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Diversity and distribution of macroinvertebrates in three dam lakes of korhogo department (Côte d'Ivoire) : Influence of environmental parameters

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Abstract
In order to assess the diversity of aquatic macroinvertebrates and their relationship with environmental parameters in three dam lakes (Koko, Nangakaha and Nindjo) located in the Korhogo department in northern Côte d'Ivoire, sampling campaigns were carried out from June 2023 to April 2024. Environmental parameters were measured using appropriate equipment. Macroinvertebrate sampling was carried out using a hand net and a Van Veen grab. The results revealed significant variations between lakes for certain environmental parameters, including conductivity, turbidity, dissolved oxygen and transparency. The Koko dam lake, located in an urban area, showed highs mineralisation, high turbidity and low dissolved oxygen concentration, indicating a degraded ecological state. A total of 4,548 individuals belonging to 3 phyla, 4 classes, 12 orders, 35 families and 89 taxa were collected. Insects, particularly Diptera (Chironomidae), dominated richness and abundance, followed by Gastropoda. Koko Lake recorded the highest abundance (45%), with a dominance of pollution-tolerant Chironomidae. The Nangakaha dam lake had the highest diversity indices (Shannon and equitability), reflecting better ecological conditions. Redundancy analysis (RDA) showed that the distribution of taxa was strongly correlated with environmental parameters. Chironomidae and certain molluscs were associated with high mineralisation, while other taxa were linked to better oxygenated and more transparent waters.

Keywords: Aquatic macroinvertebrates, dam lakes, water quality, anthropogenic pressure, Korhogo, Côte d'Ivoire

Introduction

Environmental issues represent major challenges for the survival of humanity. Recent climatic upheavals around the world and their destructive impact have contributed to increased research into conserving the balance within ecosystems (Andema and Irenge., 2018) [1]. As a result, particular emphasis is placed on aquatic ecosystems through numerous conventions. We have the Ramsar Convention (Iran) on wetlands signed on February 2, 1971, which already highlighted the sensitivity of these areas, which should then benefit from monitoring (Andema and Irenge., 2018) [1]. These upheavals have led some countries to implement measures to cope with these changes. The Ivory Coast, for example, has built dam lakes to supply water and irrigate rice crops. However, little is known about the ecological assets of these environments, particularly the macroinvertebrate communities that colonize them (Aka-Koffi *et al*., 2011) [2]. The many uses associated with water have an impact on water quality and disrupt the balance of these aquatic communities, as well as the overall functioning of these ecosystems (Brusle and Quignard., 2004) [3]. This is why the European Water Framework Directive and the Rapid Bioassessment Protocol (Barbour *et al*., 1999) [4] recommend the use of these communities, which are the first to be affected by modifications (physical, chemical and biological), to monitor the ecological integrity of surface waters. These benthic macroinvertebrates are considered good indicators of the health of aquatic ecosystems because of their sedentary nature, varied life cycle, high diversity and variable tolerance to pollution and habitat degradation (Hepp *et al*., 2013; MDDEFP., 2013) [5,6]. In addition to this role, they are an important link in the aquatic food chain. They are a source of food for many invertebrates and fish species (Kouamélan *et al*., 2000 ; Diétoa *et al*., 2007; Konan *et al*., 2008; Diomandé *et al*., 2009) [7, 8, 9,10]. Knowledge of macroinvertebrates and their functioning will lead to better management of aquatic ecosystems. The aim of this study is to contribute to a better understanding of macroinvertebrates in three dam lakes in northern Côte d'Ivoire. It will help determine the relationships between taxa and environmental variables.

