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Diversity and longitudinal dynamics of benthic macro-invertebrate populations in the shallow zone of the Chari River at Sarh (Chad, Central Africa)

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Abstract
The biology of Chadian freshwater aquatic environments is little known and works on benthic macroinvertebrates dates back to at least the 1980s thanks to the work of the office for scientific and technical research overseas (ORSTOM). This study was carried out in the Chari River, Bahr Kôh Department (Moyen Chari) over a distance of 52 km on the edge of the town of Sarh in order to assess the family diversity of macroinvertebrates.
Sampling was carried out in shallow environments with a weak current. A haze net constituted of a 1 m long sleeve and a collector with a circular opening of 30 cm diameter and a mesh size of 500 µm was used following the multi-habitat approach according to the Barbourt method adapted by Stark. Sampling was carried out on a monthly basis during the flood period from August to November 2020, which corresponds to the period of maximum lateral expansion of the Chari, and during the low-water period from February to May 2021, which corresponds to the period when the water level of the Chari reached its lowest point. The fauna surveyed is composed of 10464 individuals belonging to 98 families, 17 orders and 7 classes. Insects are the most represented and constitute 76.53% of the total richness of the macrofauna collected, followed by molluscs composed of 13.26%, including 9.18% of gastropods. Annelids, Crustacea and Chelicerata were the groups with the lowest number of individuals (of the population). Chironomidae and Dytiscidae had the highest total family richness, while Thiaridae was the most abundant family. The Kruskal-wallis test was applied to explain the good spatiotemporal diversity of the stands. Depending on the season, low diversity was observed at the end of low water and during high water. The high taxonomic richness of the entomofauna, dominated by pollutants, at stations where human activities are taking place indicates a state of disturbance linked to pollution. While the spatial distribution of total abundance was dominated by Molluscs (Thiaridae, Corbiculidae) in the downstream stations is explained by the mineralisation and enrichment in organic matter of these stations.

Keywords: Chari River, structure, diversity, macroinvertebrates, benthics

Introduction
Macroinvertebrates are animal organisms that are visible to the naked eye, have no backbone and live more or less on the bottom of rivers and lakes. They consist mainly of insects, molluscs, crustaceans and worms [1]. Macroinvertebrates also help to identify past disturbances of an environment and the toxic effects of these disturbances, which are generally inaccessible by physical-chemical methods [2]. They are the most used to assess water quality and monitor hydrosystems [3].
Freshwater ecosystems, made up of complex and fragile balances between living communities and their habitats, are both a reflection of the health of natural environments and the subject of major issues for human societies: health, economic, heritage, tourism and cultural issues [4]. Rivers are among the most complex and dynamic ecosystems [5]. They are highly diversified and play a crucial role in the conservation of biodiversity [6]. However, aquatic ecosystems are threatened by human activities with increasing pressures [7, 8, 9]. Anthropogenic activities include direct and indirect discharges of urban and industrial wastes into riverbeds, irresponsible irrigation of fields, deforestation, overgrazing and construction of hydroelectric dams on rivers and emission of greenhouse gases [10, 11]. The anthropogenic effects on river ecosystems are such that biodiversity in general and the structure of aquatic

In vertebrates in particular is destabilised [58, 33]. Deforestation could cause the disappearance of more than a million species of vertebrates, invertebrates and many other living beings by 2050 [12].

In Chad, the limited research on aquatic macrofauna is ageing [13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30]. There is also very little data on the structure of benthic macroinvertebrate populations in Chad in a context of increasing and excessive anthropic pressure. Most of this work has been carried out on Lake Chad and the benthic fauna collected is represented by three groups of macroinvertebrates such as worms, molluscs and insects, which have been the subject of intensive studies over several years.

The Chari is the main tributary of Lake Chad, whose water inflow represents about 92% of the total inflow of the lake basin [31]. It is characterised by a low slope, often deep bed and permanent flow, or almost. The floodplains give rise to rich ecosystems supporting biodiversity and key economic activities such as fishing, livestock and flood recession agriculture or market gardening as well as the establishment of small industrial units such as the Chad Sugar Company (CST), the Chad-Cotton New Company (SN), the New Chad Textile Society (NSTT) and the Sarh slaughterhouse all along the Chari River.

The wastewater from these industrial units is discharged directly into the Chari River catchment.

The general objective of this study is to assess the longitudinal distribution of benthic macroinvertebrates in the Chari River in the Middle Chari (Sarh) with a particular focus on its taxonomic diversity.

