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BIOLOGICAL QUALITY OF THE WATER OF THE NIGER RIVER FOR AGRICULTURE, FARANAH, GUINEA

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ABSTRACT

Climate change imposes numerous constraints on agriculture. By considering the development of hydro-agriculture, the water of the Niger River could meet the challenges posed by the irreversible reduction in rainfall. Unfortunately, previous studies indicate that the water of the Niger River contains agrochemicals. Its use in agriculture presupposes its quality. It is in this context that this study was conducted on the Niger River in Faranah with the objective of understanding the biological quality of the water. Three sampling campaigns were carried out at five sites. The diversity, frequency and equability of macroinvertebrates, the ratio of Ephemeroptera Plecoptera Tricoptera, the percentages of non-dipteran insects and chironomids made it possible to know the water quality. Correlation and canonical correspondence analysis verified the suitability of the water for agriculture. The results showed that the stations are rich in macroinvertebrates (88% of species are Shannon indices >2 and equitability close to 1 indicate aquatic environments capable of supporting life. The correlations established between the index of taxa sensitive to pollution and the index of cosmopolitan taxa with the water quality descriptor parameters confirmed the suitability of the waters for agriculture.

Keywords: Bioindicators, Water, Niger River, Irrigation

1. INTRODUCTION

In the Sudan-Guinea region of Africa, rainfall deficits, which have persisted for nearly 35 years, have significantly reduced runoff due to decreased rainfall, thus reducing water resource levels [1]. Guinea faces numerous climate disturbances and variability, which are manifested by early and frequent flooding, disruptions in the hydrological regime of tidal channels, drops in water table

ISSN: 2455-6939

Volume: 11, Issue: 02 "March-April 2025"

levels and drying up of rivers [2]. Analyses reveal that rain-fed rice cultivation occupies 58% of the national arable land and generates 69% of total rice production. Furthermore, nearly 70% of the agricultural workforce is engaged in this sector, contributing significantly to food security and improving rural incomes.

These constraints are likely to exacerbate the socio-economic vulnerability of the populations of Upper Guinea, a region considered the most vulnerable in the country [3] although the Niger River originating in Faranah and its tributaries provide the region with important sources of water. By considering the development of hydro-agriculture, this water can be used in irrigation fields to meet the challenges posed by the irreversible reduction in rainfall. Unfortunately, studies by [1], [4] indicate that the water of the Niger River contains organic matter, nutrients, pesticides and synthetic fertilizers used in agriculture.

Considering that water constitutes an ecosystem in its own right, any environmental analysis to be complete must imperatively include a rigorous evaluation of its biological quality in order to characterize its ecological state. The principle is to use aquatic life as evidence of its capacity to maintain life. Because some animals living in aquatic environments are sensitive to changes in pH, temperature or nutritional environment and are also recognized for their ability to reflect the state of the ecosystem [5]. For example, macroinvertebrates are sensitive to pollution and can be used for the ecological diagnosis of aquatic environments [6]; they are increasingly used in different types of biotic indices [7]. They constitute an effective method for assessing the quality of the system and the real impact of contamination.

The main objective of this study was to assess the biological quality of the Niger River waters for irrigated agriculture.

2. MATERIALS AND METHODS

2.1. Materials

2.1.1. Study environment

The Niger River is the center of major socio-economic and cultural activities in the Niger Basin Authority (NBA) member states. It originates in Kobikoro, Faranah Prefecture, Guinea. This river plays a vital role in supplying approximately 150 million people with water and food [8].

Thanks to its tributaries, the Niger River flows directly through four countries: Guinea, Mali, Niger, and Nigeria. However, its watershed also extends to Chad, Cameroon, Benin, Burkina Faso, and Côte d'Ivoire, bringing to nine the number of countries affected by its water resources.

ISSN: 2455-6939

Volume: 11, Issue: 02 "March-April 2025"

In Guinea, the Niger Basin covers the three administrative regions of Kankan, Nzérékoré and Faranah, the latter grouping together the prefectures of Faranah, Dabola, Dinguiraye and Kissidougou (see Figure 1).

For the purposes of this research, studies were carried out on the Niger River at its source in Kobikoro and on the main course and its tributaries in the city center in Faranah.

