principal components analysis yielded groups of associations: The first group of stations Taneka 2 and 3 characterized by high values of ammonium and phosphate; and low values of conductivity and TDS; the second group of Tanéka 1 and Kolokondé 1 stations with low values of pH, transparency, ammonium and phosphates; and the third group of stations Kolokondé 2, Kpébouko1, Kpébouko 2 and Affon marked by high values of conductivity, TDS, transparency, depth and temperature. The canonical correspondence analysis revealed a strong positive correlation between Nemouridae and ammonium as well as between Perlidae, Taeniopterygidae, Ephemeridae, Heptageniidae, Isonychiidae, Elmidae and phosphate. This study is a crucial step for any management and monitoring of this river.

Keywords

Macroinvertebrates, Diversity, Biotic Indices, Environmental Variables, Water Quality, Affon River

1. Introduction

Agricultural intensification is the major cause of degradation of aquatic ecosystems in rural areas [1]. The increase in production and yield requires the use of synthetic chemicals such as mineral fertilizers for soil and pesticide fertilization for weed control and phytosanitary treatment of plants. These agricultural activities on watersheds have serious ecological implications for rivers [2]. After their use, these pesticides and agricultural inputs are dispersed in different compartments of the environment. More than 99% of these pesticides are used in ecosystems to pollute water, land and air [3]. Pesticide damage is heavy for water resources, for aquatic populations in general. Because they degrade populations, cause poisoning, induce biocenotic disturbances and even sometimes lead to the extinction of biodiversity [3]. Among this biodiversity, the fauna that should be highlighted is the group of macroinvertebrates because they are excellent indicators of human impacts especially contamination [4]. These benthic macroinvertebrates are easy to sample, abundant and sedentary in all streams [5]. Unlike chemical analyzes, benthic macroinvertebrates can detect disturbances that occur even if they are no longer present at the time of sampling [6]. This makes them good witnesses to local conditions [7]. Hence these are used as bioindicators in many studies evaluating the biological quality of aquatic ecosystems. While the use of any biological community in conservation systems and/or water monitoring requires the characterization of its diversity and its structure [8]. Indeed, in Benin, some studies have been devoted to macroinvertebrates in rivers such as: Alibori [9] [10]; Oueme [11] [12]; Sô [13] and Sota [14]. These studies reinforce the state of knowledge on macroinvertebrates and know their importance. Despite these studies, our knowledge is still limited on the diversity and distribution of macroinvertebrates with respect to altitude. Therefore, the study aims to gain a better understanding of benthic macroinvertebrate distribution and biodiversity of Affon River in order to assess its ecological quality.

2. Materials and Methods

2.1. Study Area and Sampling Stations

The Affon River is located on the right bank and in the classified forest of Upper Ouémé. This river is one of the tributaries of the Ouémé River. It has a length of

152 km and a catchment area of 4320 km^2. The river is located in the Sudano-Guinean zone and is under the influence of the tropical climate characterized by the succession in the year of a single rainy season from April to October and a single dry season from November to March, marked by the preponderance of the harmattan. On the Affon River, 08 stations were selected after prospecting. They were chosen based on the sustainability of the water, the altitude, accessibility in all seasons, the depth and speed of the water [11]. **Table 1** shows the characteristics of these different stations.

2.2. Measurement of Water Physico-Chemical Parameters

At each station, the measurements of physical parameters (temperature, depth, transparency, TDS, conductivity, pH, oxygen) were carried out in situ very early in the morning between 08:00 and 12:00, before the sampling of macroinvertebrates to avoid any disturbance of the environment. Water temperature, TDS and conductivity were determined using a portable conductivity meter (HANNA HI 99300). The pH was measured with a portable pH meter (HANNA HI 98107). A Secchi disk with a graduated rope is used to measure the transparency of the water and depth of the stations. Water samples were made at each station in 500 ml plastic bottles decontaminated and stored in a cooler containing ice for transport to the laboratory for analysis of the dissolved substances. The dissolved elements concentration's determination of the water samples was carried out in the Laboratory of Hygiene, Sanitation, Ecotoxicology and Environmental Health (HECOTES) using a spectrophotometer DR 6000. The chemical parameters such as ammonium, nitrite and phosphate were respectively measured by the Nessler method [15], the iron sulphate method and the Vanadomolybdic method with persulfate digestion.