Materials And Methods

Study Environment

Sampling was carried out on three dam lakes (Koko, Nindjo and Nangakaha) in the Korhogo department (Figure 1). These lakes were chosen for their environmental role and accessibility. They are subject to heavy human pressure from anthropogenic activities such as cultivation, with the use of often unregistered chemical substances, fishing, urban, industrial and agricultural discharges (McKinney, 2002) [11]. And ater abstraction. Koko Lake is located in the heart of the city and is used to supply drinking water. Since 1973, it has been in operation on behalf of the Société de distribution d'eau de Côte d'Ivoire (SODECI). Located at coordinates longitude west 5.65° and latitude north 9.48° (Silue, 2012) [12], Nindjo Lake lies close to the town of Korhogo. With a surface area of 180 ha, it has been in operation since the 1970s. It is located at the following coordinates: 9°31'40.6"north and 5°39'31"west and Nangakaha Lake. Unlike the other two dams, this one is located in the forest. It is bordered on one side by the SODEFOR classified forest and on the other by farmers' fields. Its coordinates are 9°33'43.7"north and 5°32'28.7"west.

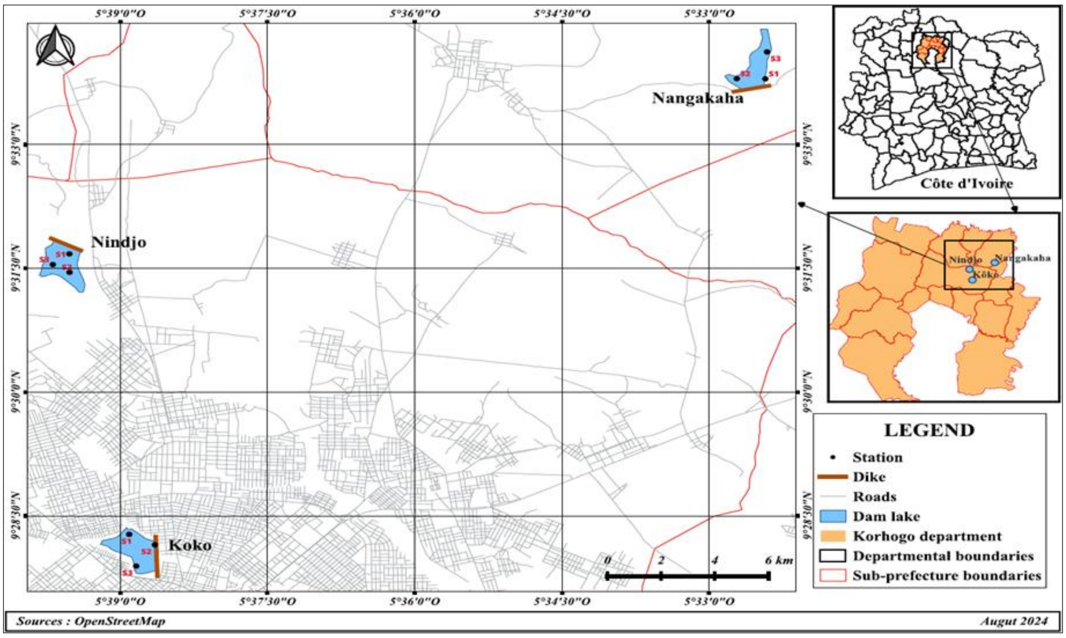


Fig 1: Location of study sites

Data Collection, Sorting and Organization Identification

Sampling campaigns were carried out every two months from June 2023 to April 2024. Samples were collected between 8 a.m. and 12 p.m. using a Van Veen grab (opening $0.042m^2$) and a hand net (350 µm mesh). Five samples were taken with the Van Veen grab and three with the hand net. These samplings were carried out on a site-by-site basis with the aim of collecting the maximum diversity (Yapo, 2013) [13]. Two buckets and two sieves with different mesh sizes were used for manual pre-sorting and washing of samples in situ. Pillboxes containing formalin were used to store samples before rinsing and sorting in the laboratory. A marker to label the pillboxes. Pills containing 70% alcohol (ethanol 70%) were used to fix the samples after rinsing and sorting in the laboratory. A digital camera was used to capture images of the sampling stations and the species identified. A Euromex Stereoblue trinocular magnifier (magnification X 40), Petri dishes, entomological forceps and keys from Dejoux *et al*. (1981) Danish Bilharziasis Laboratoiry (1981), and Tachet *et al*. (2003), de Moor *et al*. (2003a); de Moor *et al*. (2003b) and Suhling *et al*. (2014) [14, 15, 16, 17, 18, 19] were used to identify aquatic macroinvertebrates.

