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Macroinvertebrate diversity and assessment of water quality in the area under the influence of mining activities in the Yaouré basin (Kossou, central of Côte d'Ivoire)

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Abstract
The Yaouré basin is an area strongly influenced by mining activities. However, the ecological status of the waters located there remains little known. Thus, the present study aimed to assess the water quality of the Yaouré basin under the influence of mining activities from the structure of aquatic macroinvertebrate communities. Macroinvertebrate sampling was carried out in January 2020, following the upstream-downstream gradient, at twelve stations using a kick net and a Van Veen grab. The inventory made it possible to count 47 taxa divided between 37 families, 11 orders and 4 classes. Gastropods and insects mainly dominate the macrofauna in the Yaouré section. The abundance of the main taxa indicates that *Melanoides tuberculata* is the majority represented. The diversity analysis indicated that the macroinvertebrates communities in this Yaouré basin were poorly diversified and unbalanced. The quality index used reveals that the waters of this basin were polluted with organic pollution and heavy metals.

Keywords: Macroinvertebrate diversity, water quality, mining activities, Yaouré basin, Côte d'Ivoire

Introduction
The Yaouré-Kossou constituency abounds in a hydrographic network comprising rivers, lakes and the Bandama River. Also, the watershed of the Bandama River, in its section of Yaouré-Kossou, is under the influence of major gold mining operations of an artisanal and industrial nature in the open. This could generate residual mineral elements that can be found in the Bandama River and its tributaries by runoff or infiltration. Discharges of this waste into waters are likely to negatively influence the diversity and structure of the aquatic biological communities that live there, particularly macroinvertebrates. The latter represent an essential link in the food chains of freshwater fauna and are recognized as being good biological indicators of the health of aquatic ecosystems [1]. Indeed, they make it possible to develop surface water biomonitoring tools [2]. Their structures reflect the ecological state of aquatic environments because they integrate the cumulative and synergistic effects of physical, biological and chemical disturbances of their ecosystems. In addition, several studies have been carried out on the biological communities of the main Bandama River nest and have concerned macroinvertebrates [3,4], algae and fish [5]. Concerning macroinvertebrates, the work of [3] focused on the ecological state of the northern part of this river at the level of the section located in the Haut-Bandama Reserve and those of [23] on the diversity and structure of the macroinvertebrate communities of the main nest of the Bandama River precisely in the lower section of Kossou Lake. However, there is a lack of data on the ecological status and biological integrity of the waters located in the Yaouré-Kossou basin. Also, data on the use of macroinvertebrates in the assessment of the biological quality of the waters of the Bandama River and its tributaries in the section of the Yaouré-Kossou basin are rare. Consequently, the present study aims to assess the water quality of the Bandama River and its tributaries located in the Yaouré-Kossou basin from macroinvertebrates.

Material and Methods

Study area

The gold zone of Yaouré (Kossou) is a former open-pit industrial mining operation site located in the center of Côte d'Ivoire in the Bélier region (Yamoussoukro). The gold-bearing site of Yaouré (Kossou) is located between 7°00' and 16°57' north latitude and 2°10' and 5°29' west longitude and is limited to the north by the Gbêkê region, to to the east by the N'zi and Moronou regions, to the south by the Agnebi-Tiassa region and to the west by the Marahoué and Haut Sassandra regions (Fig 1).

Sampling procedure

This ad hoc study was carried out in January 2020, in the waters of the basin of the Yaouré Kossou section under the influence of mining activities. A total of 12 sampling stations were selected: three (03) in Lake Kossou (B1, B2, B11), five (05) in the main nest of the Bandama River between the Kossou dam embankment and the Bozi village (B5, B6, B7, B8, B10), three (03) in the tributaries of the Bandama river (B3, B9 and B12) and one (01) station in a lake which originated in an old mine of gold (B4) (Figure 5). The coordinates and characteristics of the various stations are mentioned in Table 1.

