Advances in Research

16(2): 1-12, 2018; Article no.AIR.43351
ISSN: 2348-0394, NLM ID: 101666096

The Impact of Wastewater from Artisanal Mining on the Pollution of Contaminated Sites: A Case Study of Betare-Oya in East Cameroon

André Talla[1,2*] and Charles Moandjim-Me-Bock[2]

[1]*Energy, Water and Environment Laboratory, National Advanced School of Engineering, University of Yaounde I, P.O.Box 8390, Yaounde, Cameroon.*
[2]*Research Center, National Advanced School of Public Works, P.O.Box 510, Yaounde, Cameroon.*

Authors' contributions

This work was carried out in collaboration between both authors. Author AT designed the study, performed the statistical analysis, wrote the protocol, wrote the first draft of the manuscript and managed the analyses of the study. Author CMMB managed the literature searches and managed the collection of water samples from the Mbal stream for laboratory analysis. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AIR/2018/43351
Editor(s):
(1) Dr. Salem Aboglila, Assistant Professor, Department of Geochemistry & Environmental Chemistry, Azzaytuna University, Libya.
Reviewers:
(1) Şana Sungur, Mustafa Kemal University, Turkey.
(2) Fábio Henrique Portella Corrêa de Oliveira, Universidade Federal Rural de Pernambuco, Brazil.
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(4) Sirajo Abubakar Zauro, Usmanu Danfodiyo University, Nigeria.
Complete Peer review History: http://www.sciencedomain.org/review-history/26179

Original Research Article

Received 6th June 2018
Accepted 30th August 2018
Published 11th September 2018

ABSTRACT

The aim of this work was to evaluate the impact of the wastewater from artisanal mining on the pollution contaminated sites in the Betare-Oya locality in East Cameroon. Water samples were collected from the Mbal stream exposed to artisanal mining on the upstream and downstream, and analysed for contamination loads in the laboratory. Water samples were taken on four different positions of the stream course and analysed in the laboratory. The laboratory analysis quantified the loads of pollutants including the heavy metals in the water samples and their physicochemical and bacteriological parameters. Results show that the levels of the water stream contamination exceeds the upper limits of the contaminations that WHO (World Health Organisation) standards allows. The suspended solid content, colour, turbidity and total coliforms were 573 mg/l, 3683 Pt-

**Corresponding author: E-mail: andre_talla@yahoo.fr;*

Co/l (Platinum Cobalt Colour per 1 l of sample), 468 NTU (Nephelometric Turbidity Unit) and 171×10^3 CFU/100 ml (Colony Forming Unit per 100 ml of sample) respectively. The analysis of heavy metals contamination showed its levels are lower than the detection limits of the plasma emission spectrometry technique. The good correlations of the major chemical elements in the water samples revealed by the study, indicates that they originate from the alteration of rocks.

Keywords: Ore mining; contaminated sites; Betare-Oya; pollution stream; physicochemical characterization; bacteriological characterisation.

ABBREVIATIONS

CFU/100 ml: Colony Forming Unit per 100 ml of sample
NTU : Nephelometric Turbidity Unit
Pt-Co/l : Platinum Cobalt Colour per 1 l of sample
WHO : World Health Organisation

1. INTRODUCTION

Water is the only resource essential for the survival of ecosystems. It plays a crucial role in the economic development of a country and its access is a recognised right for all. The district of Betare-Oya in East Cameroon has not drinking water supply networks. As a consequence, traditional water wells, boreholes and mainly surface streams are the only sources of drinking water available in the district. Unlike other African countries such as Mali, Burkina Faso, Morocco, the Democratic Republic of Congo, the exploitation of ores (gold in particular) in Cameroon in general, and in the locality of Betare-Oya in particular, is exclusively the artisanal. Although profitable, its mismanagement of effluents, residues and waste rocks exert enormous pressure on the rivers which are the source of drinking water for communities. The race to extract minerals is a nightmare for streams. According to Safe Drinking Water Fondation [1], mining, which consumes huge amounts of water that will be polluted from the outlet of contaminated sites and flow into these streams, causes victims.