Table 1. Location, geographic coordinates and characteristics of sampling stations.

Stations	Codes	Geographic coordinates	Altitude	Pollution sources
Tanéka-Koko1	Tan1	N: 09˚51'21" E: 01˚32'34"	484 m	Artisanal extraction of gold
Tanéka-Koko2	Tan2	N: 09˚53'89" E: 01˚47'48"	429 m	Laundry, dishes, artisanal extraction of gold
Tanéka-Koko3	Tan3	N: 09˚52'40" E: 01˚30'80"	415 m	Laundry, dishes, artisanal extraction of gold
Kolokondé1	Kol1	N: 09˚53'94" E: 01˚47'44"	410 m	Agricultural waste, washing of motorcycles and Laundry
Kolokondé2	Kol2	N: 09˚57'17" E: 01˚51'43"	369 m	Household waste, agricultural waste, washing of motorcycles and Laundry
Kpebouco1	Kpe1	N: 09˚57'15" E: 01˚51'43"	365 m	Agricultural, household and livestock wastes
Kpebouco2	Kpe2	N: 09˚56'58" E: 01˚50'54"	363 m	Laundry, household and livestock waste
Affon	Aff	N: 09˚57'46" E: 01˚51'78"	348 m	Watering cattle, washing of motorcycles and laundry

2.3. Sampling of Macroinvertebrates

The benthic macroinvertebrates were sampled at the 08 stations. They were taken by using a Surber sampler with a 500-µm mesh. This material was placed on the bottom of the river, the opening of the net facing the watercourse and the substrate is scraped a few centimeters with the hand. Twelve samples with a unit area of 1/20 m^2 were done per station: (08) eight on the dominant habitats and (04) on the marginal habitats as recommended by the standard IBGN and already used in the North of Benin by Abahi *et al.* (2018) [11]. The organisms collected in surber sampler were spilled in labeled jars and fixed to 10% formalin and then sent to the laboratory.

2.4. Macroinvertebrates Identification

In the laboratory, the captured macroinvertebrates were rinsed in order to rid them of the formalin and then they were sorted station by station under a binocular dissecting microscope. After the sorting, we grouped them according to their classes up to their families apart from oligochaetes, nemathelminths, hydracarians, hydrozoans, sponges, bryozoans and nemerteans that are kept aside such as Abahi *et al.* (2018) [11] has done. The following articles: "Benthic macroinvertebrates of the streams of 'la Nouvelle-Calédonie'" by Mary (2017) [16], "Identification guide of the main benthic macroinvertebrates of freshwater from Quebec" written by Moisan (2010) [17], "Freshwater invertebrates: Systematics, biology, ecology" by Tachet *et al.* (2000) [18] and "Aquatic entomology" by McCafferty (1981) were the key highlighted supports in making the taxonomic determination after which macroinvertebrates were enumerated and then stored in pillboxes containing 70% alcohol.

2.5. Data Interpretation

The identified fauna data allowed us to calculate the following metrics and indices:

Taxonomic richness (S) = number of taxa present in each station

Abundance (N) = number of individuals from a taxonomic group in each station

Relative abundance (Nr) = ratio as a percentage of the number of taxon individuals in a station to the total number of individuals of all species of all stations.

Frequency of family observation (FO) = $(F_i \times 100)/F_t$. In such, F_i = number of stations containing the family and F_t = total number of stations studied. Three families were thus distinguished as Abahi *et al.* (2018) [11] has previously demonstrated. We have "very frequent families" ($F \geq 50\%$), "frequent families" ($25\% \leq F \leq 50\%$) and "rare families" ($F \geq 25\%$).

