Natural Resources, 2026, 17(8), 223-236
https://www.scirp.org/journal/nr
ISSN Online: 2158-7086
ISSN Print: 2158-706X

Biological Assessment of Pollution in the Mfilou River Using Benthic Macroinvertebrates, Congo-Brazzaville

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How to cite this paper: Ngoulou, C., Ngot, H.F.P., Mamonékéné, V., Zassi-Boulou, A.G., Mikémbi, L.A.B., Moussounda, S.M.M. and Lenga, A. (2026) Paper Title. *Natural Resources*, **17**, 223-236.
https://doi.org/10.4236/nr.2026.178013

Received: April 23, 2026
Accepted: August 1, 2026
Published: August 4, 2026

Abstract

This study assesses pollution in the Mfilou River using only benthic macroinvertebrates collected from five sampling stations during four sampling campaigns alternating between the dry and rainy seasons, from 2018 to 2020. Specimens were collected, identified, and classified. The Chironomidae index, the Normalized Global Biological Index (IBGN) and the Family Biotic Index (FBI) were used to determine the different levels of sediment-related pollution and organic pollution. The results show moderate pollution linked to sediments at the Maraîchère Zone station and organic pollution of intensity ranging from net to severe in the Mfilou River.

Keywords

Biological Indexes, Aquatic Ecosystems, Integrity Status, Biodiversity

1. Introduction

Freshwater environments represent complex and dynamic ecosystems. They play essential roles in biodiversity conservation, organismal functioning, and the cycling of organic matter and nutrients, as well as in energy transfer [1]. However, they are exposed to anthropogenic pressures related to the exploitation of mineral, agricultural, and other resources, resulting in significant changes to the structure of the plant and animal communities that inhabit them, including benthic macroinvertebrates. Threats to the extinction of species and ecosystems have been observed, more alarming than ever in recent decades [2], to the point where intensive human exploitation of natural resources has led to the depletion, or even near-disappearance, of some of them. Nutrient accumulation in waterways is one of the most widespread ecological problems, responsible for freshwater pollution worldwide [3].

At the same time, the silting up of waterways by natural phenomena and/or human activity has serious consequences for their proper functioning, namely the decline of aquatic species, the considerable reduction of spawning grounds, and the significant deterioration of the biological functioning of aquatic invertebrates [4]. It alters the physical habitat of waterways. Formerly biogenic, habitats experience the accumulation of a layer of sand, degrading their potential. Siltation also leads to a decrease in the river's capacity to support aquatic fauna, and the services it provides are also impaired. Similar to the decrease in the river's self-purification capacity, which is directly linked to the quality of water for human consumption [4]. Moreover, excessive siltation or over-siltation, due to urbanization, runoff, agriculture, livestock farming, and reduced morphogenic flows [5] [6], is often considered an indicator of poor biological quality of the substrate [7] and can affect all aquatic communities, cause the clogging of interstices between coarse sediments, leading to a decrease in oxygenation of the hyporheic zone and threatening benthic macroinvertebrates [8]. Consequently, these profound changes deteriorate the integrity of these ecosystems, which are relatively homogeneous functional units in which a collection of living organisms interact with each other and their environment. Ecological integrity refers to the state of an ecosystem whose structure and functions are not altered by stresses attributable to human activity, and which retains its capacity to adapt. The closer an ecosystem is to this condition, the more it is considered to be intact.

Thus, ecological studies are of paramount importance in the management of natural systems on the one hand, and in the assessment of the ecological health of aquatic systems on the other hand [1]. This explains the valued use of aquatic macroinvertebrates in assessing the health of aquatic ecosystems, as they offer numerous advantages due to their great diversity and variable tolerance to pollution and habitat degradation, as well as their sedentary nature [9]. They are excellent bioindicators and reflect the ecological status of surface waters, reacting very quickly to changes in their environment [10], through the accumulation of pollutants and environmental disturbances over relatively long periods, from a few months to several years [11].

Consequently, several indices have been established [12], including indices of benthic macroinvertebrate tolerance to pollution, among which are the normalized global biological index (IBGN) and the Hilsenhofff family biotic index [13]-[15].