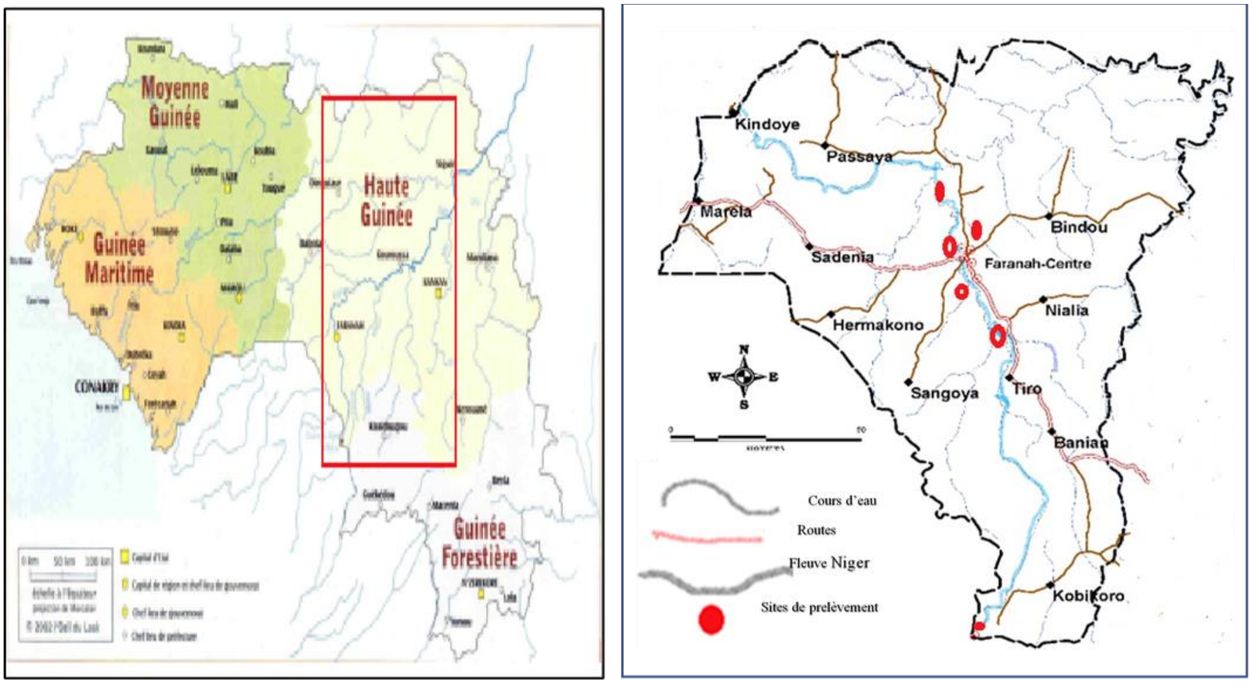

Figure 1: Geographical location of sampling points on the Niger River at Faranah.

2.1.2. Technical materials: Invertebrate macros were captured using a 500 µm mesh net. Samples were washed on a 1 mm mesh sieve and fixed with 70% alcohol in labeled vials. In the laboratory, organisms were sorted, identified and counted.

2.2. Methods

2.2.1. Sampling: As part of the macroinvertebrate inventory, six (6) campaigns (one per month) were carried out on 5 sites during three (3) hydrological regimes: low water period (March to April), rising water period (May to June), final receding period (December - January). At each sample and on each site, we measured the physicochemical parameters (temperature, pH, conductivity, dissolved oxygen and water flow velocity [9]). Sampling was carried out from 8 a.m. to 12 p.m. in a 100 m long transect at the level of the micro habitat, rocks, aquatic plants, dead wood, etc.

The selected sampling sites are listed in Table 1.

ISSN: 2455-6939

Volume: 11, Issue: 02 "March-April 2025"

Table 1: Location of sample collection points

Sampling point	Code	North Latitude (o)	Longitude W (o)	Altitude (m)
Main Course Height	CP_H	9,9862	10,71813	422
Permanent Tributary	AF_P	10,02706	10,73168	432
Main Course Lowland	CP_B	10,03704	10,74976	419
Intermittent Tributary	AF_I	10,0608	10,73248	430
Main Course Plain	CP_P	10,06369	10,75883	395

The relief of the banks was taken into account in the choice of sites, in particular the plains, the lowlands, the slopes (height).

2.2.2. Data analysis and processing

The Shannon diversity index (H) was used to assess the diversity of a population. It was obtained using the following formula: H = - Σ pi Log2 (pi), where pi is the proportion of individuals in the i-th species and Log2 (pi) is the base 2 logarithm of pi. The higher H, the greater the diversity. The frequency of a species is obtained by expressing the percentage ratio between the number of samples in which species i appears (p) and the total number of samples (P) of the biocenotic unit considered [9]; [10] according to the formula$F = \frac{p}{P_i} \times 100.$

The fairness index is calculated by:

$$R = \frac{H}{H'max} = \frac{H}{\log_2 S}$$

This index varies between 0 and 1 and tends towards 1 when the species have identical abundances in the population and towards 0 when the majority of the numbers correspond to a single species.

These indices were calculated considering the family as the taxonomic level [11].

To highlight the influence of environmental factors at these sites on the distribution of macroinvertebrates, we performed an Ascending Hierarchical Classification (ACH) using Past 3 software (PAleontological STatistics, Version 3.10, 2001). Macroinvertebrate capture stations can construct the dendrogram according to their sensitivity to contamination.

2.2.3. Determination of the biological quality of water

ISSN: 2455-6939

Volume: 11, Issue: 02 "March-April 2025"

The biological quality of the water was determined by descriptor indicators such as the ratio of Ephemeroptera, Plecoptera and Tricoptera (EPT), the percentage of red chironomids, the percentage of Non-Diptera Insects (NDI), biotic indices calculated by a scoring method called South African Index Scoring System (SASS) and Average Score Per Taxon (ASPT). These indices were calculated by considering families as taxonomic levels [11]. They were compared using the Spearman rank correlation coefficient. This non-parametric method measures the strength of the relationship between two indices. The Spearman correlation coefficient varies between -1 and 1; and these extreme values indicate a perfect correlation between the two indices considered.

