World Journal of Environmental Biosciences

Available Online at: **www.environmentaljournals.org**

Volume 6, Issue 4: 7-14

ISSN 2277- 8047

Bioassessment of Artisanal Mining's Impact on Bagoé River Water Quality in Sikasso Region.

Ibrahim Werner Traore[1*], Moussa Houhamdi[2]

[1] Higher Institute for Applied Research and Training (ISFRA), University of Bamako, Mali.
[2] Laboratory of Biology, Water and Environment, University of 08 Mai 1945 Guelma, Algeria.

ABSTRACT

The artisanal mining has rapidly expanded in recent years in Mali and has employed 100,000 to 200,000 people. Other times, the artisanal mining was done by using simple equipment (shovel, package) and the gold treatment was done by washing with the use of pan or sluice; nowadays this activity is modernized by using new equipment (Crusher, Motor pump, Metal detector, Dredge) and new techniques for the gold treatment involving the application of hazardous substances such as Cyanide, Mercury, Arsenic, and others. Although these new techniques enable increased gold production, they have also affected the environment, particularly on the water resource.
The study at three artisanal mine sites along the Bagoé river in Sikasso (Massiokocoro, Massiokocoura, and Alihamdoullilae), highlighted the fact that artisanal mining has impacted negatively on Bagoé's water quality by increasing the turbidity (Turb) with an average of Turb=232; the community of macroinvertebrate benthic has shown a species richness, S=20 families; Shannon's diversity (H) and Pielous' s Equitability Index (E) have shown a diverse community and evenness: Massiokocoura H=1.91, E=0.92; Alihamdoullilae H=1.69, E=0.66; Massiokocoro H= 1.50, E=1. The Family Biotic Index FBI=6.21 indicate a fairly poor water quality (Hilsenhoff, 1987). The canonical analysis (CA) between the mycological and faunistic data shows a positive correlation between the concentration of phosphorus (PO4), cyanide (Cn), sulfate (SO4) and the relative abundance of the dominant families of macroinvertebrate sampled all tolerant to the organic pollution (Hilsenhoff, 1988; Plafkin, 1989).

Keywords: *Artisanal Mining, Bagoé River, Macroinvertebrate Benthic, Water Quality*

Corresponding author: Ibrahim Werner Traore
Received: 12 December 2016
Accepted: 29 September 2017

INTRODUCTION

Before, the Empire of Mali was pointed out by its gold, because of Kankou Moussa's « king of gold » pilgrimage to Mecca in 1324, led to gold price decrease during this period.
In 1970 as many African's country, Mali experienced a great period of drought resulting from the abandonment of the agriculture and the reborn of artisanal mining by the local community who suffered from starvation at the time.
Mali has been rated as the third producer of gold in Africa after South Africa and Ghana (ITIE, 2015). Currently, the country produce an average of 50 tons of gold all from 09 gold producing mines and the artisanal mining also contribute considerably in this production on the average of 4 tons a year (Jeune Afrique, 2016).
Over the last few decades, the artisanal mining expended widely in Mali with more than 350 sites (Seydou Keita, 2001) divided among the three main mining regions of Mali (Koulikoro, Kaye, Sikasso) and employ 100.000 to 200 .000 workers (OIT, Mars 2009).
The region of Sikasso in south of Mali, has a rich sub soil in mining resource "Gold" which conferred to this location the status of being a mining area by excellence. In Sikasso, there are 06 industrial gold mines and more than 120 artisanal mine sites within a large part located along the Bagoé River which is one of the main rivers in Sikasso with the Baoulé and the Sankarani.
Several years ago, the artisanal mining was done by using simple tools such as shovel, bucket and the mineral treatment by panning with calabash.
Nowadays, the artisanal mining raised regarding to the materials used such as motor pump, artisanal crasher, drags, metal detectors and the mineral treatment process which use some dangerous chemicals substances such as cyanide, mercury, arsenic in order to increase gold production (Rani Parker& Fred Wood, 2006).
Water is a precious natural resource, without it life could not exist. The quality of this precious resource can have bearing on human and animal health (Kazi et *al*. 2009).
The global climate change and anthropogenic activity contribute to the rarefaction of natural water resource and the deterioration of water quality. The banks and bed rock of the Bagoé River in Sikasso region, specifically the area of Kadiolo is a suitable area for the artisanal mining because of high-grade ore (alluvium and eluvium) in there.
The artisanal mining is affecting considerably on the physical, chemical and biological qualities of Bagoé River, which is usually used by the local community for the domestically need and also is used as habitat for high biodiversity.
The purpose of this study is to do a rapid bio-assessment of the Bagoé's river water quality by using the macroinvertebrate benthic as bio-indicator of water quality (Hilsenhoff, 1988; Plafkin and al 1989; Diomandé and al 2009).