Sampling of surface macroinvertebrates was carried out using a kick net on a surface of 1 m² (2 m x 0.5 m) for 2 minutes [6]. The benthos was sampled using the Van Veen grab due to 03 samples per site, i.e. an area of 0.15 m² (3 x 0.05 m²) [7]. In situ, the samples collected were kept in labeled 1 liter jars containing 70% alcohol and then transferred to the laboratory for sorting under a binocular magnifying glass at 40x magnification, counting and identification of specimens using keys. and works by [8, 9, 10].

The measurement of the physico-chemical parameters of the water such as conductivity (µS/cm), pH, temperature (°C) and dissolved oxygen (mg/L) were measured using the multiparameter. made In-situ, between 06:00 and 09:00 in the morning at each sampling station from a *HANNA 550i* type multiparameter.

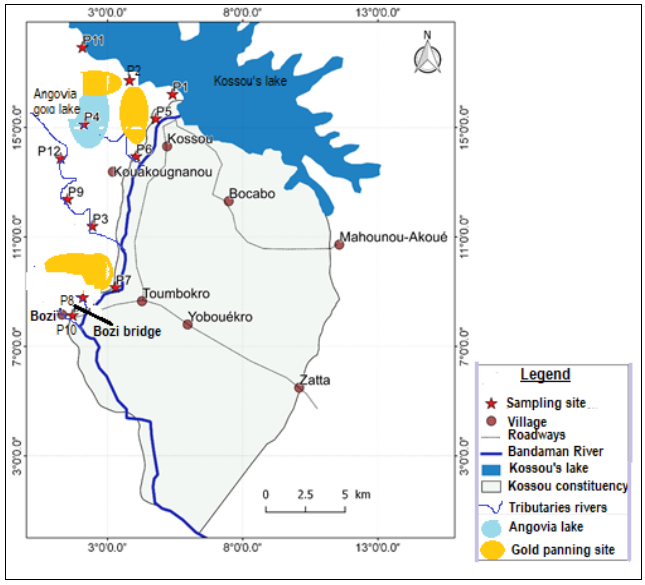

Fig 1: Location of sampling stations in the basin of the Yaouré-Kossou section

Table 1: Description of sampling stations in the basin of the Yaouré-Kossou section

Stations	Geographical coordinates		Comments
	Latitudes	Longitudes	
P1	778 680	226 842	Station B1 is located in Lake Kossou near the dam embankment, it is an area with high fishing activity
P2	780 341	223 094	Lac de Kossou near the old port of Allohou. It is an area with strong fishing, traditional gold panning and cattle park activity.
P3	770 450	221 060	Along the road near a cocoa plantation.
P4	776 806	221 247	In a water reservoir born in a former mine quarry.
P5	777 148	225 787	In the nest of the river after the dam. It is an artisanal gold panning area
P6	774 798	224 544	In the nest of the Bandama river. An area of high mining activity.
P7	766 626	223 240	In the nest of the Bandama river near the village of Toumbokro. It is an area of artisanal gold panning and swimming.
P8	654440	531447	Located in Bozi (former mining site).
P9	771969	219502	Located in a stream (tributary of the Bandama) near a cocoa plantation.
P10	764878	220529	In the Bandama (Marahoué) river near the Bozi bridge. At this station the flow of water is strong. This site is a fishing area
P11	781600	221151	Dans le lac de Kossou. On note la présence de végétaux aquatiques et de troncs d'arbres dans le lac.
P12	774877	221288	Located in a pale stream near Akakro village. We do not observe the presence of aquatic plants.

Data analysis

- The analysis of the structure was made from the indices of diversity of Shannon (H') to evaluate the diversity of the communities and of equitability of Piélou (J) to evaluate their degree of organization: H' = - Σpi *log2pi. Where: pi represents the relative abundance of species i in the sample (pi = ni/N). J = H' / log 2 S. with S was the number of species in samples.
- The assessment of water quality was carried out using the pollution tolerance index (PTI) and the Chironomidae index (CI) [2].