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Canonical correspondence analysis was used to relate the calculated biological indices (also called water quality descriptor indicators) to physicochemical variables (temperature, dissolved oxygen, pH, ammonium, nitrate, sulfate, phosphate ions). The results of these variables were published by [12].

2.2.4. Statistical analyses:

Statistical analysis software MS EXCEL used to compare captured taxa according to hydrological regimes and sites.

Past software (PAleontological STatistics, Version 3.10, 2001) was used to construct the hierarchical classification dendrogram.

SPSS 20 was used to compare the number of individuals and the number of families per station across the graphs

Using the CANOCO (Canonical Ordination of Communities) software version 4.0 (Braak and Smilauer, 1998), correspondences was used to highlight the relationship between environmental variables and biotic indices by station and by hydrological regime.

3. RESULTS

3.1. Specific richness of taxa according to the sampled watercourses

A total of 60 macroinvertebrate families were captured in the waters of the Niger River and its tributaries in downtown Faranah (Guinea). Population structure analysis showed that most benthic macroinvertebrate families collected at the sampling stations were common, but species richness varied from one stream to another. Thus, the number of families per order varied from 1 to 9 in the main stream; from 1 to 6 in the permanent tributary; and from 1 to 7 in the intermittent tributary. The stations showed very high taxonomic richness in Hemiptera (6 to 9), Ephemeroptera (3 to 8), Coleoptera (5 to 8), Odonata (4), Pulmonata (4), and Bivalves (4 to 8) in the sampled streams (Figure 2).

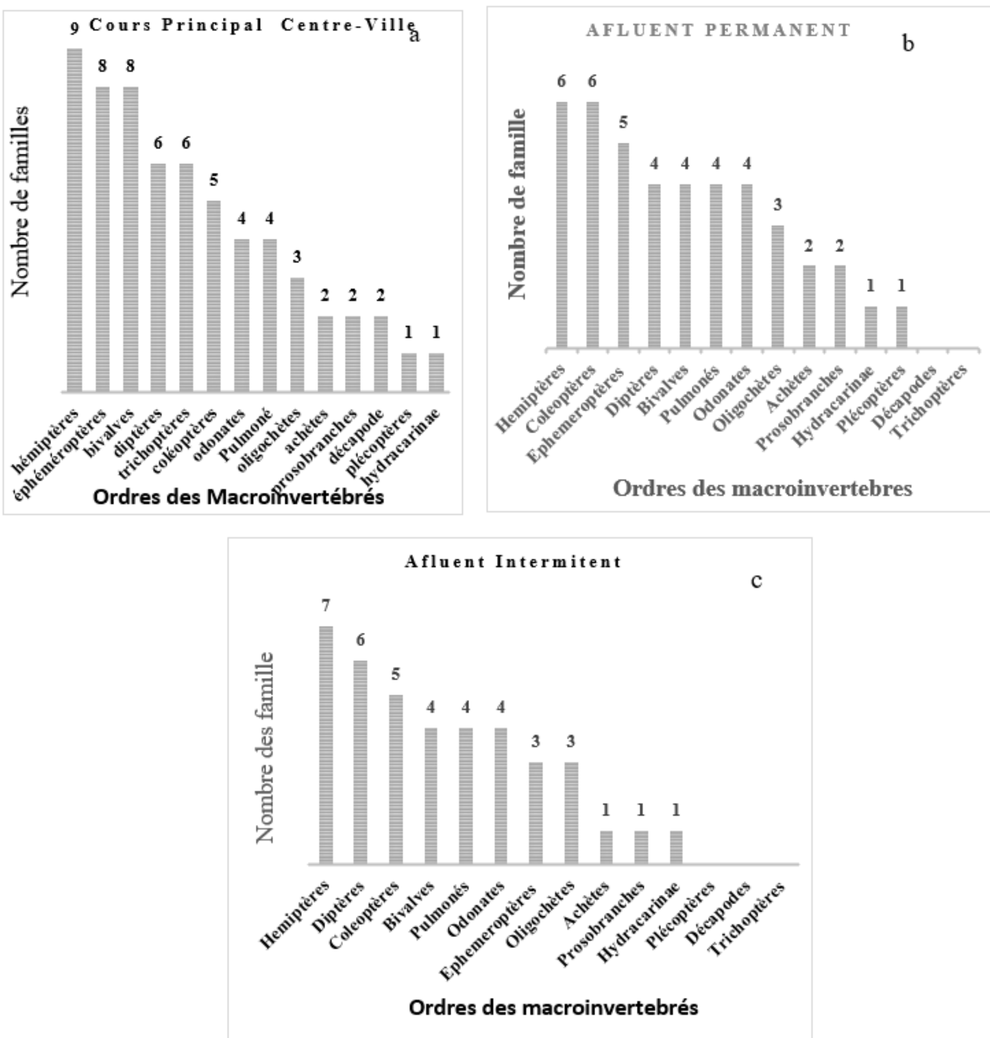


Figure 2: Presents the number of families by order in each sampled stream.

a) Number of families by order at the main course in the city center, b) Number of families by order at the permanent tributary, c) Number of families by order at the intermittent tributary.

