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Impact of Dewatering on the Spatio-Temporal Distribution of Benthic Macroinvertebrate Communities in the Okpara River, Benin

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Abstract

Surface watercourses are areas of very high ecological and heritage value. Macroinvertebrates are bioindicators of the health of aquatic ecosystems. The aim of this study was to assess the effects of dewatering and re-watering cycles on benthic macroinvertebrate (BMI) communities. Two data collections were carried out at two stations (Okpara 1 and Okpara 2) on the Okpara river before and after dewatering. Thus, 8 samples of benthic macroinvertebrates and 12 physico-chemical parameters (T˚C, pH, Transparency, Depth, Conductivity, Dissolved Oxygen that were measured *in situ*, and BOD5, COD, NH_4^+, NO_3^-, NO_2^- and PO_4^{3-}) were assayed in the laboratory. Canonical Correspondence Analysis (CCA) was used to match physico-chemical data to MIB families. Shannon and Piélou diversity indices were used to determine the effects of dewatering on MIBs. The increase in temperature values of pH, BOD5, COD, NH_4^+, NO_3^-, NO_2^- and PO_4^{3-}, after re-watering indicates the effect of dewatering on the quality of Okpara aquatic ecosystems. The benthic macrofauna collected consisted of 62.42% insects, 0.65% crustaceans, 6.48% molluscs, 0.72% worms and 0.14% arachnids. Whereas after re-watering, 21.67% insects, 0% crustaceans, 0.22% molluscs, 7.56% worms and 0.29% arachnids were recorded. Insects, crustaceans and molluscs were more abundant before dewatering than after. This was revealed by low abundances and taxonomic richness, as well as low Shannon index values of samples collected after re-watering.

Keywords

Dewatering, Benthic Macroinvertebrates, Impact, Physico-Chemical Parameters, Okpara Rivers, Nord-Benin

1. Introduction

Water is a vital element that is essential to life. It exists in different forms to meet our biological, domestic and agricultural needs (Ghoubal et al., 2018). The proportion of surface water depends on many factors, the most important of which are the duration and intensity of rainfall, climate and vegetation, and the geological, geographical and topographical conditions of the region under consideration. Low water levels in surface watercourses can lead to seasonal drying out of alluvial wetlands, resulting in a reduction and contraction of habitats, even the disappearance of the aquatic environment and the exondation of sediments (Dehédin, 2012). The drying out of riverbeds also creates major environmental risks, such as reduced water quality, loss of wetlands, soil erosion and degradation of biodiversity. Such phenomena induce profound changes in the structure of aquatic living communities and associated activities (Datry et al., 2011; Corti et al., 2011). This is because surface water loss acts as an ecological filter (Poff, 1997), and benthic macroinvertebrates have taxon-specific quantitative properties that respond to drying (Datry et al., 2014; Leigh & Datry, 2017). The drying out of aquatic environments has an immediate impact, acting above a certain threshold, at the moment it occurs, whatever the season (Leigh et al., 2016). Indeed, the cessation of surface runoff and the drying out of river beds are the main drivers of the destruction of temporary river community structure (Datry et al., 2014; Bogan & Lytle, 2011), taxonomic richness (Stubbington et al., 2017), population abundance and the functioning of aquatic ecosystems (Datry et al., 2011; Magoulick, 2014). In Africa, and particularly in Benin, only the studies by Orou Piami et al. (2023) have assessed the impacts of dewatering on invertebrate communities, and no previous study has examined the effects of dewatering on the benthic macrofauna of the Okpara River in northern Benin. Yet benthic macroinvertebrates are important in the formation of the freshwater aquatic food chain, forming part of the diet of many species of fish, birds and amphibians (Balachandran & Ramachandra, 2010). They are also used to monitor the physicochemical and biological quality of local water following anthropogenic disturbances causing environmental contamination (Piscart, 2004; Moisan & Pelletier, 2008). The aim of this study is to assess the effects of dewatering and re-watering cycles on benthic macroinvertebrate communities, in order to establish a link between changes in macroinvertebrate communities and fluctuating environmental conditions.

