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(RESEARCH ARTICLE)

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Relationship between macroinvertebrate diversity and physico-chemical parameters in the « Blondai » river at Anyama (South; Côte d'Ivoire)

Roland Kouakou Djene *, Issouf El Hadj Kamagate, Jean-Renaud Allouko and Yves Kotchi Bony

Department of Biodiversity and Sustainable Ecosystem Management, Faculty Environment, Jean Lorougnon Guede University of Daloa, Côte d'Ivoire.

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Abstract

The aim of the present study was to determine the relationships between macroinvertebrate distribution and the physico-chemical parameters that influence their distribution in the "Bondai" river in southern Côte d'Ivoire. Macroinvertebrate sampling was carried out in this river using a Van Veen bucket and a drag net over an area of 1 m^2 (2 m *0.5 m). Next, benthic community structure was studied using Shannon-Weather diversity and Piélou equitability indices. Finally, a Canonical Correspondence Analysis (CCA) was performed to highlight relationships between macroinvertebrate community distribution and physicochemical parameters. The results showed that a total of 50 macroinvertebrate individuals, divided into 03 Classes, 09 Orders and 11 Families, were identified in the "Blondai" river. The structure of this macrofauna indicates that it is composed of 50% Arthropods, 42% Mollusks, and 8% worms. The class of insects was the best represented with several orders including Diptera, Odonata, Coleoptera, Hemiptera. The orders of Basommatophora, Coleoptera, and Diptera are the most dominant, each representing 17% of the taxonomic richness. The analysis of diversity revealed that the macroinvertebrate communities of the "Blondai" river are poorly diversified and poorly balanced. The distribution of macroinvertebrates was strongly influenced by dissolved oxygen, conductivity, temperature, turbidity, pH, chemical oxygen demand (COD), biochemical oxygen demand (BOD5), total phosphorus, total nitrogen, and dissolved solids. These results lay the foundation for any biosurveillance action regarding the ecological quality of the water in this river.

Keywords: Diversity; Macoinvertebrates; River; Physico-Chemical Parameters; Côte d'Ivoire

1. Introduction

Biodiversity plays a very important role in the natural functioning and development of all aquatic ecosystems. According to [1] high biodiversity increases the stability and adaptability of all living organisms in a given environment to changes in environmental conditions. Macroinvertebrates are one of the components of this biodiversity, but little is known about them, despite their very important role in trophic chains [2]. Benthic macroinvertebrates are widely used for monitoring river quality, as they possess several attributes of good environmental indicators [3]. Knowledge of these organisms and how they function will lead to better management of aquatic ecosystems. Environmental disturbances due to anthropogenic activities such as agriculture, watering, industry and vital needs are multiplying in many parts of the world, leading to imbalances in biodiversity and pollution of both ground and surface waters [4] [5]. These activities modify water quality as well as that of aquatic and riparian habitats, resulting in biodiversity losses, more specifically with regard to aquatic macroinvertebrates [6] [7]. Assessing the state of biological communities provides information that integrates the chemical quality of both water and habitat [8]. Methods based on biological assessment use living organisms to provide a comprehensive overview of the environmental conditions and pressures experienced by aquatic

* Corresponding author: Roland Kouakou Djene

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ecosystems [9]. Various groups of species have been used for such assessments, although one of the most useful groups remains benthic macroinvertebrates [9] ; [10] ; [11].

The « Blondai » river is a peri-urban watercourse located in the town of Anyama, in the south of Côte d'Ivoire, and plays an important ecological and socio-economic role for the local community. This river flows through an environment rich and diverse in biodiversity, including wetlands, which are home to a variety of animal and plant species, including a variety of fish and macroinvertebrate species, some of which are adapted to the specific conditions of freshwater [12]. These species contribute to the ecological balance and the local food chain. It also includes aquatic plants, trees and shrubs that play a crucial role in stabilising banks, filtering water and preserving habitat for numerous animal species [13]. In terms of natural resources, in addition to its flora and fauna, the River « Blondai » is a source of water for local agriculture, particularly for market gardening and small-scale fishing. It also plays a role in managing the surrounding ecosystems, contributing to irrigation and water supply for neighbouring communities. In terms of cultural and social value, the « Blondai River » is at the heart of many of the cultural and spiritual practices of the local populations. It is perceived as an essential part of their identity, with beliefs and traditions linked to it [14]. However, the diversity and ecological quality of the river Blondai remains unknown to the scientific community and has not yet been the subject of any study. This study aims to fill this gap by providing preliminary data on the benthic macrofauna of this river. Its specific objectives are: 1) to inventory the benthic macroinvertebrates of this river and 2) to assess the structure of the macroinvertebrate communities.