In Mali the studies based on the bioassessment of the river quality is really scarce, resulting in data lack, this research is one of the first done in this field.

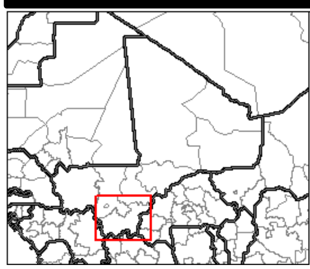
1- MATERIALS AND METHODS

1.1Description of the Study Area

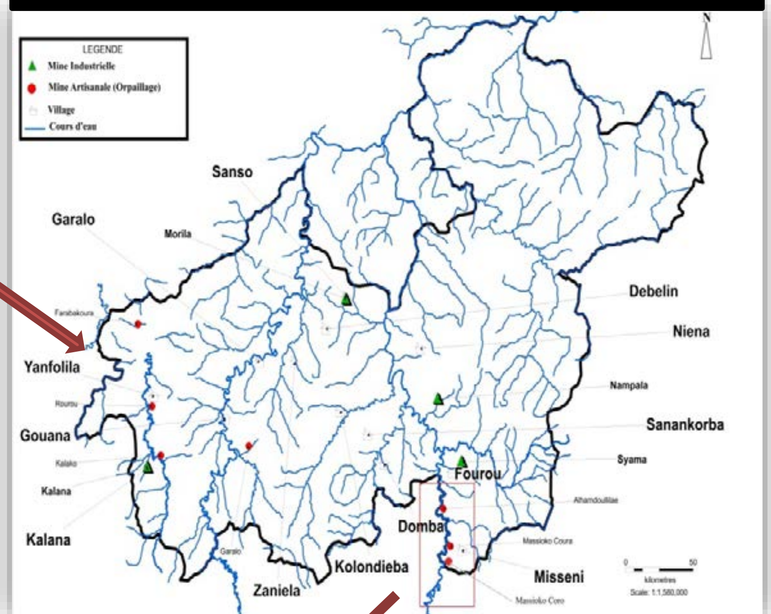
Sikasso region located in south of Mali is characterized by a climate known as Soudano Guinea with heavy rains from July to October and dry season from January to May.

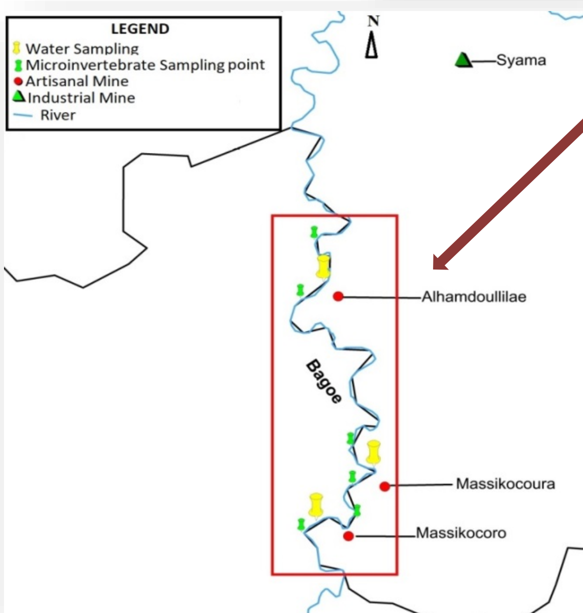
The Bagoé river has its source in Cote d'Ivoire near the village called Boundiali (9º34'46''N, 6º33'40''W). From its source, the Bagoé flows over a distance of 230 km to the North and crosses Malian border in Sikasso region. In Mali the Bagoé flows 300 km to the East where it joins the Baoulé River to form the Bani River which is one of the main tributaries of the Niger River, third (3th) biggest river in Africa coming after the Nile and Congo River. The Bagoe covers 318000 km^2 of bedrock with an average annual flow of 170 m^3/s (Station of Pankourou).

Map I: Mali



Map II: Hydrography of Sikasso Region





Map III: Study Area (Bagoé River)

1.1- Artisanal Mining Along Bagoé River

During this research study, we explored three artisanal mine sites all located along the Bagoé area; it is about the sites of Massiokocoro, Massiokocoura and Alihamdoullilae.