Several studies have established the relationship between the various artisanal mining activities and the quality of the water resources they affect, as well as the resulting impacts [2,3,4]; and that, the methods of mining, washing and processing are the main determinants of the pollution and pressure of artisanal mining on water streams and rivers [5]. A study conducted by Bamba showed that exposed mining waste from a mine site was a source of the pollution of rivers in Ivory Coast [6]. Deshaies also reported that huge volumes of displaced and treated rock material can lead to alteration and irremediable pollution of water resources [7]. Dupon revealed that massive dumping of waste rock on the slopes below the extraction zones has very serious consequences for the environment, especially on the streams [8]. In Burkina Faso, Ouedraogo [9] and Kiemtore [10] reported that the engine oils and chemical products (used batteries abandoned at the bottom of wells containing manganese or lead), cyanide and sterile sludge from washing ramps are the sources of the pollution of water resources which artisanal mining contributes to. A study Sawadogo conducted on the Fofora mine site in the province of Poni revealed that the use of chemicals such as mercury, cyanide, sulfuric acids and nitrogen caused water pollution, including the presence of bacteria (total coliforms, Escherichia Coli in the waters of Fofora) [11]. In the Democratic Republic of Congo, Assomar attributed to the pollution of water courses in the provinces of Katanga, South Kivu, North Kivu and Kinshasato the chemicals such as mercury and cyanide artisanal ores mining uses [12]. And, Ngongo blames the pollution of surface and groundwater in the Democratic Republic of Congo on the spills of the untreated-contaminated liquids discharged from the concentration and the hydro-metallurgical treatment of ores [13]. Meanwhile, Kiemtore reported that the direct releases of mercury in liquid from the processes of gold concentrates amalgamation in soils that leaks through runoff promotes mobilisation and dispersion of heavy metals in groundwater by infiltration [10]. In Cameroon, a study conducted by Mokam et al. [14], showed that the pollution of watercourses by artisanal mining in the (district or region) of Batouri (Kambele) is the cause of diseases such as typhoid fever, edema, rheumatism, and diarrheal diseases. Simo and Feudjio Fokem also reported that the degradation of the environment, including flora, fauna and water sources, stemmed from gold washing in the locality of Betare-Oya here [15] and here [16]) respectively. And, Awono

Atangana [17] noted that the soils stirred by the excavations would be leached, degraded, and the discharges of waste rock and ore dumped into a watercourse for butchering.

From the literature review this study conducted and reported above, it could be concluded that the approaches of the studies conducted to-date on the issue dwelt on here were qualitative, and none of them was quantitative which could generate instruments which enable to measure and compare the impacts of the wastewaters from variable artisanal mining on contaminated water stream sites, through which artisanal mining could be optimised for the most effective reduction of polluting effect on water stream sites. Therefore, the primary objective of the present study conducted and reported here was to evaluate the quantitative characteristics of the impact of the wastewater from artisanal mining on contaminated water stream sites in the locality of Betare-Oya, East Cameroon. The first specific objective was to appreciate the relationship between artisanal mining and the contamination of water stream sites. The second specific objective was to determine loads of the different pollutions detectable in the wastewaters from artisanal mining, and their impacts on the contaminated water stream sites of mining sites with the help of physicochemical and bacteriological characterisation.

2. MATERIALS AND METHODOLOGY

2.1 Materials

The factual data collection used the set of equipment which included:

- A Nikon brand camera for shooting;
- A Garmin GPS receiver for location of sampling points and geographic positioning;
- One (1) litre disposable polyethylene plastic bottles for the collection of wastewater samples;
- And, a cooler for the samples conservation.

2.2 Methodology

2.2.1 Collection of data

Data collection based literature search, and the direct observation of the various activities of artisanal mining to appreciate the relationship between gold panning and the degradation of water resources in the study area, which generated shots of the impacts of artisanal mining activities on the polluted sites of Betare-Oya, some of which are illustrated on Fig. 1.

Fig. 1. Different activities of artisanal mining of minerals and pollution of sites

Removal, sampling and preservation of the samples conditioned the results, hence their delicacy. Four (04) surface water points of the Mbal River were selected for sampling and three (03) water samples were taken from each of these points (total of 12 samples) in February 2017 (corresponding to the dry season). The selection of these sampling points was based on the different pressures that gold panning has on the watercourse and by the fact that these points are at the heart of pollution because the Mbal watercourse underwent gold panning upstream and downstream. The samples were loaded in disposable plastic (polyethylene) bottles of 1 litre capacity. Each sample was tagged and all of them stored in an ice-filled cooler to maintain the temperature below 4°C [18]. The set was transported to three (03) laboratories, including the laboratory of Wastewater Research Unit of the University of Yaounde I, the laboratory of Geological Analysis of Water (LAGE) at the Institute of Geological Research and Mining of Yaounde and the laboratory of Agricultural Research Institute for Development (IRAD) of Yaoundé where bacteriological, physicochemical and heavy metals analyses were carried out immediately.