2. Materials and Methods

Sampling

For this study, two data collection campaigns were carried out at two stations

(Okpara 1 and Okpara 2). Prior to the collection of litter samples, two values for each physico-chemical parameter, i.e. temperature, pH, transparency, depth, conductivity and total dissolved solids, were measured in situ between 6 a.m. and 12 p.m. at each study station. Conductivity, temperature and total dissolved solids (TDS) were measured using a HANNA HI 99300 conductivity meter. pH was measured using a pH meter (HANNA HI 98107). Water depth was measured using a graduated ruler. Transparency was measured using a Secchi disc. The length and width of the wetted bed were measured with a decameter. A water sample was taken using sterilized boxes and the chemical parameters BOD5, COD, NH_4^+, NO_3^- and PO_4^{3-} were assayed in the laboratory. Finally, a GPS navigator Garmin GPS 72 is used to determine the geographical coordinates of the sampling stations.

Macroinvertebrate sampling

Benthic macroinvertebrates were sampled in the Okpara River before dewatering of the study stations (December 2022) and after dewatering (June 2023). Two stations (Okpara 1 and Okpara 2) were selected on this river. At each station considered for the study, eight (8) benthic macroinvertebrate samples were collected using a Surber net with a mesh size of 500 µm and a surface area of 0.05 m^2. Benthic macroinvertebrates were sampled using the IBGN (Indice Biologique Global Normalisé) method, a diagnostic tool for aquatic ecosystems based on the study of benthic macroinvertebrates (AFNOR, 2010). During each harvest, the Surber net is placed in the bed against the direction of the water current. Once the Surber net is in place, the inside of the metal frame is scraped and washed by hand to a depth of around 5 cm, and pushed inside the net, with the aid of the water current, the benthic macroinvertebrate samples are collected through the net. At each station, four (4) benthic macroinvertebrate samples are taken from dominant substrates and four (4) from marginal substrates. The substrates or habitats sampled were macrophytes, litter, stones (boulders or rocks) and benthos (soil, sand or sediment). The collected macroinvertebrates are then preserved in 70% alcohol, in jars labelled by site. The samples are transported to the Ecology, Health and Animal Production Laboratory (LESPA) at the University of Parakou for sorting, observation and identification.

Sorting, observation and identification of macroinvertebrates

In the laboratory, organisms were sorted station by station. Sorting took place under a binocular magnifying glass. During this operation, invertebrates were separated according to their morphological appearance and grouped into classes, orders and families. Taxonomic determination was carried out down to the species level, unless the keys did not allow it. Specimens were identified using the following identification keys: "Macroinvertébrés benthiques des cours d'eau de la Nouvelle-Calédonie" (Mary, 2017), "Guide d'identification des principaux macroinvertébrés benthiques d'eau douce du Québec" (Moisan et al., 2013) and "Les invertébrés d'eau douce: systématique, biologie, écologie" (Tachet et al., 2000). After identification, determination was completed by preserving the organisms in 70% alcohol, and a faunal list by station was drawn up.

Data processing and statistical analysis

Taxonomic richness, taxonomic group abundances, Shannon diversity and Piélou equitability indices were determined. The Shannon diversity index (H') was calculated according to the formula (Shannon & Weaver, 1949): H' = −Σpi(log2)pi; With, pi the relative abundance of species i in the sample, which is: pi = Ni/N; Ni: number of individuals of a given taxon, i ranging from 1 to S (total number of taxa); N: total number of individuals. H' is expressed in bits.

The Equitability Index (E) (Pielou, 1969), which is the ratio of true diversity to maximum diversity, is calculated by the formula: **E** = **H'/log2S**; where S is the species richness.

After testing for normality of all biological parameters ($p < 0.05$), the variabilities of biological data and physicochemical parameters were evaluated using the Wilcoxon test at the 5% threshold with R4.1.1 software, Package Rcmd and Factominer).

