Journal of Advances in Biology & Biotechnology

Volume 25, Issue 10, Page 13-23, 2022; Article no.JABB.94908
ISSN: 2394-1081

Benthic Macroinvertebrates Structure of Two Agropastoral Dams, Nanan and Zatta: Yamoussoukro, Cote d'Ivoire

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JABB/2022/v25i10600

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/94908

Original Research Article

Received: 19/10/2022
Accepted: 20/12/2022
Published: 23/12/2022

ABSTRACT

Aims: We are investigating benthic macroinvertebrates in two rice-growing dams and assessing their pollution levels.
Place and Duration of Study: Nanan and Zatta Dams of Yamoussoukro in Côte d'Ivoire from April 2021 to March 2022.
Methodology: Samples were collected monthly with a Van Veen bucket and a dip net and the environmental variables measured.
Results: The values of the physico-chemical variables show that the waters are warm and more mineralized at Nanan than at Zatta. The species richness is higher at Zatta with 75 taxa present against 42 taxa at Nanan. The population is globally dominated by insects at Zatta, but a strong

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representation of Molluscs is observed at Nanan. The abundance of Molluscs indicates organic pollution in the Nanan dam. The water pollution tolerance index between the two dams showed a predominance at Zatta, of the Ephemeroptera group which are polluo-sensitive organisms against a predominance at Nanan, of the Diptera group which are polluo-resistant. The Shannon index and the others indexes of the two sites confirm a clear water pollution in Nanan compared to Zatta.

Conclusion: These results suggest that the Zatta dam is in better condition than the Nanan dam. However, these two dams must be bio-monitored.

Keywords: Macroinvertebrates; structure; agropastoral dams; Côte d’Ivoire.

1. INTRODUCTION

Dams are water reservoirs with multiple uses. They are used to power the turbines of a hydroelectric plant or to serve as an irrigation system in agriculture. The construction of these small dams is a form of prevention of water shortages in regions of the world in the face of the threats of climate change [1]. These environments allow for the development of fisheries, prevent flooding and facilitate agricultural yields. They therefore ensure the economic and social development of populations.

However, anthropogenic activities causing various pollutions threaten these reservoirs that host an important biodiversity, especially the benthic macrofauna [2]. According to [3], benthic macroinvertebrates play a key role in the functioning of aquatic ecosystems, especially at the lake level in the use of nutrients that limit overall productivity. They are also major players in the transfer of matter and energy to higher trophic levels [4]. Benthic invertebrates spend all or most of their lives on the bottom of a water body and have a low ability to migrate, making them good indicators of the ecological quality of aquatic environments worldwide [5-6]. Benthic invertebrates exhibit different capacities to adapt to changing environmental conditions; fluctuations in their relative abundances can provide insights into the causes and severity of pollution [7].

In Côte d'Ivoire, several studies have been conducted on these benthic organisms in various environments, particularly in lacustrine environments, such as Lake Taabo by Kouamé et al. [8]; Lake Fae by Aka et al. [9]; lakes of Bongouanou by Motchié et al. [10-11]; urban lakes of Yamoussoukro by Tapé [12]. However, to date, the benthic macrofauna of rice-growing dams is not known. The present study focuses on the structure of the benthic macrofauna of two agropastoral dams intended for the irrigation of rice fields in Nanan and Zatta.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted in two localities of the autonomous district of Yamoussoukro, in Nanan and Zatta. The district is located in the center of Côte d'Ivoire in the lake region, between latitudes 6°15 and 7°35 North and longitudes 4°40 and 5°40 West [13]. Nanan is a neighborhood located at the entrance to the city of Yamoussoukro from Abidjan between 6°45'46.7" North latitude and 5°14'10.8" West longitude. Zatta is a village located at the exit of Yamoussoukro on the Bouafle axis, about 15 kilometers from the city between 6°52'0" north latitude and 5°24'0" west longitude (Fig. 1).

2.2 Measurements of Environmental Parameters

Measurements of the environmental parameters of two lakes were carried out monthly between April 2021 and March 2022. Physico-chemical parameters were measured *in situ* using a multi-parameter HANNA model HI 98194. Nutrient salts such as phosphates, nitrites, nitrates and ammonium were measured using a mini-photometers HANNA model H1781. Water sampled were collected for field analysis.

