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Impact of gold panning activity on the structure of macroinvertebrates in Nakanbe catchment in Burkina Faso (West Africa)

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Abstract

The global warming observed in recent decades combined with the intensification of anthropogenic pressures have exacerbated the pressures on freshwater ecosystems. Thus, in Burkina Faso, the degradation of waterbodies linked to intense artisanal mining activities has become a big concern but there still is a lack of studies. We investigated on the impact of artisanal mining activities on the structure of macroinvertebrates. Macroinvertebrates were collected using hand net, and then transported to the laboratory for identification. A total of 28 macroinvertebrate taxa have been identified. Among these taxa, insects (88.41%) are very common, and were dominated by polluo-tolerant taxa: Hemiptera (37.28%) and Diptera (36.08%). The results showed that diversity indices and polluo-sensitive metrics decreased in the high stressed sites due to the intensity of pressures at those stations, and reflecting the high sensitivity of macroinvertebrates to disturbances. Biotic indices obtained here were correlated to environmental variables, and showing that the degradation of habitats resulting from mining activities disturbed the organization of macroinvertebrate communities. For the protection and sustainable management of aquatic ecosystems in Burkina Faso, it is urgent to reformulate and implement the national policy for better management of artisanal mining activities, environment, water and biological resources for human well-being.

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Introduction

The ongoing environment degradation and pollution remains common concerns for scientists and decision-makers around the world. In Africa, at the bend of the decade, rapid population growth, intense urbanization and agricultural practices have exacerbated pressures on aquatic ecosystems and resources, in particular those of fresh waters (Kaboré *et al.*, 2018, 2022; Tampo *et al.*, 2021; Masese *et al.*, 2023). Indeed, intense agriculture practices using pesticides and fertilizers, deforestation are amongst the main stressors that deteriorate the water and habitats quality in developing countries (Singh and Singh, 2017; Mukherjee *et al.*, 2023). The physical and chemical modification of aquatic ecosystems produces irreversible changes in ecosystems functioning. Thus, the ecological impoverishment can lead to the decline of aquatic ecosystems goods and services that human being depends on. With the increasing multiple human pressures and severe pollution of freshwater, there are urgent need to preserve aquatic ecosystems, especially in Africa. In West Africa, particularly in Burkina Faso, water bodies are increasingly threatened due to boom of industries and artisanal mining activities (Wright and Wright, 2015; Meza-Salazar *et al.*, 2020; Sánchez *et al.*, 2022; Gbedzi *et al.*, 2022). Despite that gold panning provides income and employment for local community, it poses a potential threat to local environment, as well as population are likely exposed to the risk of infectious diseases (Takyi *et al.*, 2021; Olalekan *et al.*, 2023). Aquatic habitats degradation, releases of toxic substances into the water (e.g., mercury, cyanide etc.) resulting from illegal mining practices is harmful to biological organisms' health, especially macroinvertebrates which play an important role in maintaining the balance of aquatic ecosystems (Kaboré *et al.*, 2016; Udodenko *et al.*, 2022; Rivera-Pérez *et al.*, 2023). Many studies have demonstrated that macroinvertebrates are very sensitive to anthropogenic perturbation including habitats degradation and water pollution (Albutra *et al.*, 2017; Huff Chester *et al.*, 2022). The stress factors from human activities can lead to decrease in abundance and richness of macroinvertebrates, as well as the disappearance of sensitive taxa (Costas *et al.*, 2018; Steyn *et al.*, 2019; Rivera-Pérez *et al.*, 2023), thus altering the overall aquatic ecosystems integrity. Because of their sensitivity, macroinvertebrates are increasingly used in environmental monitoring, but their knowledge in gold panning areas is poorly documented in Burkina Faso. However, the knowledge organisms' responses to of gold panning activities are essential for decision making and suitable management of aquatic ecosystems. This study aimed to investigate on the structure of macroinvertebrates in artisanal gold mining area with key objectives to: (1) identify and determine macroinvertebrates diversity and (2 to test the sensitivity of macroinvertebrates in the study area.