These three sites are exploiting oxidized ores of the alluvial and eluvionary type and proceed by the same technique of extraction and treatment of the minors which are of two types either:

- By digging wells ranging from 10 to 15 m depth, often interconnected in the form of a gallery in order to follow the mineralized vein either by dredging the sediments inside the Bagoé; The treatment of the minerals extracted is done by the method of gravitational concentration (pan, sluice, calabash) with the use of certain hazardous chemicals such as: mercury, arsenic, cyanide (Rani Parker & Fred Wood, Oxfam Amercia) for a larger and easier recovery of gold.
- By dredging the alluvial deposits in the Bagoé bed with the help of a crafted dredge.

Photo I: Ore extraction well (Alihamdoullilae).

Photo II: Dredge install in the bed of Bagoé (Massiokocoura).

Photo III: Washing ore at the Bagoé's edge

Photo IV: Washing ore by using pan (Massiokocoura).

Water quality is characterized by the substances it contains, the quantity and the effects they have on the ecosystem and human being. (Serge Hebert & Stéphane Legare, October 2000).

In order to assess the impact of artisanal mining on Bagoé River water quality, we carried out sampling of benthic macroinvertebrate during the dry season (January and June 2016 and 2017) from up and downstream of three artisanal mine sites (Massiokocoro, Massiokocoura and Alihamdoullilae) all located along the Bagoé River. To determine the concentration of some physical-chemical parameters, we have also sampled Bagoé's water at the same three artisanal mine sites for analysis.

- **Macroinvertebrate Benthic Sampling**

For safety measurement, we wore a waterproof suit and a life jacket before starting the sampling. By using a Haveneau net (400 µm of mesh), we sampled upstream and downstream of artisanal mine sites. The sampling was conducted on 300 meters (m) transect, along the banks of Bagoé River, where the water flow is lentic. All 24 blows of net have been done in the opposite direction of water flow for each site.

The sampled substrate was composed of sand, clay, and woody debris. After every prize, the content of net is segregated with a sieve (400 µm mesh), and plastic clamp to collect the sampled macroinvertebrate. Two white plastic jars with diluted alcohol (70%) have been used to contain the sampled macroinvertebrate, and then the plastics jars were labeled (date, time, location).

Once in lab, the sampled species were identified by using a binocular stereomicroscope (Motic, zoom 10X-30X) and the identification key «Guide d'identification des principaux macroinvertébrés benthiques d'eau douce du Quebec». The identified taxa was accounted and classified by Class, Order and Family level.

Adding to the macroinvertebrate sampling, with the multiparameter analyzer "Aquared" some physical and chemical parameters from the Bagoé River , the temperature, PH, conductivity have been measured and also, with a graduate tap and ruler, some morphologic parameters , the widths, dip (averages) and the vegetation cover (trees shade on river) have been also measured.

- **Water Sampling**

In order to determinate the concentration of some physical-chemical features from Bagoé's water influenced by the artisanal mining, we conducted Bagoé River sampling in these three artisanal mine sites (Massiokocoura, Massiokocoro, and Alihamdoullilae).

Two types of bottles (white and black) provided by SGS Lab. Bamako (in charge of analysis) was used,

- 1liter (L) white bottles were used to analyze the following parameters: Turbidity (Turb), Total Suspended Solids (TSS), Dissolve Oxygen (DO), Biological Oxygen Demand (BOD5), Nitrate (NO3), Nitrite (NO2), Total Phosphorus (PO4), Arsenic (As), Mercury (Hg), Zinc(Zn), sulfate (SO4), Cooper (Cu), Lead (Pb).
- 5 milliliters (ml) black bottles preserved by Sodium hydroxide (NaOH) were only used for Cyanide (Cn) analysis.

Using a canoe, we move in the middle of the water stream for sampling. 1L white bottle was rinsed (3 times) before filled by dipping (4cm) under water in the opposite direction of water flow, and 500 ml black bottle was filled by using a cup.

The bottles were closed properly and labeled (date, time, location) using a marker, and arranged into the coolbox with some ice block to maintain the temperature cool (4ºC). Then, the coolbox was sent to SGS Lab Bamako for the different analysis (Method: APHA 2540 D, 22ND EDITION).

1.2- Data Analysis

The results (average values) from water analysis, have been compared to European Water Framework Directive (EWFD) "Directive 2000/60/EC" standard.

The parameters with an average value higher than EWFD standard or equal with it (stream in bad condition) were represented graphically using Microsoft Excel.