In Congo, as elsewhere, certain aquatic ecosystems are experiencing intense anthropogenic pressures, and the Mfilou River is no exception. However, the assessment of the level of degradation of these ecosystems, specifically the assessment of pollution, has so far been carried out at the national level only through a physico-chemical approach. Therefore, we undertook a preliminary study focusing on the biological assessment of water pollution in the Mfilou River, using benthic macroinvertebrates. Previous studies [16] have shown that the waters of the Mfilou River are devoid of pollution-sensitive taxa (Mayflies, Stoneflies, and Trichoptera). The aim of this study is to highlight the different levels of pollution in the Mfilou River using a biological approach, specifically through benthic macroinvertebrates. It should be noted that the type and severity of pollution were determined from biological indices, without concomitant physico-chemical validation.

2. Materials and Methods

2.1. Study Area

The Mfilou River, 7740 m long, is located south of Brazzaville. It flows through three districts: Moungali, where it originates; Mfilou, where it flows; and Makélékélé, where it joins the Djoué River, a tributary of the Congo River.

The city of Brazzaville is located in the southeastern part of the Republic of the Congo, specifically between latitudes 4˚11'45" and 4˚18'45" South and longitudes 15˚11'15" and 15˚18'45" East [17] (**Figure 1**). Its climate is of the Lower Congo type, with abundant rainfall ranging from 900 to 2200 mm. Two types of seasons characterize it: a rainy season between October and May and a dry season from June to September [18] [19]. Its vegetation is dominated by herbaceous savanna. Brazzaville drains a particularly rich hydrographic network, with major rivers (Congo, Djoue, Djiri, and Djouari) each representing an inexhaustible resource. In addition to each river, there is a series of streams and rivulets (Mfilou, Mfoa, Tsiémé, etc.): suburban basins whose flow never dries up. The groundwater potential of the Brazzaville region is significant. During periods of low water, the small suburban streams are fed exclusively by groundwater. The measured flow rates correspond to the total groundwater flow for the portion of the basin intercepted by the measuring station [20].

Its climate is of the Lower Congo type, with abundant rainfall ranging from 900 to 2200 mm [18]. It experiences a short dry season of four (4) months (J-J-O-S) and a rainy season of eight (8) months (O-N-D-J-F-M-A-M). The basin's geology consists of overlying sandy formations (Batéké Plateaux Series).

Five stations were selected for data collection: Egout Laiterie, Zone Maraîchère, Diata, Mâ Campagne, and Confluence (**Table 1**). All five stations are exposed to various human activities: discharge of household wastewater, industrial wastewater, and runoff; siltation of the upstream watercourse; sand extraction; market gardening; fishing; swimming; etc.

Table 1. Geographic coordinates of the Mfilou River sampling stations.

Coordinates	Station				
	Egout laiterie	Zone maraîchère	Diata	Mâ campagne	Confluence
Longitude (s)	04˚15'02"2	04˚15'02"2	04˚16'32"1	04˚16'99"4	04˚18'06"6
Latitude (E)	015˚14'55"6	015˚14'55"6	015˚14'06"3	015˚13'93"0	015˚13'56"1
Latitude (E)	015˚14'55"6	015˚14'55"6	015˚14'06"3	015˚13'93"0	015˚13'56"1