Measurement of Environmental Parameters

A HI12883 multi-parameter handheld meter with digital display was used to measure conductivity, pH and water temperature. A HACH 2100P turbidimeter, portable with digital display, was used to measure turbidity. Dissolved oxygen was measured by a DO-5519 portable digital oximeter. All the above instruments are fitted with integrated probes.

Data analysis

The abundance and specific richness of the various macroinvertebrate taxa were calculated. The specific diversity of these organisms was determined using the Shannon index (Shannon, 1948) [20], which measures the heterogeneity of biodiversity in an environment. This index was calculated using the following formula:

$$H' = -\Sigma ((Ni/N) \times \ln (Ni/N)).$$

With Ni: number of individuals of a given species and N: total number of individuals.WWWW

The Piélou Equitability Index, which reflects the degree of equitability of organisms within habitats, was calculated to identify community equilibrium using the following formula:

$$E = H'/Hmax = H'/Log2\ S$$

With S: number of species observed.

The frequency of occurrence (F) of a taxon is the ratio between the number of samples (Pa) from a site where the taxon is present by the total number (P) of samples. Four groups are thus defined (Dajoz, 1982) [21]: the first concerns "very frequent" taxa with $F \geq 50\%$, the second group corresponds to "frequent" individuals with $25\% \leq F< 50\%$, rare taxa form, the third group with $F< 25\%$.

The Kruskal-Wallis ($p<0.05$) and **Mann-Whitney ($p<0.05$)** tests were performed to understand the level of difference in macroinvertebrate distribution according to the dam lakes surveyed.

Results and Discussion

The results of the environmental parameters, the macroinvertebrate inventory, species richness and relative abundance, as well as the ecological aspects of the three dam lakes are presented. Statistical tests were carried out to evaluate the diversity indices of the various aquatic macroinvertebrate taxa relevant to the objectives of this study.