2.3 Sampling and Identification of Macroinvertebrates

Macroinvertebrates sampling was conducted monthly at the same time as the measurement the abiotic parameters in Nanan and Zatta dams, using a Van Veen grab. Macroinvertebrates were sampled using the multihabitat approach described by [14]. At each sampling station, ten random replicate samples were taken from various habitats, for a total area of 0.5 m^2.

Sediments obtained was first examined in the field, all large (visible) invertebrates removed with forceps and put in specimen bottles containing 10% formalin. Sediments were washed through a 500 µm sieve and all Macroinvertebrates picked from the sieve. All Macroinvertebrates found on the plant surface were removed using a dip net. In the laboratory, Macroinvertebrates were identified under a binocular loupe according to [15-18]. Identified organisms were enumerated by order, family, genus and species.

2.4 Data Analysis

The analysis of community structure is based on taxonomic richness, the abundance, the Shannon diversity index, the Pielou evenness index, the Menhinick index and Hilsenhoff index [14] estimate that the structuring of macroinvertebrate communities in rivers, including metric variables and Shannon diversity indices and evenness.

The Shannon diversity index (H) was used to estimate the taxonomic diversity of the stands studied and thus to observe its evolution over time. It is one of the best known and most used by specialists because it is independent of the sample size and takes into account the relative abundance of each species [19]. It is weak when the individuals encountered all belong to a single species or when all species are represented by a single individual. The higher the index, the more stable the stand, ie it is not subject to the action of abiotic factors or a pollution factor [20]. It is obtained by the formula:

$$H = -\sum\left[\left(\frac{N_i}{N_t}\right) \times Log_2\left(\frac{N_i}{N_t}\right)\right]$$

N_i = strength of the species i; N_T = total number of individuals in the sample.

As to the Index of evenness (E), it has helped to compare the measured diversity with the maximum theoretical diversity. This index was developed to account for the relative abundance of each taxon, the regularity of distribution of taxa or equitable distribution, and the quality of stand organization [20]. If E is low, that few taxa concentrate the majority of individuals, is a polluted environment. When E is high, that individuals are well distributed within the different taxa, is a healthy environment [20].

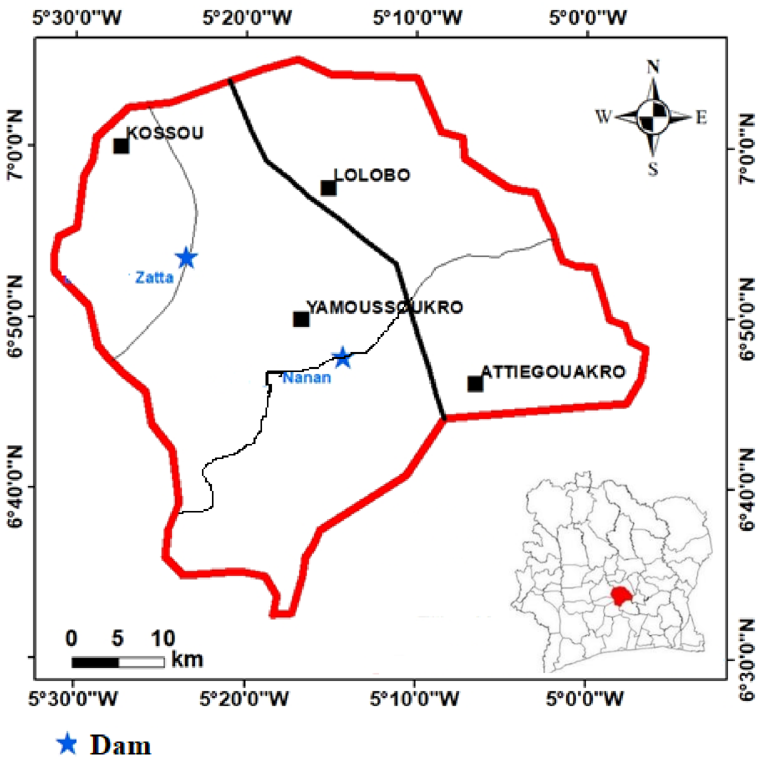

Fig. 1. Map showing the collection sites

$$E = \frac{H}{Log_2 S}$$

S = specific richness; H= Shannon index

The calculation of Menhinick's diversity index allows us to relate the number of species (S) and the total number of individuals (N) observed, it is calculated according to the formula:

$$M = \frac{S}{\sqrt{N}}$$

If the values of the Menhinick index are less than 1 this would reflect that the diversity is low in the station [21].

The similarity index (I_s), between two communities, is intended to compare communities on the basis of the presence and absence of taxa. This index is a very simple measure of biodiversity, varying from 0 (when there are no common species between the two communities) to 1, when the same species exist in both communities [20]. It is obtained by the formula:

$$I_s = \frac{2C}{(A+B)} \times 100$$

A and B is the number of species of each stand; C the number of species common to both stands.

The water pollution tolerance index was calculated to determine the biological quality of the stations. It is based on the ratio between the quantity of EPT (Ephemeroptera, Plecoptera, Trichoptera) and Chironomidae. This index is interpreted as follows [22]: a value close to 0 indicates that the water is of poor quality and when it is higher than 10, the water is of good quality.

3. RESULTS

3.1 Environmental Parameters

The average values of the measurements of the physico-chemical variables are consigned in Table 1. The recorded temperatures are warm with average values around 29°C ± 0.62. The average oxygen concentrations are 1.59 ± 0.25 mg/L at Zatta and 2.88 ± 0.29 mg/L at Nanan. The average pH values are between 6.69 ± 0.29 and 7.76 ± 0.41. As for conductivity and TDS, the measurements are inversely proportional. They oscillated between 134.00 ± 8.55 µS/cm (Nanan) and 149.20 ± 21.86 µS/cm (Zatta) for conductivity and 70.60 ± 11.50 mg/L (Nanan) and 74.6 ± 11.15 mg/L (Zatta) for TDS.

The measured nutrient salt levels have values that are lower than 1 mg/L except for ammonium ions whose average values are 6.41±14.31 mg/L at Nanan and 14.81 ± 20.27 mg/L at Zatta.

3.2 Inventory and abundance of Benthic Macroinvertebrates

In the whole of the stations of the two dams, a total of 92 taxa was identified. These taxa belong to 3 phyla that are Annelids, Molluscs and Arthropods. These taxa are divided into four classes (Achaetes, Arachnida, Gastropoda and Insect), 12 orders and 41 families (Table 2). The Insects class has the highest taxonomic richness with 72 taxa belonging to 30 families. It is followed by Gastropods with 18 taxa. As for the classes of Arachnids and Achaetes, they have respectively 2 and 1 taxa belonging to a single family.

Table 1. Mean values (±SD) of environmental variables of Nanan and Zatta dams

Parameters	Nanan Dam	Zatta Dam
T° eau (°C)	29.91 ± 0.69	29.02 ± 0.97
pH	6.69 ± 0.29	7.76 ± 0.41
OD (mg/L)	2.88 ± 0.29	1.59 ± 0.25
CND (µS/cm)	134.00 ± 8.37	149.20±21.86
TDS (mg/L)	70.6 ± 11.50	74.60 ± 11.15
NO_2^- (mg/L)	6.41 ± 14.31	14.81 ± 20.27
NO_3^- (mg/L)	0.36 ± 0.57	0.49 ± 0.54
PO_4^{2-} (mg/L)	0.10 ± 0.06	0.64 ± 1.06
NH_4^+ (mg/L)	0.46 ± 0.85	0.37 ± 0.16

T° = Temperature; pH = Hydrogen potential; OD = Dissolved Oxygen; CND = Conductivity; TDS = Dissolved solids rate; NO_2^- = Nitrite; NO_3^- = Nitrate; PO_4^{3-} = Orthophosphate; NH_4^+ = Ammonium

Table 2. Macroinvertebrates found in Nanan and Zatta dams from April 2021 to March 2022