More specifically, it aims to

1. Identify macroinvertebrates down to family rank.
2. Determine their spatial distribution along the town of Sarh.

2. Material and Method

2.1 Study environment

The Chari River is a permanent watercourse and the most important, 1200 km long, of which 800 km are in Chad. It rises in the KAGAS massif in the Central African Republic at an altitude of 500 to 600 m. At the entrance to Chad, the Chari is made up of three Central African rivers: the Bamingui (356 km long), the Gribingui (418 km) and the Bangora (355 km), which cover an area of about 80,000 km^2 to form the Chari River watershed. It accounts for 90% of the water inflow that crosses a large part of the Sudano-Sahelian strip to flow into Lake Chad [31].

With a length of about 52 km, the middle course of the Chari River in the study area extends between 09°15'49.66" and 09°2'31.88" North Latitude and between 018°18'32.38" and 018°27'21.77" East Longitude. This river is under the influence of a tropical climate characterised by two seasons, a long dry season from November to May and a short rainy season lasting only 5 months from June to October in the Sudanian zone. Temperatures are relatively high with a monthly average minimum (January) of around 25.3 °C and maximums of 31.7 °C (April) [32]. Petrographically, the bedrock of the Middle Chari is made up of ferralitic and ferruginous cuirassed soils. The extreme south, which is well irrigated (rainfall of 600 to 1,200 mm), is covered with dense vegetation of mesophilic, deciduous forest, with leguminous and combretaceae plants, dominated by: *Isoberlinia doka*, *Prosopis africana*, *Anogeissus leiocarpus*, *Burkea africana*, *Butyrospermum parkii* [33]. Anthropogenic activities in the catchment area of the study zone are essentially made up of mini-industries (slaughterhouses, CST, NSTT, etc.), market gardening and subsistence farming activities. Hospital wastewater discharge and sand collection on the riverbed are also practiced in the study area.

To assess the impact of these activities on the existing ecosystems, twelve (12) stations were selected along a longitudinal gradient of the Chari River. The choice of stations was based on the presence or absence of anthropogenic activities, the diversity of habitats (clay, clay-silt, sand, plant debris), and the accessibility and collaboration of the riparian population.

The following figure shows the location of the benthic macroinvertebrate sampling sites in the Chari River.

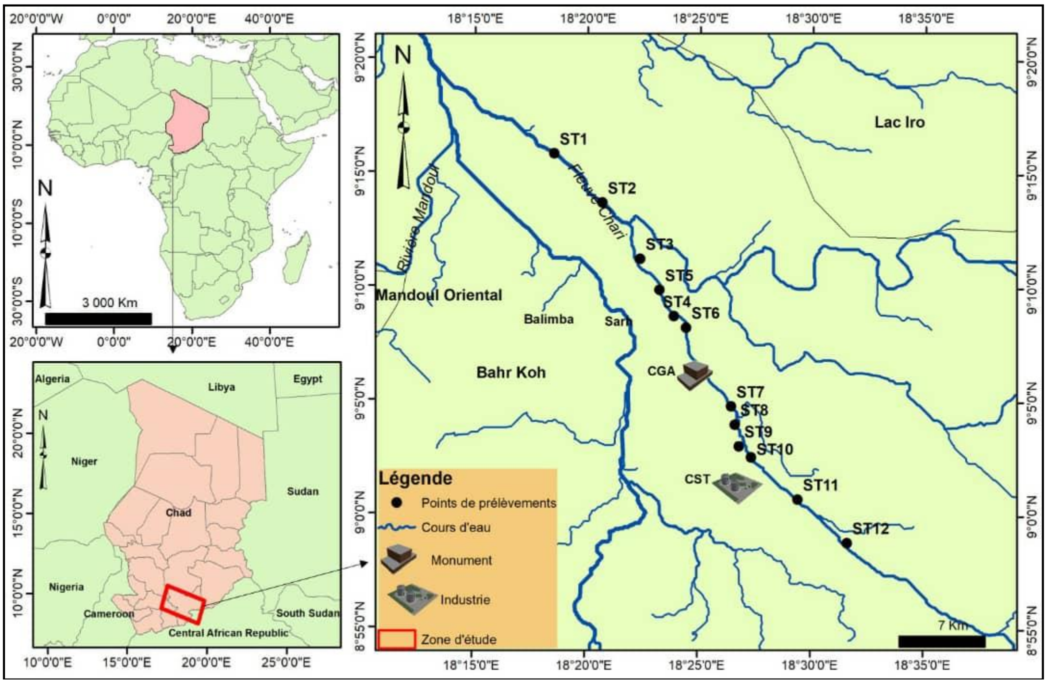

Fig 1: Map showing sampling stations of Middle stream of the Chari River

2.2 Method

2.2.1 Sampling of macroinvertebrates

Sampling was carried out on a monthly basis during the flood period from August to November, which corresponds to the period of maximum lateral expansion of the Chari, and during the low-water period from February to May, which corresponds to the period when the water level of the Chari is at its lowest level.