ISSN: 2455-6939

Volume: 11, Issue: 02 "March-April 2025"

3.2. Influence of environmental variability on species richness

The Hierarchical Correspondence Analysis dendrogram displayed two (2) clusters that represent three (3) biotopes observed in the study environment (Figure 3).

The first cluster consists of biotype 1; it is represented by the Cours Principal Hauteur (CP_H) station.

The second biotope includes clusters 2 and 3. Cluster 2 covers the Main Lowland Course (CP_B) and Main Plain Course (CP_P) stations. The results showed that the taxa collected at these sites are mainly Ephemeroptera, Trichoptera, Hemiptera, Odonata, Prosobranchs, Pulmonates, and Bivalves. The difference between these two biotopes lies in the number of families per order and the number of individuals per family as shown in Figures 2a, b, and c.;

The third cluster falling under the 2nd biotope includes the Permanent Tributary (AF-P) and Intermittent Tributary (AF-I) stations. These stations are characterized by a low number of families and individuals of Ephemeroptera, Plecoptera and Trichoptera.

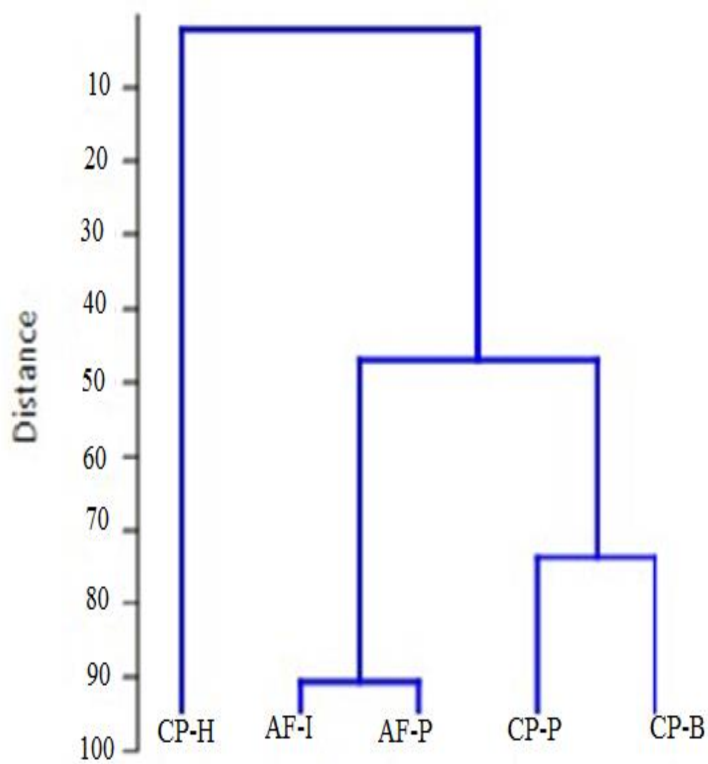


Figure 3: Presents the classification of sampling stations according to the similarity of the taxa collected. CP_H = Main Course Height, CP_B = Main Course Lowland, CP_P = Main Course Plain.

International Journal of Agriculture and Environmental Research

ISSN: 2455-6939

Volume: 11, Issue: 02 "March-April 2025"

3.3. Ecological indices

3.3.1. Frequency of occurrence

Application of the formula for calculating the percentage of occurrence for each taxon gave the following results; 88% of the taxa collected were encountered in all streams, 7% were rarely detected and 5% were accidentally found. 85% of the taxa were collected under the hydrological regimes; 8% were rarely encountered and 7% were accidentally found (Figure 4).