2. Materials and Methods

2.1. Study environment

This study was carried out in the « Blondai » river, located near the town of Anyama in the south of Côte d'Ivoire, between 380,500 UTM and 383,000 UTM north latitude and between 609,300 UTM and 61,000 UTM west longitude. Three (03) sampling stations, ES1, ES2 and ES3, located respectively in the upstream, midstream and downstream sections of the river, were selected on the basis of the sustainability of the water, their accessibility and the human activities to which they were subject. The table and figure below show the characteristics of the various sampling stations :

Table 1 Summary table of sampling station characteristics

Code	**ES1**	**ES2**	**ES3**
Types of ecosystems	River	River	River
Situation	Upstream	Median price	Downstream
Latitude	382804.00 m E	382055.00 m E	381925.00 m E
Longitude	609863.00 m N	609933.00 m N	609847.00 m N
Appearance of the water	Slightly cloudy	Claire	Claire
Substrate	Sandy	Sandy	Sandy
Flow speed	0.10 m/s	0.15 m/s	0.20 m/s
Depth (cm)	56 cm	17 cm	55 cm
Canopy	15%	0%	5%
Right bank	Chinese bamboo (*Bambusa vulgaris*) and macrophytes	Chinese bamboo (*Bambusa vulgaris*) and macrophytes	Chinese bamboo (*Bambusa vulgaris*) and macrophytes
Left Bank	Chinese bamboo (*Bambusa vulgaris*) and macrophytes	Chinese bamboo (*Bambusa vulgaris*) and macrophytes	Chinese bamboo (*Bambusa vulgaris*) and macrophytes

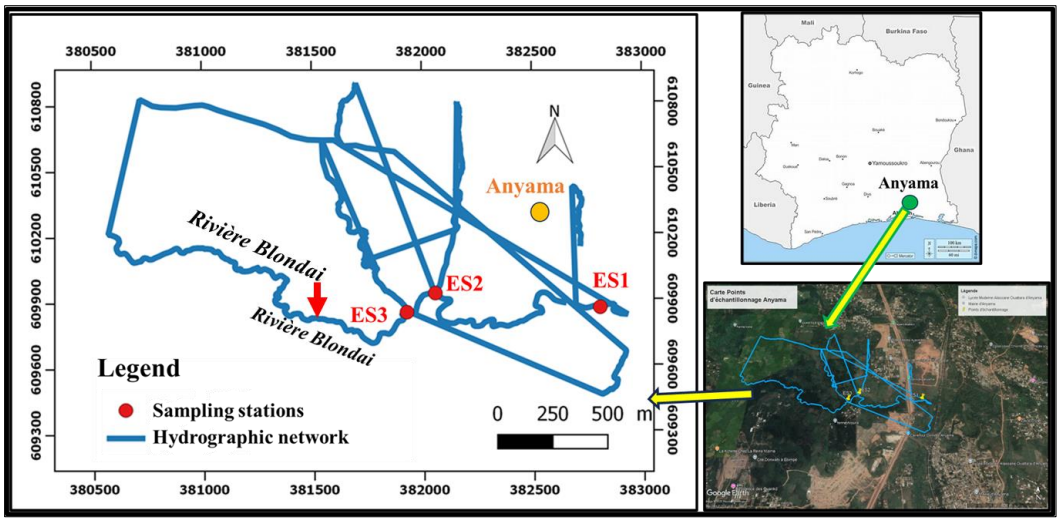


Figure 1 Presentation of sampling stations

2.2. Methods

2.2.1. Analysis of physico-chemical parameters

Physicochemical parameters were measured in the field and in the laboratory. Temperature, dissolved oxygen content, pH, electrical conductivity and turbidity were measured in situ using an AZOTA multimeter. Water transparency and depth were assessed by fully immersing a Secchi disc attached to a rope until it reached a level below the bottom of the watercourse.

Water samples were also taken at the various stations along the river in 500 ml polyethylene bottles. They were transported to the ENVAL laboratory in coolers containing ice packs, where they were kept refrigerated at 5°C before being analysed. These water samples were used to measure total nitrogen (N), total phosphorus, BOD5, COD and dissolved solids in accordance with the standard protocols of the Association Française de Normalisation [15].

2.2.2. Sampling of macroinvertebrates in the river

Macroinvertebrates were sampled using a stainless steel Van Veen bucket for sediment organisms and a dip net for submerged macroinvertebrates. For the benthos, a sediment sample corresponding to a total surface area of 0.15 m2 was taken at each station.

For submerged organisms, the turbid net (250 µm mesh) was used according to the SASS (South African Scoring System) method [16]. Samples were collected for 3 minutes by submerging the net and dragging it through the water column over an area of 1 m^2 (2 m * 0.5 m). The collected organisms were fixed with 70% ethanol in labelled jars and transported to the laboratory.

2.2.3. Sample sorting, observation and analysis

In the laboratory, each sample, previously preserved in alcohol, was rinsed with tap water. The samples were then sieved and the individuals collected sorted using a binocular magnifying glass to separate the fauna from the debris and sedimentary particles. The organisms collected were counted, photographed and identified to the lowest possible taxonomic level using the appropriate determination keys [17] [18] and preserved in 70% ethanol.

2.2.4. Data analysis method

Method of Diversity Analysis

Taxonomic richness, taxonomic group abundances, Shannon diversity indices and Piélou equitability indices were determined for the diversity analysis.