Material and methods

Study sites

Nakanbé river catchment with an area of 70,000 km² is located in the central part of Burkina Faso (Fig. 1).

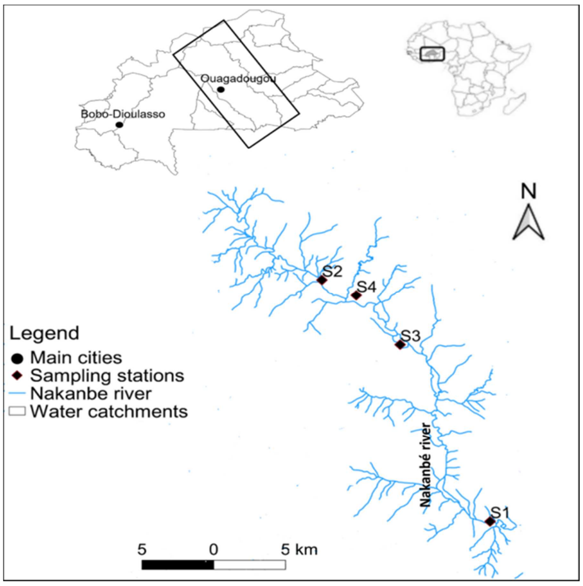

Fig. 1. Map showing Burkina Faso and sampling stations location in river Nakanbé

The climate is tropical semi-arid with regular rustic savanna and exhibits the highest human densities (Melcher *et al.*, 2012). Nakanbé river is highly impounded, and dry out during the dry season (Kaboré *et al.*, 2016). The Data was obtained from two categories of sites; S3 and S4 were highly stressed sites with damaged and eroded riverbanks associated with livestock grazing, row crop agriculture, and obvious most destructive change in the riparian zone due to the radical modification due to mining activities (Fig. 2, S3 & S4). These sites were characterized by mounds of sterile ore, and wells, thus reflecting the serious degradation of the river bed. The sites were also exposed to non-approved chemicals substances that constitute serious threats to water quality, while S1 and S2 are only characterized by agriculture including irrigated vegetables and seasonal crops farming, grazing (pasture), as well as fisheries (Fig. 2, S1 & S2).

Fig. 2. Showing high stressed stations (HSS): S3 and S4 with disrupted river bed, and low stressed stations (LSS): S1 and S2 with riparian land use for seasonal crops and vegetables farming, cattle's watering and water abstraction

Data collection

In situ key parameters such as, pH, electrical conductivity, and temperature were measured with field multimeters (WTW 340i) before macroinvertebrate sampling. Benthic macroinvertebrates were collected between and September and October 2017, during the period when surface water flow was evident at all study sites. Benthic macroinvertebrates were sampled with a hand net (rectangular opening: 25 cm × 25 cm, mesh size: 500 µm). Following the multi-habitat sampling approach (Moog, 2007) adapted, and described by Kaboré *et al.* (2016). A pooled sample, consisting of 20 sampling units, was taken from all habitat types of the study area. The number of sampling units allocated to each habitat type was proportional to the area coverage of the latter. Samples were then fixed in 90% ethanol and sieved in the laboratory. The animals were sorted under a microscope and identified using taxonomic manuals and keys (Lévêque and Durand, 1981; Tachet *et al.*, 2010)