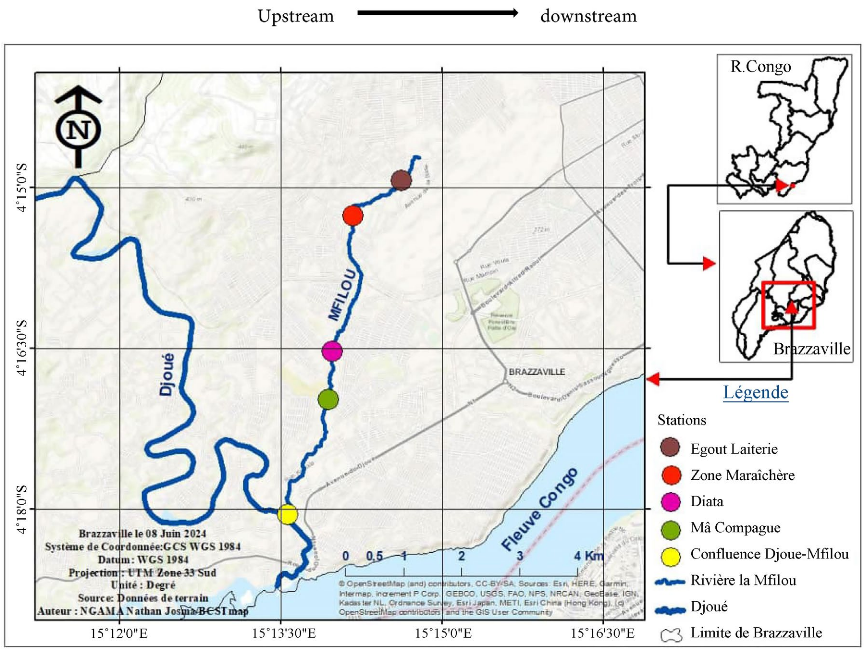

Figure 1. Map of the Mfilou River sampling area (Congo-Brazzaville).

2.2. Macroinvertebrate Sampling

The macroinvertebrates included in this study were collected from five stations distributed along the Mfilou River from upstream to downstream. Four seasonal sampling campaigns of benthic macroinvertebrates were conducted between October 2018 and January 2020, using a Surber net and a Troubleau net. The collected specimens were sorted in the field and in the laboratory, then identified and counted using an OPTIKA binocular microscope and a Carl Zeiss 2000 optical microscope [16], at the Department of Oceanography and Environment of the National Institute for Research in Exact and Natural Sciences (IRSEN). These organisms were fixed in 95% alcohol and preserved in 1.5 cm × 6 cm and 6 cm × 12.5 cm jars. Several identification keys were used at the Oceanography and Environment Department of the National Institute for Research in Exact and Natural Sciences (IRSEN) [21]-[24].

2.3. Data Analysis

The taxonomic composition, species richness, abundances, and biotic indices presented below were determined during this study. The data were processed using Excel 2013.

Chironomidae index

The Chironomidae index represents the ratio of Chironomidae abundance to the total abundance of organisms present at a monitoring station [25]. It allows for the determination of sediment pollution in a watercourse. This index is calculated using the following formula:

$$\text{Chironomidae Index} = \frac{\text{Chironomidae Abundance}}{\text{Totale Abundance}} \times 100$$

proposes the following classification based on the relative abundance of Chironomidae:

A scale for interpreting the Chironomidae index based on their abundance was proposed by [26]. Thus:

- % Chironomidae > 75%: Highly polluted water;
- 20% < % Chironomidae ≤ 75%: Moderately polluted water;
- 5% < % Chironomidae ≤ 20%: Slightly polluted water;
- % Chironomidae ≤ 5%: Very good water quality.

The Normalized Global Biotic Index (IBGN) is determined using a table of 14 taxonomic variety classes and 9 indicator faunal groups, with values ranging from 1 to 20 [27]. In the absence of a significant number of indicator taxa (n < 3 or 10 individuals), the IBGN score is 0 [28]. This index provides a value between 0 and 20, corresponding to 5 quality classes [27]. The average reference value determined by [29] was used to distinguish between good-quality and poor-quality sites. The IBGN was determined according to the relationship proposed in [30], and **Table 2** allows for the interpretation of the results obtained.

Table 2. Variation intervals and interpretation of the IBGN.

interval	Quality	Pollution level	Pollution type
IBGN ≤ 4	Very poor	Excessive pollution	
5< IBGN < 8	Poor	Significant pollution	
9< IBGN < 12	Average	Net pollution	Organic pollution
13 < IBGN < 16	Good	Moderate pollution	
IBGN ≥ 17	Very good	Excellent water quality	

The Hilsenhoff Family Biotic Index (FBI) (pollution tolerance and intolerance) is widely used to assess the biotic integrity of benthic invertebrate communities [31]. According to [32], the variant used is based on family identification (FBI). Each family is associated with a pollution tolerance value by which the number of sampled individuals is multiplied. The results for each family are summed and then divided by the total number of organisms collected. The final index score (one per station) is then converted to the Hilsenhoff scale to correlate it with a corresponding water quality (**Table 3**). The Hilsenhoff index takes into account the tolerance ranges assigned to each organism composing the community [33]-[35].

$$FBI = \frac{x_i * t_1}{N} : \text{où}$$

x_i = Number of individuals of an identified taxon;

t_i = tolerance of this same taxon;

N = total number of individuals in the sample.

