Environmental Impact of Mine tailings from the Betare-Oya Gold Area (East Cameroon) On Surface water Sources

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Abstract

Trace elements are regarded as an important contaminant of the environment, if present in amounts exceeding natural concentrations. This study aimed at determining the environmental impact of mine tailings from the Betare-Oya Gold Area (East Cameroon) on surface water Sources using trace element pollution indices and physicochemical parameters. Surface waters are tested in-situ for (pH, electrical conductivity, and total dissolved solids) and chemically by the determination of trace elements (Cu, Zn, Ni, Mn, Fe, Cr, As, V, Cd, Co, Ba, Li, Au, Sr, and Pb). The results of physicochemical parameters reveal that waters of this gold mining zone are slightly acidic to alkaline (5.92-9.52), mineralized (4-332 μs/cm), and made up of total dissolved solids (2.68-222.4 mg/L). The determination of trace elements in water samples shows that manganese, gold and lead concentrations are above the World Health Organization limits. This indicates pollution. The pollution indices of surface waters from Betare Oya were characterized by DC as considerable degree to very high degree of contamination, PLI<1 indicates that there is no pollution while Igeo indicates moderate to extreme pollution. The government and other stakeholders could implement measures to prevent trace element pollution as a matter of urgency, particularly in relation to Mn, Au, and Pb whose concentrations are above permissible limits.

Keywords: Pollution indices, Mine tailings, Surface water, Betare-Oya, Cameroon

1.1 Introduction

Water quality is a fundamental component of the water supply system [1], which must meet requirements for public, commercial, and industrial activities [2].

The consumption of water with unfit quality has the potential to result in bad effects. Hence, it is important to understand the quality of the water resource before use [3]. According to [4], out of roughly 200 million people that reside in sub-Saharan Africa, approximately 60–90% of them mainly rely on groundwater for living.

In developing countries, lack of access to clean drinking water adversely affects the population's general health and life expectancy [5]. Clean surface water is radically subordinate, and people are devoted to groundwater sources [6]. Due to rapid population growth, urbanization, agricultural fertilizers, and planting industrial waste, drinking water quality in many cities and rural areas is affected [7]. The health-hazardous nature of these primarily depends on the concentration of the toxicants present in the drinking water, which has gained the attention of national regulatory agencies and the WHO [8]. The human health risk from unsafe drinking water is due to prolonged exposure to chemicals present in the drinking water [9].

Water is at the center of all socioeconomic processes, regardless of the level of development of society. Increasing mining activities are putting increasing pressure on the planet's fresh water supplies. Indeed, these activities generate a wide variety of chemicals which flow into the water cycle, endangering the fragile natural balance which has allowed life to develop on Earth. Often, the chemicals in wastewater are difficult to biodegrade, and the lack of treatment systems leads to their accumulation in the water cycle [10]. Extraction of solid minerals has been identified as a major entry point for heavy metals into the environment, thereby polluting various environmental components such as soil, water, and air [11]. In the process of extracting particular metal, the entire mass of soil is excavated and exposed to environmental agents of weathering, degradation, and transport, which leads to soil erosion and significant contamination of surrounding areas. As in most developing countries, Cameroon has seen great progress in gold mining, mainly in the Adamawa and Eastern regions (Batouri, Colomines, Yokadouma, Meiganga, and Betare-Oya [12].

In the latter case, the gold sites are exploited in an artisanal to semi mechanized manner, thus predisposing surface waters to serious environmental pollution [13]. The mining perimeter of

Betare-Oya is chosen as the study area because of artisanal and semi mechanized anarchic mining operations and subject to such pollution risks. Solid, liquid, physical, and chemical waste resulting from artisanal activities and the semi mechanized exploitation of gold deposits in the region could lead to the degradation of the water quality of the region and even of the Sanaga whose Lom is a tributary.

Several studies have been conducted on the impacts of industrial, artisanal, and semi mechanized mining on water resources and their contamination by heavy metals [14–16]. These works support the fact that the release of heavy metals in surface water is mainly due to the alteration of tailings and waste rock. In Cameroon, very few studies have been carried out on the physicochemical characterization of the waters and sediments of a mining operation. Some authors [12, 17, 18] studied the impacts of gold mining exploitation on the surface water quality.