- -*Taxonomic richness* used to highlight the total number of species encountered at the various sampling stations [19].

- *-Abundance of taxonomic* groups was used to determine the structure and distribution of macroinvertebrate communities in the Blondai River. It represents the ratio of the number of individuals of taxon (i) present to the total number of individuals [19]. It varies in space and time. Relative abundance is expressed as follows:

$$Pi = ni/N$$

where Pi is the relative abundance of species (i), ni is the number of individuals of species (i) and N is the total number of individuals.

- *The Shannon-Weaver diversity index* has been used to measure specific diversity within macroinvertebrate communities. It is based on the number of species and the regularity of their frequency of distribution. H' = - Σ p i log 2 pi where pi represents the relative abundance of species i in the sample (p i = n i /N). H' fluctuates between 0 and log S. A high Shannon index corresponds to favourable environmental conditions allowing many species to establish themselves. Generally, the value of H' is between 0.5 (very low diversity) and 4.5 or 5 (most diverse communities).

- *Piélou Equitability*, has been used to evaluate the degree of homogeneity in the distribution of macroinvertebrate taxa, independently of their specific richness [20].

$$\mathbf{J} = \boldsymbol{H\ log2\ (S)}$$

Where H is the Shannon diversity index for a sample and S is its species richness. Equitability varies from 0 to 1.

2.3. Statistical method

The Shapiro-Wilk normality test was used to test the normality of the various data. The Kruskal-Wallis test was used to compare the various parameters measured at different sampling stations.

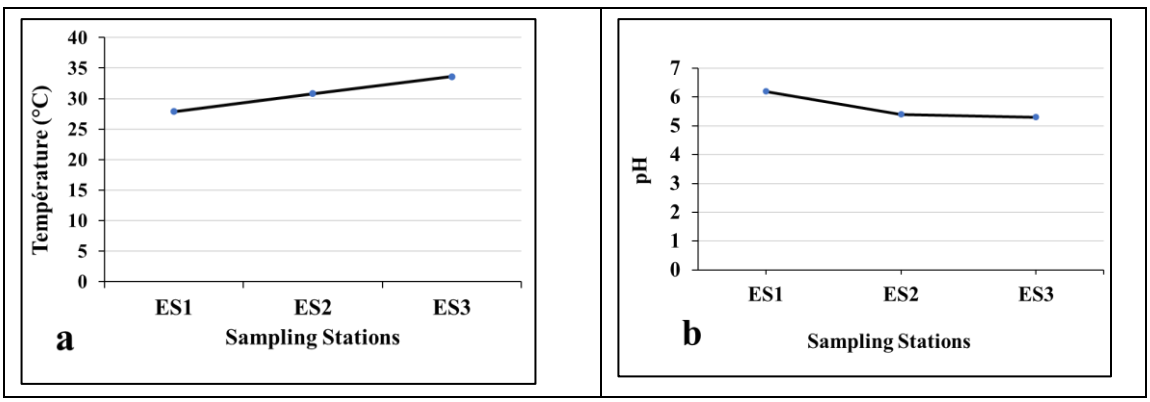
Canonical Correspondence Analysis (CCA) was performed using Past 3.4 software [21] to map biotic data to abiotic data obtained during sampling. All static analyses were carried out using Past 3.14 and the software.

3. Results

3.1. Spatial variations in the river's physico-chemical parameters

Temperature values varied between 27.9 °C and 33.6 °C. The minimum value was recorded at station ES1, while the maximum was observed at station ES3. For pH, the minimum and maximum values observed in the river were 5.3 (ES3) and 6.2 (ES1) respectively. Conductivity values in the river ranged from 54.2 µS/cm (ES1) to 75.5 µS/cm (ES2). Spatial variation in dissolved oxygen in the river ranged from 4 mg/L (ES2) to 7.7 mg/L (ES1). Total nitrogen values varied between 0.55 mg/L and 1.11 mg/L. The minimum value was recorded at station ES3, while the maximum value was observed at station ES1.

Spatial variation in turbidity at the river stations ranged from 19.8 NTU (ES2) to 41.7 NTU (ES1).