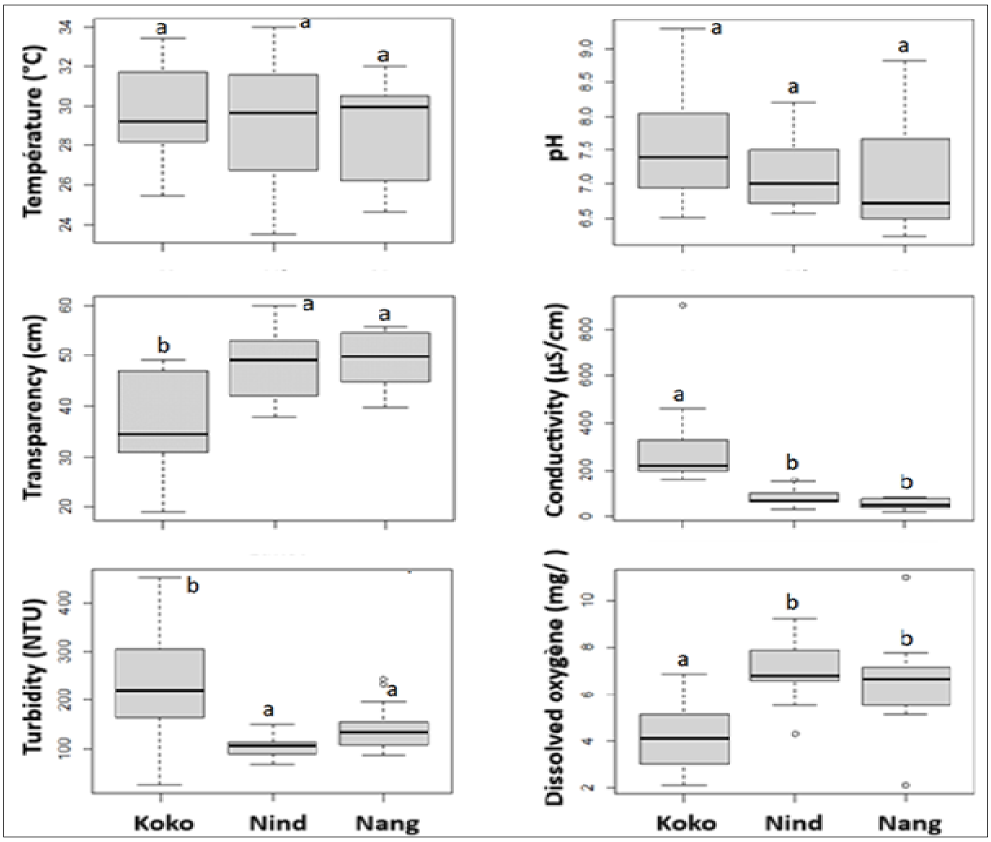


Fig 2: Inter-lake physico-chemical parameters of depth, transparency, nitrate, phosphate, ammonium and carbonate of three dam lakes. Korhogo, northern Côte d'Ivoire Koko; Nind=Nindjo and Nang= Nangakaha. Different letters (a and b) on box-plots denote significant differences between lakes (Mann-Whitney, $P < 0.05$)

Environmental Parameters of the Three Dam Lakes

Figure 2 shows the variation of environmental parameters. Analysis of environmental parameters of the three dam lakes studied revealed some significant variations between lakes (Kruskal-Wallis test, $P< 0.05$), reflecting differences in their hydrological and environmental characteristics. Water temperature, which fluctuated between 23.5°C and 33.4°C, showed no significant variations between the three lakes (Kruskal-Wallis test, $P>0.05$). This thermal homogeneity could be explained by similar exposure to local climatic conditions, particularly sunshine. However, the maximum value that was recorded in Koko lake (33.4°C) could indicate a shallower depth or greater exposure to solar radiation (Avit *et al*., 1999; Koumba *et al*., 2017) [22, 23]. Hubert (1998) [24] reports that the sun's rays penetrate the shallow waters of dams and warm them evenly.The pH, ranging from 6.24 to 9.22, showed no significant differences, suggesting a relatively stable acid-base regime in the three lakes, although the lower pH of Lake Ng (6.24) may reflect a stronger influence of allochthonous inputs or specific biological activity influencing organic acid production.Transparency was significantly lower in Koko lake (19 cm), which may be attributed to a high suspended particle load and high turbidity. Indeed, turbidity reached a maximum value of 323 NTU in this lake, demonstrating a significant load of suspended matter, probably due to terrigenous inputs and bank erosion. Conductivity showed marked variability between lakes, with values ranging from 20 µS/cm (Nangakaha) to 900 µS/cm (Koko). The higher conductivity in Koko lake indicates greater mineralization of the water, possibly due to the greater influence of anthropogenic inputs. Indeed, the Koko dam lake is an urban lake located in the heart of the city of Korhogo. Intensive market gardening takes place on the shores of this lake. When it rains, runoff from the surrounding neighborhoods drains large quantities of waste into the lake, along with pesticide residues and chemical fertilizers. The heavy discharge of waste and nutrients into the lake contributes to elevated conductivity values. According to Ndongo *et al*. (2012) [25], in tropical zones, high conductivity levels are often associated with environments receiving large inputs of mineral salts. Dissolved oxygen concentrations ranged from 2.1 mg/L to 9.2 mg/L, with significantly lower values in Koko Lake. A concentration as low as 2.1 mg/L is often indicative of hypoxic conditions, which may result from a high organic matter load or intense microbial activity consuming dissolved oxygen. According to Patil *et al* (2012) [26], a dissolved oxygen value of less than 3 mg/L in freshwater is synonymous with intense pollution. In contrast, the maximum value observed in Lake Ni (9.2 mg/L) can be explained by better aeration of the water body, more active photosynthetic production or a lower organic matter load. Overall, these results underline the importance of environmental and anthropogenic factors in structuring the physico-chemical characteristics of dam lakes.