Table 3. FBI Interpretation scale.

FBI Values	Water Quality	Interpretation
0.00 - 3.75	Excellent e	No organic pollution
3.76 - 4.25	Very good	Slight organic pollution possible
4.26 - 5.00	Good	Organic pollution likely
5.01 - 5.75	Average	Fairly substantial organic pollution
5.76 - 6.50	Ratger poor	substantial organic pollution
6.51 - 7.25	Poor	Very substantial organic pollution
7.26 - 10.00	Very poor	Severe organic pollution

3. Results

3.1. Taxonomic Composition of Benthic Macroinvertebrates

The benthic macroinvertebrates communities collected in the Mfilou River comprise 17,325 specimens belonging to 169 taxa unevenly distributed among 62 families, 16 orders, 6 classes and 4 phyla, including Arthropoda (39 families and 76 taxa), Mollusca (13 families and 32 taxa), Annelida (9 families and 20 taxa) and Nematomorpha (1 family and taxon) (**Figure 2**).

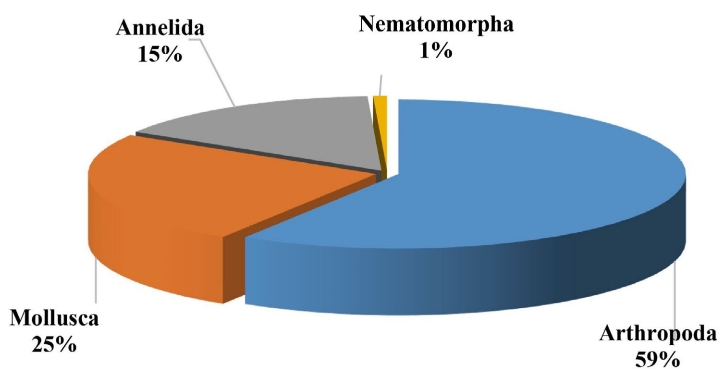

Figure 2. Taxonomic composition of benthic macroinvertebrates in the Mfilou River.

The class Insecta dominates this benthic community, followed by Gastropods and Clitellates. Insects comprise 6 orders, 37 families, and 74 taxa, representing 57.36% of the taxonomic richness of the studied benthic community; Gastropods have 3 orders, 12 families, and 30 taxa, representing 23.26%; Clitellates, 3 orders, 9 families, and 20 taxa, representing 15.50%; Aranea, with 2 families and 2 taxa, representing 1.55%; and Gordioida, with a single order, family, and species, representing 0.78% of the overall taxonomic richness.

Diptera represent 21% of the order richness, with 21% of families present in the benthic community, followed by Hemiptera (15%) and Coleoptera (11%). Rhynchobdellida, Ephemeroptera, Litthorinimorpha, and Arhynchobdellida represent the least diverse orders, each accounting for 3% of the taxonomic richness (**Figure 3**).

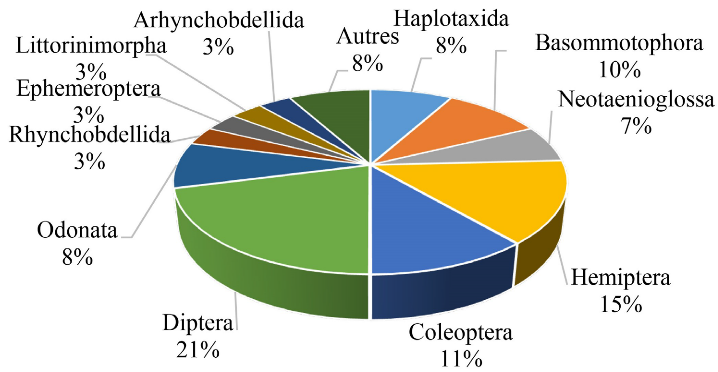

Figure 3. Richness of benthic macroinvertebrates orders recorded in the Mfilou River.

