Afropolitan Journals

ISSN: 3027-2637 www.afropolitanjournals.com

Assessment of Macro-Invertebrates of Gubi and Waya Dams in Bauchi State, Nigeria

Salifu, Ugbede Augustine [1]; Abdulkarim, Mohammed[1]; Sani, Ibrahim[1]; and Idris, Muhammed Sanusi[2]

[1]Department of Animal Production, Faculty of Agriculture and Agricultural Technology, Abubakar Tafawa Balewa University, Bauchi, Bauchi State, Nigeria. [2]Departments of Applied Geology, Federal University of Lafia, Nasarawa State, Nigeria.

Corresponding author: salifuugbedeaugustine@gmail.com

DOI: *https://doi.org/10.62154/y5myp116*

Abstract

This study assessed the diversity, abundance, and composition of macro-invertebrates in the Gubi and Waya Dams in Bauchi State. Macro-invertebrates were collected fortnightly from different locations in the upper and lower parts of the dams using a D-frame net with a mesh size of 250 µm. Samples were preserved in 10% formaldehyde and identified. In Gubi Dam, 62 individual macro-invertebrates belonging to 7 orders and 9 families were identified, while Waya Dam had 108 individuals from 8 orders and 10 families. Both dams had Coleoptera with three families, followed by Odonata with two families, and other orders with one family each. In Gubi Dam, the most abundant macro-invertebrates were *Psephenus spp*. (24.1%), *Paragomphus genei* (17.74%), and *Phaon camerunensis* (16.13%). In Waya Dam, *Paragomphus genei* (29.63%) and *Phaon camerunensis* (25.93%) were the most abundant. Gubi Dam had a Shannon-Wiener index of 2.00, a Margalef's index of 1.99, Pielou's evenness index of 0.91, and a Simpson's index of 0.86. Waya Dam had a Shannon-Wiener index of 1.88, a Margalef's index of 1.92, an evenness index of 0.82, and a Simpson's index of 0.81. The study concluded that both dams provide stable and moderate aquatic environments for the growth and survival of macro-invertebrates as well as other aquatic organisms. Continuous monitoring of the water bodies, especially Waya Dam, using water indices and pollution indicator macro-invertebrates to obtain vital information on ecological status is recommended.

Keywords: Macro-Invertebrates, Diversity Indices, Gubi Dam, Waya Dam.

Introduction

Macro-invertebrates are animals without a backbone or bony skeleton that inhabit sediments and play a crucial role in aquatic ecosystems (Chowdhury *et al.*, 2022). In lotic environments, they occur under stones or woody debris, buried in sand or sediment, and crawling or sprawling on rocks, leaf packs, and snags (Magaji *et al.*, 2020). Due to their limited mobility, macro-invertebrates serve as indicators of water quality status and can remain in an area for extended periods (Magaji *et al.*, 2020; Mohammed *et al.*, 2020). Their presence or absence is commonly used to assess water quality, reflecting both chronic and acute changes caused by pollutants (Magaji *et al.*, 2020; Emeka *et al.*, 2020). Species from the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies)

are considered intolerant to environmental stress, and their presence signifies relatively clean water (Jonah & Akpan, 2021). In contrast, groups like Chironomids (biting midges), Hirudinea (leeches), Crustaceans (crayfish and amphipods), Mollusca (aquatic snails), Oligochaetes (Tubifex spp.), and Polychaetes (Capitella spp.) are considered pollution-tolerant (Jonah & Akpan, 2021).

Macro-invertebrates contribute significantly to the aquatic food chain, serving as food sources for larger organisms and participating in nutrient recirculation (Magaji *et al.*, 2020; Adeyemi-Ale & Tijani, 2022; Barua *et al.*, 2019). A decrease in the diversity of macro-invertebrates can lead to a decline in the diversity of fish, as different species rely on various macro-invertebrates as their food source (Magaji *et al.*, 2020). The composition and abundance of macro-invertebrates are influenced by physical, biological, and chemical factors such as temperature, pH, salinity, dissolved oxygen, sediment, and organic matter (Magaji *et al.*, 2020; Ukpohwo, 2021; Arumsari & Adharini, 2021).