The frequency of observation (FO) of families was determined. It is the ratio between the number of stations where the family is present and the total number of stations studied. Three groups are thus defined (Dajoz, 2000): "very frequent" families have a frequency of observation greater than or equal to 50%; "frequent" families have a frequency of observation of between 25% and 50%; and "rare" families have a frequency of observation of less than 25%.

A canonical correspondence analysis (CCA) was used to match the benthic macroinvertebrate families, the two station qualities (reference station and polluted station) and the two sampling periods (before and after dewatering).

3. Results

Physico-chemical parameter variables

Table 1 shows the mean values and standard deviations of ten (10) physico-chemical parameters of Okpara river water quality before and after dewatering of the Okpara aquatic ecosystem beds. The Table shows that after dewatering the two study stations, the pH of the Okpara river water is slightly acidic (7.75 and 8.40), with low transparency (10.5 - 12) and high conductivity, ammonium, nitrate and orthophosphate. Similarly, the values of physico-chemical parameters on the same line not sharing the same letters (a, b and c) showed significant deviations ($p < 0.05$).

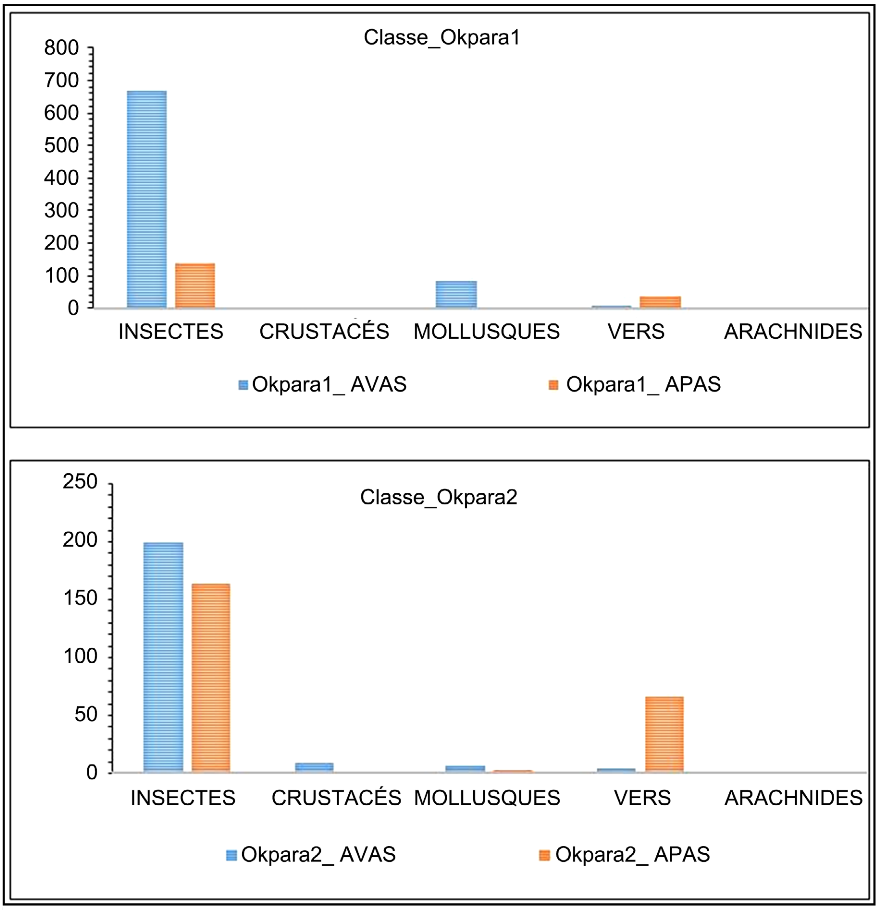
Effect of dewatering on benthic macroinvertebrate classes in the Okpara River

Figure 1 shows the composition of the benthic macroinvertebrate community at the two study stations in the Okpara river. Overall, the macrofauna collected belonged to 5 classes and 14 orders. The insect class was dominant at both study stations during both seasons (before and after dewatering), with higher abundance before dewatering than after re-watering. In general, all recorded classes were more abundant after rewatering than before, with the exception of worm taxa, which were much more abundant after rewatering.