The fantastic data from the macroinvertebrate sampling were used to calculate the traditional biodiversity measurement and the water quality index.

A statistical analysis was done in order to understand the physical-chemical parameters that influencing the distribution of macroinvertebrate in the Bagoé River. The calculations and analyzes are as follows:

- **Species Richness (S)**

The species richness is the total number of species compositing a considered settlement in considered ecosystem (Ramade, 1984 in Louadi et al, 2010).

- **Shannon Diversity Index (H)**

This index accounts for both, abundance and evenness of the species present. In this study, we have calculated Shannon (H) index by the following formula:

$$\mathbf{H} = \sum_{i=1}^{S} \mathbf{PilnPi}$$

H = Shannon's Diversity Index
S = Total number of species in community (richness)
Pi = Proportion of (S) made up of the ith species

- **Pielous Equitability(evenness) index (E)**

Equitability assumes a value between 0 and 1 with 1 being complete evenness, this index is maximum when the stands have the same abundance and going to 0 when only one taxa represented the community. We have calculated the Equality (E) using the formula below:

$$\mathbf{E} = \frac{\mathbf{H}}{\mathbf{Hmax}}$$

E= Equitability index
H= Shannon's index
H max= Ln S (Shannon's index).

- **Jaccard Similarity Index (J)**

The Jaccard similarity index (sometimes called the Jaccard similarity *coefficient*) compares members for two sets to see which members are shared and which are distinct. It is a measure of similarity for two sets of data, ranging from 0% to 100%.

$$\mathbf{J} = \frac{\mathbf{Nc}}{(\mathbf{Na} + \mathbf{Nb} - \mathbf{Nc})} * \mathbf{100}$$

J= Jaccard Similarity Index
Nc= Species present on site a and b
Na=Species present only on site a
Nb=Species present only on site b

- **Ephemeroptera ,Plecoptera, Tricoptera (EPT) Index:**

This index estimates the water quality by the relative abundance of three major orders of streams insect considered as sensitive to various form of pollution. A large percentage of EPT taxa indicates high water quality. The following formula is used to calculate the EPT index:

$$\mathbf{EPT\ Index} = \frac{\mathbf{Total\ EPT}}{\mathbf{Total\ Taxon\ Number}} * \mathbf{100} = \mathbf{\%\ Abundance}$$

E= Ephemeroptera
P= Plecoptera
T= Tricoptera

- **Ratio EPT and Chironomidae (EPT/C)Abundance**

The abundance of EPT and Chironomidae (EPT/C) indicates the balance of the community, since EPT is considered to be more sensitive and Chironomidae (C) less sensitive to environmental stress (Plafkin et al., 1989). The EPT/C index is calculated by dividing the sum of the total number of individuals classified as Ephemeroptera, Plecoptera, and Tricoptera by the total number of individuals classified as Chironomidae.

- **Family Biotic Index (FBI):**

The Family Biotic index (FBI) was developed to detect organic pollution and toxic pollutant. The FBI is based on the original species level index, and for each macroinvertebrate family, tolerance values from 0 to 10 are calculated (Hilsenhoff, 1988; Plafkin et al, 1989). More the tolerance values increase from 0 to 10, more the quality of water decreases. The following formula is used to calculate Bagoé's River FBI:

$$\mathbf{FBI} = \frac{\sum \mathbf{Xi} * \mathbf{ti}}{\mathbf{n}}$$

FBI = Family Biotic Index
Xi = Individual number of taxa i
ti = Tolerance value of taxa i
n = Total number of individuals sampled

Table 1: Evaluation of water quality using the family-level biotic index (Hilsenhoff, 1987).

Family Biotic Index	Water Quality	Degree of Organic Pollution
0.00-3.75	Excellent	Organic pollution unlikely
3.76-4.25	Very Good	Possible slight organic pollution
4.26-5.00	Good	Some organic pollution probable
5.01-5.75	Fair	Fairly substantial pollution likely
5.76-6.50	Fairly Poor	Substantial pollution likely
6.51-7.25	Poor	Very substantial pollution likely
7.26-10.00	Very Poor	Severe organic pollution likely

- **Statistical Analysis**

Using the statistical analysis software R 4.3.1, we have done correspondences analysis (CA) of the mycological data (physical-chemical) with the faunistic data of sampled Macroinvertebrate's families who have a high relative abundance.

2- RESULTS AND DISCUSSION

2.1- Results:

Figure 1: Temperature of Bagoé River Compared to EWFD Standards.