The preference for macro-invertebrates over other biological groups in environmental assessments is due to several reasons. Firstly, the advantages of using benthic macro-invertebrates and, secondly, their long history in evaluating the long-term effects of anthropogenic river pollution (Namba *et al.*, 2020). Some of these advantages include their ease of sampling, sedentary life cycles that span from many generations per year to one generation in many years, and high species diversity with varying degrees of sensitivity to anthropogenic pollution (Iwasaki *et al.*, 2018). The sensitivity of macro-invertebrates means that the dominance of pollution-sensitive taxa in a system indicates overall good water quality, while the dominance of pollution-tolerant taxa shows an impacted water system (Zhou *et al.*, 2020).

Statement of the Problem

The environmental quality of freshwater ecosystems is intrinsically linked to the health and diversity of macro-invertebrate communities. In Gubi and Waya Dams, the increasing levels of pollution, habitat alteration, and the effects of climate change are likely to have significant impacts on these populations (Jourdan *et al.*, 2018). Macro-invertebrates play crucial ecological roles in aquatic ecosystems, yet their diversity and abundance are increasingly threatened by various anthropogenic activities. Despite the importance of these communities, comprehensive studies on macro-invertebrate populations in Gubi and Waya Dams in Bauchi State are notably scarce (Keke *et al.*, 2021). Given that these dams are vital water resources for the surrounding communities, understanding the state of macro-invertebrate diversity is essential for the development of effective conservation strategies and sustainable management practices.

Objective

This study assessed the diversity, composition, and abundance of macro-invertebrates in the Gubi and Waya dams in Bauchi State, Nigeria.

Materials and Methods

Study Location

Study Area 1: Gubi Dam

The study was carried out at the Gubi dam, located at Piro village in the Bauchi Local Government Area of Bauchi State, Nigeria. Gubi Dam lies within 9° 5' 30" E and 10° 24' 32" N. The function of the dam is to supply the state capital and its environs with portable water supply, fishing, and irrigation. The embankment of the dam has a length of 3.86 km. The area has two distinct seasons: a short (June–September) wet season and a long (October–May) dry season (Magaji *et al*., 2020; Umar *et al*., 2020).

Study Area 2: Waya Dam

Waya Dam is located in the Ganjuwa local government area of Bauchi State, Nigeria, and is about 25 km away from Bauchi town. Its longitude is 10.0142°N and its latitude is 10.3453°E. The water retention time is between 3–4 months in the rainy season, while the water residence time in the dry season is a few days due to high evaporation (Umar *et al*., 2020).

Research Design and Methods

Selection of Sample Sites

Macro-invertebrate was sampled from two dams, Gubi Dam and Waya Dam. Each dam had two sampling points, classified into upper and lower parts. The sampling period covered both dry and wet seasons.

Collection of Macro-Invertebrate Samples

This study employed a stratified random sampling technique to collect macro-invertebrate samples from Gubi and Waya Dams during both wet and dry seasons. Sampling was conducted fortnightly over a five-month period from August 2023 to December 2023. At each sampling point in both dams, samples were collected using a combination of D-frame nets (250µm mesh) and sieves, following the method described by Andem *et al*. (2012).

The collected macro-invertebrates were preserved in a 10% formaldehyde solution for subsequent identification in the laboratory. In the lab, specimens were carefully sorted using forceps, examined under a microscope, and identified using relevant taxonomic keys and monographs. The identified macro-invertebrates were then classified into various orders and families, and their abundance was recorded.

Data Analysis

To assess the biodiversity and evenness of macro-invertebrate populations in the two dams, several diversity indices were calculated. These included the Shannon-Wiener index, Margalef's index, Pielou's evenness index, and Simpson's diversity index. The composition of the macro-invertebrate community was evaluated by expressing the abundances of individual species as percentages within each order.

The macro-invertebrate data were analyzed using various biological diversity indices to quantify species richness and evenness within the community. These indices included the Shannon Index (H'), Simpson's Dominance Index (D), Evenness (E), and Margalef's Diversity Index (R), as detailed by Ogbeibu (2005).

$Shannon\ diversity\ index$:

$$(H') = -\sum(pi) \times in(pi) \quad \ldots 1$$

Where

H' = diversity index

Pi = proportion of the total sample represented by species

ln = natural logarithm

i = division of the number of individuals in each species by the total number of samples.