Table 1. Maximum and minimum values for Okpara physico-chemical parameters during experimentation.

Stations	OKP1_AVAS	OKP1_APAS	OKP2_AVAS	OKP2_APAS
T°C	31.50 ± 0.71a	34.80 ± 0.42b	32.50 ± 0.71ab	33.49 ± 0.83ab
pH	7.64 ± 0.23a	7.75 ± 0.04a	7.58 ± 0.05a	8.40 ± 0.01b
Transp (Cm)	21.5 ± 4.95c	12.0 ± 2.83a	17.5 ± 2.12b	10.5 ± 0.71a
Depth (Cm)	26.5 ± 2.12a	15.0 ± 7.07a	17.5 ± 3.54a	17.0 ± 1.41a
Cond	187.00 ± 1.41a	298.00 ± 1.41b	184.75 ± 0.49a	299.35 ± 13.93b
OD	8.66 ± 0.65ab	7.05 ± 1.20bab	9.75 ± 0.01a	6.52 ± 0.08b
BOD5	17.50 ± 0.71a	28.780 ± 1.64b	18.205 ± 0.57a	37.600 ± 1.70c
COD	32.00 ± 2.83b	49.44 ± 0.70a	35.15 ± 0.49b	49.80 ± 0.85a
NH_4^+ (mg/l)	0.08 ± 0.01a	1.86 ± 0.07b	0.09 ± 0.02a	2.35 ± 0.2c
NO_3^- (mg/l)	0.20 ± 0.02a	0.57 ± 0.16a	0.31 ± 0.10a	0.66 ± 0.26a
NO_2^- (mg/l)	0.004 ± 0.001a	0.13 ± 0.007b	0.004 ± 0.00a	0.15 ± 0.01b
PO_4^{3-} (mg/l)	1.19 ± 0.15a	4.15 ± 1.06bc	1.70 ± 0.35ab	5.05 ± 0.64c

Legend: Opk = Okpara, AVAS = Before Dewatering, APAS = After Dewatering, SS = Dry Season, Transp = Transparency, Prof = Depth, Cond = Conductivity, OD = Dissolved Oxygen, BOD5 = Biochemical Oxygen Demand for 5 days, COD = Chemical Oxygen Demand, NH_4^+ = Ammonium, NO_3^- = Nitrate, NO_2^- = Nitrite and PO_4^{3-} = Orthophosphate.



Legend: AVAS = Before Dewatering; APAS = After Dewatering.

Figure 1. Variation in benthic macroinvertebrate classes as a result of Okpara dewatering.

Effect of dewatering on benthic macroinvertebrate orders in the Okpara River

Figure 2 shows the taxonomic composition of the benthic invertebrate community at two stations (Okpara 1 and Okpara 2) before and after dewatering. According to this figure, comparison of orders according to their contribution to taxonomic richness shows that the order Odonata occupied first place, followed by Diptera, Ephemeroptera, Oligochaeta and Gastropoda respectively. The other orders were marginal communities. In addition, all the taxa collected were more abundant before dewatering than after rewatering of the sampling stations, with the exception of Oligochaetes, which were more abundant after dewatering.

Effect of dewatering on taxon diversity in the benthic macroinvertebrate community of the Okpara River

The community structure of benthic macroinvertebrates collected at the two Okpara stations is presented in **Table 2**. Through this table, 49 families were obtained with a total number of 1389 individuals. Of all the families recorded, the Libelludiae were the most dominant, followed respectively by the Chironomidae, Caenidae, Oligochaetes and Baetidae. In addition, the study obtained a higher number of MIB families before dewatering than after rewatering the stations.