Phylums	Classes	Orders	Families	Species	Nanan Dam	Zatta Dam
Annelids	Acheta	Hirudinida	Haemopidae	*Haemopis sanguisuga*	0	1
Molluscs	Gastropoda	Basomatophora	Ampullariidae	*Laccobius starnuehlneri*	1	0
				Lanistes andansoni	0	1
			Physidae	*Aplexa marmorata*	1	10
			Planorbidae	*Afrogyrus rodrignezensis*	1	1
				Biompholaria pfeifferi	4	0
				Bulinus africanus	4	0
				Gyraulus corinna	5	74
				Gyraulus costulatus	4	0
				Bulinus forskali	0	2
				Ceratophallus natalensis	0	10
				Gyraulus sp.	2	0
		Ceanogastropoda	Thiaridae	*Melanoides manguensis*	5	2
				Melanoides tuberculata	1433	211
			Paludomidae	*Cleopatra guillemi*	0	1
			Ampullariidae	*Pila ovata*	0	1
		Mesogastropoda	Hydrobiidae	*Cleopatra bulimoides*	1	0
		Heterobranchs	Valvatidae	*Valvata* sp.	2	0
Arthropoda	Arachnida	Arachnideae	Pisauridae	*Thalassius* sp.	0	1
		Araneae	Lycosidae	*Arectina aquatica*	6	27
	Insects	Coleoptera	Dytiscidae	*Canthydrus minutus*	5	3
				Canthydrus xanthinus	2	3
				Heterhydrus senegalensis	6	0
				Hydrobius sp.	1	2
				Hydrocanthus micans	5	2
				Hydroglyphus sp.	2	0
				Cybister tripuctatus	0	1
				Hydaticus flavolinéatus	0	1
				Hydaticus sp.	0	1
				Hydrometra sp.	0	3
				Hydrophylus senegalensis	0	3
				Hyphydrus sp.	0	1
				Hyphydrus careyrus	0	9
			Elmidae	*Potamodytes* sp.	0	2
			Hydrophilidae	*Amphiops* sp.	3	82
				Anisops sp.	8	250
				Enochrus sp.	0	3
				Laccophilus sp.	0	3
		Diptera	Chironomidae	*Nilodorum fractilobus*	385	0
				Polypedilum fuscipenne	20	68
				Polypedilum laterale	2	0
				Xenochironomus trisetosus	5	0
				Polypedilum sp.	0	5
				Strictochironomus puripennis	0	4
				Tanytarsini sp.	0	1
			Culicidae	*Aedes* sp.	1	0
				Culiseta longiareolata	3	1
				Anopheles coustani	0	7
				Culex fatigans	0	13
			Dixidae	*Dixa* sp.	0	2
			Psychodidae	*Clogmia* sp.	0	2
			Syrphidae	*Eristalis* sp.	0	4
			Tabanidae	*Tabanus* sp.	0	1
			Tanypodinae	*Tanypus lacustris*	0	4

Table 2. Continued

Phylums	Classes	Orders	Families	Species	Nanan Dam	Zatta Dam
Arthropoda	Insects	Ephemeroptera	Ameletidae	*Metreletus balcanicus*	0	2
			Baetidae	*Baetis* sp.	1	0
				Cloeon sp.	175	554
		Heteroptera	Belostomidae	*Diplonychus* sp.	26	270
				Limnogeton fieberi	2	0
				Appasus sp.	0	2
			Corixidae	*Micronecta* sp.	0	23
				Micronecta scutellaris	0	35
			Gerridae	*Limnogonus chopardi*	4	19
				Eurymetra sp.	0	2
				Gerisella sp.	0	1
				Gerris sp.	0	1
				Limnoganus sp.	0	2
			Mesoveliidae	*Mesovelia* sp.	0	5
				Mesovella vittigera	0	2
			Naucoridae	*Naucoris* sp.	23	18
			Nepidae	*Laccotrephes ater*	1	0
			Notonectidae	*Enithares* sp.	2	41
			Pleidae	*Plea pullula*	0	1
			Ranatridae	*Ranatra parvipes*	10	5
				Ranatra sp.	21	42
			Veliidae	*Microvelia* sp.	0	2
				Rhagovelia reitteri	1	0
		Odonata	Aeshnidae	*Anax mauricianus*	0	1
			Calopterygidae	*Phaon iridipennis*	0	2
			Coenagriidae	*Ceriagrion* sp.	24	50
			Cordulegasteridae	*Cordulegaster* sp.	0	11
			Corduliidae	*Pseudagrion wellani*	24	1
				Phyllomacromia bifasciata	0	1
				Pseudagrion punctum	0	7
			Corduliidae	*Pseudagrion* sp.	0	10
				Pseudocentroptilum sp.	0	83
			Gomphidae	*Microgomphus* sp.	0	17
			Libellulidae	*Zygonyx* sp.	15	133
				Zyxomma petiolatum	1	5
				Hemicordulia atrovirens	0	2
				Trithemis werneri	0	1
				Urothemis sp.	0	2
3	**4**	**12**	**41**	**92**	**2247**	**2176**