Spatial variation in overall taxonomic richness and abundance of benthic macroinvertebrates

The number of taxa in the Mfilou River varies from one station to another, ranging from 25 taxa at the Egout Laiterie station to 61 taxa at the Confluence station. The number of families, meanwhile, ranges from 17 at the Egout laiterie station to 34 at the Diata station (Figure 4).

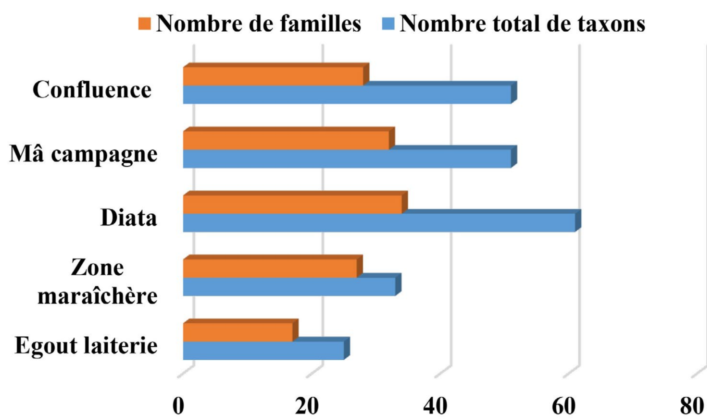

Figure 4. Spatial variation of taxa and families recorded in the Mfilou River.

3.2. Biological Quality

Chironomidae Index

Chironomidae represent 24.45% of the sample size of the Mfilou benthic community. However, variability in their relative abundance was observed at the sampling stations, with values ranging from 0.02% at the Mâ Campagne station to 22.15% at the Zone Maraîchère station (Table 4).

Normalized Global Biological Index

Organic pollution was assessed using the normalized global biotic index (NGBI), measured at all stations along the Mfilou River. The NGBI values obtained ranged from 7 at the Egout Laiterie station to 11 at the Diata station (Figure 5).

Family Biotic Index (FBI) of the Mfilou River

In this study, the FBI values for the five stations in Mfilou show overall fluctuations, with a maximum of 8.00 recorded at the Zone maraîchère station and a minimum of 6.11 at the Diata station (Figure 5).

Table 4. Spatial variations of the Chironomidae index in the Mfilou River during the study period.

Stations	Chironomidae Index Value (%)	Interpreting	Pollution type
Egout laiterie	1.41	Very good water quality	Sediment-related pollution
Zone maraîchère	22.15	Moderalety polluted water	
Diata	0.19	Very good water quality	
Mâ campagne	0.02	Very good water quality	
Confluence	0.67	Very good water quality	

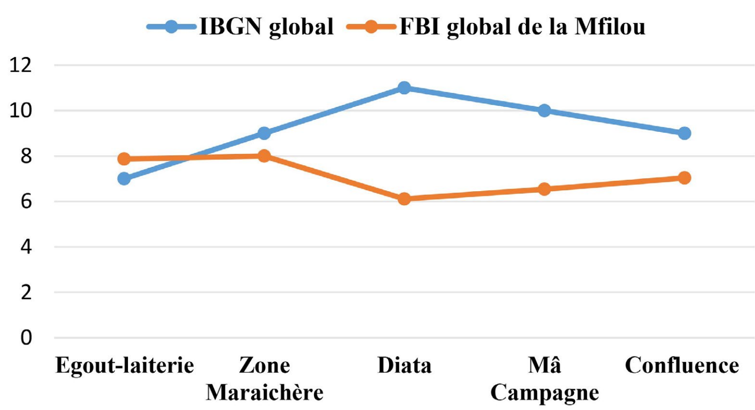

Figure 5. Spatial variation of the IBGN and Hilsenhoff Family Biotic Index (FBI) at the Mfilou station.