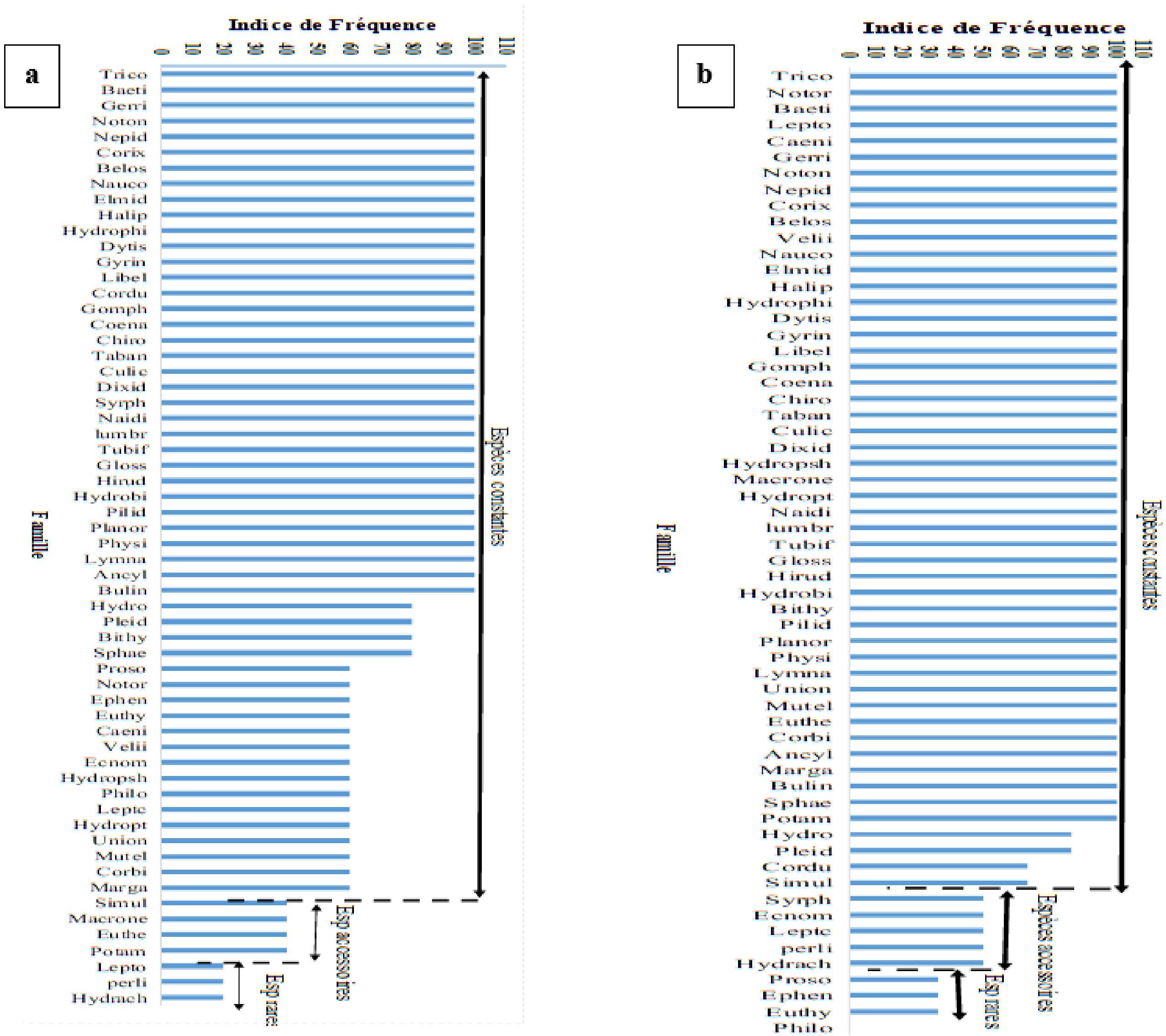


Figure 4: a) Frequency of occurrence by Families b) Frequency of occurrence by Families depending on the stations, depending on the hydrological regimes.

ISSN: 2455-6939

Volume: 11, Issue: 02 "March-April 2025"

F represents the frequency of occurrence.

F < 25% (accidental taxa),

25% ≤ F ≤ 50% (rare taxa),

F ≥ 50% (frequent taxa).

3.3.2. Shannon diversity and Equitability indices by station and by hydrological regime

Compared to the rivers studied, the Main Course, with a Shannon diversity index equal to 4.3, displayed a greater population diversity compared to the Permanent Tributary (3.58) and at the Intermittent tributary (3.56). (Table 2a)

Taking into account hydrological regimes, the period of flood recession experienced a greater diversity of macroinvertebrates collected compared to the period of low water (3.89) and rising water (3.67) (Table 2b).

Compared to the Pielou Equitability Index, as indicated by the Shannon Diversity Index, the minimum value (0.96) was observed during the period of rising water; while the maximum value (0.99) was observed during the period of falling water (Table 2b). All these values are close to 1. The Pielou Equitability Index was 0.99 in the main course. This index was equal to 1 for the Permanent and Intermittent Tributaries.

Whether it is a question of type of watercourse or hydrological regime, the values of the Pielou equitability index, varying globally from 0.96 to 1, are all close to 1. This indicates that the species have identical abundances in the benthic macroinvertebrate population of the waters studied (see table 2 a and b).

Table 2: Shannon diversity and Equitability indices by stations and by hydrological regimes

a - the indices of Shannon and Equitability by water course

Type of watercourse	Taxa	Individuals	Shannon	Fairness
Main Course	59	165	4.03	0.99
Permanent Tributary	39	36	3.58	1
Intermittent Tributary	38	35	3.56	1

ISSN: 2455-6939

Volume: 11, Issue: 02 "March-April 2025"

b - the indices of Shannon and Equity by Hydrological Regimes

Periods	Taxa	Individuals	Shannon	Fairness
Decrease	60	232	4.05	0.99
Low water	52	204	3.89	0.98
Rising waters	45	120	3.67	0.96

3.3.3. Biological indices EPT, ASPT, %Red Chironomids and %IND

Report Ephemeroptera, Plecoptera and Trichoptera (EPT)

As shown in Figure 5a, the EPT biological index was more marked at the stations of the main course (Niger River), the values varied from 25.64 Main Course Plain to 43.30% Main Course Height; at the level of the stations of the Tributaries the proportions were lower. They varied from 1.99 Intermittent Tributary to 2.05% Permanent Tributary.