Data analyses

Macroinvertebrates community structures were described through relative abundance and diversity parameters. Species diversity parameters such as taxa richness, true estimator (Chao 1987; Colwell and Coddington, 1994), species heterogeneity using Shannon–Weiner diversity index ((Shannon and Wiener, 1949) and Simpson index (Simpson, 1949) were calculated. The total taxa richness was simply taken as a count of number of taxa or species present in each station; true estimator "Chao 1 diversity" were used to calculate the estimated true species diversity in the two categories of sites, respectively. The key polluo-tolerance metrics including total number of trichopterans, ephemeropterans and plecopterans taxa and Average Score Per Taxon (ASPT) were used to test their potential indication of ecosystems health in two categories of stations (Sawadogo, 2022). The Redundancy Analysis (RDA) (Van den Wollenberg, 1977) was performed to establish the relationships between environmental variables and macroinvertebrates community indices, as well as spearman correlation was used to established the relationships between water variables and macroinvertebrates indices. The statistical significance of each variable selected was judged by a Monte Carlo permutation test ($p< 0.05$). The Canoco (Canonical Ordination of the Communities) for Windows package, version 4.5 (Ter Braak and Smilauer, 2002) was used for the analysis.

All, these indices were calculated following the equations (1–5).

$$N = \frac{ni}{Nt} \times 100 \quad (1)$$

Where ni is the proportion of individuals in the "ith" taxon of the community and N is the total number of taxa in the community

$$\text{Chao}-1\ \text{diversity} = S_{obs} + \frac{n_{1(n_1-1)}}{2(n_2+1)} \quad (2)$$

S_{obs} = the observed number of species, n_1 is the number of species with only a single occurrence in the sample and n_2 is the number of species with exactly two occurrences in the sample.

$$\text{Shannon–Wiener index} = -\sum_{i=1}^{s} p_i ln p_i \quad (3)$$

Where pi is the proportion of individuals in the "ith" taxon of the community and s is the total number of taxa in the community.

$$Simpson\ Index = 1 - \frac{\sum ni\,(ni-1)}{N(N-1)} \quad (4)$$

Where (ni) Number of individuals in the *i*-th species; and (N) Total number of individuals in the community.

The Average Score Per Taxon (ASPT) was calculated as following the equation 5.

$$\text{ASPT} = \frac{\sum_{i=1}^{n} \text{Scorei}}{n} \quad (5)$$

Where Scorei is the score of taxon i and n is the number of taxa considered in the calculation.

Results

Macroinvertebrate abundances distribution

Relative abundance of the various macroinvertebrate taxa encountered at the different sampling stations is presented in Table 1. All the stations were dominated by insects (88. 41%), represented mostly by Hemiptera (37.28 %) and Diptera (36.08 %) followed by the Crustaceans (8 %) and Molluscs (3.23%). The sensitive orders of insects (Ephemeroptera, Trichopterans) were dominated in S1 and S2, while Hemiptera and Oligochaeta were mainly recorded in S3 and S4. In regards of taxa distribution, most of polluo-sensitive's taxa including, *Ephoron*, Heptageniidae, *Ecnomus* and Elmidae were only encountered in the stressed sites, while the majority of Tanypodinae, *Micronecta*, Nepidae, Iridinidae and Oligochaeta were reported in high stressed sites.

Table 1. Composition and relative abundance of benthic macroinvertebrates encountered in sampling stations