TPI= (ETP Abundance) / (Chironomidae Abundance). A TPI ratio close to 0 indicates water of poor biological quality, while a TPI greater than 10 indicates good quality water [11].

Results

Water Physicochemical characteristics

The point values of the physicochemical parameters measured in the waters of the Yaouré basin are presented in Table 2.

The results revealed that the temperature varied from 27.2°C (P5) to 28.6°C (P10), the pH varied from 6.8 (P12) to 7.8 (P7). The conductivity values fluctuated from 84 µs/cm (P12) to 145 µs/cm (P7) while the dissolved oxygen level fluctuated from 4.1 mg/L (P5) to 5.2 mg/L (P2). Physicochemical parameters did not vary significantly between stations (Chi-square test, $p > 0.05$).

Table 2: Water physicochemical characteristics

	Sampling sites											
Parameterss	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12
Temperature	27.4	27.6	28.1	27.7	27.2	27.7	28.3	28.5	27.4	28.6	27.5	27.8
Conductivity	75	76	70	88	115	121	125	120	76	118	79	74
pH	7.7	7.1	7.1	7.3	7.6	7.7	7.8	7	6.9	7.5	7.2	6.8
Dissolved oxygen	4.3	4.3	4.8	4.4	4.1	4.2	4.3	4.9	5.19	4.8	4.15	5.2

Taxonomic compositions

The taxonomic composition of aquatic macro-invertebrates inventoried at the various sampling stations in the Yaouré area (Kossou) is presented in Table 3. On all 12 stations, 47 taxa distributed between 37 families, 11 orders and 4 classes (Insects, Gastropods, Bivalves and Malacostracans) have been identified. Of these classes, insects and gastropods are the most diverse. Insects with 6 orders and 28 families have 35 taxa, or 76.08% of the global taxonomic richness. As for gastropods, they have 3 orders, 5 families and 8 taxa, i.e. 17.39% of the total number of taxa. The classes of Malacostraca and Bivalves, with 2 taxa distributed between 01 order and 02 families each, are the least rich in taxa. They represent 4.35% of taxa inventoried.

In the class of Insects, the order of Diptera is the best represented in taxa (9 taxa), i.e. 25.71% of the taxonomic richness of insects. This order is followed by that of Odonata and Hemiptera, which with 8 taxa each represent 22.85% of the number of insect taxa. Among the gastropods, the order of the Basommatophores is the most diversified (4 taxa), i.e. 50% of the taxonomic richness of the gastropods. It is followed by the order of Sorbeoconcha (2 taxa) which represents 25% of gastropods.

The spatial distribution of collected taxa revealed that:

- Thirteen taxa were only collected in the lakes. They are: the Odonate Aeshmidae confined to station B1. The Hemiptera Mesovelia sp., the Diptera Ceratopogonidae, the Coleoptera Leptelmis sp. and Odonate Trithemis sp. identified at station B2. The Coleoptera Aulanogyrus sp., the Diptera Ceratopogonidae, the Ephemeroptera Caenidae, the Hemiptera Eurymetra sp. And Ranatra sp. collected at station B4. The Elmidae beetle, the Odonata Phaon iridipennis and the Trichoptera Ecnomus sp. to the associated with station B11.
- Ten taxa are only listed in the tributaries of the Bandama River, these are: Adenophlebides sp. at station B3. Sehirus cinctus, Pisidium abditum) and Cleopatra guillemei, Helisoma duryi and Lanistes neavei at station B9. Stenocorixa protrusa) and Odonata (Phyllomacromia sp., Urothemis sp. and Syrphidae at station B12.
- Eight taxa are subservient to the current course of the Bandama River located downstream of the dyke. These are: Procladius sp (Diptera) and Paragomphus hagenis (Odonata) recorded at station B6. From Labiobetis sp. (Ephemeroptera) at station B8. Iphigenia truncata (Bivalve), Ilyocoris cimicoides (Coleoptera), Psychodidae (Diptera), Abedus lutarium (Hemiptera) and Varuna litterata (Decapod) at station B10.
- On the other hand, Melanoides tuberculata (Sorbeoconcha) is common to 10 of the 12 stations sampled, with the exception of stations B5 and B7 located in the Bandama River.