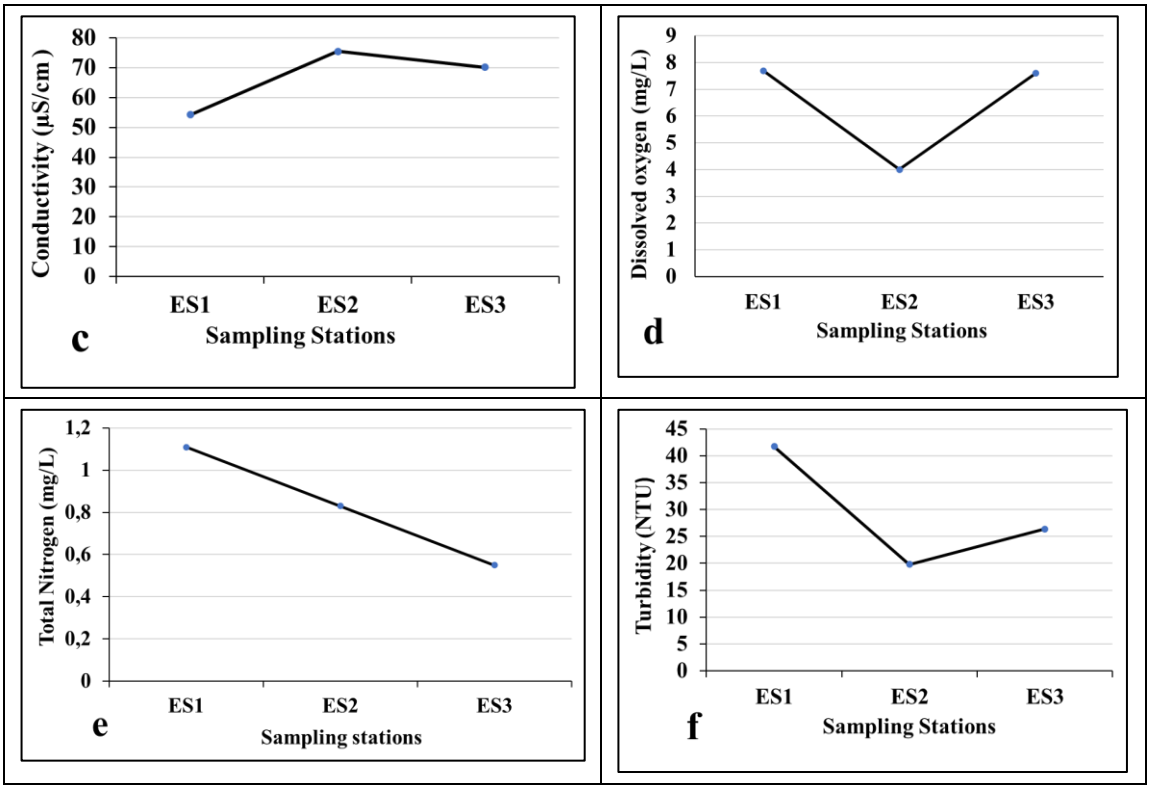


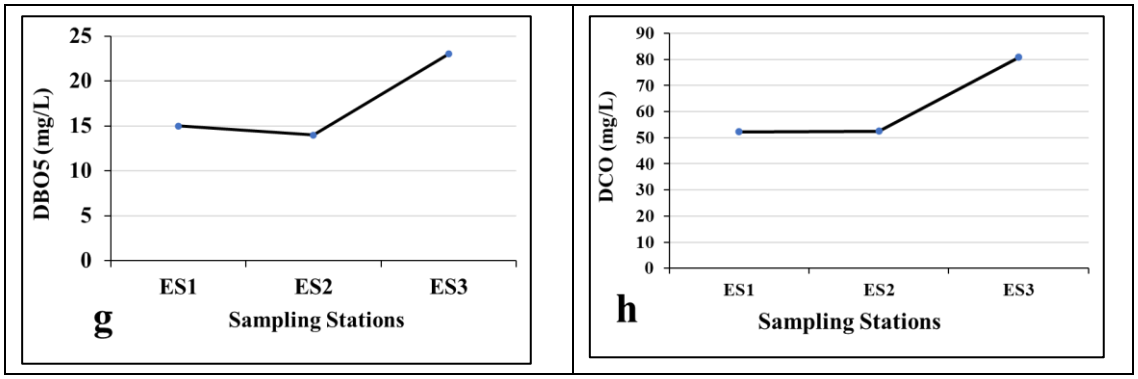
Figure 2 Spatial variations in temperature, pH, conductivity, dissolved oxygen, total nitrogen and turbidity at stations on the River « Blondai ». ES = indicates river points. The Arabic numbers 1, 2, 3 associated with the station abbreviations indicate the different stations in the river

The minimum and maximum BOD5 values observed at the river stations are 14 mg/L (ES2) and 23 mg/L ES3) respectively.

COD concentrations measured at the river stations ranged from 52.28 mg/L (ES1) to 80.79 mg/L (ES3).

Total phosphorus values varied between 0.04 mg/L and 0.13 mg/L. The minimum value was recorded at stations ES1 and ES3, while the maximum value was observed at station ES2.

Dissolved matter concentrations at the river stations ranged from 13 mg/L (ES3) to 15 mg/L (ES1). Variations in all the parameters measured in the river were not significant at the stations studied (Kruskal-Wallis test, p-value > 0.05).