The main objective of this study is to characterize, physically and chemically, surface water and sediments in the gold mining environment of the study area in BetareOya (East Cameroon)

1.2 Description of Study Area

The Betare-Oya gold district is located in the eastern region of Cameroon, Lom and Djerem Department. It extends in the Sanaga basin. The study area is located in Bangbel and Koumbokoro (Figure 1). The climate of this area is equatorial type with four seasons (wet, wet-dry, dry and dry-wet seasons) with some variations which are particular to them due to the location at the foot of the Adamawa Plateau. The study areas are watered by two main rivers: the Lom and the Pangar. These two rivers receive water from a large network of small rivers, the most important of which are Mba, Mari, Mbal, and Kpawara (Figure 1). The hydrologic regime of the river Lom in Betare-Oya is controlled by rainfall.
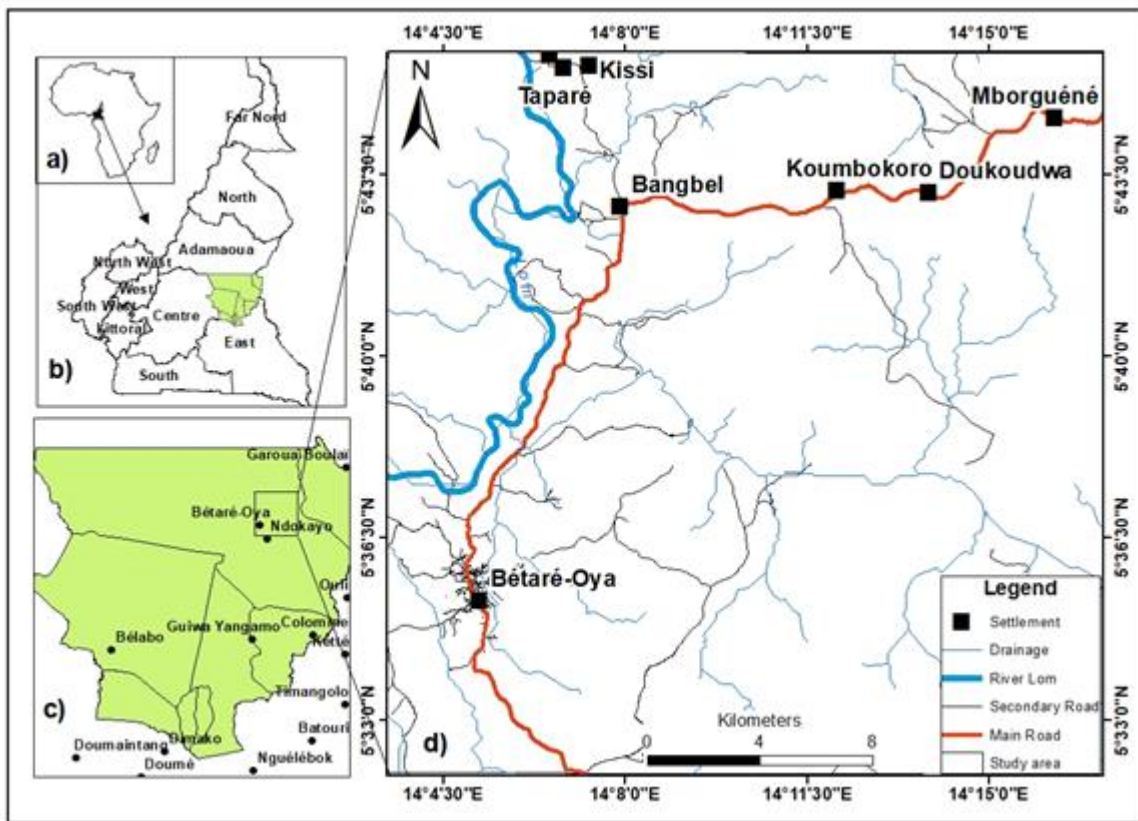
Figure 1: Location of the study area

1.3 Geology of the study area

Betare Oya is part of the Neoproterozoic (700 - 1100 Ma) volcano-sedimentary formations of Cameroon known as the lower Lom series [19] [20]. The Lom Series is made up of a NE-SW discontinuous narrow belt comprising of a Lower and Upper Groups [21]. It represents a syn-tectonic pull-apart basin associated with the Sanaga shear zone and was deposited between 613 and 600 Ma [22]. The Lower and Upper Lom Series is made up of metatuffs, volcanoclastic and sedimentary derived schists, staurolitegarnet mica schists and quartzites with local conglomerate layers [22]. The schists were metamorphosed under greenschist facies conditions [21]. The volcanoclastic rocks are felsic to intermediate in composition [20]. The lowpressure (garnet-andalusite-staurolite assemblage) regional metamorphism that was associated with transpressive tectonics in the Lom Series involved a high thermal gradient related to widespread crustal melting that produced the dominant S-type granitoids in the region [22].