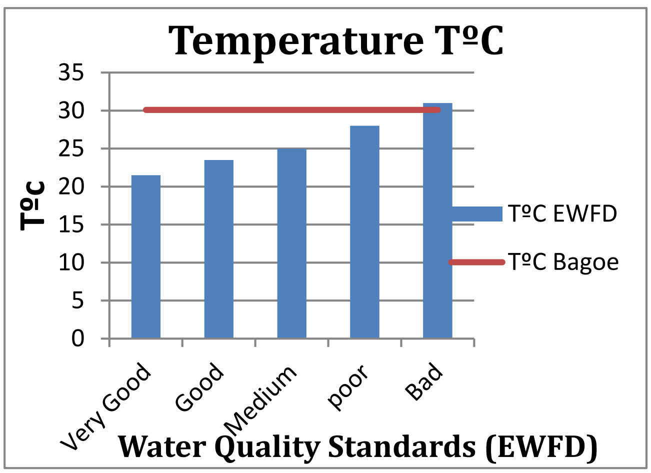
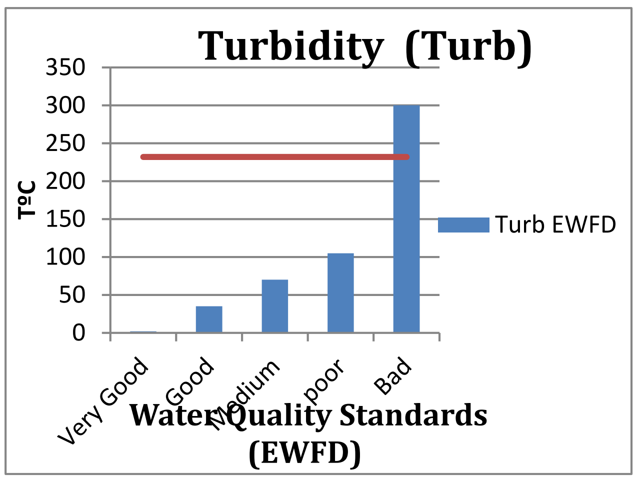


Figure 2: Turbidity of Bagoé River Compared to EWFD Standards



The analysis of physical-chemical parameters of Bagoé River, shown a temperature (TºC) and turbidity (Turb) values (average) higher than the EWFD standard (Bad quality).

- **Macroinvertebrate Community Structure in Bagoé river**

The sampling season has allowed to collect a total of 146 individuals macroinvertebrate benthic in Bagoé's stream for a total species richness S=20 families. The taxa was composed of 70% insects; 17% Mollusc; 13% Crustaceans.

The Shannon diversity index (H) and Pielous Equitability (E) index varies slightly from a site to theirs: Massiokocoura H=1.91, E=0.92; Alihamdoullilae H=1.69, E=0.66; and Massiokocoro H= 1.50, E=1.

The relative identified abundant families are: Lymnaeidae (Lym); Gammaridae (Gam); Chironomidae (Chi); Ceratogonidae (Cer); Libellulidae (Lib); Hydrobiidae (Hyd); Coenagrionidae (Coe).

Jaccard index (J) is about 23% between Massiokocoro and Massiokocoura; 16% between Massiokocoura and Alihamdoullilae; 31% between Massiokocoro and Alihamdoullilae.

The EPT index varies slightly from a site to theirs: Massiokocoura ETP=0%; Alihamdoullilae ETP=5% and Massiokocoro ETP= 6%.

The ETP/Chironomidae has given for Massiokocoura ETP/C= 0; Alihamdoullilae ETP/C= 5; Massiokocoro ETP/C=0.2.

The Family Biotic Index (FBI) calculated with all the individuals (146) sampled at the three gold panning sites (Massiokocoro, Massiokocoura, and Alihamdoullilae) is FBI= 6.21.

Table 2: Result of Biotic Index Calculated from Bagoé River.

Biotic Index	Massiokocoro	Massiokocoura	Alihamdoullilae
Shannon's Index (H)	1.50	1.91	1.69
Equitability Index (E)	1	0.92	0.66
ETP Index	6%	0%	5%
ETP/C	0.2	0	5
Family Biotic Index (FBI)	6,21		

Table 3: Environmental Parameters Measurement from Bagoé River.

Environmental Parameters	Massiokocoro	Massiokocoura	Alihamdoullilae
Bagoe's Width	34m	26m	47 m
Sampling Dip	0.38 cm	65.35 cm	63 cm
Coverture of Vegetation	70%	30%	56%

Table 4: List of Macroinvertebrate Sampled.