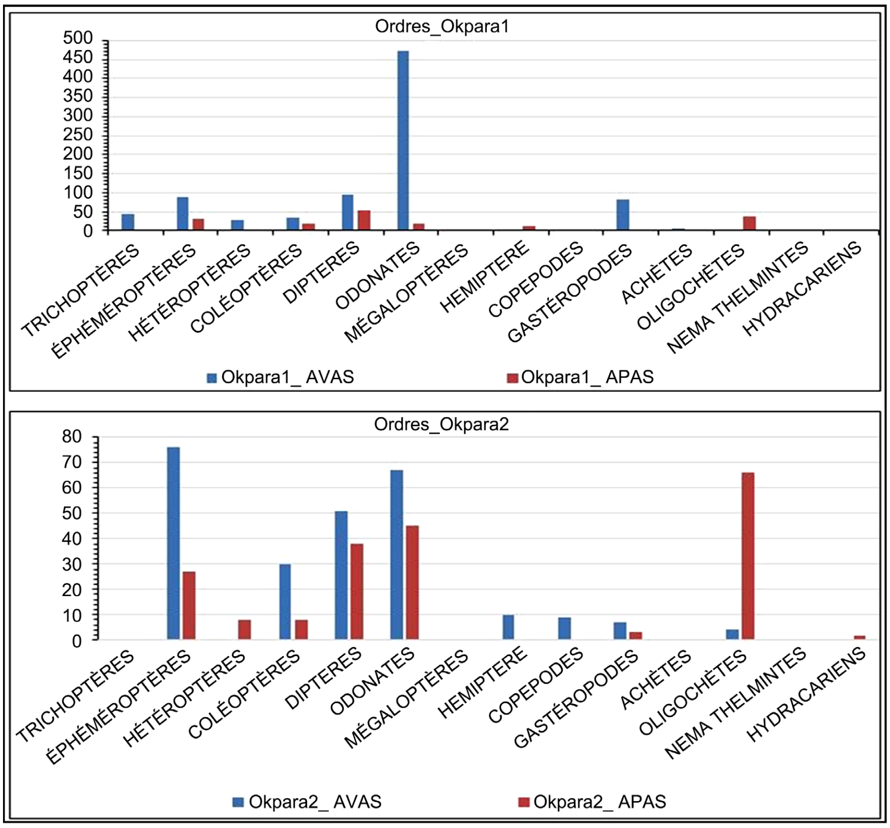


Figure 2. Variation in benthic macroinvertebrate orders due to dewatering of the Okpara River.

Table 2. Variation in taxonomic diversity of benthic macroinvertebrates.

Families	Okpara 1_AVAS	Okpara 1_APAS	Okpara 2_AVAS	Okpara 2_APAS
Hydropsychidae	39	0	0	3
Hydroptilidae	1	0	0	0
Lepidostomatidae	3	0	0	0
Leptoceridae	2	0	0	0
Polycentropodidae	0	0	0	0
Baetidae	15	7	74	9
Caenidae	68	23	2	18
Ephemerellidae	4	0	0	0
Pleidae	4	0	0	1
Corixidae	19	1	0	0
Naucoridae	4	0	0	5
Mesoveliidae	1	0	0	0
Veliidae	1	2	0	2
Dytiscidae	20	8	11	7
Eubriidae	0	0	0	1
Elmidae	0	1	0	0
Gyrinidae	0	1	0	0
Hydraenidae	5	2	0	0
Hydrophilidae	8	0	3	0
Heteroceridae	0	0	16	0
Scirtidae	0	6	0	0
Ceratopogonidae	13	6	14	3
Chironomidae	76	33	14	20
Culicidae	0	2	4	0
Simuliidae	1	3	6	24
Syrphidae	0	0	0	2
Tabanidae	3	6	0	2
Thaumaleidae	0	1	0	0
Tethinidae	0	3	0	0
Coenagrionidae	6	0	0	0
Gomphidae	25	1	6	0
Lestidae	36	0	25	6
Libelludiae	309	18	14	61
Platycnemididae	5	0	0	0
Sialidae	0	2	0	0
Aphididae	0	3	0	0
Cercopidae	0	0	8	0
Cicadellidae	0	0	1	0
Delphacidae	0	0	1	0
Ceropidae	0	8	0	0
Copepodes	0	0	9	0

Continued

Limnaeidae	65	0	0	0
Neritidae	0	0	7	0
Physidae	18	0	0	1
Planorbidae	0	0	0	2
Glossiphoniidae	5	0	0	0
Oligochètes	0	36	66	4
Nemathelmintes	1	3	0	0
Trombidiformes	2	0	0	2
Total = 1389	**759**	**176**	**281**	**173**
***p*-value**	**0.003577**		**0.3862**	

Legend: AVAS = Before Dewatering, APAS = After Dewatering.