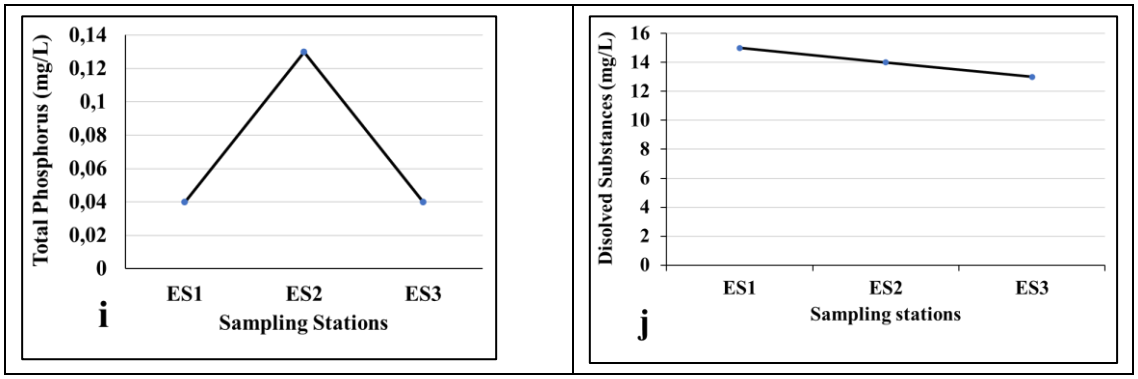


Figure 3 Spatial variations in BOD5, COD, total phosphorus and dissolved solids in water from stations on the « Blondai» river. ES = indicates points on the river. The Arabic numbers 1, 2, 3 associated with the station abbreviations indicate the different stations in the river

3.2. Benthic macroinvertebrates identified in the river

The count of individuals collected at all the sampling stations (Table 2) gave a total of 50 individuals divided into 9 orders, 11 families and 12 taxa. These taxa are divided into 3 phyla (Annelids, Molluscs and Arthropods) and 3 classes (Clitellates, Gastropods and Insects).

Arthropods are dominated by the class of Insects (6 taxa, i.e. 50% of the 12 collected), divided into 4 orders (Diptera, Odonata, Coleoptera, Hemiptera). They are followed by Molluscs (5 taxa, i.e. 42% of the total taxa) divided into 04 Orders (Archaeogastropoda, Basommatophora, Littorinimorpha and Sorbeoconchae). The Annelids collected (1 taxa, i.e. 8% of the total taxa) are characterised by the species *Barbrania* sp. of the Class Clitellate and Order Rhynchobdellida.

The most diverse orders are Basommatophora, Coleoptera and Diptera, with 02 species each, or 17% of the species richness. The other orders are less rich, with 01 species each, or 08% of species (Figure 3). The most diverse family is the Chironomidae, with 2 taxa (*Polypedilum laterale* and *Polypedilum abyssiniae*).

The downstream part of the river is the richest in species (10 species). However, the middle and upstream sections are the least diverse, with 02 species each. *Grenitis* sp and *Polypedilum abyssiniae* are the species most commonly found in the three parts of the river (upstream, midstream and downstream).

Table 3 below shows the presence or absence of benthic macroinvertebrate taxa collected at the various sampling stations.

Table 2 Taxonomic composition of sampling stations

						Upstream	**Median**	**Downstream**
Branches	**Classes**	**Orders**	**Families**	**Species**	**Code**	**ES1**	**ES2**	**ES3**
Annelids	Clitellate	Rhynchobdellida	Erpobdellidae	*Barbrania* sp.	Bar	-	-	+
Molluscs	Gastropods	Archaeogastropods	Neritidae	*Clithon* sp.	Cli	-	-	+
		Basommatophora	Physidae	*Aplexa marmorata*	Apl	-	+	-
			Planorbidae	*Afrogyrus rodrignezensis*	Afr	-	-	+
		Littorinimorphs	Hydrobiidae	*Tomichia differens*	Tom	-	-	+
		Sorbeoconches	Thiaridae	*Melanoides tuberculata*	Mel	-	-	+
	Insects	Coleoptera	Gyrinidae	*Dineutus* sp.	Din	-	-	+

Arthropods			Hydrophilidae	*Grenitis* sp.	Gre	+	-	+
		Diptera	Chironomidae	*Polypedilum laterale*	Pol	-	+	-
				Polypedilum abyssiniae	Poa	+	-	+
		Hemiptera	Belostomatidae	*Diplonychus* sp.	Dip	-	-	+
		Odonates	Libellulidae	*Zygonyx torrida*	Zyg	-	-	+
Total =3	3	9	11	12		2	2	10