ARTISANAL MINING SITE	CLASS	ORDER	FAMILY	NUMBER
Massiokocoura	Insect	Hemiptera	Pleidae	3
	Insect	Hemiptera	Belostomidae	1
	Insect	Hemiptera	Gerridae	1
	Insect	Hemiptera	Naucoridae	1
	Bivalve	Venorida	Sphaeriidae	2
	Gastropod	Basommatophora	Lymnaeidae	4
	Insect	Odonata	Calopetrygidae	1
	Insect	Odonata	Libellulidae	1
Alihamdoullilae	Insect	Odonata	Libellulidae	4
	Gastropod	Neotaenioglossa	Hydrobiidae	2
	Bivalve	Venorida	Sphaeriidae	5
	Insect	Odonata	Coenagrionidae	5
	Insect	Ephemeroptera	Ephemerellidae	2
	Insect	Hemiptera	Notonectidae	1
	Insect	Tricoptera	Molannidae	2
	Insect	Plecoptera	Pteronarcydae	1
	Insect	Diptera	Chironomidae	1
	Gastropod	Basommatophora	Lymnaeidae	39
	Malacostraca	Amphipoda	Gammaridae	35
	Malacostraca	Decapoda	Cancridae	2
	Insect	Odonata	Petaluridae	2
Massiokocoro	Crustacean	Decapoda	Cambaridae	14
	Gastropod	Neotaenioglossa	Hydrobiidae	3
	Gastropod	Basommatophora	Lymnaeidae	1
	Bivalve	Venorida	Sphaeriidae	2
	Insect	Odonata	Petaluridae	1
	Insect	Tricoptera	Dipseudopsidae	2
	Insect	Diptera	Chironomidae	10

•

- **Influence of Environmental Variables on Macroinvertebrate Distribution in Bagoé River.**

Cam = Cambaridae, Lym = Lymnaeidae, Gam = Gammaridae, **Sph =** Sphaeriidae,
Hyd = Hydrobiidae, Chir = Chironomidae, Lib = Libellulidae, Coe= Coenagrionidae,
from Bagoé Rive

Turb = Turbidity, NO = Nitrate, NO2 = Nitrite, TSS = Total Suspended Solid ,
PO4 = Total Phosphorus , SO4 = Sulfate, Zn = Zinc, Hg = Mercury, T(ºC) = Temperature
EC = Conductivity, Pb = Lead, BOD5 = Biological Oxygen Dissolve,
DO = Dissolve oxygen, As = Arsenic.