Shannon diversity index (H) = $-£ p_i \cdot \log_2 p_i$, with p_i meaning the relative abundance of the i species in the sample. The Shannon index is expressed in bits. It was determined by station. Shannon index values obtained were used to assess water quality. The Shannon index is subdivided into three classes of water quality: $2 \leq H$ for clean water; $1 < H < 2$ for moderately polluted water and $H \leq 1$ for polluted water.

Piélou index (E) = H'/log2S with S standing for the total number of individuals.

Simpson index (D) = 1 − $\sum_{i=1}^{S}\left(p_i\right)^2$ with S standing for the total number of individuals and pi = meaning the relative abundance.

Family biotic index (Hilsenhoff index): To determine the water quality of the different stations, the family biotic index developed by Hilsenhoff was used. It has been calculated as follows:

$$FBI = \frac{\sum_i^F n_i t_i}{N}$$

in which F is the family number, n_i is the number of individuals, t_i is the tolerance value of the family i and N is the total number of individuals. The tolerance values of the macroinvertebrate families come from Hilsenhoff (**Table 2**).

2.6. Statistics Analysis of Data

The obtained data was processed using Excel 2010 software and R3.4.4 software [19]. The taxonomic richness, the taxonomic abundance, the average values of the physico-chemical parameters were calculated per each station. Parametric and non-parametric tests (test t student and test of Kruskal-Wallis) were used to evaluate the variability of the taxonomic richness of the abundances and diversity indices at the 5% threshold with the R3.4.2 software [19]. Moreover, the factorial correspondence analysis (FCA) was used for grouping the stations according to the similarity association of macroinvertebrate families. In addition, a canonical correspondence analysis (CCA) was performed using PAST statistical package [20].

3. Results

3.1. Relationship between Macroinvertebrates and Physico-Chemical Parameters

A canonical correspondence analysis (CCA) was performed to correlate physico-chemical parameters and macroinvertebrate densities (**Figure 1**). The contained information in the variables is controlled at 63.48% by the system of axis 1 and 2. Perlidae, Taeniopterygidae, Ephemeridae, Heptageniidae, isonychiidae, Elmidae, phosphate, depth, conductivity and TDS are strongly and positively associated with axis 1 whereas Pyralidae, Leptophlebiidae, Hydrophilidae, Tabanidae, Viviparidae, hydrophiloidae, Nemouridae, Dytiscidae and ammonium are negatively associated with this axis. In addition, Nemouridae, Dytiscidae, ammonium and phosphate are positively associated with axis 2 whereas Baetidae, Physidae, Veliidae, Ceratopogonidae, Gyrinidae, conductivity and TDS are negatively related to axis 2. On the other hand, there is a strong positive correlation (r = 0.78) between Nemouridae and ammonium whereas between Perlidae, Taeniopterygidae, Ephemeridae, Heptageniidae, Isonychiidae, Elmidae and phosphate there is strong positive correlation (0.60).

Table 2. Score pattern of Hilsenhoff index.

Value of FBI	Water quality	Degree of organic pollution
0.00 à 3.75	Excellent	Without organic pollution
3.76 à 4.25	Very good	Slight organic pollution
4.26 à 5.00	Good	Probable organic pollution
5.01 à 5.75	Average	Substantially organic pollution
5.76 à 6.50	Rather bad	Substantial organic pollution
6.51 à 7.25	Bad	Very substantial organic pollution
7.26 à 10.00	Very bad	Serious organic pollution