$Simpson\ Index\ diversity$

$$(SDI) = 1 - \frac{\sum n(n-1)}{N(N-1)} \quad \ldots 2$$

Where:

n = Number of individual species

N = Total number of individuals

Σ= Sum of the calculations

$Pielou's\ Evenness$:

$$(J) = \frac{\boldsymbol{H'}}{\boldsymbol{In(S)}} \quad \ldots 3$$

Where *H* = is Shannon diversity index

***ln S* =** natural log of species richness (The total number of species)

$Margalef's\ species\ richness\ index$:

$$(R) = \frac{(\boldsymbol{S-1})}{\boldsymbol{lnN}} \quad \ldots 4$$

Where d = Species richness index

S = Number of species population

N = total number of individual species

Results and Discussion

Results

Table 1: Abundance and Composition of Macro invertebrates in Gubi dam and Waya dam

Order	Family	Species	Gubi Dam			Waya Dam		
			Wet season No (%)	Dried season No (%)	Over all proportion	Wet season No (%)	Dried season No (%)	Over all proportion
Coleoptera	Psephenidae	*Psephenus spp*	8(24.24)	5(17.24)	13(20.97)	10(16.67)	5(10.42)	15(13.89)
	Elmidae	*Ancyronyx variegatus*	0	2(6.90)	2(3.23)	5(8.33)	2(4.20)	7(6.48)
	Dytiscidae	*Dytiscus marginalis*	5(15.15)	3(10.34)	8(12.90)	3(8.33)	3(6.25)	6(5.56)
Hemiptera	Nepidae	*Nepa cinerea*	0(0)	0(0)	0(0)	2(3.33)	3(6.25)	5(4.63)
Littorinimorpha	Bithynidae	*Gabbiella humerosa*	0(0)	3(10.34)	3(4.84)	2(3.33)	1(2.08)	3(2.78)
Megaolptera	Corydalidae	*Corydalus cornutus*	0(0)	1(3.44)	1(1.61)	0(0)	0(0)	0(0)
Neotaenioglossa	Thiaridae	*Melanoides tuberculata*	3(9.09)	5(17.24)	8(12.90)	5(8.33)	7(14.48)	12(11.11)
Odonata	Gomphidae	*Paragomphus genei*	9(27.27)	4	13(20.97)	19(31.67)	13(27.08)	32(29.63)
	Calopterygidae	*Phaon camerunensis*	8(24.24)	3(10.34)	11(17.74)	11(18.33)	13(27.08)	24(22.22)
Rhynchobdllida	Glossiphoniidae	*Hirudo medicinalis*	0(0)	0(0)	0(0)	1(1.70)	0(0)	1(0.93)
Unionida	Margaritiferidae	*Margaritifera margaritifera*	0(0)	3(10.34)	3(4.84)	2(3.33)	1(2.08)	3(2.78)
Total			33	29	**62**	60	48	**108**

Source: field survey, 2023

The composition and abundance of macro-invertebrates collected in the Gubi and Waya dams are presented in Table 1. A total of 62 individual macro-invertebrates belonging to 7 orders and 9 families were identified in Gubi Dam. Coleoptera had three families, followed by Odonata, which also had two families, while Littorinimorpha, Megaloptera, Neotaenioglossa, Rhynchobdllida, and Unionida had one family each. The species are In Gubi Dam, the most abundant macro-invertebrates were *Psephenus spp*. 15 (24.1%), *Paragomphus genei* 11 (17.74%), *Phaon camerunensis* 10 (16.13%), *Dytiscus marginalis* 7 (11.29%), and *Ancyronyx variegatus* 7 (11.29%). The least abundant species were *Melanoides tuberculata* 5 (8.06%), *Margaritifera margaritifera* 3 (4.83%), *Gabbiella humerosa* 3 (4.83%), and *Corydalus cornutus* 1 (1.61%). The wet season in Gubi dam had fewer individuals's macro-invertebrates (29) than the dried season (33). At Waya Dam, a total of 108 macro-invertebrates' individuals belonging to 8 orders and 10 families were identified. Coleoptera had three families, followed by Odonata with two families, and Hemiptera, Littorinimorpha, Neotaenioglossa, Rhynchobdllida, and Unionida had one family each.

Paragomphus genei 32 (29.63%), *Phaon camerunensis* 28 (25.93%), *Melanoides tuberculata* 17 (15.74%), *Psephenus spp*. 8 (7.40%), *Dytiscus marginalis* 6 (5.56%), *Ancyronyx variegatus* 5 (4.63%), and *Nepa cinerea* 5 (4.63%), while the least abundant species were *Margaritifera margaritifera* 3 (2.78%), *Gabbiella humerosa* 3 (2.78%), and *Hirudo medicinalis* 1 (0.93%). Wet season had more individual macro-invertebrates (60) than dried season (48) in Waya dam.