Table 1: List and frequency of occurrence of macroinvertebrate taxa by site and lake. Koko ; Nind= Nindjo ; Nang= Nangakaha

Phylum	Classes/Orders	Families/Taxa	Dame lakes		
			Koko	Nind	Nang
Arthropoda	Insects				
	Diptera	Chironomidae	+++	+++	+++
		Culicidae	-	+	-
		Tabanidae	-	-	+
		Cératopogonidae	-	-	+
		Simuliidae	++	-	+
		Cylindrotomidae	-	+	-
		Chaoboridae	-	-	++
	Odonata	Gomphidae	+++	+++	+++
		Libellulidae	+	++	+++
		Macromiidae	++	++	+++
		Coenagrionidae			
	Ephemeroptera	Polymitarcyidae	++	+++	+++
		Leptophlebiidae	-	+	-
		Baetidae	++	-	+++
	Trichoptera	Philopotamidae	-	-	+
		Hydropsychidae	-	-	++
		Limnephilidae	-	-	++
	Heteroptera	Corixidae	-	+	++
		Notonectidae	++	+	+++
		Gerridae	+	+	-
		Belostomatidae	+	-	++
		Nepidae	+	-	+
	Coleoptera	Hydrophilidae	+	+	+++
		Elmidae	-	-	+
		Dytiscidae	+	+	-
	Lepidoptera	Crambidae	-	+	-
	Arachnids				
	Araneae	Pisauridae	+++	++	-
		Tetragnathidae	-	+	+
Annelids	Clitellata				
	Arhynchobdellida	Hirudinidae	+	-	-
Molluscs	Gastropoda				
	Mesogastropoda	Ampullariidae	+	-	+++
		Thiaridae	+++	++	++
	Basommatophora	Planorbidae	+++	-	+++
		Lymnaeidae	+++	+	++
	Littorinimorpha	Bithyniidae	+	-	-
		Hydrobiidae	+++	-	-
3	4/12	35	24	19	27

Table 2 : Proportions of rare, frequent and very frequent taxa in the three dam lakes surveyed in the Korhogo department from June 2023 to April 2024

Lakes	Rare (%)	Frequent (%)	Very frequent (%)
Koko	47.3%	27.3%	25.4%
Nindjo	53.5%	30.2%	16.2%
Nanagakaha	34.6%	34.6%	30.8%