The study was carried out in shallow areas with a weak current on various mineral habitats (sand, clay) and/or under vegetation (floating macrophytes, bank heliophytes). A haze net consisting of a 1 m long sleeve and a collector with a circular opening of 30 cm diameter and a mesh size of 500 µm was used following the multi-habitat approach according to the method of [34], adapted by [35].

At each station of about 100 m, a total of 20 net shots were given in micro-habitats (substrate/velocity). The net was dragged over the sediment for a distance of 50 cm from downstream to upstream.

Floating solids and roots of surface and bank macrophytes were collected for organism sampling. The collected organisms were collected in jars containing 90% alcohol and clearly labelled for each sampling site. Before each collection, the net is completely cleaned to avoid mixing the samples.

2.2.2 Sorting and identification

After cleaning the samples, the organisms were sorted under a Nikon binocular loupe and with stainless steel forceps. During this operation, the invertebrates were separated according to their morphological appearance and grouped by class and order.

Taxonomic determination was carried out up to family and genus or species level under the binocular loupe and with the help of available identification keys such as [36, 37, 38, 39, 10, 41, 42].

2.2 Data analysis and processing

2.3.1 Stand analysis

The taxonomic richness corresponds to the number of taxa present in each sample. This S-index can be used to analyse the taxonomic structure of the stand. The richness was determined per station.

The percentage of occurrence (C) is used to obtain the constancy of a species in a given environment. It is the ratio expressed as a percentage between the numbers of samples (p) in which the species i appear and the total number of samples (P) of the biocenosis unit considered [43]. It is obtained according to the formula:

$$C = \frac{px100}{P}$$

The value of C makes it possible to distinguish three groups of species [43]:

- Constant species ($C \geq 50\%$).
- Accessory species ($25\% \leq C < 50\%$).
- Accidental species ($C < 25\%$).

The abundance of macroinvertebrates was determined at each station. It corresponds to the number of individuals (N) of a species or taxonomic group in a given sample. Relative abundance (Nr) is the percentage ratio of individuals number of a species of a station to the total number of individuals of all species at all stations.

2.3.2 Diversity analysis

These are mathematical formulae or graphical representations that provide information on the structure of the stand and allow a quick assessment of the stand [44]. The PAST software was used.

The Shannon index is the most useful index that best expresses stand diversity. It has the advantage that it is not dependent on any prior assumptions about species diversity or the distribution of species and individuals [45].

It is an index that takes into account the relative abundance of each species and the species richness [46].

$$H' = -\sum_{i=1}^{S}[\text{Pi log2 (Pi)}]$$

Where:

Pi=Ni/N, where Ni is the number representing the species of i and N = the total number of individuals;

S is the number of species and Pi the proportion of the itch species (i varying from 1 to S).

This index has as unit the "bit", its value depends on the number of species present, their relative proportions and the logarithmic base.

Equitability (Eq) [47] was developed to account for the relative abundance of each taxon, the regularity of the distribution of taxa or equi-partition and the quality of organisation of the stand. Indeed, the more balanced a stand is (no largely dominant taxon), the more stable it is. Conversely, any outbreak of a species is a sign of imbalance due to a natural or anthropogenic cause.

Equitability (E) is the ratio between the effective diversity (H') of the community and its maximum diversity (log2S) [48]. It reflects the quality of the organisation of a stand [49].

It is obtained according to the formula:

Eq= H'/log2 (S) where H' is the Shannon index and S is the species richness.

It varies between 0 and 1. Eq is 0 when a single species dominates and 1 when all species have the same dominance.

The dominance index of [47] measures the dominance effect rather than the richness of a group of species. Simpson's dominance index (D) gives the probability of occurrence of each individual within a large species community. If individuals can be counted, it is advisable to use the formula for the dominance index (D) such as:

$$D = \Sigma\ (ni(ni-1)/N(N-1),$$

Where:

S = Species richness.

ni = Number of individuals of species i.