2.2.2 Physicochemical analyses

All physicochemical characterisations of the samples were performed at LAGE according to the reference method of the AFNOR Standard NF EN ISO 90-106 (2000) with the following standard protocol described by Rodier et al. [18]:

- The temperature of the water was taken using an electrode thermometer before each manipulation, graduated to 1/10 of a degree and reading was done after immersion for 10 minutes;
- The pH was measured using a pH-meter equipped with a combined electrode previously calibrated with buffer solutions pH = 4 and pH = 7. The method consisted in immersing the electrode in the sample contained in a beaker in which the bar of a magnetic stirrer homogenises the sample. After stabilising the display on the pH meter dial, we noted the pH;
- Conductivity was determined in the laboratory by measuring the electrical resistance of each sample through a conductivity meter. When immersed in water, a voltage is applied between two electrodes in the sample, and the voltage drop due to the resistance of the solution is used to calculate the conductivity per centimetre;
- For the determination of suspended solids (MES), the filter disc filtration method was used. A sample is filtered through a rinsed glass filter membrane and dried at 105 °C. The materials retained on the filter are dried at 105° C and then weighed with the filter;
- The colour was determined by the platinum-cobalt method, which consisted in dissolving potassium chloroplatinate and cobalt chloride in a small amount of water containing hydrochloric acid, then extending to 1 litre after dissolution;
- The determination of alkalinity was based on the neutralisation of a certain volume of water by a dilute mineral acid in the presence of a coloured indicator. To accurately determine the equivalence point, we used the Gran curve deduced from the pH variation curve as a function of the volume of acid added;
- The main cations (Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}) and anions (Cl^-, F^-, NO_3^-, PO_4^{3-}, SO_4^{2-}) were determined by ion chromatography. The devices used are the Dionex ICS-90 and ICS-1100 models.

2.2.3 Bacteriological analysis

The bacteriological analyses were carried out at the laboratory of the Wastewater Research Unit of the University of Yaounde I, according to the reference method of the AFNOR Standard NF EN ISO 9308-1 (2000) by the membrane filtration technique and counted in accordance with standard protocol described by Rodier et al. [18]. This technique consisted in filtering 100 ml of samples to be analysed on a membrane with pores with a uniform diameter of 0.45 μm using sterile dilution water, using a filtration device connected to a vacuum pump. Two test portions of the water to be analysed, thoroughly homogenised by stirring, were carried out. The membrane was placed on a TTC lactose agar plate and Tergitol, then put into incubation dishes. These media were then placed in incubators at 37°C for faecal streptococci and 44.5°C for faecal coliforms for 24 hours. After incubation, the yellow and red-pink colonies marking the presence of faecal coliforms and faecal streptococci respectively were counted and their total effluent loads were estimated by the formula below:

$$\text{UFC} = \frac{\text{Number of colonies counted}}{\text{Volume of filtered sample (ml)}} \times 100$$

2.2.4 Heavy metals analysis

The principle is based on the determination of traces of metallic elements in water using the new method such as inductively coupled plasma optical emission spectrometry (ICP-OES). This method consisted in measuring the emission of light by an optical spectroscopy technique. The samples were nebulised and the aerosol thus produced was transported in a plasma torch where excitation occurred. Characteristic emission spectra were produced by a high frequency inductive coupling (ICP) plasma. The spectra were dispersed by a grating spectrometer and the intensity of the lines was evaluated by a detector. The detector signals were processed and controlled by a computer system. Finally, the Piper plot was used to characterise the geochemical facies of the waters of the study area.

3. RESULTS

3.1 Physical Parameters of Artisanal Mineral Wastewater along the Mbal Watercourse

The results of the analysis of the physical and organoleptic parameters are illustrated in Fig. 2. The analysis of this figure reveals that wastewater from artisanal mining in the Betare-Oya locality had temperatures varying between 22.1°C and 22.6°C with an average of 22.4°C. Suspended solid (SS) levels were gradual and all exceed WHO discharge standards, with a minimum value of 77 mg/l and a maximum of 573 mg/l, an average of 235.3 mg/l. As for colour, it had values that varied from one point to another ranging from 759 Pt-Co/l to 3683 Pt-Co/l, with an average of 1603.3 Pt-Co/l, well above the standard of the WHO advocating a maximum value of 15 Pt-Co/l. Turbidity also had gradients and remains very high, compared to WHO standards. It varied between 42 and 468 NTU, with an average of 168.5 NTU. The electrical conductivity was between 30.7 µs/cm and 49.9 µs/cm with an average of 208.4 µs/cm. The minimum and maximum values of alkalinity were respectively 203 and 227.0 with an average of 214.5.

The different values of WHO Standards used are those cited by Rodier et al. [18]. These results showed a high pollutant load in artisanal mineral wastewater in the Betare-Oya locality in Cameroon, which is evolving gradually from downstream to upstream.