Class	Order	Taxa	Low stressed sites		High stressed sites	
			S1	S2	S3	S4
		Caenomedea (Thew, 1960)	-	46.34	17.07	36.59
	Ephemeroptera	*Baetis (Leach, 1815)*	66.67	16.67	-	16.67
		Heptageniidae	-	100.00	-	-
		Ephoron	100.00	-	-	-
		Bezzia (Kieffer, 1924)	62.50	6.25	25.00	6.25
	Diptera	Tabanidae	42.86	28.57	14.29	14.29
		Tanypodinae	-	-	100.00	-
		Chironomidae	15.64	36.36	40.00	8.00
		Belostomatidae	50.00	50.00	-	-
		Micronecta (Kirkadly, 1897)	9.09	18.94	37.88	34.09
	Hemiptera	Helotrephidae	50.00	25.00	25.00	-
Insects		*Notonecta* (Linnaeus, 1758)	32.14	35.71	-	32.14
		Hydrometra (Limnaeus, 1758)	100.00	-	-	-
		Nepidae	-	18.18	81.82	-
		Chlorocyphidae	-	-	50.00	50.00
		Coenagrionidae	100.00	-	-	-
	Odonata	Corduliidae	-	-	-	100.00
		Gomphidae	37.50	12.50	25.00	25.00
		Libellulidae	44.44	11.11	44.44	-
	Trichoptera	Ecnomus (McLachlan, 1864)	100.00	-	-	-
		Dytiscidae	32.14	32.14	7.14	28.57
	Coleoptera	Elmidae	100.00	-	-	-
		Hydrophilidae	35.29	41.18	23.53	-
Crustaceans	Decapoda	*Caridina Africana* (Kingsley, 1882)	4.76	26.98	22.22	46.03
		Macrobranchium	-	75.00	25.00	-
Molluscs	Bivalvia	Iridinidae	-	20.00	-	80.00
		Coelatura	63.64	18.18	9.09	9.09
Annelids		Oligochaeta	-	-	100.00	-

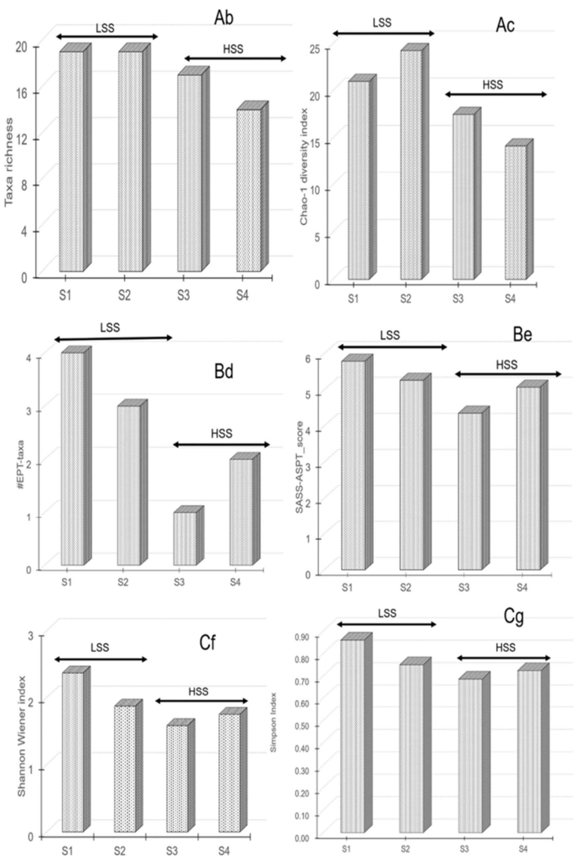

Fig. 3. Histogram showing the variations of taxa richness, true chao 1 index, Ephemeroptera, Plecoptera and Trichoptera (EPT), Average score per Taxa (ASPT), Shanon Wiener and Simpson index between High stressed sites (HSS) and low stressed sites (LSS)

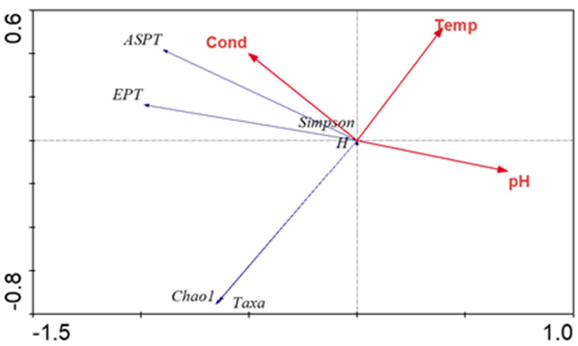

Fig. 4. Redundancy analysis (RDA) of macroinvertebrates taxa and environmental variables