Analysis of the distribution of taxonomic richness (cf, Table 3) shows that the highest taxonomic richness (with 14 taxa) was recorded in the lake at station B2. It is followed by station B12 (with 13 taxa) located in the tributaries of the Bandama. On the other hand, the lowest taxonomic richness (1 taxon) is noted in the Bandama River at station B5.

Table 3: Taxonomic composition and occurrences of macroinvertebrate taxa collected in the waters of the yaouré-kossou basin

Classes	Orders	Families	Taxons	Acr	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
Bivalves	Veneroides	Donacidae	*Iphigenia truncata*	Iph	-	-	-	-	-	-	-	-	-	*	-	-
		Sphaeriidae	*Pisidium abditum*	Pis	-	-	-	-	-	-	-	-	*	-	-	-
Gastéropodes	Architaenioglossa	Ampullariidae	*Lanistes neveai*	Lvi	-	-	-	-	-	-	-	-	*	-	-	-
	Basomatophores	Ampullariidae	*Lanistes varicus*	Nis	*	*	-	-	*	*	-	-	-	*	-	*
		Planorbidae	*Biomphalaria* sp.	Bio	-	-	*	*	-	-	-	-	-	-	-	-
			Bulinus sp.	Bul	-	-	-	*	-	-	*	-	-	-	-	*
			Helisoma duryi	Hel	-	-	-	-	-	-	-	-	*	-	-	-
		Viviparidae	*Bellamya unicolor*	Bel	-	*	-	-	-	-	*	-	-	*	-	-
	Sorbeoconcha	Paludomidae	*Cléopatra guillemei*	Cgu	-	-	-	-	-	-	-	-	*	-	-	-
		Thiaridae	*Melanoides tuberculata*	Mtn	*	*	*	*	-	*	-	*	*	*	*	*
Insectes	Coleoptères	Dytiscidae	*Hydaticus* sp.	Dat	-	-	-	-	-	-	-	-	-	*	-	*
		Elmidae	*Elmidae* sp.	Elm	-	-	-	-	-	-	-	-	-	-	*	-
			Leptelmis sp.	Pte	-	*	-	-	-	-	-	-	-	-	-	-
		Gyrinidae	*Aulanogyrus* sp.	Aul	-	-	-	*	-	-	-	-	-	-	-	-
		Hydrophilidae	*Hydrobiinae* sp.	Hyd	-	*	-	-	-	-	-	-	-	*	-	*
		Naucoridae	Ilyocoris cimicoides	Lly	-	-	-	-	-	-	-	-	-	*	-	-
	Diptères	Ceratopogonidae		In1	-	*	-		-	-	-	-	-	-	-	-
				In2	-	-	-	*	-	-	-	-	-	-	-	-
		Chironomidae	*Chironomini* sp.	Min	*	*	-	*	-	*	-	*	-	*	-	*
			Chironomus sp.	Mus	*	*	-	-	-	-	-	-	-	-	-	-
			Procladius sp.	Diu	-	-	-	-	-	*	-	-	-	-	-	-
	Diptères	Culicidae	*Culex* sp.	Cul	-	-	-	*	-	-	-	-	-	-	-	*
		Psychodidae	*Psychodidae* sp.	Psy	-	-	-	-	-	-	-	-	-	*	-	-
		Syrphidae	*Syrphidae* sp.	Syr	-	-	-	-	-	-	-	-	-	-	-	*
		Tanypodinae	*Ablabesmya* sp.	Abl	*	-	*	*	-	-	-	-	-	-	-	-