N = Total number of all individuals of all species.

Indeed, Simpson's dominance index increases in the opposite direction of the diversity index. To use this Simpson index to express diversity, it is necessary to use its form (1/D) (or more rarely 1-D) which is the Simpson diversity index. 1/D varies from 1 to S and is interpreted as the number of equally common species that generated the heterogeneity in the sample or that is the basis for the Simpson dominance value D obtained.

3. Results

3.1 Taxonomic composition of the major zoological groups of the macrofauna

The study of benthic macroinvertebrates collected in this part of the Chari River allows them to be classified into different major zoological groups (Figure 2). In total, an inventory of 98 families representing 10464 individuals. These families are grouped into 17 orders and 7 classes. The population is largely dominated by insects, which contain 75 families, i.e. 76.53% of the total richness of the macrofauna collected. The insects are divided into 7 orders. Molluscs are composed of 4 orders divided into 13 families and represent 13.27% of the total richness. Annelids are made up of 4 orders and 4 families. Crustaceans and Chelicerates each comprise 1 order and 3 families.

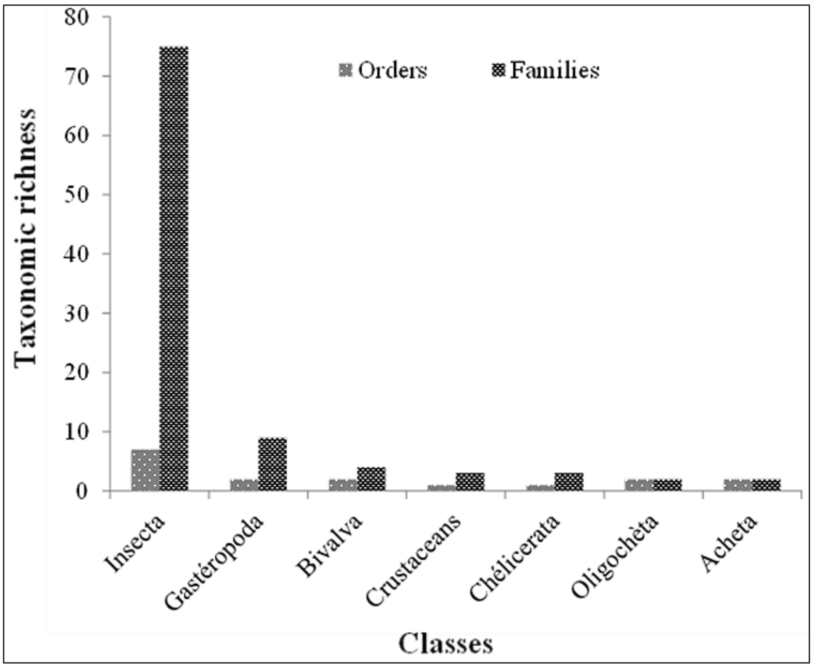

Fig 2: Overall taxonomic composition of the major macroinvertebrate groups of the Chari River

3.1.1 Family composition of macroinvertebrates

Figure 3 shows that Coleoptera and Diptera are represented by 21 families each (20%), followed by Odonata, Mesogastropoda and Hemiptera with 10 families each (9.52%). Next come Ephemeroptera (8.57%) and Trichoptera (5.71%).

At the family level, Odonata dominate with 54 families, i.e. 22.31% of the total richness, followed by Coleoptera (46 families) and Diptera (34 families), i.e. 19.01% and 14.05% respectively. Mesogastropoda (28 families), Hemiptera (23 families) and Ephemeroptera (21 families) represent respectively 11.57%, 9.50% and 857% of the total richness. As for the Unionida, Trichoptera and Lamellibranchs, they constitute less than 5% of the total wealth.