Table 2: Diversity and Dominance Indices of macro-invertebrates in Gubi Dam and Waya Dam

Parameter	Gubi dam	Waya dam
Shannon-Wiener index (H')	2.02	1.94
Margalef's index (d)	1.90	1.92
Pielou evenness index (j)	0.92	0.84
Simpson's index (D)	0.15	0.18

Source: field survey, 2023

The diversity indices of macro-invertebrates in the study area are presented in Table 2. In Gubi Dam, the Shannon-Wiener index was 2.00, Margalef's index was 1.90, Pielou's evenness index was 0.91, and Simpson's diversity index was 0.86. In contrast, Waya Dam recorded a Shannon-Wiener index of 1.88, Margalef's index of 1.92, Pielou's evenness index of 0.82, and Simpson's diversity index of 0.81.

Discussion

Table 1 presents the data on the abundance and composition of macro-invertebrates in the Gubi and Waya dams. Gubi Dam recorded a total of 62 macro-invertebrates, with 33 individuals in the wet season and 29 in the dry season, indicating a decrease in abundance during the dry season (Table 1). In contrast, Waya Dam had a total of 108 macro-invertebrates, with 60 in the wet season and 48 in the dry season. This decline in species biomass and dominance suggests environmentally unfavorable conditions, as stressed biological populations often exhibit reduced diversity and population size (Newall and Walsh, 2005). The 62 individuals in Gubi Dam (Table 1) are lower compared to the 108 macro-benthic invertebrates reported by Maggaji *et al*. (2020) and the 128 reported by Olawusi-Peters (2017) in Owena Reservoir. Similarly, Waya Dam exhibited seven orders, ten families, and ten species (Table 1), which is higher than the five families and five species documented by Olawusi-Peters (2017) at the Owena Reservoir but lower than the 20 families reported by Mohammed *et al*. (2020) at Moussa Stream, Bida, Nigeria.

The observed variations in macro-invertebrate species may be due to ecological instability caused by anthropogenic activities and sediment characteristics (Jonah *et al*., 2020a) (Table 1). Abundance variations between wet and dry seasons can be influenced by changes in water flow, temperature, and habitat. The higher abundance in Waya Dam (Table 1) suggests it may be more resilient to seasonal fluctuations. The abundant species in both dams, *Paragomphus genei*, *Psephenus spp*., *Phaon camerunensis*, *Melanoides tuberculata*, and *Dystiscus marginalis* (Table 1), indicate wide ecological tolerance and adaptability

(Mohammed *et al.*, 2020). Their higher abundance during the wet season aligns with findings from other studies, suggesting increased food availability and breeding activity contribute to this pattern (Jonah *et al.*, 2020a). The presence of pollution-tolerant species such as *Melanoides tuberculata*, *Hirudo medicinalis*, and *Nepa cinerea* (Table 1) may be attributed to agricultural activities and organic matter pollution (Jonah *et al.*, 2020a).

During the rainy season, a greater abundance of macro-invertebrates was observed compared to the dry season. This disparity can be attributed to increased water volume, intensified flow characteristics, and increased surface runoff, which likely disrupted habitat structure. Conversely, in numerous streams across Nigeria, a higher abundance of macro-invertebrates was documented during the dry season.

Diversity and Dominance Indices

The differences observed in these indices may be indicative of variations in environmental conditions, habitat quality, or human impacts between the two dams (Dabessa *et al.*, 2021). The Shannon-Wiener index, which measures species diversity, was higher in Gubi Dam (2.00) compared to Waya Dam (1.88), indicating a richer macro-invertebrate community in Gubi Dam. Both dams fall within the range of moderately degraded environments, as values less than one indicate heavily degraded environments, and values between one and two characterize moderately degraded environments. A value above three signifies stable environmental conditions (Neetu *et al.*, 2019). The values obtained in this study are within the range of 1.72 to 2.27 reported by Zahraddeen *et al.* (2029), higher than the range of 1.717 to 1.923 documented by Anyanwu *et al.* (2019) at Ossah River, Umuahia, Southeast Nigeria, and higher than the findings of Adeyemi-Ale and Tijani (2022) on the heavy metals and benthic macro-invertebrates diversity and abundance of Oyun River. However, these values are lower than the 2.91 at Site A and 2.81 at Site B reported by Iyiola and Asiedu (2020) in Ogunpa River, South-Western Nigeria.