	Ephéméroptères	Baetidae	*Labiobetis* sp.	Lab	-	-	-	-	-	-	-	*	*-	-	-	-
		Caenidae	*Caenidae* sp.	Cae	-	-	-	*	-	-	-	-	-	-	-	-
		Leptophlebiidae	*Adenophlebiodes* sp.	Eno	-	-	*	-	-	-	-	-	-	-	-	-
	Hemiptères	Belostomatidae	*Abedus lutarium*	Abl	-	-	-	-	-	-	-	-	-	*	-	-
			Diplonychus sp.	Chu	-	*	-	*	-	*	-	-	-	*	-	*
		Corixidae	*Stenocorixa protrusa*	Ste	-	-	-	-	-	-	-	-	-	-	-	*
		Cydnidae	*Sehirus cinctus*	Sci	-	-	-	-	-	-	-	-	*	-	-	-
		Gerridae	*Eurymetra* sp.	Eur	-	-	-	*	-	-	-	-	-	-	-	-
		Mesoveliidae	*Mesovelia* sp.	Sov	-	*	-	-	-	-	-	-	-	-	-	-
		Ranatridae	*Ranatra* sp.	Ran	-	-	-	*	-	-	-	-	-	-	-	-
		Veliidae	*Microvelia* sp.	Vel	-	*	-	*	-	-	-	-	-	-	-	-
	Odonates	Aeshmidae	*Aeshmidae* sp.	Ase	*	-	-	-	-	-	-	-	-	-	-	-
		Calopterygidae	*Phaon iridipennis*	Pha	-	-	-	-	-	-	-	-	-	-	*	-
		Coenagrionidae	*Ceriagrion* sp.	Rio	*	*	-	-	-	-	-	-	*	*	-	-
		Corduliidae	*Phyllomacromia* sp.	Llo	-	-	-	-	-	-	-	-	-	-	-	*
		Gomphidae	*Ichinogomphus* sp.	Ich	*	*	-	-	-	*	-	-	-	-	-	-
			Paragomphus hagenis	Hao	-	-	-	-	-	*	-	-	-	-	-	-
		Libellulidae	*Trithemis* sp.	The	-	*	-	-	-	-	-	-	-	-	-	-
			Urothemis sp.	Oth	-	-	-	-	-	-	-	-	-	-	-	*
	Trichoptères	Ecnomidae	*Ecnomus* sp.	Ecn	-	-	-	-	-	-	-	-	-	-	*	-
Malacostracés	Décapodes	Atyidae	*Atyoida serrata*	Tyo	-	-	*	-	-	-	-	*	-	-	*	*
		Varunidae	*Varuna litterata*	Ter	-	-	-	-	-	-	-	-	-	*	-	-
4	11	38	47		8	14	5	12	1	7	2	4	7	12	5	13

Community Diversity Analysis

Fig2 presents the spatial variations of the Shannon (H') and Equitability indices of the macroinvertebrate communities collected in the Yaouré (Kossou) section. In all the stations, the values of the Shannon index vary from 0.24 bits in the Bandama River (station B5) to 1.4 in the tributaries (station B3). As for the values of the equitability index, they are included in the Bandama River between 0.1 (station B5) and 0.9 (station B7).