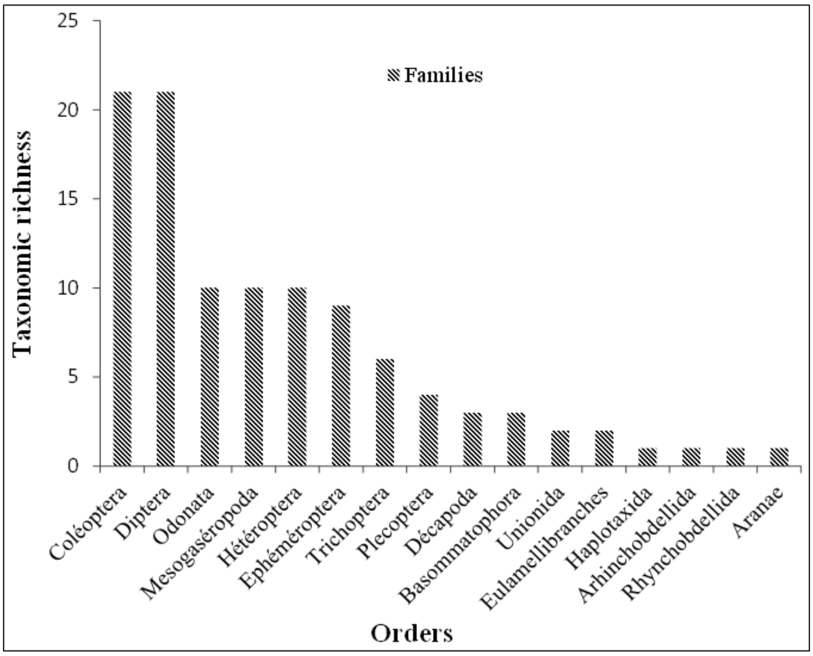

Fig 3: Family composition of Chari macroinvertebrates

3.1.2 Spatial variation in family wealth in the Chari River (Sarh, Moyen Chari)

The distribution of family wealth at the station level is quite variable (Figure 3). Wealth ranged from 16 to 51 families. The lowest richness was observed at station ST10 (7.1%) in the upstream part of the Chari and the highest richness was noted at station ST1 (22.8%) downstream. This explains the dominance of the downstream stations in terms of macro-invertebrate numbers.

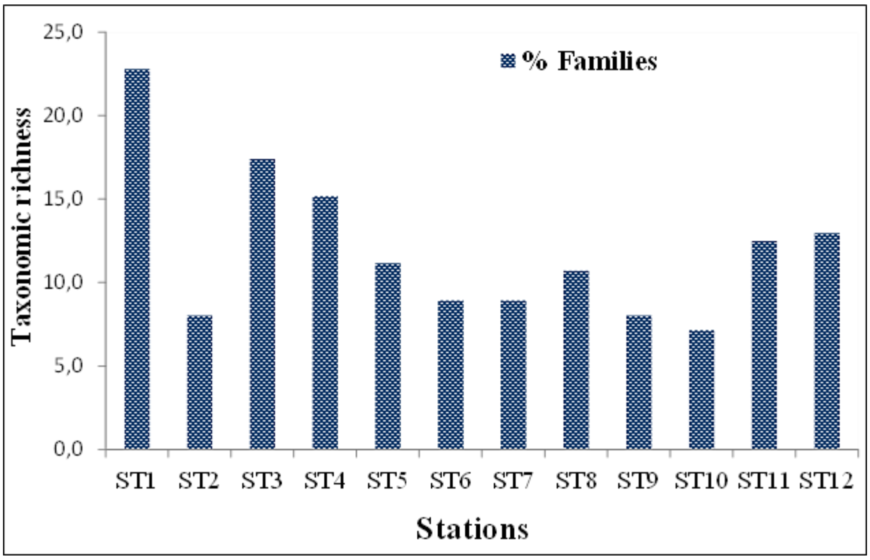

Fig 4: Spatial distribution of the taxonomic richness of Families per station

3.1.3 Family abundance of benthic macrofauna

Figure 4 illustrates the abundance of macroinvertebrates collected during the study by family. The study shows two particularly abundant families. The Thiaridae, with 4622 individuals, i.e. 44.2% of the total abundance, are the richest, followed by the Corbiculidae with 1356 individuals, 13.0% of the total. The Caenidae, Paludomidae and Chironomidae are represented by 5.39%, 4.03%, 3.25% and 3.16% of the total abundance respectively. The other families have a relative abundance of less than 3%.