(+) : Présent, (-) : Absent

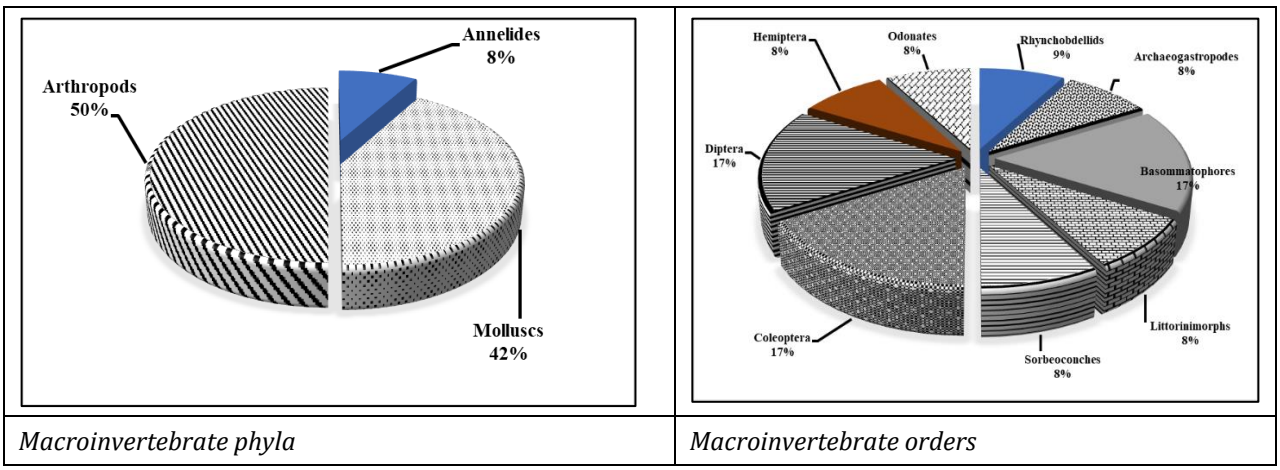


Figure 4 Relative abundance of benthic macroinvertebrate phyla and orders in the river « Blondai »

3.3. Spatial distribution of taxonomic richness and number of individuals

Maximum abundance (46 individuals) was recorded at station ES3 downstream from the river, while minimum abundance was observed at station ES1 (2 individuals) upstream from the river. Station ES3 recorded the highest taxon richness with 10 taxa, while the lowest taxon richness was recorded at stations ES2 and ES3 with 2 taxa each (Figure 5).

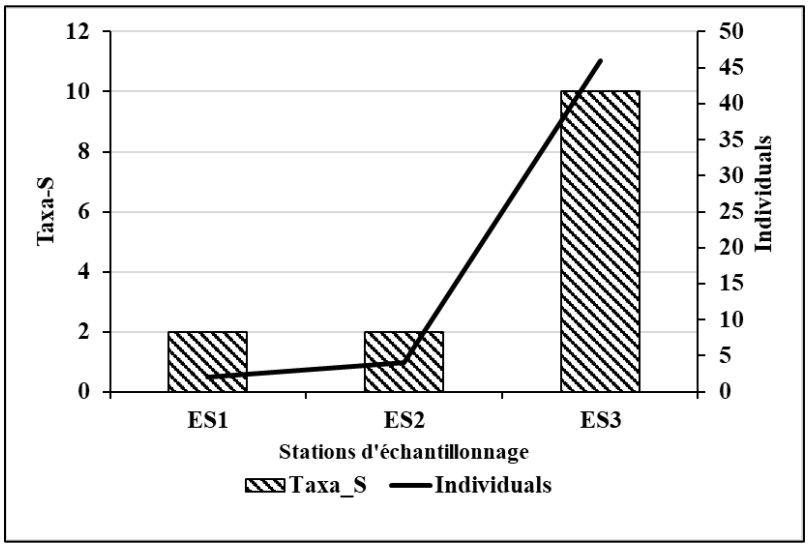


Figure 5 Spatial trends in abundance and species richness of macroinvertebrates in the river

3.4. Spatial distribution of the Shannon Index (H) and Equitability Index (E)

Figure 6 shows the spatial evolution of the Shannon diversity and Piélou equitability indices. It shows that the highest value of the Shannon diversity index (1.65 bits) is observed at station ES1 downstream from the river, while the lowest value of this index (0.69 bits) is recorded at stations ES2 and ES3 in the river. The Piélou equitability index shows a different trend to that of the Shannon index. The maximum value of equitability (1) is observed at stations ES1 and ES2, while the lowest value of the index (0.72) is recorded at station ES3 downstream of the river. Analysis of the indices using the Kruskal-Wallis test revealed no significant difference between stations ($p > 0.05$).