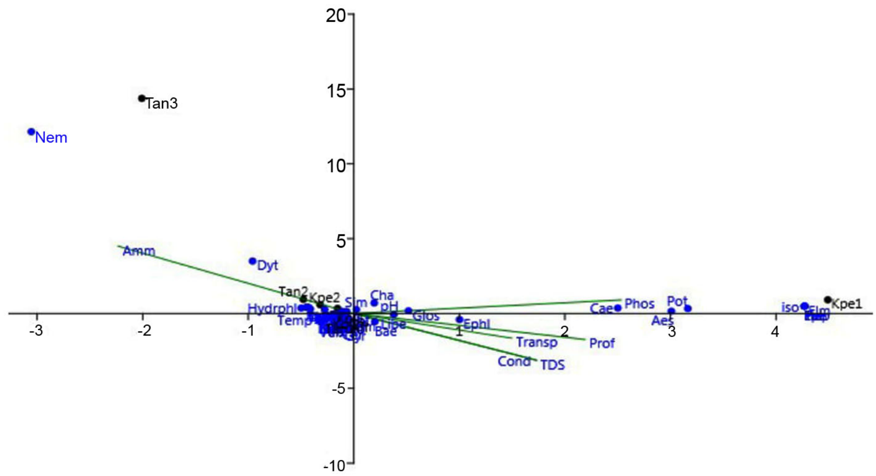

Figure 1. Canonical correspondence analysis of macroinvertebrates and physiochemical variables.

3.2. Ecological Quality of the Affon River Waters

Spatial variation of the Shannon biodiversity index (*H'*)

Table 3 presents the values of the Shannon index and the water quality of the stations studied. Thus, the values of the Shannon index vary between 0.55 bit (Kolokondé 2 and Kpébouco 2) and 1.74 bits (Kpébouco 1). These results show that the water quality of the Affon River varied between polluted and moderately polluted (Table 3). In addition, Shannon index values showed significant differences between stations ($p = 0.001$).

Spatial variation of Piélou and Simpson's equitability indices

The spatial variations of Piélou and Simpson's equitability indices are presented in Table 4. The Piélou equitability index ranged from 0.18 (Kpekouco 2) to 0.63 (Tanéka 2). While, Simpson's index fluctuated between 0.20 (Kpekouco 2) and 0.73 (Kpekouco 1). Finally, these indices showed significant differences ($p > 0.05$) between the stations (Table 4).

Spatial variation of the EPT and EPT/Chironomidae indices

Table 5 presents the values of the EPT and EPT/C indices per station. It reveals that Kpébouco 1 station has the highest value of the EPT index (54.1%) while the lowest value (1.2%) is observed at Kpébouco station 2. These low values

Table 3. Shannon index values and ecological status of the stations.

Stations	Value of Shannon (H’)	Water quality
Tan1	1.48	Moderately polluted
Tan2	1.31	Moderately polluted
Tan3	1.07	Moderately polluted
Kol1	0.96	Polluted
Kol2	0.55	Polluted
Kpe1	1.74	Moderately polluted
Kpe2	0.55	Polluted
Aff	1.46	Very polluted

Table 4. Piélou and Simpson equitability indices.

Stations	Tan1	Tan2	Tan3	Kol1	Kol2	Kpe1	Kpe2	Aff	p
Index of Pielou	0.43	0.63	0.59	0.33	0.19	0.58	0.18	0.49	0.01
Index of Simpson	0.59	0.62	0.55	0.4	0.22	0.73	0.2	0.62	0.001

Table 5. EPT and EPT/Chironomidae indices.

	Stations							
Descriptors	Tan1	Tan2	Tan3	Kol1	Kol2	Kpe1	Kpe2	Aff
Taxonomic richness	30	8	6	19	19	20	20	20
EPT Richness	8	1	2	4	4	10	3	3
Total abundance	2652	98	43	756	2940	468	1459	1339
EPT abundance	447	23	2	13	228	253	17	320
Chironomidae abundance	1645	55	12	577	2594	169	1306	780
% EPT	16.9	23.5	4.7	1.7	7.8	54.1	1.2	23.9
% Chironomidae	62.0	56.1	27.9	76.3	88.2	36.1	89.5	58.3
EPT/Chironomidae	0.3	0.4	0.2	0.0	0.1	1.5	0.0	0.4

of the EPT index reflect the deterioration of the water quality of the Affon River. Regarding the percentage of Chironomidae, it is higher than 55% on all stations except Tanéka 3 and Kpébouco 1 stations. In addition, the values of the EPT/C index of the different stations are generally low and close to zero. These results indicate that the waters of the different stations are of poor ecological quality and reveal the environmental stress suffered by the Affon River.