Percentages of red chironomids

Unlike the EPT index, the percentage of red Chironomids at the Main Course stations was relatively low (0.78 - 1.47%) compared to the Tributaries stations where it was very high (8.42 – 8.65%; Figure 5b).

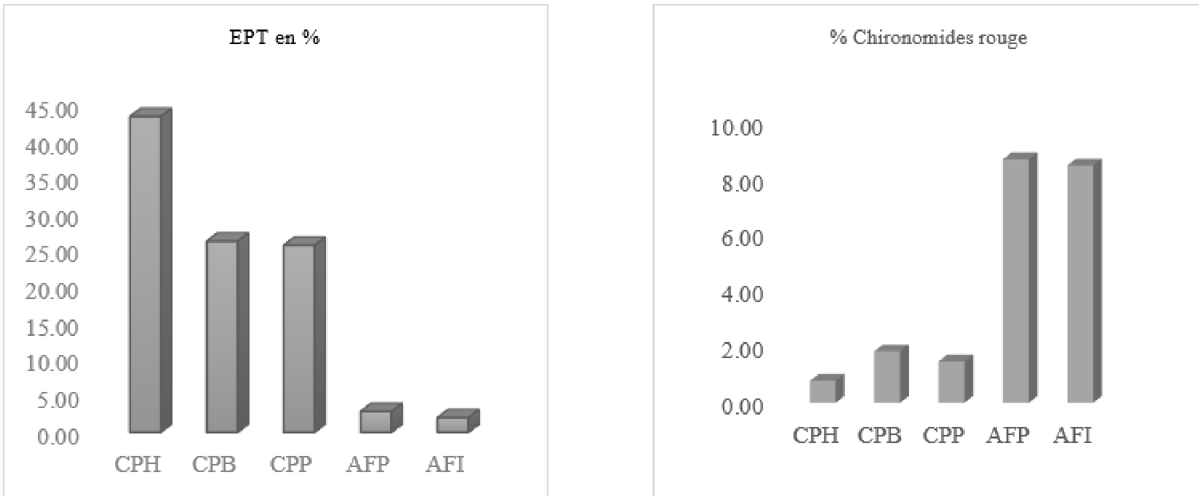
Figure 5d showed the evolution of the ASPT biological index. The values of this index were relatively higher at the Main Course stations (5.57 - 5.98) compared to the Tributary stations: 4.61% (Intermittent Tributary) and 4.66% (Permanent Tributary).

Percentage of Non-Diptera Insects (%IND)

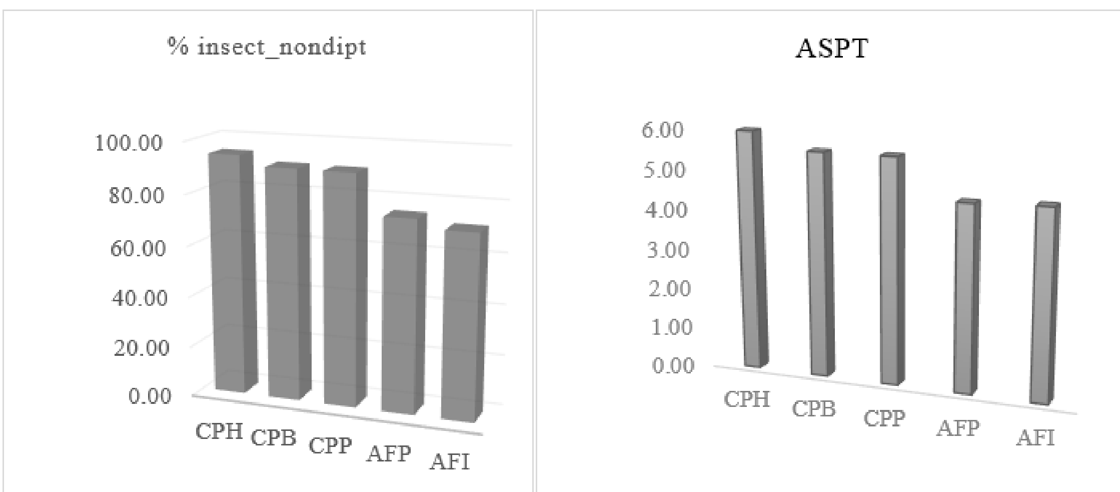
Figure 5c shows that the IND percentage is high at all sampling stations. It ranged from 71.83% (Intermittent Tributary) to 94.48% (Heights Main Course).

ISSN: 2455-6939

Volume: 11, Issue: 02 "March-April 2025"



a) Ephemeroptera Plecoptera Tricoptera (EPT) ratio b) Percentage of red chironomids.