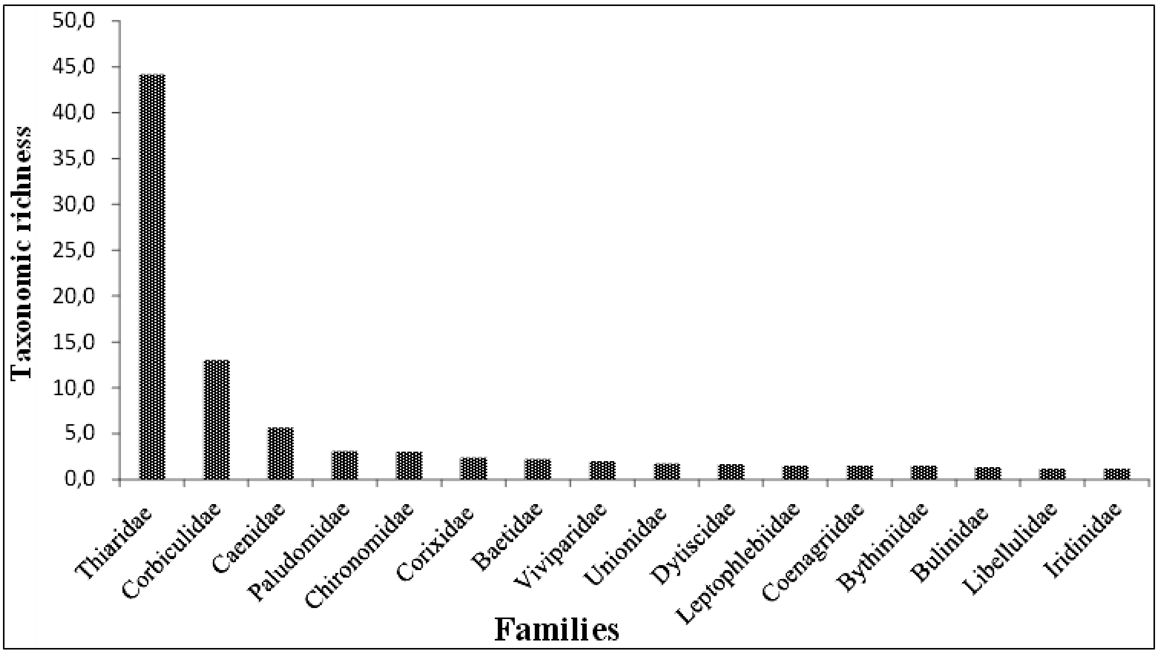

Fig 5: Relative abundances by family of macroinvertebrates collected in the Chari River

3.2 Settlement structure

3.2.1 Spatial variation in richness and abundance of macrofaunal families

The study of the spatial variation of the indices of specific diversity and abundance was expressed in figures 5.

The Shannon index varied from 0.63 bits at station ST9 to 3.07 bits at station ST11. Like the Shannon index, the Piélou Equitability index also showed significant variability between the downstream stations ST3 (0.19), ST8 ST11 and the other stations ($p<0.05$).

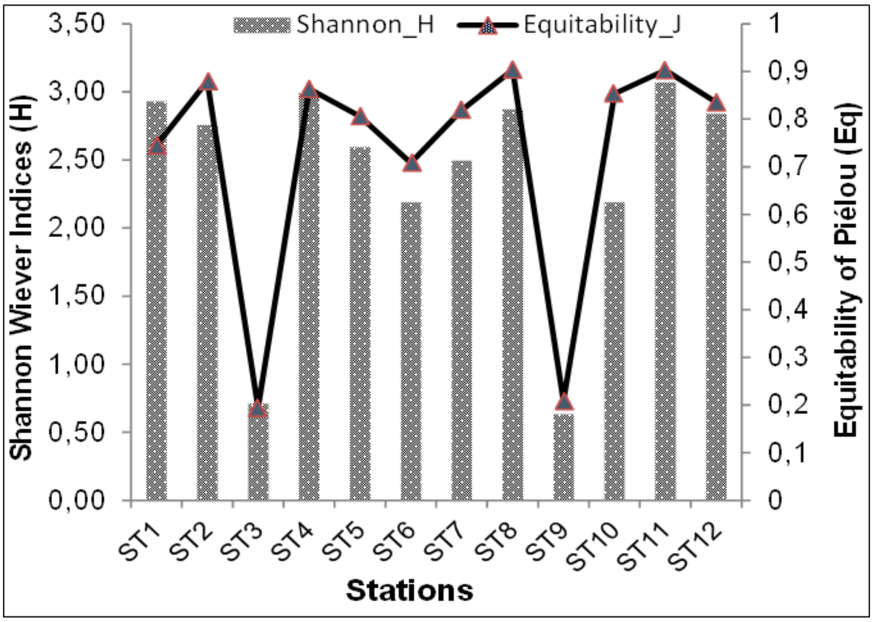

Fig 6: Spatial variations in species richness and abundance

3.2.2 Temporal variation of the Shannon index and Piélou equitability

The temporal variations of the Shannon index, illustrated in Figure 7, were represented by its highest value (4.95 bits) at the end of the rainy season (November) and its lowest value (0.65 bits) at the end of the dry season (May).