Family Biotic Index (Hilsenhoff Index)

Figure 2 shows the spatial evolution of the Hilsenhoff index. Indeed, the maximum value of the Hilsenhoff index is observed at Kpébouco 2 station (7.72) while the minimum value is observed at Kpébouco 1 station (5.65). Thus, the water of the studied stations varies from average quality (rather substantial organic pollution) to very bad quality (serious organic pollution). The family biotic index

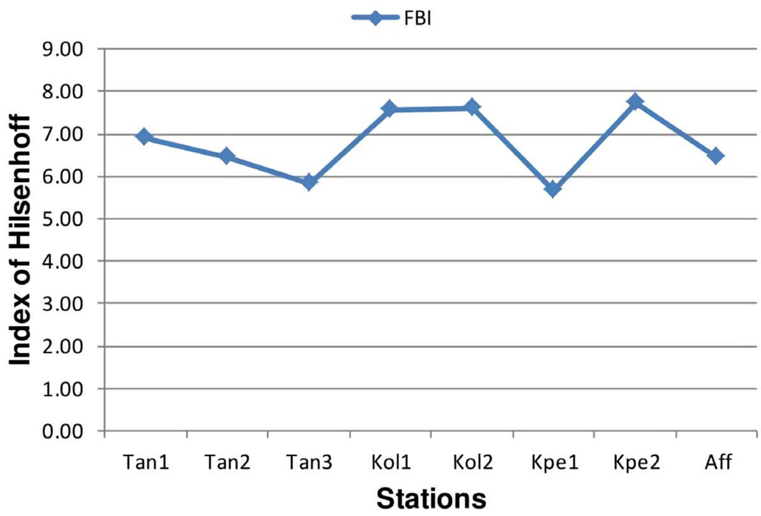

Figure 2. Hilsenhoff index variation.

(FBI) calculated for the Affon River is 7.14. This high value of the family biotic index indicates that the water of this river is of poor quality and that it presents a very substantial organic pollution.

4. Discussion

4.1. Ecological Quality of Affon River Waters

The calculated Shannon-Weaver index is less than 2 indicating that the waters of the stations have qualities varying between moderately polluted, polluted and very polluted. These results also reflect a lower biological diversity in the studied stations. The values of the Shannon diversity index recorded are lower than the values obtained by Foto *et al.* (2013) [21] in the Nga streams in Cameroon and by Koudenoukpo *et al.* (2017) [13] in the Sô River in southern Benin. But the low obtained values are consistent with the results of the river reported by Ibezute *et al.* (2016) [22] on the Ikpoba River in Nigeria. The maximum obtained values of Piélou's equitability index and Simpson's index are respectively 0.63 and 0.73. These results show that macroinvertebrates are more or less well distributed at some stations of the Affon River. The low values of these indices at some stations show that they have minimal diversity and that the distribution of macroinvertebrates is less balanced, poorly organized and dominated by a single species. Overall, the waters of the Affon River have deteriorated. Similar findings have already been reported in several studies [10]. Indeed, the low percentage of pollution-sensitive families coupled with the percentage of Chironomidae indicates globally that the Affon River would have been deteriorated [5]. The low EPT/Chironomidae density values obtained are a perfect illustration of the environmental stress suffered by the Affon River, which would translate the bad quality of this river. These results are comparable to those observed by Foto *et al.* (2011) [23] in an anthropised watercourse in Cameroon and by Abahi (2018) [24] at the upper part of the Ouémé River. In addition, the strong obtained values of the family biotic index (FBI) confirm once again and indicate that the water of the Affon River is of very poor quality and subjected to a very substantial organic pollution. These high values of the Hilsenhoff index indicate a degraded environment and are due to the preponderance of pollution-sensitive families such as Chironomidae [25]. These observations corroborate those made by Nuamah *et al.* (2018) [26] at Nima stream in Ghana. The observed water degradation can be attributed to discharges into the stream of agricultural and domestic effluents that contain nutrients [26] [27].