Effect of dewatering on the abundance and taxonomic richness of the benthic macroinvertebrate community in the Okpara River

The taxonomic abundance and taxonomic richness (number of families) of benthic macroinvertebrates in the Okpara River varied significantly (paired Wilcoxon test, $p < 0.05\%$) before and after rewatering of the study stations. Across all study stations, the highest taxonomic abundances (number of individuals) were obtained before dewatering, and the lowest were observed after rewatering the study stations. Taxonomic abundance and richness were highest at the Okpara 1 station before dewatering and lowest at the Okpara 2 station after rewatering (Figure 3).

Variation in Shannon diversity and Piélou equitability indices under the effect of Okpara dewatering

Figure 4 shows the degree of organization of the benthic macroinvertebrate community collected before and after re-watering. Overall at these two study stations, Shannon diversity index values ranged from 2.204 bits (Okpara 2_APAS) to 2.541 bits (Okpara 2_AVAS), while Piélou equitability index values ranged from 0.6663 bits (Okpara 1_APAS) to 0.7996 bits (Okpara 1_AVAS). The Shannon diversity and Piélou equitability indices were proportional and followed an identical trend at all sampling stations. Figure 4 shows that at both study stations, the highest Shannon diversity and Piélou equitability index values were recorded before the study station beds were drained. Of all the study stations, Okpara 1 had the highest value for both indices.

Relationships between benthic macroinvertebrates and physico-chemical parameters under the effect of dewatering

A canonical correspondence analysis (CCA) was carried out between physico-chemical parameters, benthic macroinvertebrate families and the different sampling stations, to see the difference between reference stations and those most affected by agricultural disturbance. This analysis reveals that the first two axes express 88.57% (axis 1: 61.282% and axis 2: 27.289%) of the information (Table 3).

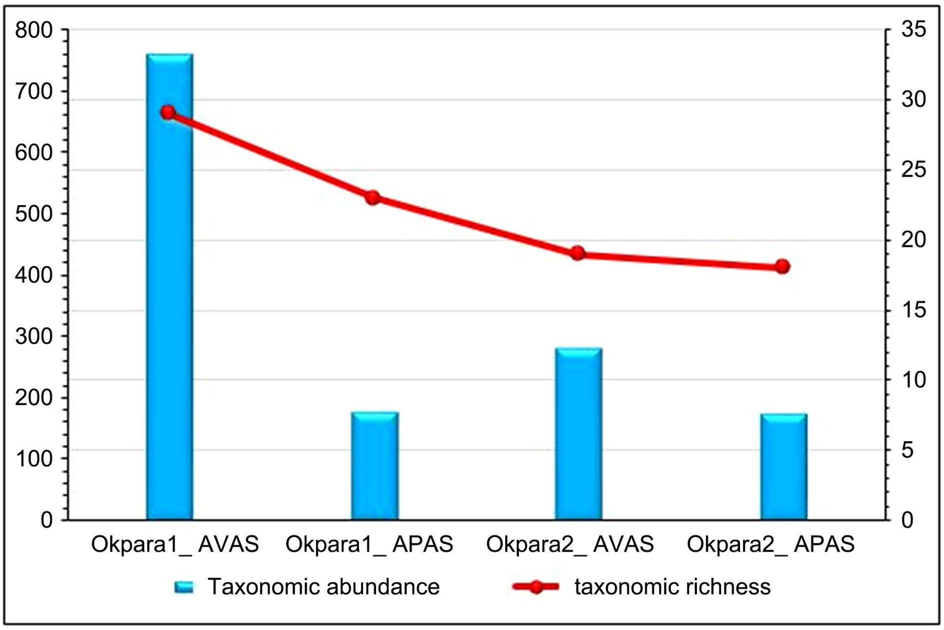


Figure 3. Variation in abundance and taxonomic richness of the benthic macroinvertebrate community under the effect of dewatering.