Margalef's index, which assesses species richness, was slightly higher in Waya Dam (1.92) compared to Gubi Dam (1.90), suggesting a marginally higher number of species in Waya Dam. These values are lower than the range of 2.796 to 2.968 across three stations recorded by Anyanwu *et al.* (2019) at Ossah River, Umuahia, Southeast Nigeria, but higher than 1.71 at Site A and 1.70 at Site B reported by Iyiola and Asiedu (2020), and higher than the value of 1.5 obtained by Magaji *et al.* (2020) in their study at Gubi Dam.

Pielou's evenness index, measuring the distribution of individuals among species, was higher in Gubi Dam (0.91) compared to Waya Dam (0.82). This indicates a more even distribution of individuals across various species in Gubi Dam. These values are higher than those of 0.49 to 0.62 reported by Zahraddeen *et al.* (2029), 0.428 to 0.684 by Anyanwu *et al.* (2019), and 0.75 by Magaji *et al.* (2020) at Gubi Dam, but lower than 3.45 at Site A and 3.33 at Site B documented by Iyiola and Asiedu (2020).

Simpson's index, which assesses species dominance, was lower in Gubi Dam (0.86) compared to Waya Dam (0.81), indicating lower dominance and higher diversity in Gubi Dam. These indices collectively suggest that Gubi Dam supports a richer, more diverse, and more evenly distributed macro-invertebrate community than Waya Dam. Gubi Dam had a

higher number of species, with individuals more evenly distributed among them, and no single species dominated the community, which is higher than the value of 0.26 reported by Magaji *et al*. (2020), but within the range of 0.76 to 0.85 reported by Zahraddeen *et al*. (2029).

Conclusion

This study assessed the composition and abundance of macro-invertebrates in Gubi and Waya Dams, Bauchi State, Nigeria. In Gubi Dam, a total of 62 individual macro-invertebrates were identified, representing 7 orders and 9 families. The most abundant species were *Psephenus spp.* (24.1%), *Paragomphus genei* (17.74%), and *Phaon camerunensis* (16.13%). The least abundant were *Corydalus cornutus* (1.61%) and *Margaritifera margaritifera* (4.83%). The dry season exhibited a higher abundance of macro-invertebrates (33 individuals) compared to the wet season (29 individuals).

In contrast, Waya Dam had a higher total count of 108 individual macro-invertebrates identified, representing 8 orders and 10 families. Dominant species included *Paragomphus genei* (29.63%), *Phaon camerunensis* (25.93%), and *Melanoides tuberculata* (15.74%). The least abundant were *Hirudo medicinalis* (0.93%) and *Margaritifera margaritifera* (2.78%). The wet season showed a higher abundance (60 individuals) compared to the dry season (48 individuals).

Diversity indices indicated moderate diversity in both dams, with Gubi Dam exhibiting slightly higher values in Shannon-Wiener and Simpson's diversity indices compared to Waya Dam. However, Margalef's and Pielou's evenness indices were relatively similar between the two dams, suggesting a comparable distribution of species.

Recommendations

- Implementing systematic and continuous monitoring of macro-invertebrate populations in both Gubi and Waya Dams is valuable. This will help track changes in species composition and abundance over time, providing crucial data to identify emerging threats and inform conservation strategies.
- Using water chemistry parameters such as dissolved oxygen, pH, and nutrient levels is essential for obtaining vital information on ecological status, biological composition, and water suitability for human consumption in Nigeria.
- Addressing the sources of pollution impacting both dams. This includes enforcing stricter regulations on agricultural runoff, industrial discharges, and waste management to protect macro-invertebrate habitats and overall water quality.