3.2 Chemical Parameters of Artisanal Mineral Wastewater along the Mbal Watercourse

The results of the analysis of major cations and anions were presented in Table 1. The chemical parameters, especially the major ions, are shown in Fig. 3. The concentrations of the major ions vary between 0 mg/l (NH_4^+ and PO_4^{3-}) and 13.85 mg/l (HCO^{3-}). The wastewater in the study area was characterised by the predominance of bicarbonate ions over nitrate and sulphate ions, all of which were small in this wastewater. Among the cations, the calcium ions constituted the most important cations with an average content of 2.5 mg/l, then come Na^+, K^+ and Mg^{2+}, which have average contents of 2.25, 1.55 and 0.95 mg/l respectively. The NH_4^+ and PO_4^{3-} ions were practically non-existent in this wastewater. The different concentrations of major ions complied with WHO standards. The pH varied between 6.7 in the Endorheic Lake and 7.2 upstream with an average of 7.0. PH values were normal compared to WHO standards.

Table 1. Concentrations of chemical elements in the study area

Parameters	Sampling position				Min	Average	Max.	WHO standard [18]
	P_1	P_2	P_3	P_4				
Na^+ (mg/l)	2.70	2.24	2.05	2.01	2.01	2.25	2.70	200 mg/l
NH_4^+ (mg/l)	0	0	0	0	0	0	0	1.5 mg/l
K^+ (mg/l)	1.97	1.45	1.42	1.35	1.35	1.55	1.97	-
Mg^{2+} (mg/l)	1.22	0.85	0.92	0.84	0.84	0.95	1.22	-
Ca^{2+} (mg/l)	2.78	2.48	2.18	2.36	2.18	2.5	2.78	25 mg/L
F^- (mg/l)	0.21	0.10	0.12	0.09	0.09	0.13	0.21	-
Cl^- (mg/l)	0.25	0.12	0.13	0.11	0.11	0.15	0.25	250 mg/l
NO_3^- (mg/l)	1.52	0.35	0.52	0.28	0.28	0.7	1.52	50 mg/l
PO_4^{3-} (mg/l)	0	0	0	0	0	0	0	≤ 10 mg/l
SO_4^{2-} (mg/l)	0.47	0.30	0.32	0.31	0.30	0.35	0.47	-
HCO_3^- (mg/l)	13.12	12.99	13.85	12.38	12.38	13.1	13.85	-

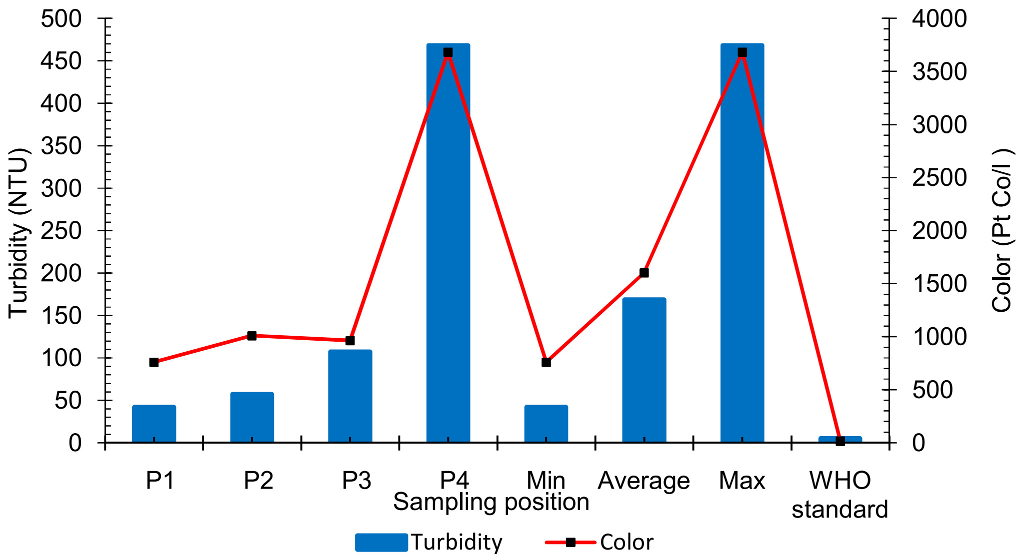
The projection of wastewater samples from the study area on the Piper diagram, in Fig. 4, showed that water of the Mbal stream is primarily made of bicarbonate, calcium and magnesium wastewater.