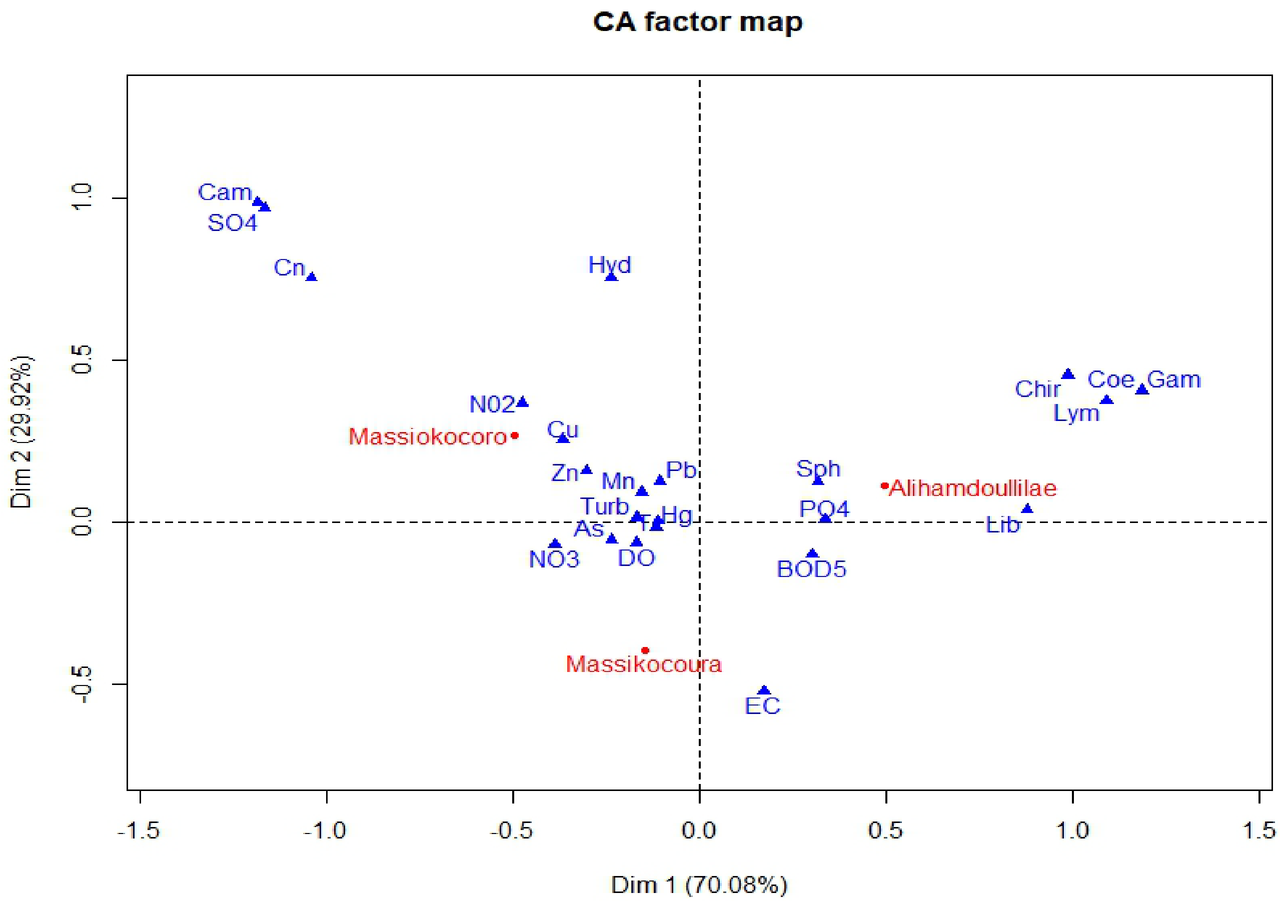


Figure 3: Correspondences Analysis (CA) of Macroinvertebrate and Physical-Chemical Parameters from Bagoé River

2.2- DISCUSSION

The physical-chemical analysis has shown a turbidity average (Turb =232) higher than EWFD standard (stream in a bad condition).

This high value of turbidity reflects the impacts of the dredging operation done in Bagoé's bed, the ore washing on the banks of Bagoé and also runoff the sterile deposits rusting of artisanal mining to the Bagoé.

The composition of macroinvertebrate in the Bagoé river correspond to a typically African fresh water benthos (Dejoux C, Lauzane; Lévêque C, 1969) dominated by Insect = 70%.

The biotic indexes calculated through the macroinvertebrate sampling have shown a total species richness of S=20 families (Massiokocoura, Alihamdoullilae, Massiokocoro); the Shannon's index indicates an high diversity of macroinvertebrate at Massiokocoura H=1, 91 than Alihamdoullilae H=1.61 and Massiokocoro H=1.50 but this diversity is more evenness in Massiokocoro E=1 than Massiokocoura E=0.92 and Alihamdoullilae E=0.66 dominated by the family of Lymnaeidae.

The water quality indexes calculated from Ephemeroptera, Plecoptera and Tricoptera (EPT) which are considered as the sensitive family of macroinvertebrate to organic pollution (Hilsenoff,1988, Plafkin 1989, EPA,2007) have shown the gold panning activity at Massiokocoura impact negatively on Bagoé quality with EPT = 0% than Massiokocoro ETP= 6% and Alihamdoullilae ETP= 5%.

The ratio ETP/C has shown a lower value, which indicates polluted stream, at Massiokocoura the ETP/C= 0, Massiokocoro ETP/C= 0.2 and Alihamdoullilae EPT/C=5. These values relate the intensity of the gold panning activity at each site.

The Family Biotic Index (FBI) of the Bagoe calculated from the family tolerance value to organic pollution (Hilsenhoff, 1988; Plafkin 1989; Digital Key to Aquatic Insects of North America) of sampled macroinvertebrate families, has given a FBI=6.21, which indicates an fairly poor water quality (Hilsenhoff,1987).

The canonical analysis (CA) done with the statistic software R 3.4.1 of the faunistic data (Macroinvertebrate) and physical-chemical parameters of Bagoé show the following indication:

- On the second axe (Dim1) we can see a positive influence of phosphorus (PO4) at Alihamdoullilae and a negative influence of Biological Oxygen Dissolved (BOD5) on the relative abundance of Lymnaeidae (Lym); Chironomidae (Chir); Spheridae (Sph); Libellulidae (Lib); Gammaridae (Gam), Coenagrionidae (Coe).
- At the same axe (Dim2) at Massiokocoro, we can also note a high influence of Sulphate (SO4) and Cyanide (Cn) on the Cambaridae (Cam) relative abundance.