C) Percentage of Non-Diptera Insects (NDI) d) Average score values per Taxa (South Scoring System (ASPT)

Figure 5: Showing the evolution of the biological indices EPT, % Red Chironomids, %IN and ASPT according to the stations

3.4. Water quality for irrigation

3.4.1. Correlation between calculated biological indices and physicochemical variables indicating water quality

The matrix analysis shows that:

ISSN: 2455-6939

Volume: 11, Issue: 02 "March-April 2025"

- There is a positive and highly significant correlation between EPT index, ASPT, % IND and dissolved oxygen at the 1% level, while there is a significant negative correlation between % red chironomid index and dissolved oxygen, EPT, IND and ASPT.
- There is a negative correlation between the biological indices EPT and IND and nitrates at the 1% threshold (Table 3).

Table 3: Shows the Spearman rank correlation matrix between different biological indices and descriptors of physicochemical parameters of water quality.

	T	Ph	O2 says	NH4	NO3	PO4	EPT	%ChiroR	%IND	ASPT
T	1,000									
Ph	-,975**	1,000								
O2 says	-,359	,300	1,000							
NH4	,053	-,051	-,667	1,000						
NO3	,368	-,359	**-,975****	,684	1,000					
PO4	,053	-,051	-,667	**,975****	,684	1,000				
%EPT	-,359	,400	**,900***	-,667	**-,975****	-,667	1,000			
%ChiroR	,667	-,600	**-,900***	,359	**,872***	,359	**-,800***	1,000		
%IND	-,359	,400	**,900***	-,667	**-,975****	-,667	**,975****	-,800	1,000	
ASPT	-,684	,667	**,872***	-,368	**,895***	-,368	**,872***	**-,975****	**,872***	1,000

The values of statistically significant correlations (or simple correlations) between variables physicochemical with biotic indices are marked in bold.

**highly significant correlation (p<0.01); *significant correlation (p=0.05); EPT = ratio of Ephemeroptera to Plecoptera and Trichoptera; IND = Non-Diptera Insects; ASPT =average score per Taxa =to the SASS report on the total number of families; SASS = South Scoring System; Chiro R = Chironomids rouge

ISSN: 2455-6939

Volume: 11, Issue: 02 "March-April 2025"

3.4.2. Canonical Correspondence Analysis

Canonical correspondence analysis made it possible to establish a relationship between the physicochemical parameters describing the quality of the waters studied and the calculated biological indices. Figure 6 shows an ecological gradient that distinguishes two groups of biological indices.

- The first group shows that the values of the biological index EPT were highly compatible with the values of dissolved oxygen; the values of the biological indices %IND and ASPT were highly compatible with the values of dissolved oxygen and pH.
- In the second group the values of the % red chironomid index showed an affinity to the variables NO3, NH4 and PO4.

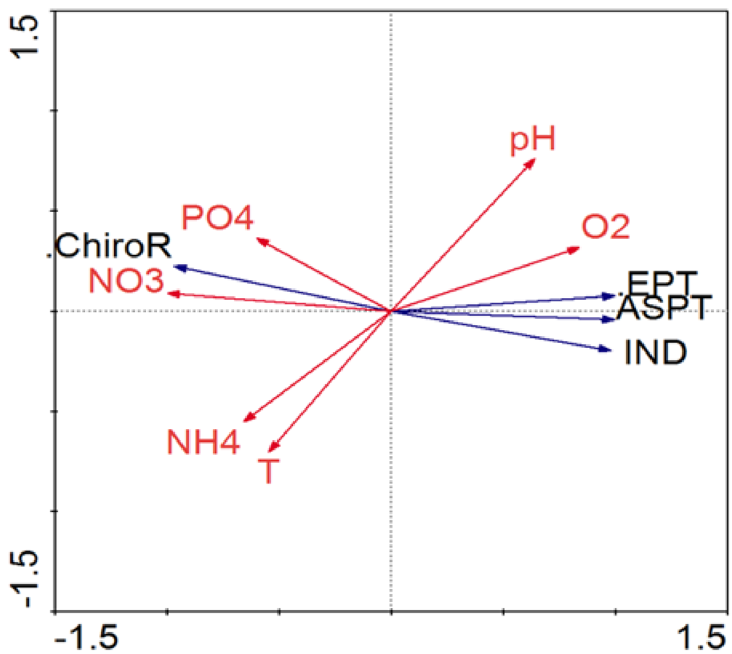


Figure 6: Presents the degree of affinity between the calculated biological indices and the physicochemical parameters describing water quality.

4. DISCUSSIONS

The family as a taxonomic level is commonly used in Europe in the calculation of biological quality index of watercourses [13]; [11] and [14]. Our results (60 families of macroinvertebrates captured) are superior to those of [15] in Lake Taabo in Ivory Coast (43 families); of [16] in a river in Benin (49 families) and of [16] in the Agnéby River in Ivory Coast (50 families). Our results also exceed those of [17] in fish ponds in the south of Ivory Coast (35 families) [18] in a lake in the north of the same country (33 families) [19] in a dam lake-effluent-river continuum in Burkina

ISSN: 2455-6939

Volume: 11, Issue: 02 "March-April 2025"

Faso (35 families), [20] in the hippopotamus pond of Bala in Burkina Faso (33 families); [19] in three water bodies of the Volta Basin in Burkina Faso (33 families) [14] in the Mpungwe River of the southwest flank of Bukavu in the DRC (31 families) recorded a little more than half.