3.3 Bacteriological Parameters of Artisanal Mineral Wastewater along the Mbal Watercourse

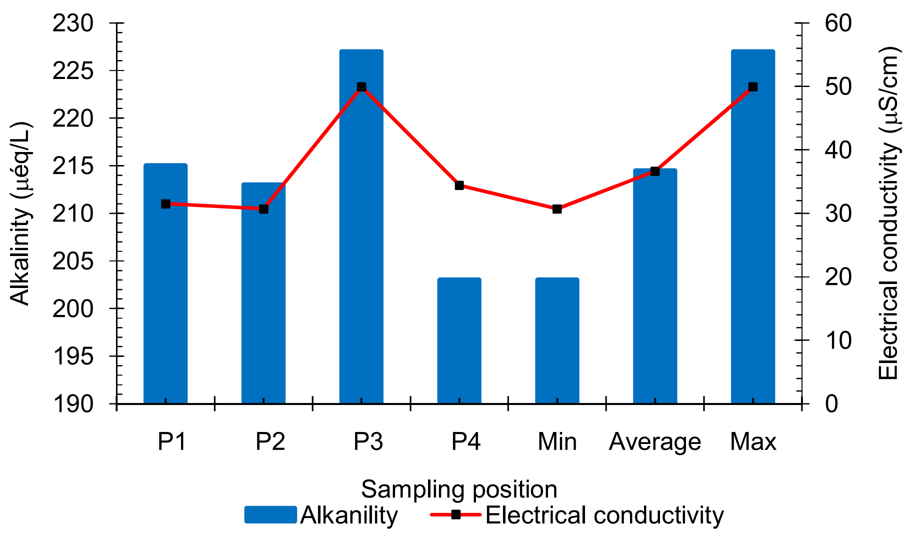
Fig. 5 shows the results of bacteriological analysis. These results indicated a strong presence of total germs in the wastewater studied and with a gradual evolution. Total coliforms posed a significant threat to water in the study area with concentrations ranging from 53×10^3 CFU/100 ml to 171×10^3 CFU/100 ml. High concentrations were observed upstream of the watercourse. The values recorded were far from WHO standards (1000 CFU/100 ml).

3.4 Heavy Metal of Artisanal Mineral Wastewater along the Mbal Watercourse

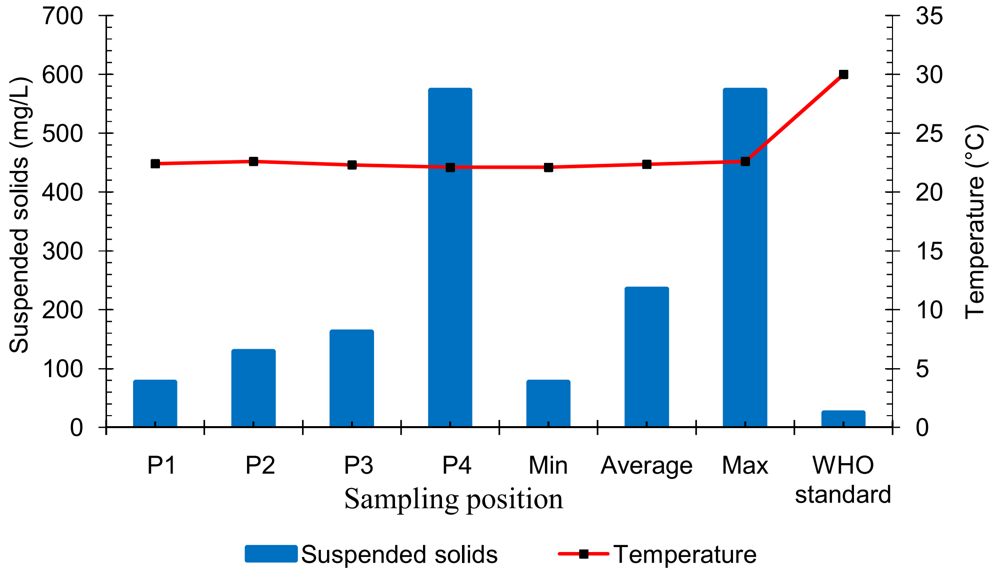
The analysis of heavy metals, in particular Mercury, Zinc, Lead, Cadmium and Manganese, indicates levels lower than the detection limits of the plasma emission spectrometric determination technique.