Concerning the orders of the class of Insects (Table 2), the Heteroptera has the greatest number of taxa (20). Then come the Coleoptera, Diptera and Odonata with 18, 16 and 15 taxa respectively. Ephemeroptera have the lowest taxonomic richness (3 taxa).

A total of 4423 macroinvertebrates was counted. The Insect class is the most abundant with 2612 individuals, or 59.05%. This class is followed by Gastropods with 1776 individuals, or 40.15% (Table 2). Arachnids and Achaetes with 34 and 1 individuals respectively represent 0.77% and 0.03% each. At the level of each dam, the Insects always have the highest abundance at Zatta, with 1834 individuals counted or 70.21% of the total number of Insects inventoried against 29.79% at Nanan (778 individuals). On the other hand, in Nanan, Gastropods are best represented by 1463 individuals or 82.38% of the total number of Gastropods, with almost all for the species *Melanoides tuberculata* (1433 individuals).

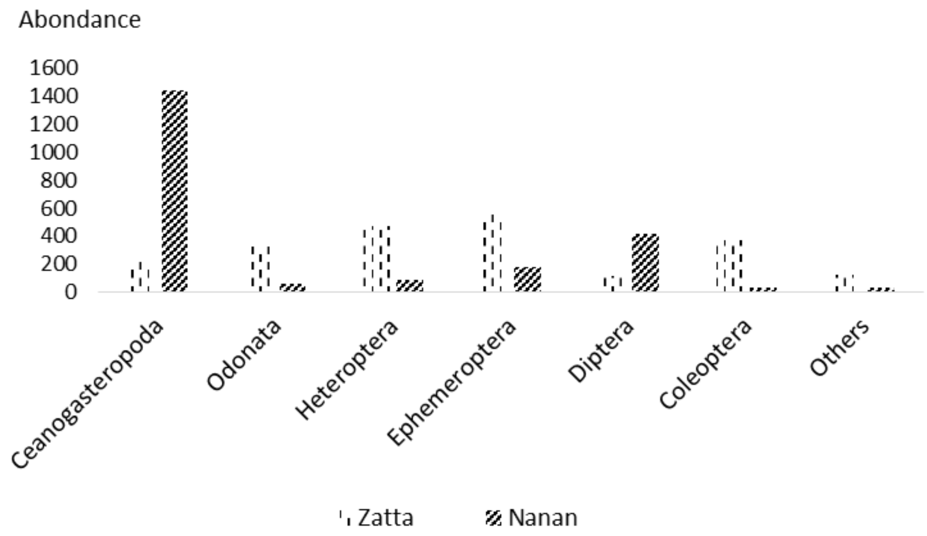

Fig. 2. Abundance of the orders

Concerning the abundance of orders of the Insects class, the most abundant is that of Ephemeroptera with 732 individuals, or 28.02 %. It is followed by Heteroptera with 561 individuals (21.48%) and Diptera with 528 individuals (20.21%).