Performance of macroinvertebrate metric in detecting gold spanning impacts

We found that artisanal gold mining activity adverse macroinvertebrates community structure, as shown in the Fig. 2. Taxa richness (19±0.00) and True Chao 1 diversity (22.62±1.62) increase in low stressed sites, and then dropped to 15.50±1.50, 15.83±1.66 in high stressed sites, respectively (Fig. 3 Ab, Ac). Shannon–Weiner diversity index (2.12 ±0.25) and Simpson index (0.8±0.05) showed the same trend, and decreased to 1.66±0.08, 0.70±0.02 in high stressed sites (Fig. 3 Bd, Be). Finally, the key tolerance metrics, such EPT-taxa and ASPT-SASS-score showed their sensitivity to gold spanning activity and decrease across the categories of sites (Fig.3 Cf, Cg). EPT-taxa and ASPT-SASS-score were represented in high impaired sites by small number of taxa (1.50±0.5) and low tolerance value of 4.71±0.35. All these findings showed that macroinvertebrates community are very sensitives to aquatic habitats degradation, and clearly allow us to distinguish the low stressed from those of artisanal gold mining land use.

Role of environmental variables on macroinvertebrate communities' indices

The key water variables including pH (7.85±0.22), temperature (30.82±0.28) and conductivity (339.07±8.52) were slightly high in the intense mining land use compared to those of low stressed sites, 7.74±0.26, 30.05±0.45, 328.70±15.90, respectively, and may affects aquatic life but also overall aquatic ecosystems health. Fig. 4 shows the biplots of species and physical–chemical parameters with eigenvalues for axes 1–2, 80.8%, 18.6%, respectively, and only the two axes were used for interpretation. The first two axes captured about 99.4% of information in species-environment correlations. The chemical variables, such as pH (r = 69,48%) is positively correlated with axis 1, while the electrical conductivity (r = -50.20%) displayed a negative association with the first axis, but it influences macroinvertebrates tolerance metrics (EPT-index (r = 0.46) and ASPT-score (r = 0.54) (Table 2). Whereas, the temperature (r = 51.77%) is positively correlated to axis 2, but it is opposed to macroinvertebrates richness's (Taxa, r = -0.59; Chao1, r = -0.74) as supported (see table 2). Simpson (r = -0,76), Shannon wiener (r = -0,76), ASPT-score (r = -0.77) and EPT index (r = -0.65) appear to be highly and negatively influenced by pH in mining area.

Table 2. Correlation matrix of water variables and biological Indices. EPT indicate (Ephemeroptera, Plecoptera and Trichoptera); Tem (Temperature), Cond (Conductivity) and ASPT (Average score per Taxa).

Biotic indices/Water variables	Taxa richness	Simpson index	Shannon and Wiener	Chao1 index	ASPT-score	EPT-index	PH	Temp	Cond
Taxa Richness									
Simpson index	0.55								
Shannon and Wiener	0.56	0.99							
Chao-1 diversity	0.93	0.45	0.45						
ASPT-Score	0.42	0.93	0.93	0.45					
EPT-index	0.60	0.95	0.95	0.61	0.98				
PH	0.12	-0.76	-0.76	0.19	-0.77	-0.65			
Temp	-0.59	0.27	0.26	-0.74	0.21	0.05	-0.78		
Cond	-0.10	0.19	0.19	0.22	0.54	0.46	-0.29	-0.09	1