(a) Turbidity et color



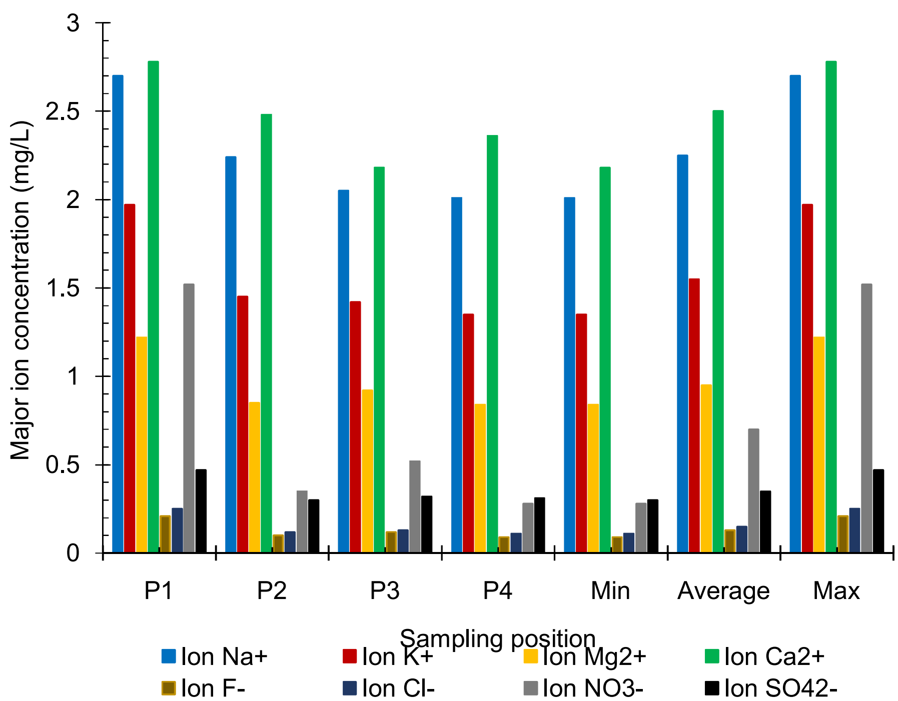
(b) Alcalinité et conductivité électrique



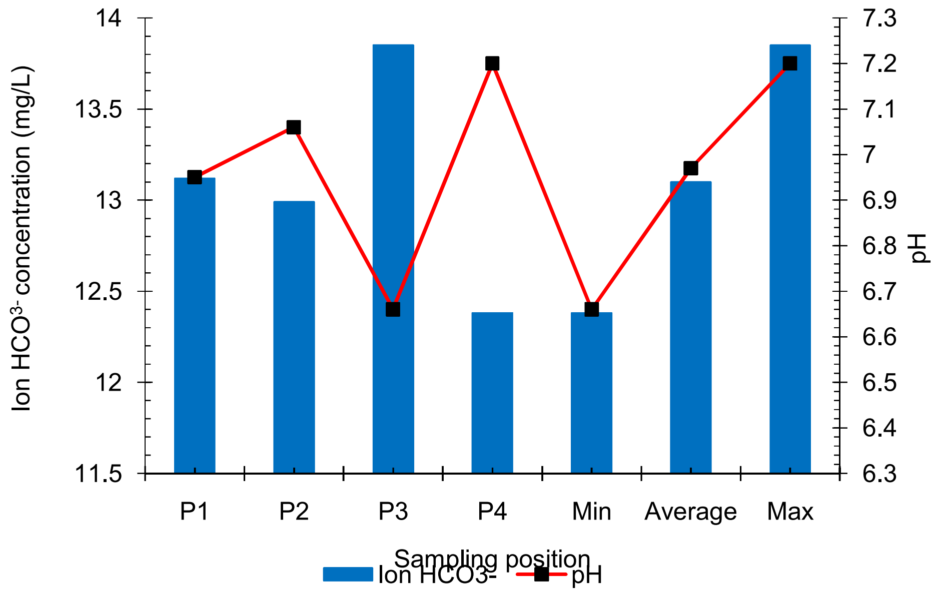
(c) Suspended solids et temperature

Legend: P1: Downstream Mbal watercourse; P2: Point of rejection; P3: Endorheic lake; P4: Upstream Mbal watercourse

Fig. 2. Concentration of physical and organoleptic parameters along the Mbal watercourse polluted by wastewater from the artisanal mineral exploitation zone



(a) Major ion concentration along the Mbal watercourse



(b) Ion HCO^{3-} concentration and pH along the Mbal watercourse

Legend: P1: Downstream Mbal watercourse; P2: Point of rejection; P3: Endorheic lake; P4: Upstream Mbal watercourse

Fig. 3. Concentration of chemical parameters along the Mbal watercourse polluted by wastewater from the artisanal mineral exploitation zone

4. DISCUSSION

Variations in the different element levels in wastewater indicated a significant and irregular contamination. The average temperature of the wastewater studied was 22.4°C, the standard advocating values below 30°C. This wastewater conforms to the WHO recommendation.

PH values, ranging from 6.7 to 7.2, had an average of 7.0; which indicated almost neutral pH. The values obtained are higher than those observed in the work of Simo [15] reporting a very acidic pH with the presence of heavy metals in wastewater. These pH values, which were almost neutral, can be explained by levels lower than the detection limits of heavy metals (Mercury, Lead, Nickel, Cadmium and Zinc) in the wastewater of the study area.