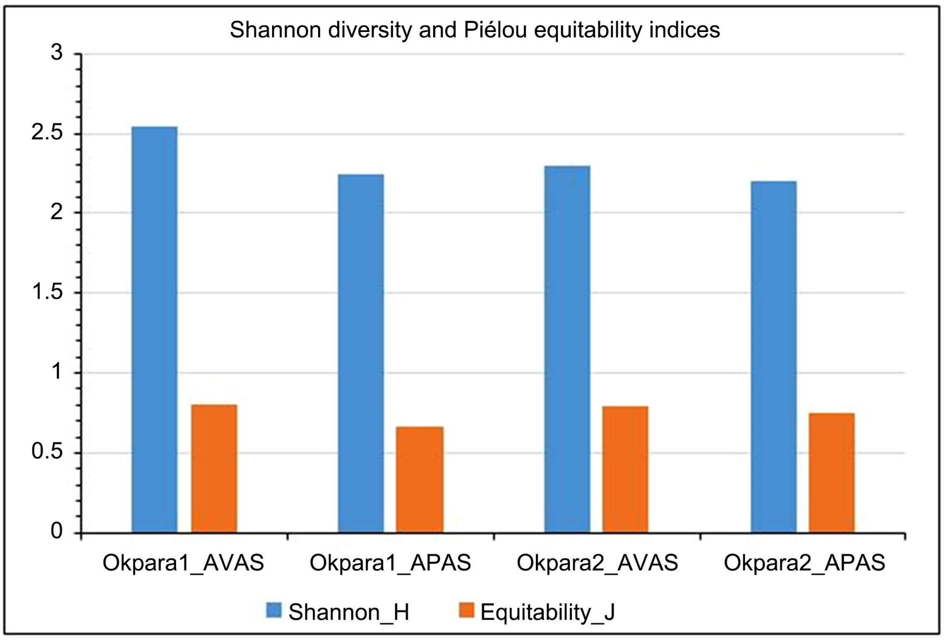


Figure 4. Shannon diversity and Piélou equitability indices under the effect of dewatering.

Table 3. Percentages of information distributed in a system of axis dimensions defined by ACC.

Axis	Eigenvalue	% of total	Cumulative
1	0.33182	61.282	61.282
2	0.147762	27.289	88.572
3	0.0618806	11.428	100

The Axis 2 is strongly and positively correlated with the Okpara 2_AVAS station and with high Transparency and dissolved oxygen values. This station (Okpara 2_AVAS) is linked to the Baetidae, Ceratopogonidae, Culicidae, Neritidae and Oligochaetes families. The same axis is also strongly and negatively correlated with the Okpara 1_AVAS station. This station is associated with the families Ephemerellidae, Hydropsychidae, Physidae, Libelludiae, Dytiscidae, Gomphidae and Lestidae. The Axis 1 is strongly and positively represented by the Okpara 1_APAS and Okpara 2_APAS stations. These two stations are strongly linked to Neritidae, Nemathelmintes, Veliidae, Tabanidae, and high values of Conductivity, BOD5, COD, Ammonium, Nitrate, Nitrites and Orthohosphate.