Significant Contribution of the Study

This study contributes significantly to understanding the ecological health and biodiversity of freshwater ecosystems in Bauchi State, Nigeria. By providing a detailed assessment of the diversity, composition, and abundance of macro-invertebrates in Gubi and Waya Dams, this research highlights several key findings:

- This study establishes baseline data for macro-invertebrate populations in the two dams, which is essential for future monitoring and conservation efforts. It identifies the presence of various species and their relative abundances, contributing to the knowledge of aquatic biodiversity in the region.
- The study uses macro-invertebrate diversity indices (Shannon-Wiener, Margalef's, Pielou's evenness, and Simpson's diversity) to assess the environmental quality of the dams. These indices indicate that Gubi Dam has a slightly richer and more evenly distributed macro-invertebrate community compared to Waya Dam, suggesting differences in habitat quality or anthropogenic impacts between the two sites.
- The research highlights the seasonal variations in macro-invertebrate abundance, with Gubi Dam showing higher abundance in the dry season and Waya Dam showing higher abundance in the wet season. This information is crucial for understanding how seasonal changes affect aquatic ecosystems and can inform water management practices.
- The presence of pollution-tolerant species, such as *Melanoides tuberculata* and *Hirudo medicinalis*, indicates potential anthropogenic impacts, such as pollution from agricultural activities. This finding emphasizes the need for pollution control and sustainable management practices in the region.

Study Limitations

- The study is limited to Gubi and Waya Dams and does not include other water bodies in the region. Expanding the study to include more sites would provide a more comprehensive understanding of macro-invertebrate diversity in Bauchi State.
- The study covers a limited time frame, focusing on seasonal variations within a single year. Long-term studies are needed to understand inter-annual variations and the impacts of longer-term climatic changes.
- The sampling methods and frequency might not capture the full range of macro-invertebrate diversity. Increasing the frequency and spatial coverage of the sampling could improve the accuracy of the data.

Areas for Future Study

To build on the findings of this research, future studies should consider the following areas:

- **Long-term Monitoring**: Conducting long-term monitoring of macro-invertebrate populations to understand trends over time and assess the impacts of climate change and other long-term environmental changes.
- **Expanded Geographic Scope**: Including additional water bodies in Bauchi State and neighboring regions to provide a more comprehensive assessment of aquatic biodiversity and identify regional patterns.

- **Impact of Land Use Practices**: Investigating the effects of different land use practices, such as agriculture, urbanization, and deforestation, on macro-invertebrate communities and water quality.
- **Detailed Pollution Studies**: Conducting detailed studies on the sources and types of pollution affecting the dams and their impacts on macro-invertebrate populations. This could inform targeted pollution control measures.
- **Conservation Strategies**: Developing and implementing conservation strategies based on the findings, focusing on protecting and restoring habitats to maintain and enhance macro-invertebrate diversity.

References

Adeyemi-Ale, O. A., and Tijani, T. O. (2022). Heavy metals and benthic macro-invertebrates diversity and abundance of Oyun River sediments, Ilorin, Kwara State, Nigeria. *World Journal of Applied Science and Technology*, *14*(1), 30-35.

Andem, AB; Okorafor, KA; Udofia, U; Okete, JA; Ugwumba, AAA (2012). Composition, distribution and diversity of benthic macro-invertebrates of Ona River, South- West, Nigeria. Europ. J. Zool. Res. *1*(2), 47- 53.

Anyanwu, E. D., Okorie, M. C., and Odo, S. N. (2019). Macro-invertebrates as bio-indicators of water quality of effluent-receiving Ossah River, Umuahia, Southeast. *ZANCO Journal of Pure and Applied Sciences*, *31*(5), 9-17. DOI: 10.21271/ZJPAS.31.5.2

Arumsari, P. L., and Adharini, R. I. (2021). Structure and distribution of macrobenthos community in Code River, Yogyakarta, Indonesia. *Indonesian Journal of Limnology*, *2*(2):21-27. DOI: 10.51264/inajl.v2i2.17

Barua, P., Mohasin Meah., M., and Rahman, S. H., (2019): Abundance of macrobenthos with special reference to some environmental parameters of south-eastern coastal area, Bangladesh. *Asian Journal of Water, Environment and Pollution, 16*(4), 51–60. https://DOI.org:10.3233/AJW190048

Chowdhury, A. J. K., John, A., Aqilahd, N. U., Abdullaha, R., Salihaha, N. T., Basira, K. H., and Marsal, C. J. (2022). Macro-invertebrates community towards sustainable aquatic ecosystem: A systematic review along the coastal waters of Malaysia. *Geology, Ecology, and Landscapes*.

Dabessa, M., Lakew, A., Devi, P., and Teressa, T. (2021). Effect of environmental stressors on the distribution and abundance of macro-invertebrates in upper Awash River at Chilimo Forest, West Shewa, Ethiopia. *International Journal of Zoology*, DOI: 10.1155/2021/6634168

Iwasaki, Y., Schmidt, T.S., Clements, W.H., 2018. Quantifying differences in responses of aquatic insects to trace metal exposure in field studies and short-term stream mesocosm experiments. Environ. Sci. Technol. *52*, 4378–4384.