Fauna Analysis

During this study, 3 phyla, 4 classes, 12 orders and 35 families were collected (Table 1). These organisms are part of the animal component generally observed in aquatic ecosystems in West Africa (Tapé, 2020 ; Tanon *et al*., 2020 ; Sanogo *et al*., 2021 ; Bancé *et al*., 2021 ; Kaboré *et al*., 2023 ; Tampo *et al*., 2021 ; Aimé *et al*., 2022 ; Zongo *et al*., 2023) [27, 28, 29, 30, 31, 32, 33, 34]. Organisms collected in lacustrine water bodies show that dam lakes are among the ecosystems that contribute to the biodiversity of macroinvertebrate assemblages (Yapo *et al*., 2020) [35]. The animal component of the dam lakes surveyed in this study is less diverse, when compared with those collected by Tapé (2020) [27] in the urban lakes of Yamoussoukro (107 taxa) and Aimé (2023) [36] in lakes in northern and central Côte d'Ivoire (99 taxa). The low value observed for taxonomic composition compared with the work of the authors cited could be explained on the one hand by the fact that in our study we prospected only 3 lakes, unlike Tapé (2020) [27] who collected in 10 lakes and Aimé (2023) [36] whose work was carried out in 8 lakes. On the other hand, this difference in taxonomic composition could be linked to the presence or absence of aquatic plants, which act as important habitats for the macroinvertebrate community. In fact, the strong presence of aquatic plants was noted in the Yamoussoukro lakes, in contrast to what we observed in the three sampled lakes. The composition of the macroinvertebrates collected was characterized by the dominance of insects in terms of taxonomic richness, corresponding to 27 of the 35 families, i.e. 74% of the families sampled. The results obtained are similar to those obtained in other lakes in the sub-region by Tapé (2020) [27] and Aimé *et al*. (2022) [33] in Côte d'Ivoire and in Burkina faso by Zongo *et al*. (2023) [34] and Bancé *et al*. (2024) [37]. The strong presence of insects in terms of taxonomic richness is linked to the fact that these organisms constitute one of the most important groups of freshwater invertebrates, notably due to their diversity (Tachet *et al*., 2003) [16]. With 21 taxa, or 32.30% of all taxa, the Diptera is the richest order in the insect class. Within the Diptera order, the Chironomidae is the richest family, with 14 of the 22 taxa in this order. Moreover, Tachet *et al.* (2003) [16] point out that in aquatic environments, the Chironomidae family is the most important of the Diptera families. The dominance of Chironomidae within the order Diptera was noted by Yapo *et al*. (2017) [38] in fish farm ponds in southern Côte d'Ivoire. This finding could be due to the general state of health of these surveyed dam lakes. As these organisms (Chironomidae) are pollutant-resistant, they proliferate better in environments faced with anthropogenic pressures. This could also be linked to the environment and climatic context, as shown by previous work (Alhou *et al*., 2009 ; Mboye, 2012 ; Mboye, 2014) [39, 40, 41] and by Diomandé and Gourène (2005) [42]. In terms of taxonomic richness, the Insects class is followed by the Gastropods with 19 species, 6 families and 3 orders. The orders Mesogastropoda and Basommatophora are the richest, with 9 and 8 species respectively. The high diversity of these molluscs could be explained by the high nutrient enrichment of the lakes sampled. Indeed, the immediate environment of the dam lakes explored is used by the population for market gardening. Farmers use organic and chemical fertilizers on the banks of the lakes. When these latter inputs are transported into the aquatic environment, they enrich it, promoting the production of algae (Kaboré *et al*., 2016) [43], an important food source for many gastropods (Strong *et al*., 2008) [44]. The value of the Shannon-Wiener index varies between 1.60 bits (Koko) and 2.74 (Nangakaha). As for the Piélou equitability index, its values range from 0.55 (Koko) to 0.92 (Nangakaha). The highest values of the Shannon-Wiener and equitability indices were observed in the Nangakaha dam lake. The Kruskal-Wallis test revealed that there was no significant difference (p>0.05) between the Shannon-Wiener and equitability diversity indices (Figure 3). Taxa from the Koko, Nindjo and Nangakaha dam lakes were collected on the basis of frequency, and grouped into three categories (Table 2). Rare taxa are more abundant in Nindjo (53.5%) and less so in Nangakaha (34.6%). The Koko dam lake recorded the lowest rate (27.3%) of frequent taxa, while the Nangakaha dam lake had the highest percentage of very frequent taxa (34.6%). The following taxa *Nilodorum fractilobus*, *Nilodorum brevibucca*, *Nilodorum rugosum*, *Chironomus imicola*, *Ictinogomphus* sp. were very frequent in all three dams. Quantitatively, 4,548 macroinvertebrate specimens were collected in the three dam lakes (Koko, Nindjo and Nangakaha). Koko Lake recorded 2,050 specimens (45%), Nangakaha Lake 1,478 (33%) and Nindjo Lake 1,020 (22%) (Figure 4). Macroinvertebrate abundance in these lake environments is dominated by the insect community with 71.15% of the total abundance of organisms identified. Cayrou *et al*., (2000) [45] and Tchakonté (2016) [46] emphasize that the preponderance of insects over other taxonomic groups and their dominance in terms of abundance confirm their cosmopolitanism and therefore their ability to colonize heterogeneous ecological niches. Diptera, with 42.06% of individuals, dominate abundance within the insect class. Within Diptera, the Chironomidae family was found to dominate abundance. *Nilodorum brevibucca* and *Nilodorum brevipalpis* are the most abundant species within the Chironomidae family. Insects are followed by gastropods with 28.07% of the total abundance of organisms collected. Mesogasteropods, with 18.10%, dominate the abundance of gastropods. They are followed by the order Littorinimorpha (5.52%) and Basommatophora (4.46%). *Potadoma liberiensis*, *Potadoma togoensis*, *Potadoma freethi*, *Bulinus globosus*, *Lymnaea natalensis* and *Hydrobia accrensis* are the most abundant gastropods. The abundance of the two chironomid species *Nilodorum brevibucca* and *Nilodorum brevipalpis* is remarkable in the Koko dam lake. Similarly, the highest abundance values for molluscs (*Potadoma liberiensis*, *Potadoma togoensis*, *Potadoma freethi*, *Bulinus globosus*, *Lymnaea natalensis*) were recorded in Koko Lake.