In Zatta, the 2 best represented orders are Ephemeroptera with 554 individuals and Heteroptera with 471 individuals (Fig. 2). In Nanan on the other hand, the order of Ceanogasteropoda is the most abundant with 1438 individuals that is 63.99 %. It is followed by Diptera, with the species *Nilodorum fractilobus* belonging to the family Chironomidae with 412 individuals or 18.34%.

3.3 Index Evaluation

The values of the index calculations are recorded in Table 3. The Shannon diversity index (H) varies from 1.38 ind/bits (Nanan) to 2.76 ind/bits (Zatta). As for Pielou's equitability, its maximum value 0.63 was obtained in Zatta and its minimum value 0.37 was obtained in Nanan. Concerning Menhinick's diversity index, the maximum value 1.60 was obtained in Zatta and the minimum value 0.88 in Nanan.

The similarity index indicates a partial similarity of 42.73 % between the different macroinvertebrate taxa inventoried in the 2 dams. They have 25 taxa in common, 50 are specific to Zatta and 17 are observed only at Nanan.

As for the Hilsenhoff index, it is 5.32 at Zatta and 6.75 at Nanan. These values reflect an average water quality in Zatta and poor in Nanan.

For the pollution tolerance index, the highest value (7.13) was obtained at Zatta and the lowest value (0.43) was recorded at the Nanan station.

4. DISCUSSION

The average temperatures recorded at the two study stations are around 29°C. This temperature value indicates that the waters at these two stations are relatively warm. According to [23], the average water temperatures of aquatic environments in intertropical Africa are high and most often above 20°C. Water temperatures between 25 and 30°C, are favorable for the development of aquatic life [24].

Table 3. Metrics and diversity indices in Nanan and Zatta Dams

	Nanan Dam	Zatta Dam
Taxonomic richness	42	75
Abundance	2247	2176
Shannon index	1.38	2.76
Menhinick index	0.88	1.60
Equitability	0.37	0.63
Hilsenhoff	6.75	5.32

High oxygen levels (2.88 ± 0.292) were noted in Nanan dam compared to Zatta dam (1.59 ± 0.25). This would be due to good dissolution of atmospheric oxygen in this ecosystem whose surface is permanently free of aquatic plants. In addition, the high coverage of the Zatta dam by macrophytes considerably decreases the exchanges with atmospheric oxygen, thus contributing to lowering the redox potential value [25]. This oxygen is regularly consumed by benthic organisms in the respiration and decomposition reactions of organic matter [6].

The values (136.75 and 157.25 µS/cm) of conductivity recorded in this study are higher than those (123.2 and 133.8 µS/cm) obtained by [26] on the Bama and Boura agricultural perimeter in Burkina Faso. These high values indicate that the waters at these two sites are highly mineralized. This high mineralization would be due to the use of chemical fertilizers by rice farmers [27]. According to [28], the electrical conductivity of Yamoussoukro waters generally exceeds 100 µS/cm. A proportionality is notable between TDS and conductivity values. Buhungu et al. [29] made an identical finding.

For nutrient salts, the levels do not exceed the recommended standards [30]. The value of nitrate (NO_3^-) fluctuates between 0.45 and 0.47 mg/L. Nitrate, the final stage of nitrogen oxidation, is necessary for the development of aquatic flora. However, high nitrate from runoff carrying away sediments containing nitrogen compounds is hazardous to the aquatic ecosystem (25 mg/L) and to human health (50 mg/L) [31]. The differences in nutrient salt concentrations observed in the two dams, would be due to anthropogenic activities. Indeed, the occupation of the banks by market gardening in Nanan, the presence of rice pits in the perimeters and the use of chemical fertilizers by farmers, is the cause of a significant discharge of nutrients in these dams. According to [32], the high presence of phosphates in natural waters is linked to intense fertilization of the land (chemical fertilizers) and the decomposition of organic matter discharged into the water by urban waste. The study also identified 92 taxa of benthic macroinvertebrates in the two reservoirs studied. The macrofauna observed is composed mainly of insects and gastropods. According to some studies, this taxonomic trend is common to continental environments, particularly artificial lake environments [9-12].