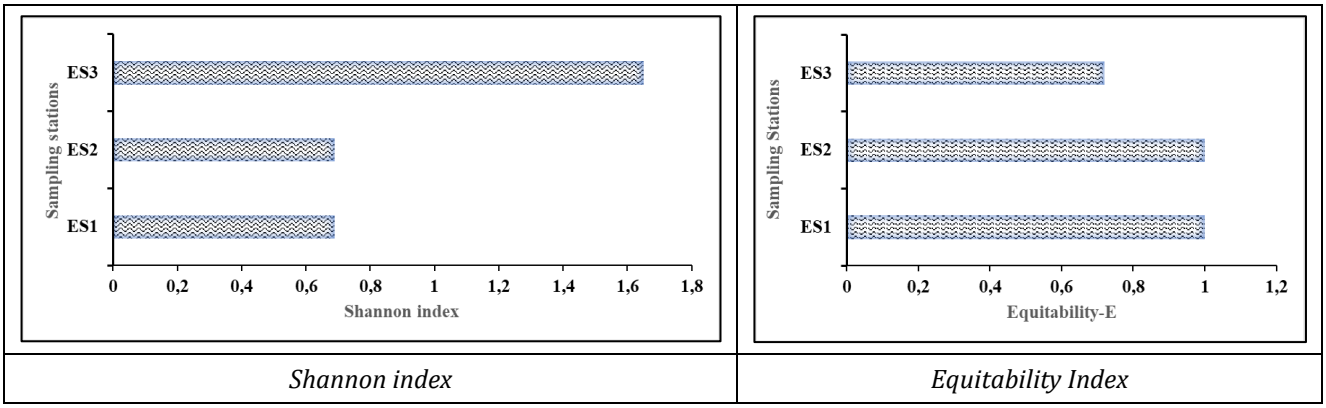


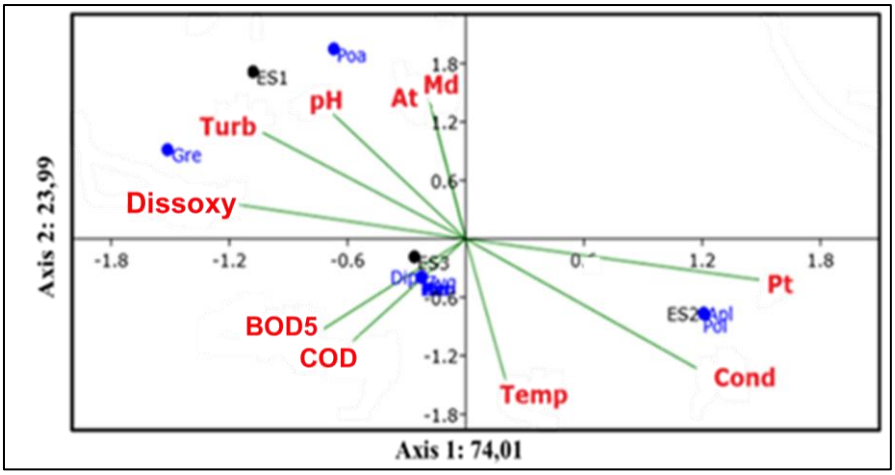
Figure 6 Distribution of the Shannon Diversity (H) and Equitability (E) indices in the different stations of the river

3.5. Relationship between the distribution of macroinvertebrates and the physico-chemical parameters of the river « Blondai »

The following graph shows the results of the CCA carried out between physico-chemical parameters and the abundance of benthic macroinvertebrate species in the river 'Blondai' (Figure 7). The information contained in the variables is 98% controlled by the axes 1 and 2 system. The first axis is negatively and strongly correlated with dissolved oxygen concentration, turbidity and pH. This same axis is positively and strongly correlated with conductivity and total phosphorus. The second axis is negatively and strongly correlated with temperature, conductivity, Biochemical Oxygen Demand (BOD5) and Chemical Oxygen Demand (COD). It is also strongly and positively correlated with pH, total nitrogen, turbidity and dissolved solids concentration. Dissolved oxygen, conductivity, temperature, turbidity, pH, COD, BOD5, total phosphorus, total nitrogen and dissolved solids therefore influence the distribution of macroinvertebrate species. The projection of macroinvertebrate species onto the vector axes of environmental parameters (Figure 7) shows that on axis 1, there is a strong negative correlation between Grenitis sp., Polypedilum laterale and pH, Turbidity and Dissolved Oxygen at station ES1 located upstream in the river. On the same axis, there is a strong positive correlation between Aplexa marmorata, Polypedilum abyssiniae, and total phosphorus and conductivity at station ES2 in the middle of the river. On axis 2, between *Barbrania* sp, *Clithon* sp. *Afrogyrus rodrignezensis*, *Tomichia differens, Melanoides tuberculata*, *Dineutus* sp., *Grenitis* sp., *Polypedilum abyssiniae*, *Diplonychus* sp., *Zygonyx torrida*, and station ES3 located downstream of the river, a positive association was observed.

Table 3 *E*igenvalues of physico-chemical parameters on the axes

Parameters	Temp	pH	Cond	DBO5	At	DCO	Oxydiss	Pt	Turb	Md
Axis 1	0.13	-0.52	0.78	-0.48	-0.12	-0.38	-0.99	0.99	-0.81	-0.12
Axis 2	-0.96	0.99	-0.88	-0.61	0.96	-0.69	0.3	-0.27	0.86	0.96



Legend: Bar : Barbrania sp., Cli : Clithon sp., Apl: Aplexa marmorata., Afr : Afrogyrus rodrignezensis ; Tom : Tomichia differens, Mel : Melanoides tuberculata, Din : Dineutus sp., Gre : Grenitis sp, Pol : Polypedilum laterale, Poa: Polypedilum abyssiniae, Dip: Diplonychus sp., Zyg : Zygonyx torrida. Temp : Temperature, Cond : Conductivity, Turb: Turbidity, Oygdiss: Dissolved oxygen, pH, COD : Chemical Oxygen Demand, BOD5 : Biochemical Oxygen Demand, Md : Dissolved matter, At : Total nitrogen, Pt : Total phosphorus

Figure 7 Canonical Correspondence Analysis of benthic macroinvertebrate species and physico-chemical variables at stations in the river « Blondai »

4. Discussion

Physico-chemical factors condition life in the aquatic environment [22]. The most important of these factors are temperature and dissolved oxygen levels. In our study, the range of temperature values was relatively high (27.9-33.6°C). This can be explained by the existence of a low canopy and therefore exposure of the water surface to solar radiation. Such high temperature values could have a negative influence on dissolved oxygen concentration [23]. Average dissolved oxygen concentrations in the Blondai River fluctuate between 4 mg/L and 7.7 mg/L.