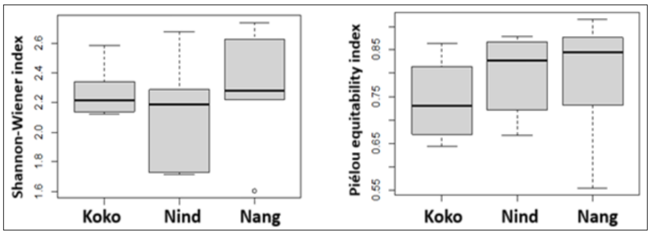


Fig 3: Spatial variations of Shannon-Wiener index and Pielou equitability index in the three lakes. No variation in this index was observed between stations (Kruskal-Wallis ; p > 0.05)

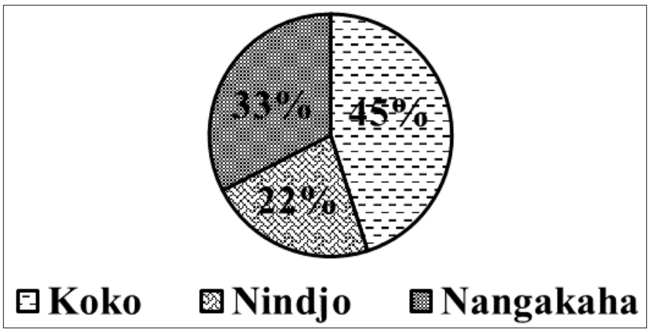
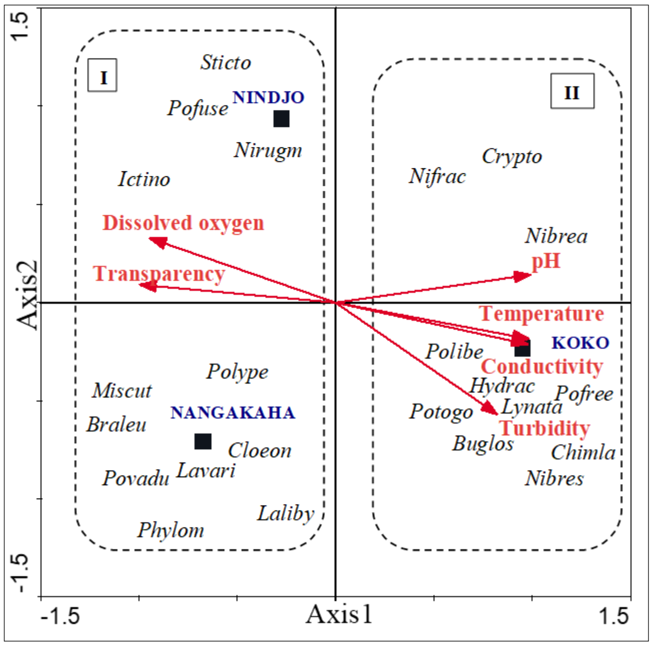


Fig 4: Proportions of macroinvertebrates by lake



Nibres=*Nilodorum brevipalpis*, ***Polibe***=*Potadoma liberiensis*, ***Potogo***=*Potadoma togoensis*, ***Hydrac***=*Hydrobia accrensis*, ***Pofree***=*Potadoma freethi*, ***Buglos***=*Bulinus glosus*, ***Lynata***=*Lymnaea natalensis*, **Phylom**=*Phylomacromia sp*, ***Laliby***=*Lanistes libycus*,***Pofuse***=*Polypepdilum fuscipenne*