The taxonomic richness is higher at Zatta with 75 taxa against 42 taxa inventoried at Nanan. This difference in the benthic composition of the 2 dams could be explained by the fact that the anthropic activities are more accentuated at Nanan than at Zatta. Indeed, due to its location in the middle of a city, Nanan receives most domestic and industrial effluents. [10-11], made the same observations in the Bongouanou dams in southeastern Côte d'Ivoire. Several works have already reported the influence of human activities on the distribution of macroinvertebrates due to the modification or destruction of habitats [33-34].

Furthermore, it is important to note the qualitative (72 taxa, or 78.26%) and quantitative (59.05%) abundance of insects in general and in particular in the Zatta dam. This dominance of insects in aquatic ecosystems was also reported by Kouamé et al. [8] in Taabo Lake, by Aka et al. [9] in lake Faé, by Tapé [12] in urban lakes of Yamoussoukro.

According to [35], the most diverse taxonomic group among aquatic macroinvertebrates is the insects. They colonize all aquatic environments because of their great capacity of dispersion with a strong preference in fresh water [12]. Tchakonté [36] also notes their ubiquitous character so their capacity to colonize heterogeneous ecological niches.

The great representativeness of Gastropods is also notable with 1776 individuals of which 1463 in Nanan, that is 82.38 %. The species *Melanoides tuberculata* (1433 individuals, or 80.69 %) is the most abundant mollusc. There are several reasons for the abundance of Gastropods. They have a longer life cycle and also have the ability to hide in the substrate to escape potential predators [37]. Some authors have reported parthenogenetic reproduction at *M. tuberculata* [38-39] hence its potential multiplication in the habitats. This dominance of Molluscs at Nanan would reflect significant organic pollution, as they are pollutant-resistant organisms. The same is true for the Chironomidae, which are strongly represented at the Nanan station. The abundance of these benthic invertebrates would confirm the significant pollution of this environment. According to [2], the presence of Chironomidae in a hydrosystem indicates its poor biological quality.

At Zatta, Ephemeroptera and Heteroptera dominate the stand. This result is similar to that of [40] who reported the abundance of these Insects in Banco National Park. The abundance of Ephemeroptera and Heteroptera at Zatta would reflect a relatively good quality of these waters compared to Nanan. According to Demoulin [41], Ephemeroptera is known to live in well oxygenated environments of good quality.

Pielou's equitability, Menhinick's diversity and Shannon indices indicate low values at Nanan (E= 0.37; M=0.88 and H= 1.38) compared to Zatta (E= 0.63; M=1.60 and H= 2.76). According to KampShijik [42], the low values of these indices reflect a structural imbalance in macroinvertebrate communities with the regression of sensitive taxa. This would justify the low taxonomic richness at Nanan. The high value of the Shannon Weaver index observed at Zatta would reflect a relatively better ecological health of this dam compared to Nanan. Also, the water pollution tolerance index given by [22], shows that only the Zatta dam presents a average biological quality with an EPT/C ratio equal to 7.

As for the similarity index, with a value of 42.73% indicates that there is a similarity between the macroinvertebrates taxa of the two dams. Indeed, out of the 41 families counted, 19 are common to both stations; 19 families are specific to Zatta against 3 to Nanan. In addition 25 species are common to the 2 dams, 50 specific to Zatta and 17 to Nanan.

The differences noted in number of families and species between the two stations would confirm the environmental disturbances due to anthropic activities at Nanan. In this regard, [43] state that domestic sewage inputs and waste due to anthropogenic activities deteriorate water quality.

5. CONCLUSION

The study of the physico-chemical parameters of the two rivers shows that the waters are generally warm with a strong mineralization. The physico-chemical parameters have an impact on the water quality and consequently, influence the distribution of macroinvertebrates. The benthic macrofauna studied shows that insects are the most abundant and diverse. The diversity of macroinvertebrates is greater at Zatta than at Nanan. The Zatta dam has a good biological quality contrary to that of Nanan. However, these two dams must be bio-monitored.

ACKNOWLEDGEMENTS

We would like to thank Dr. Kamagaté and Misters Diaby, Aimé, Bamba and Kouassi, for help in data collection and taxa identification.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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