Jonah, U. E., and Akpan, I. I. (2021). Application of multimetric index on water quality assessment of Qua Iboe River Estuary, Akwa Ibom State, Nigeria. *International Journal of Ecology and Environmental Sciences*, *3*(3), 126-134.

Jonah, U. E., Iwoke, E. S., and Hanson, H. E. (2020a). Impacts assessment of coastal activities on water quality of upper segment of Qua Iboe River, Akwa Ibom State, South-South, Nigeria. *Journal of Applied Science and Environmental Management, 24*(7), 1217-1222. https://doi.org/10.4314/jasem.v24i7.14

Jourdan, J., O'Hara, R. B., Bottarin, R., Huttunen, K. L., Kuemmerlen, M., Monteith, D., Muotka, T., Ozoliņš, D., Paavola, R., Pilotto, F., Springe, G., Skuja, A., Sundermann, A., Tonkin, J. D., & Haase, P. (2018). Effects of changing climate on European stream invertebrate communities: A long-term data analysis. *Science of the Total Environment*, *621*, 588–599. https://doi.org/10.1016/j.scitotenv.2017.11.242

Keke, U. N., Omoigberale, M. O., Ezenwa, I., Yusuf, A., Biose, E., Nweke, N., Edegbene, A. O., & Arimoro, F. O. (2021). Macroinvertebrate communities and physicochemical characteristics along an anthropogenic stress gradient in a southern Nigeria stream: Implications for ecological restoration. *Environmental and Sustainability Indicators*, *12*, 100157. https://doi.org/10.1016/j.indic.2021.100157

Magaji, I. M., Abdulkarim, M., Yusuf, Z. A., and Aliyu, M. H. (2020). Assessment of Macro-benthic Invertebrates of Gubi Dam, Ganjuwa – Bauchi State. In: Mancha, Y.P., Kalla, D.J.U., Abdulkarim, M., Igila, T., and Danbirni, S. Proceeding of 45th Annual Conference of Nigerian Society for Animal Production (NSAP). 984- 989.

Mohammed, Y. M., Arimoro, F. O., Ayanwale, A. V., Adama, B. S., Keke, U. N., Auta, Y. I., Umar, B. I. (2020). Seasonal changes in the abundance of benthic macro-invertebrates and environmental condition of Moussa Stream Bida, Nigeria. *Tropical Freshwater Biology*, *29*(1), 57-70. DOI: 10.4314/tfb.v29i1.4.

Namba, H., Iwasaki, Y., Heino, J., Matsuda, H., 2020. What to Survey? A Systematic review of the choice of biological groups in assessing ecological impacts of metals in running waters. Environ. Toxicol. Chem. 1–8. https://doi.org/10.1002/etc.4810

Neetu, N., Anupma Kumari, A. K., Kedia, D. K., and Sinha, R. K. (2019). Assessment of benthic macro-invertebrates to assess water quality of treated sewage fed pond at Pahari, Patna.

Newall, P., and Walsh, C. J. (2005). Response of epilithic diatom assemblages to urbanized influences. *Hydrobiologia, 532*, 53-67.

Ogbeibu, A. E. (2005). *Biostatistics: A practical approach to research and data handling*. Mindex Publishing Company Limited.

Olawusi-Peters, O. O. (2017). Composition and abundance of macro-benthic invertebrates in Owena reservoir, Ondo State, Nigeria. *International Journal of Aquatic Science*, *8*(2), 83-90.

Ukpohwo, A. R. (2021). Macro-invertebrates composition and distribution in River Jameson of Otefe community in Oghara Delta-State Nigeria. *Innovative Journal of Science*, *3*(3), 73-84.

Umar, K. H., Kyari, E. M., and Mbaya, Y. A. (2020). Assessment of some physicochemical parameters of Gubi and Waya reservoir in Bauchi State, Nigeria. *International Journal of Scientific and Technology Research*, *9*(2):2277-8616

Zhou, O., Yang, N., Li, Y., Ren, B., Ding, X., Bian, H., Yao, X., 2020. Total concentrations and sources of heavy metal pollution in global river and lake water bodies from 1972 to 2017. Global Ecology and Conservation 22.