The homogeneity of the benthic macroinvertebrate families collected in our stations with slight difference in specific richness in places corresponds to that of freshwater Africa, in particular West Africa [18].

Hemiptera and Ephemeroptera displayed a higher taxonomic richness than Diptera. This suggests good water quality [11]. Also, the presence of Coleoptera, Odonata, and Pulmonata (gastropods) in our waters denotes an appreciable water quality insofar as [20] link the presence of these macroinvertebrates to an aquatic environment free from pollution. Furthermore, the work carried out in rivers by [21]; [17], revealed that taxonomic richness depends on the stability of the environment. Ephemeroptera, Trichoptera, Hemiptera, Odonata, Prosobranch, Pulmonata, and Bivalves were mainly identified in the first two biotypes of the dendrogram of the Hierarchical Classification Analysis. The third biotype grouped stations characterized by a low number of individuals from these families. In both cases this faunal composition indicates a good state of aquatic systems because Odonata, Prosobranchs, Ephemeroptera, Plecoptera and Trichoptera are often listed as taxa sensitive to pollution [22]; [17]. This is also confirmed by the work in rivers by [21], which indicates that the species richness of Ephemeroptera and Plecoptera decreases with the pressure of anthropogenic activities

The percentage of occurrence for each taxon in our studied waters made it possible to highlight that 88% of the macroinvertebrates collected in the different watercourses are frequent, 85% are according to hydrological regimes. These results indicate that all the stations subject to these hydrological regimes have a capacity to support life. The frequency of occurrence is a good indicator of the ecological quality of a station. The more stable a species is in its environment, the more favorable the habitat is for it.

The Shannon index values which varied from 3.56 to 4.05 (hydrological regimes and watercourses combined) in our aquatic environment are all higher than those found by [23] in the rivers of Gombe (1.7) and Kinkusa (1.6) and in places (2.6) by [24] in the rivers of the northeast of the island of Idjwi in the Democratic Republic of Congo. These values are close to those (3.4) found by [23] in the Mangengenge river of the city province of Kinshasa. These latter values are all higher than 2. [25] showed at this level of classification that degraded areas have lower indices compared to non-degraded areas of Algerian rivers.

The value of the Pielou index (0.70 on average) of [24] in the rivers of the north-east of the island of Idjwi in the Democratic Republic of Congo and that (0.7) of [23] for the Mangengenge river are close to the values (0.96 – 1.00) of our waters (hydrological regime and type of watercourse combined). All these values were closer to 1 than to 0.01 or close to 1.

Overall, ecological indices show the presence of a highly diverse and stable benthic fauna. This indicates that the water at the study sites is suitable for agriculture.

Within the framework of canonical correspondence analysis, the relationship between the physicochemical parameters describing the quality of the waters studied and the calculated indices made it possible to distinguish two groups of biological indices.

In the first group, biological indices did not show an affinity to the variables NO3, NH4 and PO4. This behavior reflects the sensitivity of Ephemeroptera, Plecoptera and Trichoptera (EPT) and non-dipteran insects (NDI) to biodegradable organic matter and organic pollution. This is confirmed in the work of [23] [26]; [19] according to which Ephemeroptera, Plecoptera and Trichoptera are the most pollutant-sensitive taxa.

In the second group, the correlation highlighted between the values of the % red chironomid index and the variables NO3, NH4 and PO4 means that these taxa can resist environmental disturbances by organic matter. This is confirmed in the results of [27] which state that Diptera are known to be resistant to disturbances, while Ephemeroptera are more pollutant-sensitive.

EPT, ASPT and IND are indicators of good quality and the red Chironomids present in our studied waters are not necessarily indicators of pollution. Indeed, chironomids are cosmopolitan and are found in running, stagnant, brackish, clean or polluted waters. According to [7]. These insects participate in the mineralization of organic matter, the oxygenation of the environment and the elimination of bacteria.

5. CONCLUSION

At the end of the research, the characterization of the waters based on macroinvertebrate populations indicated that the studied waters are of good quality. All sampled stations are rich in benthic macroinvertebrates; the stability, diversity and equitability of most taxa reflect the capacity of the water to support cultivated plants. In addition, all the descriptor indices used for the analysis in this study position the sampling stations as aquatic environments that would not be significantly affected by degradation processes. This allowed us to confirm that the studied water was of good quality for irrigated agriculture. The taxa collected showed that the study area has not yet experienced widespread overt pollution; however, increasing population pressure and its impact on the environment, as well as agricultural development using chemical inputs, can make the waters vulnerable and expose them to greater pollution.

ISSN: 2455-6939

Volume: 11, Issue: 02 "March-April 2025"

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