4.2. Composition and Distribution of Macroinvertebrates

The study has identified in the Affon River 9755 macroinvertebrates divided into 49 families. The observed taxonomic abundance is very low compared with the one reported by Agblonon Houelome *et al.* (2017) [9] at the Alibori River (39,718 individuals). On the other hand, it is higher than that of the upper Ouémé River, where there were 3657 individuals of macroinvertebrates [11]. As for the taxonomic richness, it is identical to the one reported at the Niger River [28] and at the Agnéby River in Côte d'Ivoire [29], while it is much higher than the one obtained by Abahi *et al.* (2018) [11] at the upper part of the Ouémé River. The differences observed with the study by Abahi *et al.* (2018) [11] in the same area are due to the Surber net and the sampling period. In fact, during this study, we used a 500 micrometer Surber net during floods, while Abahi *et al.* (2018) [11] used a 100 micrometer Surber net in low water. The diversity of the macroinvertebrate community harvested at the Affon River is marked by the importance of the Diptera (76.90%) dominated by the Chironomidae family which represent 73.17% of the total abundance. In Benin, the study conducted by Abahi *et al.* (2018) [11] at the upper Ouémé River, also revealed the predominance of Insects (85.23%), Diptera (81.65%) and Chironomidae (67.35%). Similarly, in Burkina Faso [30] and Kabré *et al.* (2000) [31] reported the dominance of Chironomidae in their studies. In addition, the study revealed the low diversity of pollution-sensitive orders (Ephemeroptera, Trichoptera and Plecoptera) both in terms of richness (14 families) and in terms of numbers (1303 individuals), which would probably reflect a poor water quality in the study area. These results, characteristics of the watercourses located in anthropized zones, corroborate well with the results obtained by (Abahi *et al.*, 2018) [11] at the upper part of the Ouémé river, by Imorou Toko *et al.* (2012) [10] in the Benin cotton basin and by Orou Piami (2018) [14] at the Sota River. Most encountered families are represented by only a few individuals. But Chironomidae (Diptera) are frequently (FO = 100%), and abundantly represented at all stations. Thus, the diversity of the Diptera order observed and especially of the Chironomidae family reveals an accumulation of nutrients in the ecosystem; consequences of intense human activities [26] [32]. Anthropogenic activities near ecosystems disturb benthic communities and contribute to reduced species richness and even species distribution [30] [33]. In addition, the correlations established between families and the physicochemical parameters show a strong positive correlation between Nemouridae and ammonium on the one hand and between Perlidae, Taeniopterygidae, Ephemeridae, Heptageniidae, isonychiidae, Elmidae and phosphate where there was a strong positive correlation. These correlations show the invulnerability of these families, which are mostly pollution-sensitive families, at the doses of phosphate and ammonium measured in this study.

5. Conclusion

The present study inventoried 9755 macroinvertebrate individuals belonging to four classes, fourteen orders and forty-nine families. Insects were the most dominant with 97.40% of the total richness. Taxonomic richness and abundance tend to follow an altitudinal gradient. The analysis of the indices reveals an undiversified population and the environmental stress that this river undergoes. The strong positive correlations observed between Nemouridae and ammonium on the one hand and between Perlidae, Taeniopterygidae, Ephemeridae, Heptageniidae, isonychiidae, Elmidae and phosphate show the invulnerability of these families, which are mostly pollution-sensitive families, at the doses of phosphate and ammonium measured in this study. Nevertheless, certain protection and recovery measures must be taken to preserve and improve the ecological status of the Affon River waters. It involves the implementation of a sustainable river management plan, the promotion of organic farming, the awareness of the population on the importance of water and its quality. In addition, a long-term investigation based on biomonitoring and a sustainable management program are recommended to conserve the biodiversity of this river.

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Conflicts of Interest

The authors declare that they have no conflict of interest.

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