As for the Piélou Equitability, the index ranged from 0.15 in August to 0.59 in October. This shows that there is a significant difference between these stations and the others ($p<0.05$).

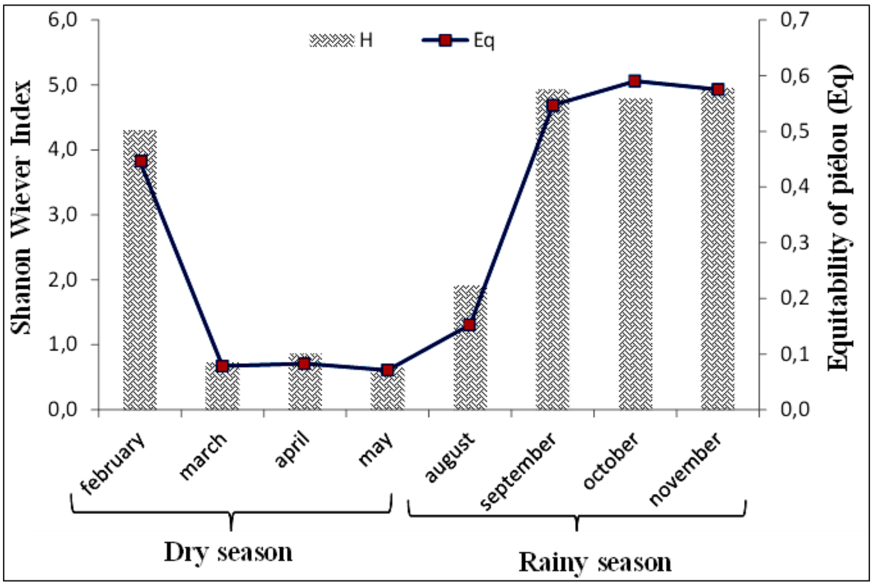

Fig 7: Temporal variations of the Shannon Index (H') and Equitability (Eq)

3.2.3 Spatial variation of Simpson's index

Figure 8 showed the spatial variation of Simpson's diversity index. It varied significantly between station ST9 (0.06), station ST11 (0.8) and the others ($p<0.05$).

At station ST9, the family Corbulidae, Pachycereeae, Lamnidae, Paludomidae, Unionidae varied significantly from the other families and 10 stations ($p<0.05$) except at station ST11.

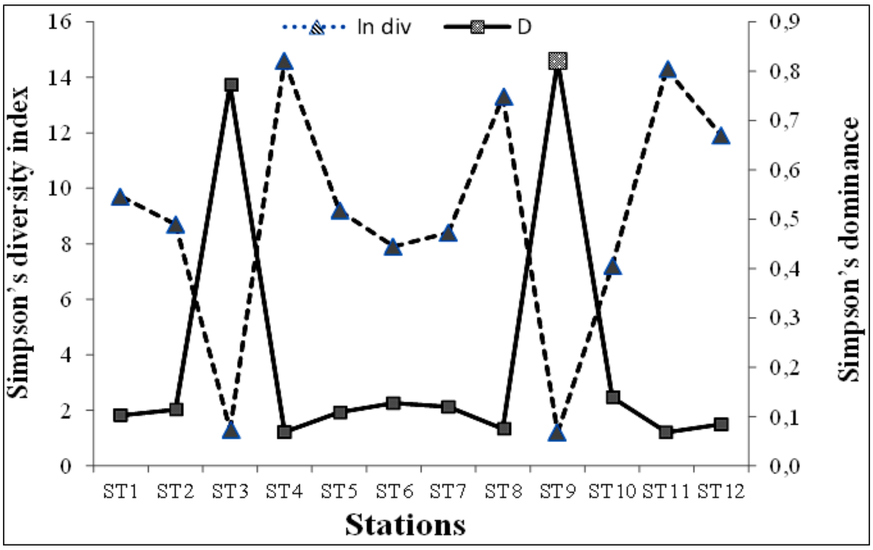

Fig 8: Spatial variations of Simpson's index

3.3 Constancy of taxa

The percentage of occurrence calculated from the presence-absence matrix made it possible to determine the frequency of families in the Chari River section (Table 2). Thus, 22.45% of taxa were constant during the sampling campaign, 21.43% of taxa were incidental and 17.35% were accidental. The remaining taxa (38.77%) whose frequency was below 15% were considered rare in the Middle Chari.