These formations occur discordantly on the Pan-African basement made up of migmatites and granitic to ortho-gneissic and biotite rich rocks (Figure 2). They are confined to the NE-SW trending shear zones as part of the Central African and Cameroon shear zone system [23] along which granitic plutons are common. The Betare Oya gold field is found within a major shear

zone that represents extentional relays, oblique to the Sanaga fault line. This structure is transtentional situated within grabens and horsts formed during sinistral shearing, displaying features similar to those of pull-apart basins [24].
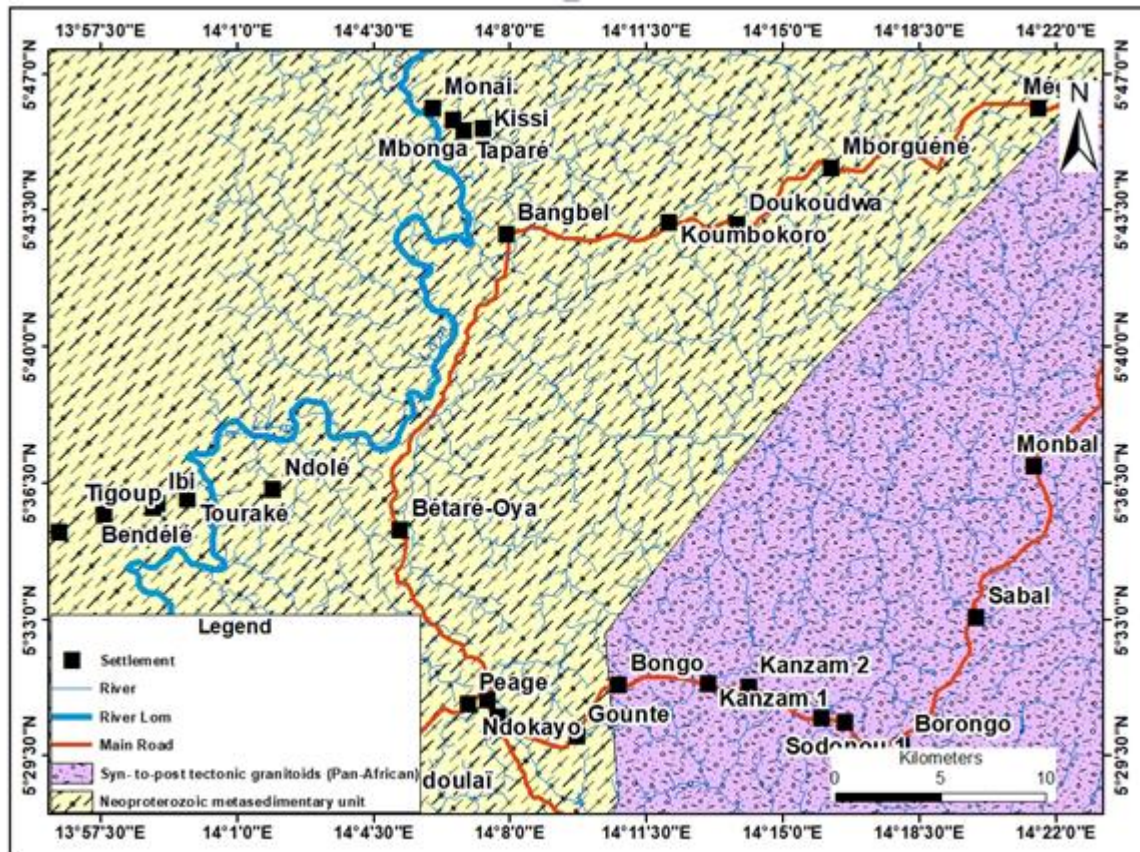

Figure 2: Geologic map of the study area

2.1 Materials and Methods

2.1.1 Field measurements

Ten surface waters were tested in-situ for: electrical conductivity (EC), pH, total dissolved solids (TDS) and Temperature (^{o}C).

2.1.2 Laboratory Measurements

Prior to sampling, the pre-cleaned sample bottles were rinsed with sample water. Water was withdrawn with the use of a 50 ml syringe, and then filtered through the 0.2 µm mixed cellulose ester filter into 50 ml high-density polyethylene HDPE containers. The sample was preserved by

acidifying to pH < 2 by adding nitric acid and sealed using a permanent tape. The samples were labeled and put into the sample bottle collection bag. Ten (10) filtered water samples were later shipped to the Activation laboratory in Canada for trace metal analysis by Inductive Coupled Plasma Mass Spectrometer ICP-MS.