4. Discussion

Taxonomic diversity

The benthic macroinvertebrates of Mfilou comprise 129 taxa belonging to 62 families, 16 orders, 6 classes, and 4 phyla. They are unevenly distributed across the different stations, with the Diata station being the richest in taxa. Despite the observed anthropogenic pressure (market gardening, household and industrial wastewater discharges, siltation, and even over-siltation, etc.), this taxonomic richness remains high. This situation is similar to the observations made by [36], who showed that taxonomic richness is high in the most heterogeneous areas of the foothills and lower mountains (200 to 500 m altitude). Conversely, our results contrast with those obtained by [37], who identified 22 taxa belonging to 18 families, 8 orders, 3 classes, and 2 phyla among 365 specimens collected in a reserve where increased human pressure was observed. However, the high taxonomic richness of benthic macroinvertebrates observed in the Mfilou River is not synonymous with good hydrological quality of its waters. Indeed, the benthic macroinvertebrates community of the Mfilou River is composed of only 57.21% insects. The absence of Trichoptera and Plecoptera, and the near-total absence of Ephemeroptera (only 2 taxa, representing 3.23% of the taxonomic richness, were identified), clearly demonstrate the severe degradation of this river [16]. In fact, the individuals in this group are pollution-sensitive. It should be noted that insects are an indicator group of the ecological integrity of any ecosystem, due to their plasticity, and that they represent the most important animal group in terms of taxonomic richness, far exceeding that of all other groups present, even combined, in the same ecosystem. because they represent nearly 95% of the organisms present in the environment [38] [39]. Among the 129 taxa listed, the Diptera *Chironomus* sp. (Chironomidae), the Neotaenioglossa *Melonia tuberculata* (Thiaridae), and the Haplotaxida Naidiidae are the most numerous groups. Some authors, including [40], attest that these taxa, which colonize all environments, are ubiquitous and are often present in very large numbers.

Chironomidae Index

Often considered indicators of organic and/or metallic pollution, in this study, Chironomidae were also used to investigate other types of pollution, such as sediment-related pollution. The approach involved calculating the Chironomidae index, the values of which allow for the identification of the degree of sediment pollution at different sampling stations along a watercourse [26]. Thus, the Chironomidae index values obtained at the five study stations show that the waters present a dual diagnosis: clean water at the Egout Laiterie, Diata, Mâ Campagne, and Confluence stations, and moderate pollution at the Zone Maraîchère station. This station is characterized by a strong dominance of sediments, specifically sand-silt, which represented 87% of the substrate at this station during the study period. This could explain the overwhelming dominance of *Chironomus* larvae (Chironomidae, Chironominae, Chironomini) at this site, where they represent nearly 98.00% of the sample size and 22.15% of the specimens collected in the Mfilou River. Indeed, it is likely that they prefer soft, homogeneous sediments for building their tubes. [41] support this hypothesis, as the sedentarization of the larvae ensures good representation in their environment, since they are in contact with the sediments throughout their larval (2 to 4) and pupal stages. This preference would explain their proliferation at the Zone maraîchère statiton [42].

Normalized Global Biological Index (IBGN)

The values of the Normalized Global Biological Index allow the waters of the Mfilou River to be grouped into two quality classes. Class 2, characteristic of waters of average hydrological quality, reflects significant organic pollution at the Zone maraîchère, Diata, Mâ Campagne, and Confluence stations, where IBGN scores range from 9/20 to 11/20. The other class is designated as Class 3, characteristic of waters of poor hydrological quality, indicating high organic pollution at the Egout Laiterie station, where the IBGN score is 7/20. These results show a low number of taxa at the Egout Laiterie station due to more challenging environmental conditions, including high levels of sand-silt and suspended solids (SS). The indicator faunal groups are *Chironomus* sp. and *Melanoides tuberculata*. This high taxonomic richness, present across all stations and ranging from 17 to 34 taxa, is strongly dominated by *Melanoides tubercluta* (67.73%) and *Chironomus* sp. (22.15%).