Table 1: Classification of benthic macrofauna taxa in the Middle Chari on the basis of frequency of occurrence

Constant Taxa	Incidental Taxa	Accidental Taxa
Corixidae	Belostomidae	Gelastcoridae
Naucoridae	Gerridae	Macroveliidae
Coenagridae	Mesoveliidae	Ephemeridae
Corduliidae	Saldidae	Ephemerellidae
Gomphidae	Veliidae	Leptophlebidae
Libellulidae	Calopterygidae	Potamanthidae
Baetidae	Lestidae	Hydrochidae
Caenidae	Macromiidae	Hydraenidae
Hydrophilidae	Leptophlebidae	Sciomyzidae
Noteridae	Polymetarcyidae	Culicidae
Ceratopogonidae	Elmidae	Tabanidae
Chironomidae	Scatophagidae	Tipiludae
Culicidae	Ecnomidae	Polycentropodidae
Bulinidae	Hydropsychidae	Haplotaxida
Bythiniidae	Philopotamidae	Sphaeriidae
Pilidae	Spercheidae	Indéterminé
Paludomidae	Paleomonidae	Glossiphoniidae
Thiaridae	Indéterminé	
Viviparidae	Pisauridae	
Iridinidae	Lymnaeidae	
Unionidae	Erpobdellidae	
Corbiculidae		

NB. Accidental taxa have an occurrence rate of over 15%.

4. Discussion

The study of benthic macroinvertebrates collected in the Chari River in the Barh-Koh (or Sarh) Department revealed 10464 individuals, divided into 98 families, 7 orders and 7 classes. This faunal composition of the benthic macrofauna appears to be more diverse than that found in the Oued Khoumane River in Morocco [3] and the Nga River in Cameroon [50]. On the other hand, it seems close to the results of work carried out [51] in the watercourses of the Moukalaba Doudou National Park in south-west Gabon, the urban and peri-urban watercourses of Douala in Cameroon [52] and the Niger River in Niamey [53], which reveals that the family richness of the watercourses of Chad corresponds perfectly to the richness of the macroinvertebrates of African freshwater [54].

The macrofauna of the Middle Chari is mainly made up of insects. It is dominated by Diptera and Coleoptera. These insects are found in stations where human activities are taking place, indicating a state of disturbance linked to pollution [9]. This assertion is explained by the low presence of Heteroptera, Ephemeroptera and Trichoptera, which are pollution-sensitive insects whose presence indicates good water quality [55, 9, 34].

The taxonomic richness of the malacological fauna was less representative than that of the insects, but it almost matches the richness of the Molluscs inventoried in the aquatic environments of African freshwater [34]. The distribution and proliferation of these Molluscs in continental waters is based on the type of vegetation, the calcium content, the nature of the substrate and the speed of the water current [42]. The total richness of the Gastropod families is represented by the Pilidae while that of the Bivalves is made up of the Unionidae. This result corroborates that obtained in the Alibori River in Benin [6].

The spatial distribution of the total abundance of Molluscs in the Middle Chari is dominated by the Mesogasteropods, of which the Thiaridae occupy the first place, followed by the Eulamellibranchs dominated by the Corbiculiidae. This colonisation of the Molluscs was observed in the stations downstream of the river. This can be explained by the mineralization and enrichment in organic matter of the stations downstream due to agricultural and market gardening activities and the discharge of wastewater from the slaughterhouse. This observation highlights the importance of the existence of aquatic plants on which these molluscs feed in these stations [56].

The temporal variation in the abundance of families evolves dynamically with rainfall and flooding, which accelerates the productivity of aquatic ecosystems and a denser vegetation cover of habitats. This contributes to the multiplication and development of benthic macroinvertebrate larvae [56, 49].

The results of the diversity indices show that values of the Shannon index are higher than 3 bits in most of the stations reflecting a good diversity of benthic macroinvertebrates in these stations except at ST3 and ST9 where Thiaridae and Corbiculiidae dominate respectively. While the Piélou Equitability values were close to (E<1) in most of the stations, supporting the Shannon index results obtained above [45].
Simpson's diversity index showed that the values are lower than 0.1 in all stations but they were close to 1 in stations ST3 and ST9. This result reinforces the statements of Shannon [47].

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