Fig 5 : Redundancy analysis (RDA) showing the influence of environmental variables on the main macroinvertebrate taxa collected in the Nindjo, Nangakaha and Koko dam lakes. ***Polype***=*Polypepdilum sp*, ***Miscut***=*Micronecta scutellaris*, ***Phylom***=*Phylomacromia sp*, ***Ictino***=*Ictinogomphus sp*, ***Nirugm***=*Nilodorum rugosum*, **Crypto**=*Cryptochironomus sp*, **Chimla**=*Chironomus imicolan*, **Sticto**=*Stictochironomus sp*, **Polype**=*Polypepdilum fuscipenne*, **Nifrac**=*Nilodorum fractilobus*, **Braleu**= *Brachythemis leucosticta*, **Povadu**=*Povilla adusta*, **Cloeon**=*Cloeon sp.*, **Lavari**=*Lanistes varicus*, **libycus**=*Lanistes libycus*. ***Nibrea***=*Nilodorum brevibucca*,

Influence of physico-chemical parameters

A redundancy analysis (RDA) was carried out to highlight the correlation between physico-chemical parameters and the abundance of the main macroinvertebrate taxa in the Koko, Nindjo and Nangakaha lakes (Figure 5). In this analysis, we only considered the main taxa whose relative abundance was at least 0.9 % in each lake. The Monte Carlo permutations test indicates that the result of this analysis is significant ($p < 0.05$). The total percentage of variance explained was 98.1% for the first two axes, with 59.9% for the first and 38.2% for the second. The first two axes are therefore considered in expressing the results. The redundancy analysis diagram (ADR) clearly separates the samples into two groups. Group I contains samples from Lakes Nindjo and Nangakaha. These samples were characterised by waters with high values of transparency and dissolved oxygen. An increase in these parameters is favourable to the abundance of the taxa *Stictochironomus* sp, *Polypepdilum fuscipenne*, *Nilodorum rugosum*, *Ictinogomphus* sp, *Polypepdilum* sp, *Micronecta scutellaris*, *Brachythemis leucosticta*, *Cloeon* sp, *Povilla adusta*, *Lanistes varicus*, *Phylomacromia* sp, *Lanistes libycus*. Group II consists of samples from Lake Koko. These samples were characterised by high temperature, conductivity, turbidity and pH. The taxa that abound in these conditions were *Cryptochironomus* sp., *Nilodorum fractilobus*, *Nilodorum brevibucca*, *Potadoma liberiensis*, *Hydrobia accrensis*, *Potadoma freethi*, *Lymnaea natalensis*, *Potadoma togoensis*, *Bulinus glosus*, *Chironomus imicolan*, *Nilodorum brevipalpis*. Conductivity reflects water mineralisation, which is often influenced by geological conditions and anthropogenic inputs (Eblin *et al*., 2014) [47]. Chironomidae (*Nilodorum brevibucca and Nilodorum brevipalpis*) and molluscs (*Potadoma liberiensis*, *Potadoma togoensis*, *Potadoma freethi*, *Bulinus globosus*, *Lymnaea natalensis*) would favour a highly mineralised environment, as confirmed by canonical correspondence analysis. Species of the genus *Chironomus* were strongly represented in the Koko dam lake. The high presence of molluscs and species of the genus *Chironomus* in the Koko dam lake reflects the poor ecological conditions of this lake. These results showed that aquatic macroinvertebrates are good indicators of environmental variations, confirming their relevance in the ecological monitoring of freshwater ecosystems. The heterogeneity of physico-chemical parameters between lakes could have been influenced by differences in land use, human activities and the morphology of water bodies.

Conclusion

This study assessed the diversity of aquatic macroinvertebrates and their relationship with environmental parameters in three dam lakes in the Korhogo department in northern Côte d'Ivoire. A total of 4548 individuals divided into 89 taxa were recorded. Insects, mainly Diptera (Chironomidae), dominated the fauna collected, followed by Gastropoda. The Koko dam lake, which is subject to strong anthropogenic pressures, has a low ecological quality, marked by turbidity, high conductivity and low dissolved oxygen content, conditions that are favourable to pollution-tolerant taxa such as Chironomidae Diptera and several species of Gastropoda. In contrast, the Nangakaha and Nindjo dam lakes, with their clearer, better oxygenated waters, are home to more sensitive taxa and are of better ecological quality. Redundancy analysis revealed a strong correlation between faunal composition and environmental parameters. Aquatic macroinvertebrates are therefore excellent indicators of water quality, underlining the importance of sustainable management of these freshwater ecosystems.

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