The higher dissolved oxygen values can be explained by the renewal of the water due to run-off during this period. Run-off helps to stir up the water and therefore increase oxygenation.

Also, the solubility of dissolved oxygen is greater at low temperatures than at high temperatures and also low in stagnant water situations [24].

Other authors such as [25] have also shown that low water transparency could also lead to a reduction in the dissolved oxygen content of the water.

In addition, low dissolved oxygen levels could pose a threat to aquatic organisms and reduce oxidation processes. In addition, low electrical conductivity values (54.2-75.5 µS/cm) were observed, reflecting low mineralisation [26] at the river sampling stations. Highly mineralised waters generally have high electrical conductivities [27]. In the present study, the low mineralisation is confirmed by the low concentrations of calcium ions. This condition could favour better development of the molluscs due to the availability of calcium salts, a constituent element of their shells. The concentrations of total nitrogen and total phosphorus obtained in the river are low. These low concentrations of nitrogen and phosphorus may reflect the low impact of agricultural inputs on the aquatic ecosystem. However, this impact would be localised because the banks of the zone are largely occupied by agricultural activities [28]. This finding implies that a more extensive sampling effort should be carried out throughout the reservoir in order to better determine the impact of agricultural activities.

The river water is acidic, with pH values of 5.3 and 6.2 respectively. The acidity could be linked to the geological bedrock over which the river flows.

In the context of this study, the sampling period was characterised by low levels of turbidity, MES, COD and BOD5. The low values for these parameters are due to the rapid turnover of water in the river, which carries with it particles of varying size, depending on the quantity of water in motion and the gradient [29]. Overall analysis of these physico-chemical variables reveals fairly good water quality.

The taxonomic inventory yielded three (03) classes of macroinvertebrates, with insects dominating. The taxonomic composition of the river « Blondai » decreases from upstream to downstream. It is made up of 50% insects and 8% annelids, with a predominance of the orders Basommatophores, Coleoptera and Diptera, each accounting for 17% of the species richness. This taxonomic richness is comparable to that of the Agnéby rivers in Côte d'Ivoire [10]. This is one of the characteristics of African freshwater rivers ([30] [10]).

The numerical and taxonomic importance of the insect classes followed by that of the gastropods was noted in this study. This predominance of Insects in terms of taxonomic richness and abundance observed in the river would be due to the diversity of species that this class contains and also to their larvae, most of which are exclusively aquatic [31]. Our results are consistent with those of [32] and [33].

Biodiversity analysis indicates that the « Bondai » river has low diversity. The Shannon index value of less than 2 at all the sampling stations indicates low macroinvertebrate diversity. In contrast, the Pielou Equitability Index shows average regularity in the distribution of taxa. This low diversity could be explained by the average ecological quality of this river. Macroinvertebrate diversity depends on the ecological quality of the environment. An environment of very good ecological quality is likely to harbour macroinvertebrate taxa that are sensitive to pollution, which increases diversity [34].

The correlation between physico-chemistry and benthic macroinvertebrates in the « Bondai»river showed that temperature, dissolved oxygen, conductivity, turbidity, pH, COD, BOD5, total phosphorus, total nitrogen and suspended solids are the physico-chemical parameters that significantly influence the abundance of benthic macroinvertebrates. The canonical analysis showed that these physico-chemical parameters explain 98% of the variability of benthic macroinvertebrates in the “Blondai” river. The remaining 2% of variability could be explained by the influence of environmental variables other than physicochemical ones.

5. Conclusion

This work made it possible to characterise the benthic macrofauna of the river « Blondai». It also enabled a physico-chemical characterisation of the river. Generally speaking, the water at the various stations in the river studied is acidic, has low conductivity, is moderately oxygenated and has low concentrations of nitrogenous matter, phosphorus, suspended matter, chemical oxygen demand and biochemical oxygen demand. This study enabled 50 macroinvertebrate individuals to be inventoried, corresponding to 3 faunal groups (Annelids, Molluscs, Arthropods), 03 Classes, 09 Orders and 11 families. Among these different classes, insects were the most abundant and diverse taxonomic group. Analysis of the structure of the benthic fauna reveals a poorly diversified and poorly organised population in the ‘Bondai’ river. Canonical correspondence analysis showed that dissolved oxygen, conductivity, temperature, turbidity, pH, COD, BOD5, total phosphorus, total nitrogen and dissolved matter are the parameters with the greatest influence on the distribution of macroinvertebrates. These results provide a basis for any action to biomonitor the ecological quality of the water in this river in the light of the various human activities taking place in its catchment.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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