Discussion

Many recent studies have demonstrated that macroinvertebrates taxa are diversified in freshwater bodies, and are expected to be correlated to water habitats conditions (Costas *et al.*, 2018; Kaboré *et al.*, 2022; Faith and Norris, 2022; Tampo *et al.*, 2023). The present study made major contributions to understanding of ecological organization of macroinvertebrates in impaired areas. We found that insects are the most abundant and most diversified with 24 taxa identified. This could be explained by the fact that insects have a great capacity to colonize various habitats, even those of disturbed habitats (Kaboré *et al.*, 2016; Masese *et al.*, 2020). Authors have demonstrated that most of resistant taxa found in stressed sites belong to insects' group (Kaboré *et al.*, 2016; Bancé *et al.*, 2021a; Tampo *et al.*, 2021), justifying the high abundance of hemipterans and dipterans reported in the present study. The total number of taxa found here is lower compared to those of Sanogo *et al.* (2014, 2023) who obtained (33, 55 taxa, respectively), and Bancé *et al.* (2021a, b) who also listed (34, 33 taxa, respectively). This could be explained by the fact that the intense of agricultural practices using fertilizers and pesticides combined with illegal gold mining technics are harmful for macroinvertebrates community. All these activities have an obvious negative impact on macroinvertebrates communities, as demonstrated by some authors (Udodenko *et al.*, 2022; Masese *et al.*, 2023; Rivera-Pérez *et al.*, 2023). From field observation, we found a clear evidence of highly degraded landscapes, habitats fragmentation and floodplains degradation because of intense mining activities in the study area. However, macroinvertebrates appear successful in profiting from the positive intactness effects of floodplains that is essential in nutrient uptake, organic matter, and food supply, as well as in river bank stabilization, as confirmed by others authors (Kaboré *et al.*, 2018; Camara *et al.*, 2019; Sitati *et al.*, 2021). The others adverse impacts of mining activities are also the shrinking of river networks because of high rate of siltation dynamics that seriously cause the disrupting of aquatic ecosystem in study area, as well as macroinvertebrates community, as demonstrated by Olalekan *et al.* (2023). Any changes that occur in aquatic habitat can adverse macroinvertebrates community because they are strongly associated with abiotic parameters (Tampo *et al.*, 2021; Kaboré *et al.*, 2022). In the present study, decreases in macroinvertebrates structure and abundance, as well as metrics in the high stressed sites could be explained by environmental changes due to mining activities that often take place in the river bed. Indeed, the clearance of riparian vegetation and mining removals, and the presence of mounds of sterile ore can lead to the impoverishment of macroinvertebrates community in study sites due to dramatical modification of hydro-morphology. In addition, undeveloped techniques involve considerable use of amount of mercury and cyanide during mineral processing that may lower water quality, thus modifying the distribution of macroinvertebrate assemblages (Wright *et al.*, 2016; Costas *et al.*, 2018; Xiao *et al.*, 2019). Notably, Nakanbé River is strongly under multiple anthropogenic stressors including intense agriculture, urbanization, mining activities, overexploitations which have brought radical modification of River landscape.

Here, we found that macroinvertebrates are good indicators of local conditions of freshwater ecosystem health because they are taxa-diverse and ubiquitous to reflect the ecological condition of the present study sites, as revealed by authors (Armellin *et al.*, 2017; Tampo *et al.*, 2021; Kaboré *et al.*, 2022). This confirmed an already previous acknowledged of advantage of using macroinvertebrates, as far we observed a strong correlation between macroinvertebrates indices and water variables. Similar results were obtained by other authors who have showed that macroinvertebrates composition and diversity are strongly linked to aquatic habitats, thus reflecting their sensibility (Tampo *et al.*, 2021; Masese *et al.*, 2023). Our finding confirmed that artisanal mining activities are amongst the strongest destructive aquatic habitats and water quality in western African regions, but extensive studies including sources of contaminants in freshwaters and food webs are still need to highlight the high risks of uncontrolled gold panning activity in ecology and human health, and to refine ours results.

Conclusion

This study shows clearly that mining activities has a strong negative impact on macroinvertebrate communities, thus reflecting the sensitivity of macroinvertebrate in detecting anthropogenic impairment in water environment. Local decision makers must pay more attention in controlling illegal mining activities because the protection of aquatic habitats is fundamental for biodiversity preservation in West Africa, especially in Burkina Faso. In addition, the implementation and application of national law must be stronger to mitigate threats of hydro systems in west Africa, and call for restoration of the abandoned sites to avoid the dramatic hydrological changes of Nakanbé river basin.

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