Table 1: Field Equipment, Softwares, their specifications and functions used in the study

Equipment/Softwares	Specifications	Functions
Syringe	50 Ml, 100 Ml Polystyrene	Acidification and filtration of sample
Nitric acid	98% Pure Nitric Acid	Sample preservation by acidifying to pH < 2
Filter	Cellulose Ester Filter 0.2µm	Filtration of sample
Sample bottles	Polyethylene (HDPE) 50ml	To hold sample for onward transmission to laboratory
Sealing Tape and marker	Permanent Tape and marker	Sealing of sample bottle and labeling for transmission to the laboratory
IBM SPSS Statistics	Version 24.0	Statistical analysis for PCA
Global Mapper	Version 11	GIS Geolocation of surface water
Surfer Golden Software	Version 12	Map production

2.2 Trace element pollution indices

Pollution indices are estimated for a specific use of water under consideration. Some of these trace element pollution indices include: Degree of contamination, Pollution load index, and Geo-accumulation index as in Table 2.

Table 2: Parameters and formulae of pollution evaluation indices for trace elements

Trace element pollution indices	Formulae	Reference
Degree of Contamination	$DC = \sum_{i=1}^{n} C^i_f$	[25]
pollution load index	$PLI = \sqrt[n]{C_{f1} \times C_{f2} \dots C_{fn}}$	[26]
Geo-accumulation index	$I_{geo} = \log_2 [C_i / (1.5 C_{ri})]$	[27]

3.1 Results and Discussion

3.2 Physicochemical Parameters

Physicochemical results of water samples are presented in Figure 3, 4, 5 and 6. pH values range from 5.92 to 9.52(Figure 3) indicating that the water is slightly acidic to alkaline. These values are not in agreement with the range of values recommended by [28] standard. This slightly acidic to alkaline nature is attributed to the presence of sulfides, in particular the pyrite

accompanying the gold, the hydrolysis of which acidifies the environment. Such pH ranges systematically induce an increase in the rate of absorption of trace elements in surface sediments. The slightly acidic nature of the water sources could also be linked to the formation and dissolution of minerals and also influenced by biochemical processes in solution [29].

Electrical conductivity (EC) is one of the most important properties for controlling the quality of water. It reflects the degree of overall mineralization and provides information on the salinity rate. The electrical conductivity values range from 4-332 μS/cm and are below the standard value of [28] (Figure 6) for all the samples. This indicates that waters are mineralized [30]. This could be due, on the one hand, to the time of contact with sediments and soils which is much longer and, on the other hand, to the exposure of mine tailings, so leaching is more pronounced.

The TDS values ranged between 2.68- 222.4 mg/L (Figure 5). This TDS could be as a result of heavy run-off at the peak of the rainy season, infiltration, percolation from dumpsites, agricultural activities, abattoirs, domestic waste and leachates located near the water sources. Temperature values ranged between 23.8- 28.7°C (Figure 4). This low to high temperature might unfavorably retard dissolution of oxygen and therefore, could amplify odour due anaerobic reaction, with which the water conceivably unfavorable for drinking.
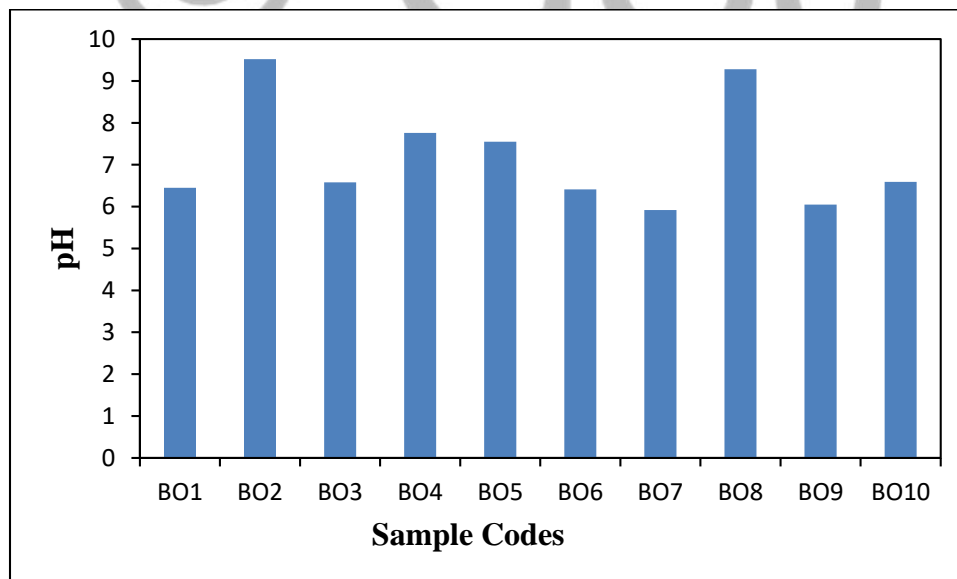