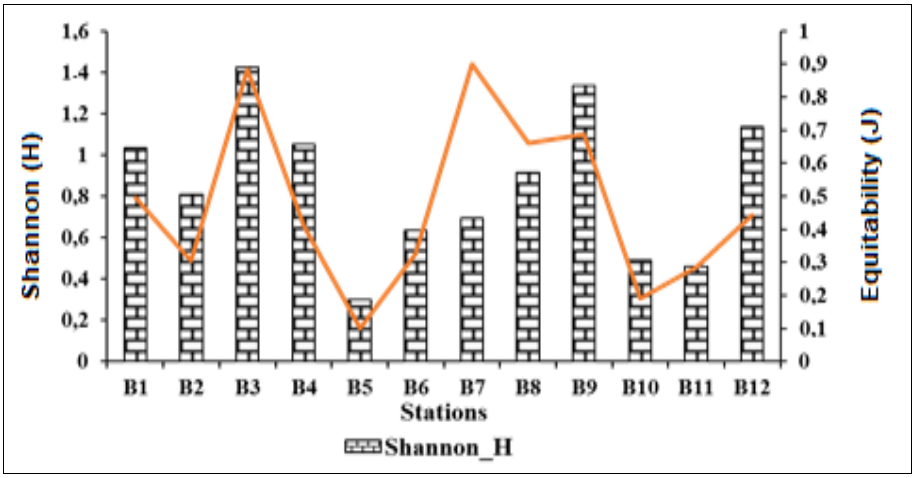

Fig 2: Spatial variations of Shannon (H') and Equitability (J) indices of macroinvertebrate communities collected in the Yaouré section (Kossou)

Biological water quality

Analysis of the table 4 shows that in all stations, the number of Chironomidae exceeds that of EPT. Similarly, the values of the pollution tolerance index (TPI) of all the stations are low and very close to zero and are all lower than the values of the percentages of Chironomidae, which indicates waters of poor biological quality.

Stations P1, P2, P4, P5, P6, P9, P4, P3 and P9 recorded percentage values of Chironomidae between 20% and 69%, which indicates moderately polluted conditions, while stations P7 and P10 show percentages in Chironomidae greater than 75% indicating highly polluted waters.

Table 4: Spatial distribution of the values of the quality indicators studied

	Sampling stations											
Index	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**P11**	**P12**
Individuals	116	122	32	48	15	176	32	25	89	410	105	45
ETP		1	1	1				1	1		1	3
Chironomidae	80	62	22	25	10	93	25	6	46	311	24	10
% Chirnomidae (in %)	69.0	50.8	68.8	52.1	66.7	52.8	78.1	24.0	51.7	75.9	22.9	22.2
Pollution Tolerance Index (PTI)	0.0	0.02	0.05	0.04	0.0	0.0	0	0.17	0.02	0.0	0.04	0.30
Quality class	LQ	LQ	LQ	LQ	LQ	LQ	LQ	LQ	LQ	LQ	LQ	LQ

* PTI = Pollution Tolerance Index; LQ= Low quality

Discussion

The physico-chemical parameters of the waters and the structure of the communities of aquatic macroinvertebrates. The analysis of the physico-chemical parameters of the waters of the basin of the Yaouré section (Kossou) showed that the values of pH, conductivity, temperature and dissolved oxygen did not vary significantly from one station to another which indicates a communication between the waters of the different ecosystems. This same observation was made by [12]. on four coastal rivers in the south-east of Côte d'Ivoire.

The measured values of the water temperature of the Yaouré basin (Kossou) are between 27.2 and 28.6°C. These values indicate that these waters are relatively warm. This result would be due to the exposure of watercourses to the sun inherent to an absence of canopy. This result corroborates with that of [11] who made the same observation in the water of the Okpara River in Benin. According to this author, in intertropical Africa, average temperatures are high and most often above 20°C. Indeed, according to [13], the temperature measured at the surface of the water was strongly influenced by that of the air.

The pH values recorded in these waters varied from 6.8 to 7.8. These pH values could be linked to the geological base on which these waters flow [2]. However, these values are within the tolerable pH limit for the survival of most aquatic species. Indeed, water with a pH between 6.50 and 8.50 is water in which life develops optimally [14].

The water conductivity values of the basin of the Yaouré Kossou section were relatively low and range from 70 to 125 µs/cm. These values were relatively high but were different from those obtained by [15] on Lake Kossou for which the conductivity values oscillated around 77.01 ± 3.84 µS/cm at this time of the year. This difference could be due to an increasing supply of dissolved salts and to the geological substrate. Moreover, one of the main sources of the strong mineralization recorded in the tributaries of the Bandama at station B12 would be the presence of numerous aquatic plants (macrophytes). Indeed, the decomposition of macrophytes in the lake would favor the enrichment of the environment in phosphate ions.