4. Discussion

The present study recorded ten physico-chemical parameters (Transparency, Depth, Conductivity, Dissolved Oxygen, Biochemical Oxygen Demand for 5 days, Chemical Oxygen Demand, Ammonium, Nitrate, Nitrite and Orthophosphate). All these recorded parameters varied significantly between before and after dewatering (a, b and c) ($p < 0.05$). The highest temperature values were measured in the stations after re-watering and would be due to the effects of solar radiation on the water due to deforestation of the stream bank in favor of agricultural production. These observations are similar to those of Toumi et al. (2016), who revealed that temperature fluctuation is related to local climatic conditions, and more specifically to air temperature and water evaporation phenomena. The low transparency recorded after dewatering is explained by the presence of organic and mineral waste and sludge drained by runoff from the fields into the aquatic environment (Orou Piami et al., 2023). The high turbidity reflects the high suspended solids content, which represents the totality of mineral and organic particles contained in plant water after re-watering. The high concentration of all nitrogenous compounds could lead to a reduction in the water's self-purification capacity, particularly for the nitrogenous forms NH_3 and NO_3, and Orthophosphate, which is toxic in high concentrations, is thus strongly disrupted during dewatering (Dehédin, 2012).

From the point of view of the taxonomic composition of benthic invertebrates, before dewatering of the study stations, high numbers of all taxa were recorded, with the exception of Oligochaetes, which were more abundant after dewatering. The high density of Oligochaetes obtained after dewatering is similar to the results of Orou Piami et al. (2023). These authors revealed that Oligochaetes are endowed with cysts capable of secreting mucus, enabling them to keep their bodies moist and also to get through the period when their living environment dries out. Oligochaetes also have the ability to burrow deep into the soil and wait for moisture to return during the rainy season (Fenoglio et al., 2006). Other authors, (Hose et al., 2003; Vander Vorste et al., 2016), have revealed that moist subsoil sediments form an important refuge for macroinvertebrates during bed dewatering. The difference in taxonomic richness obtained between before and after rewatering is thought to be due to the impact of dewatering on certain taxonomic groups of benthic macroinvertebrates in the Okpara River. The Shannon diversity index and Piélou equitability index values are higher at the pre-dewatering reference stations and lower at the heavily polluted post-dewatering stations. The Shannon index is highest when all individuals are equally distributed across all taxa, while the Piélou equitability index shows the regularity of the distribution. The low values of the Shannon diversity index and Piélou equitability index after Okpara dewatering reflect the presence of low-diversity benthic macroinvertebrate communities with a very low degree of organization and dominance of one species in the post-rewatering study (Camara et al., 2014).

The benthic macrofauna data submitted to canonical correspondence analyses (CCA) showed in the axis 2, the correlation of pre-drying stations (Okpara 1_AVAS and Okpara 2_AVAS) and the majority of families highly sensitive to complete drying, as well as high transparency and dissolved oxygen. These results are similar to those of Arscott et al. (2010) who reveal that variation in invertebrate community structure in intermittent streams results primarily from the gradual disappearance of sensitive taxa. In addition, biotic responses to dewatering can be species-specific (Lake, 2003). CCA results in the Axis 1 showed a correlation between post-reclamation stations (Okpara 1_APAS and Okpara 2_APAS) and the families Neritidae, Nemathelmintes, Veliidae, Tabanidae, as well as high values for Conductivity, BOD5, COD, Ammonium, Nitrate, Nitrite and Orthohosphate. This may be due to the effects of the dewatering and rewatering cycle on the biodiversity of benthic invertebrates. Increased ammonium and nitrite concentrations result in numerous impacts on fauna, including a reduction in invertebrate diversity (Claret et al., 1999). On the other hand, the effects of dewatering and re-watering cycles of river beds are less well known (Larned et al., 2010), yet dewatering of surface river beds is likely to compromise the life, or development cycle, of many aquatic macroinvertebrate species (Descloux et al., 2013).

5. Conclusion

The present study recorded 1040 individuals of benthic macroinvertebrates belonging to 5 classes, 14 orders and 33 families before dewatering and 349 individuals belonging to 10 orders and 31 families after the study stations were rewatered. The decrease in abundance and taxonomic richness, as well as the low values of Shannon's diversity and Piélou's equitability indices, was due to the dewatering of the study station beds. The results also showed that all the taxa collected, with the exception of the Oligochaetes, were affected by drying phenomena. This was the reason for the increase in Oligochaete numbers in the Okpara river after re-watering.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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