3- CONCLUSION

This research outcome has highlighted the impacts of artisanal mining on the Bagoé River water quality. The set of calculated analysis and indexes show that the gold panning is impacting negatively on the physical-chemical and biological quality of this river which is useful for the local community, hence there is a need to take action for better framing of this activity and plan the restoration and rehabilitation program of the Bagoé River for the sustainable development of this precious resource in Sikasso region .

ACKNOWLEDGING

This research has been supported by Resolute Mining Limited.

CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCE

1. Bailey, R., R.H. NORRIS and T.B. REYNOLDSON (éd.). 2004. Bioassessment of Freshwater Ecosystems: Using the Reference Condition Approach. Norwell (Massachusetts), Kluwer Academique Publishers. 170 pages.
2. Clarke RT, Furse MT, Gunn RJ, Winder JM & Wright JF, 2002 Sampling variation in macroinvertebrate data and implications for river quality indice Freshwater Biology, 47,1735-1751
3. Dejoux C, Elouard J M, Forge P and Maslin J L 1981 Catalogue iconographique des insectes aquatiques de Côte d'Ivoire. ORSTOM 42, 178 p.
4. Dejoux C, Lauzanne L and Lévêque C 1969 Evolution qualitative et quantitative de la faune benthique dans la partie est du lac Tchad. Cah. ORSTOM, Hydrobiology. 3-58p.
5. Diomandé D, 2001. Macrofaune benthique et stratégies alimentaires de Synodontes.
6. France Ministry of Ecology, Energy, Sustainability Development and Territorial layout, Mars2009. Guide technique actualisant les règles d'évaluation de l'état des eaux douces de surface de métropole.
7. Gauthier Nathalie 1996. L'impact des polluants métalliques (As, Hg, Pb) sur les invertébrés d'eau douce.
8. Gertrude Marie Mathilda COULIBALY, 2013. L'évaluation environnementale et analyse des risques dans le domaine de l'exploitation minière les conséquences du non-respect des obligations environnementales.
9. Hilsenhoff, W. L. 1982. Using a biotic index to evaluate water quality in streams. Technical Bulletin Wisconsin Department of Natural Resources 132
10. Hilsenhoff, W. L. 1987. An improved biotic index of organic stream pollution. Great Lakes Entomologist 20:31-39
11. Hilsenhoff, W. L. 1988. Rapid field assessment of organic pollution with a family-level biotic index.
12. ITIE-Mali, 2015. Rapport ITIE pour l'année 2013. 22p.
13. Jeune Afrique, Juillet 2016 les exportations d'or atteignent 70 tonnes en 2015.
14. K. Saad, Octobre 1970. Etude hydrogéologique du sud du Mali (Niger supérieur et Bani), 11-13p.
15. Malian Mining Ministry, 2009. Annuaire Statistique du Secteur des Mines et Géologies.
16. Malian Mining Ministry, February 2012. Mining Code 1-3.p
17. Needham R 1962. A guide to the Study of Freshwater Biology. San-Francisco Holden Day, Inc., 105 pp.
18. ODHD/LP, Mines et Développement Socio-Economique au Mali 2011.
19. Oxfam America 2006. A la recherche des revenus de l'exploitation aurifère au Mali. 23p.
20. Parlement européen et du Conseil, octobre 2000. Directive 2000/60/CE, 2000.
21. Plafkin et al, 1989. Rapid Bioassessment Protocols for use in Streams and Rivers: Benthic Macroinvertebrate and Fish. U.S. Environmental Protection Agency. EPA 440/4-89/001. 8 chapitres, Appendices A-D.
22. PNUD-PNUE ,2008. Evaluation Economique et Gestion Environnementale au Mali : Couts et Bénéfices.
23. Rani Parker, Fred Wood, 2006. Hidden Treasure,21.pp
24. Seydou Keita, 2001. Etude sur les mines artisanales et les exploitations minière à petite échelle au Mali.
25. Wendmi Raoul florentin Sorgho, 2007. Evaluation environnementale et sociales des sites d'orpaillage et stratégie de compensation, 18-22p.
26. Williams DD & Smith MR, 1996 Colonization dynamics of river benthos in response to local changes in bed characteristics. Freshwater Biology, 36, 237-248.
27. Y. SANOGO et al, 2015.Diversité du peuplement ichtyologique de la rivière Bagoé (Bassin du Niger, Mali).