The dissolved oxygen values fluctuate between 4.1 and 5.8 mg/L. these values are above the threshold of 2 mg/L required for the survival of aquatic organisms. These values show that the waters of this Bandama River basin are relatively moderately oxygenated. The results obtained in this study corroborate those of [15] who noted a dissolved oxygen level in the dry season of 5.50 ± 0.88 mg/L in the waters of Lake Kossou.

Regarding the taxonomic composition of macroinvertebrates in the waters of the Yaouré section (Kossou), this study has identified 47 taxa distributed among 37 families, 11 orders and 4 classes. The taxonomic richness recorded in this study was lower than that obtained during the work of [6]. and [16]. made in Ivory Coast. These authors respectively identified 98 taxa in Lake Taabo and 97 taxa in the Comoé River. This difference in taxa could probably be related to sampling effort and frequency. Indeed, these authors, during their work carried out a seasonal sampling, unlike this study which took place on an ad hoc basis in a single campaign during the dry season.

Furthermore, the low taxonomic richness recorded in the Bandama River at stations B5 (1 taxon) and B7 (2 taxa) could be explained by the unfavorable ecological conditions offered by its stations and the indirect impact of the effects of exploitation. mining carried out in the vicinity of the watercourses of this basin. Indeed, they are under strong human pressure, including artisanal gold miners. Additionally, the B7 station is near a local Whiskey distillery and also serves as a laundry, dishwashing and swimming area. According to [2], the proliferation of taxa on an environment would depend on the stability of the immediate environment and its degree of pollution.

In terms of abundance, the aquatic macrofauna in the Yaouré section (Kossou) is dominated by Gastropods and Insects. This predominance of Gastropods and Insects has already been demonstrated by the work of [17]. and [6]. in the anthropized waters of Africa.

The analysis of the communities diversities indicated the values of the Shannon index ranging between (0.24 to 1.4 bits) and equitability values ranging from (0.1 to 0.9). These values would indicated that the macroinvertebrate communities in the Yaouré section (Kossou) would be relatively undiversified and balanced [18].

The pullulation of Chironomidae and oligochaetes would be due to the strong presence of organic matter at the stations. These observations corroborate those of [19]. in Nigeria and and [20]. in New Caledonia. These authors showed that the strong presence of Chironomidae was characteristic of rivers polluted by organic matter and heavy metals. These results were confirmed by the low presence of Ephemeroptera, Trichoptera and the absence of Plecoptera, which are pollution-sensitive orders at our stations. These results corroborate those of [21] in other rivers which reported a decrease in the diversity of pollutant-sensitive orders and a better adaptation of pollutant-tolerant taxa such as Chiromidae in polluted environments. Thus, the dominance of Chironomidae highlights a deterioration in the ecological status of the waters of this Yaouré basin. This is confirmed by the low values (0.00 to 0.05) recorded of the EPT/C index which make it possible to confirm an organic type pollution of the waters inherent to the anthropic activities which take place in the catchment area of these rivers water. These results are similar to those of [11]. obtained on the Ouémé River in Benin which showed that the low value of the EPT/C index attested to the environmental stress suffered by the Okpara River. The poor water quality observed in the study stations would therefore be related to the mining, agricultural and domestic activities that take place in the basin around these watercourses.

Conclusion

The influence of mining activities on the water quality of the Yaouré basin (Kossou) was assessed using indicators relating to the diversity of macroinvertebrates collected in these waters. The results highlighted a low taxonomic richness of 47 taxa from 37 families, 11 orders and 4 classes. It also emerges from the low abundances of the taxa of the EPT complex and a preponderance of Chironomidae despite values of physicochemical parameters acceptable for the survival of aquatic organisms. The low values of the EPT and EPT/C indices indicate organic-type pollution associated with heavy metal pollution of the water. The analysis of diversity indices showed a degradation of water quality by human activities such as mining and agricultural activities. To preserve the biodiversity of these waterways, protective measures must be taken and a biomonitoring program should be set up for these waters.

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Conflict of Interest
The authors declare that there are no conflicts of interest that is relevant to the content of this article.

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