Hilsenhoff Family Biotic Index (FBI)

The Hilsenhoff Family Biotic Index (FBI) used in this study incorporates all taxa present in the benthic macroinvertebrates community to demonstrate the level of degradation experienced by the ecosystem under study [13]. Thus, the FBI values obtained for the waters of the Mfilou River during this study highlighted the existence of three distinct hydrological qualities, including (i) very poor water quality, indicating severe organic pollution in the Egout laiterie and Zone Maraîchère stations; (ii) The water quality at the Diata station is rather poor, indicating substantial organic pollution, and (iii) the water quality at the Ma Campagne and Confluence stations is poor, illustrating very substantial organic pollution. The waters of the Mfilou River are therefore polluted from upstream to downstream, albeit to varying degrees.

The level of pollution in the Zone maraîchère station clearly illustrates the pressure exerted by human activities and the silting or over-silting due to runoff water on the Mfilou River, which would explain the proliferation of Chironomidae in this station. This situation reveals the nature of the pollution present: sediment-related pollution and organic pollution. The latter was evidenced by the presence of taxa that are highly tolerant to pollution, such as Diptera, Annelida, and Gastropod Molluscs. Thus, [43] state that the biodiversity of aquatic insect communities in a given ecosystem often reflects its ecological state; sensitive species colonizing these habitats due to unfavorable environmental conditions are gradually eliminated, while tolerant species establish colonies and thrive. Our results are consistent with observations made by [32] in the Oued El Abiod (Eastern Algeria) and [44] in the Kahuwa River (in Democratique Republic of Congo), which are of poor quality, evidence of severe pollution in downstream stations where human activity is significant. The same is true for the studies by [45], who observed significant pollution at the station crossed by the pipelines, and for those by [37], who found substantial, very substantial, and severe organic pollution at water stations in the Upper Bandama Fauna and Flora Reserve (RFFHB), located in the central part of northern Côte d'Ivoire, where hunting, non-timber forest product harvesting, fishing, mining, livestock farming, and agriculture were recorded.

The biological assessment of water pollution in the Mfilou River using the IBGN and FBI revealed varied trends. The observed discrepancies could be explained by the difference in quality class levels and categorization systems: 5 levels for the IBGN classes versus 7 for the FBI classes [32]. However, both indices highlight a worrying situation for the waters of the Mfilou River and establish that they are unfit for human consumption.

5. Conclusions

This publication aims to highlight the different levels of alteration in the integrity of the Mfilou River using a biological approach, specifically benthic macroinvertebrates.

Despite threats of all kinds (siltation of the main channel, market gardening, wastewater discharge, etc.), the waters of the Mfilou River maintain a high level of benthic macroinvertebrate diversity: 129 taxa were identified, unevenly distributed among 62 families belonging to 16 orders, 6 classes, and 4 phyla, out of a total of 17,325 collected individuals. *Melanoides tubercula* and *Chironomus* sp. were the two dominant taxa in the studied benthic communities.

The biological assessment of pollution in the Mfilou River, based on the collected benthic macroinvertebrates, revealed pollution related to sediments (sand-silt) at the Zone maraîchère station and organic pollution from upstream to downstream of the studied river. The scores obtained from the Normalized Global Biological Index (IBGN) highlighted two levels of organic pollution: i) significant organic pollution at the Zone maraîchère, Diata, Mâ Campagne, and Confluence stations, and ii) severe organic pollution at the Egout laiterie station. Molluscs and Baetidae (Mayflies, Insects) are the indicator faunal groups for this river. The Hilsenhoff index (Biological Family Index or FBI) revealed three degrees of organic pollution: i) severe organic pollution at the Egout laiterie and Zone maraîchère stations; ii) substantial organic pollution at the Diata station; and (iii) very substantial organic pollution at the Ma Campagne and Confluence stations. The waters of the Mfilou River are all polluted and therefore unfit for direct or indirect human consumption.

Conflicts of Interest

All authors confirm that they have read and approved the content of the submitted manuscript. They also declare that there are no conflicts of interest amoung the authors or with the publication ethics of the journal.

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