The average values of the recorded electrical conductivity and alkalinity were respectively 36.6 and 214.5 µS/cm. The different sampling points had a slightly different conductivity. It increased slightly, at the level of the Endorheic Lake, by 49.9 µS/cm.

The concentrations of suspended solids (SS) observed, evolved gradually with an average of 235.3 mg/l and a peak of 573 mg/l upstream of the Mbal watercourse. These levels were well above the WHO standards. This high concentration of SS indicated significant pollution that can be attributed mainly to artisanal mining activities in the locality; we will quote, in particular, the large excavations, the clearing of forests, and the loading of mounds of waste rock on the bed of the river which traps the sediments. In addition, runoff comes loaded with sediment. These results corroborated those of Simo [15]. This high level of SS resulted in low oxygen concentration and low transparency Traore et al. [19]. This reduced the penetration of light into the water and increased the turbidity of the watercourse, hindering photosynthesis, which is responsible for the production of organic matter in aquatic life [20].

The observed concentrations of turbidity were evolving along with the suspended solids in a graded manner, with a peak of 468 NTU observed upstream and an average of 168.5 NTU. These levels were above WHO standards and indicate the presence of high levels of suspended particles in these wastewater. These results correlated with those of Bamba [6] on the Bonikro gold mine, Sawadogo [11] on the Fofona site and those of Simo [15] on the Mari mine site in Betare-Oya. As an impact, the disappearance of certain aquatic species was observed by asphyxia which was caused by the lack of oxygen in these waters and the major impact would result in the treatment of this water for the supply of drinking water in this locality which would require advanced equipment that would be expensive. It was also important to note that these high levels inhibited photosynthesis, which was the main source of organic matter for these aquatic organisms.

The recorded colour values were well above the WHO standards, which was indicated at 15 Pt-Co/l. The colour contents had an average of 1603.3 Pt-Co/l and varied from one sample point to the other. The discharge of wastewater from a mining company and the upstream of the river had high colour rates respectively 1008 Pt-Co/l and 3683 Pt-Co/l, which was explained by the fact that at the exit of the company, the wash water matched the colour of the parent rock in place.

The results of the analysis of major cations and anions presented in Table 1 show that the major ions (Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}, F^-, Cl^-, NO^{3-}, PO_4^{3-}, SO_4^{2-}, HCO^{3-}) can be considered eligible and above all had no impact on the quality of this wastewater. The hydrochemical study revealed the predominance of the bicarbonate ions with the main facies, the bicarbonate-calcium-magnesium facies. This result was in line with that found by Simo [15]. The dominance of bicarbonate facies in basement water was related to the origin of the production of bicarbonate ions [21]. The bicarbonates were in fact produced essentially by the silicate weathering during the acquisition of the salt load of the water in the aeration zone. The dominant major cations associated with bicarbonate ions were in order of average levels: HCO^{3-} (13.1 mg/l)> Ca^{2+} (2.5 mg/l)> Na^+ (2.25 mg/l)> K^+ (1.55 mg/l)> Mg^{2+} (0.95 mg/l)> NO^{3-} 0.7 mg/l)> SO_4^{2-} 0.35 mg/l)> Cl^- 0.15 mg/l)> F^- (0.13 mg/l). These different ions came from the alteration of bare rocks following the general hydrolysis of the rocks.

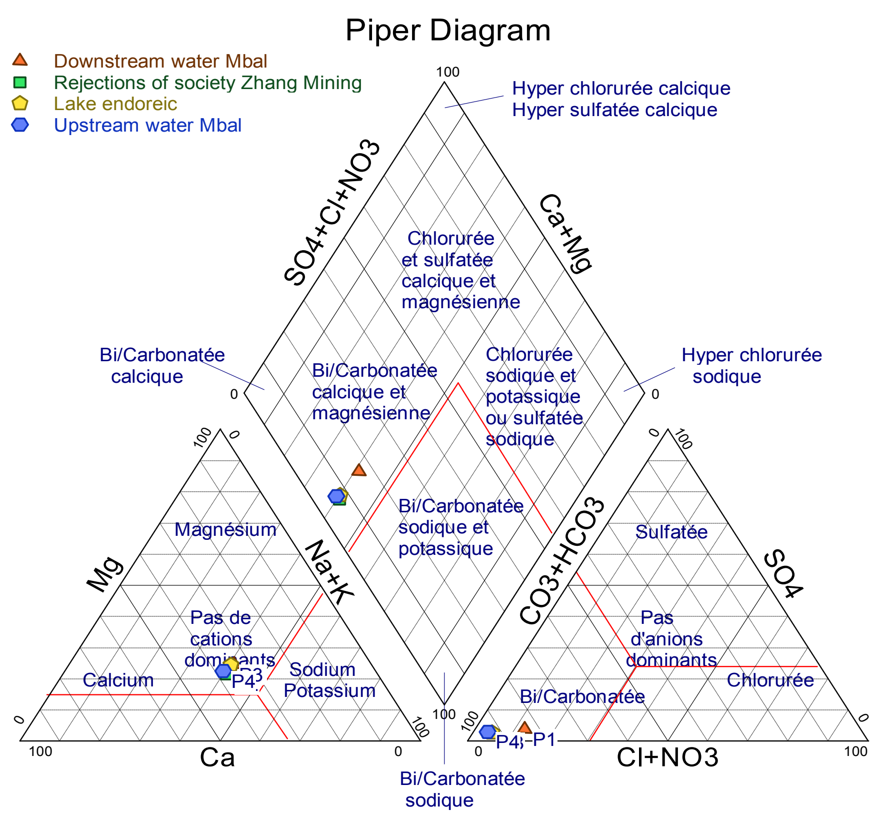
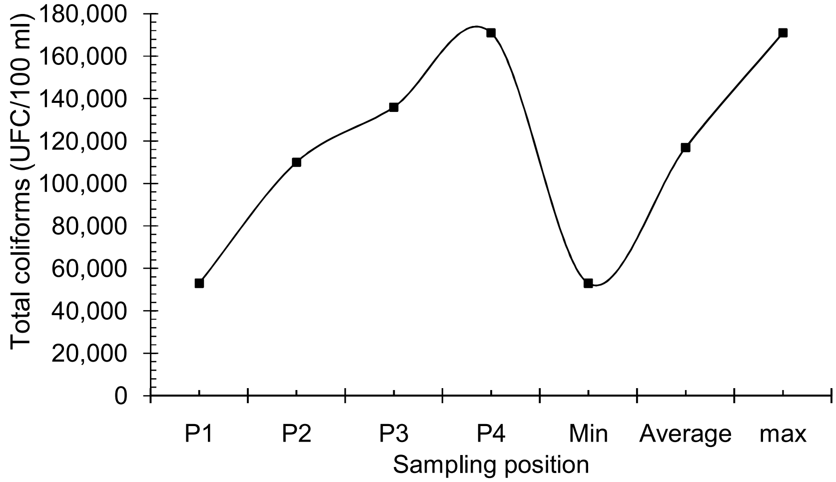


Fig. 4. Hydrochemical classification of Mbal stream wastewater



Legend: P1: Downstream Mbal watercourse; P2: Point of rejection; P3: Endorheic lake; P4: Upstream Mbal watercourse

Fig. 5. Concentration of total coliforms in artisanal mineral wastewater along the Mbal watercourse

In the wastewater of the study area, analysis of heavy metals (mercury, zinc, lead, cadmium and nickel) indicated levels below the detection limits of the plasma emission spectrometric determination technique.

Bacteriological analysis showed the presence of high levels of total coliforms in the wastewater. All the points sampled had high levels of total coliforms and these levels were gradually evolving with an average of 117×10^3 CFU/100 ml and a peak of 171×10^3 CFU/100 ml upstream. These results were found during the work of Sawadogo [11] on the Fofora mine site. The origin of coliforms could be attributed mainly to the artisanal mining of minerals on the water resource, which, through the deposits of mounds of waste rock and tailings on the bed of the watercourse, had consequences for the latter. We had, in particular the decrease of its flow which favoured the main activity of the locality (cattle breeding) to develop. Pastoralists used these low-flow stream and lake to water their herds of cattle, resulting in direct loading of animal faeces in this water. The lack of a sanitation system in the mining villages added to this. With coliform levels higher than the WHO standards, artisanal mineral wastewater in the Betare-Oya locality was contaminated and unusable for domestic and nautical uses, and presented a real danger to the populations of this area.

5. CONCLUSION

The interaction between the artisanal mining of gold ores and the deterioration of the quality of water resources was at the heart of the crisis of the situation of contaminated sites in the village of Betare-Oya in East Cameroon. The results of the physicochemical analysis of wastewater from contaminated sites showed that pH, temperature, electrical conductivity, major ions, and heavy metals considered eligible by WHO standards and posed no major hazard. It should be noted that wastewater from contaminated sites of Betare-Oya showed high concentrations of suspended solids, turbidity, colour and total coliforms. The presence of these pollutants indicated a contamination and a serious pollution of these sites which constitute, without a doubt a threat for the local populations which draw the water necessary for the majority of their needs.

ACKNOWLEDGEMENTS

The authors express their sincere thanks to the National Advanced School of Public Works, and to the National Advanced School of Engineering of the University of Yaounde I for their collaborations.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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