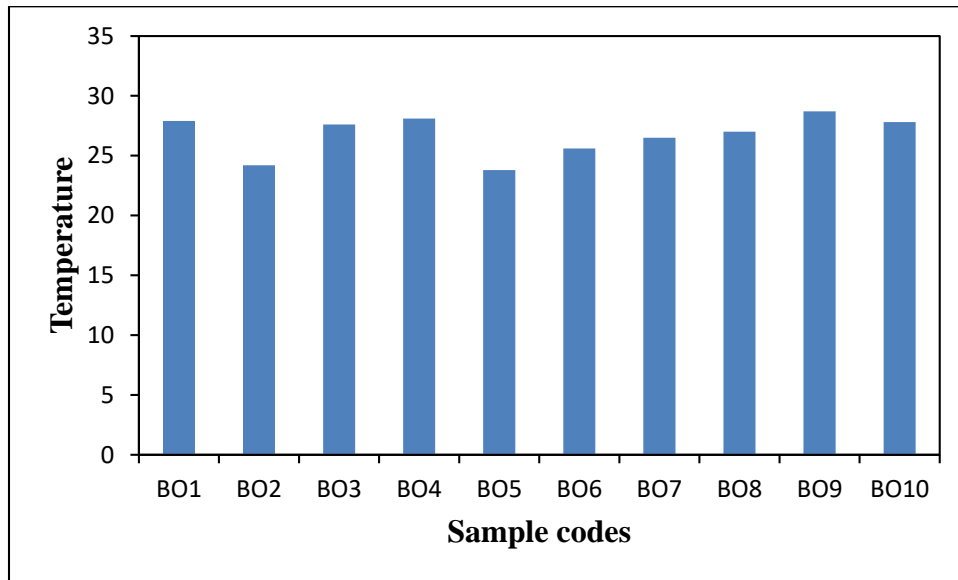Figure 3: Spatial variation of pH in surface water of Betare Oya

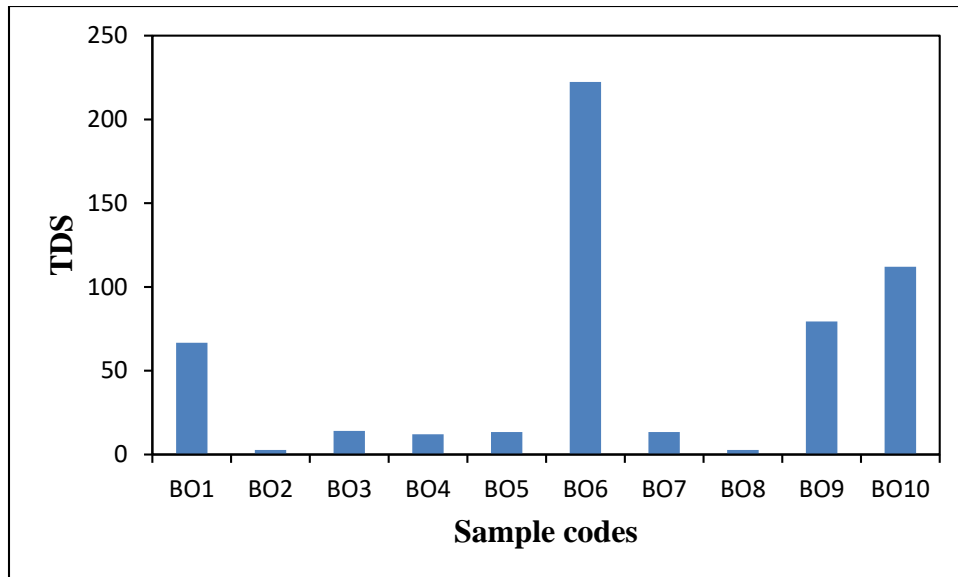Figure 4: Spatial variation of temperature in surface water of Betare Oya

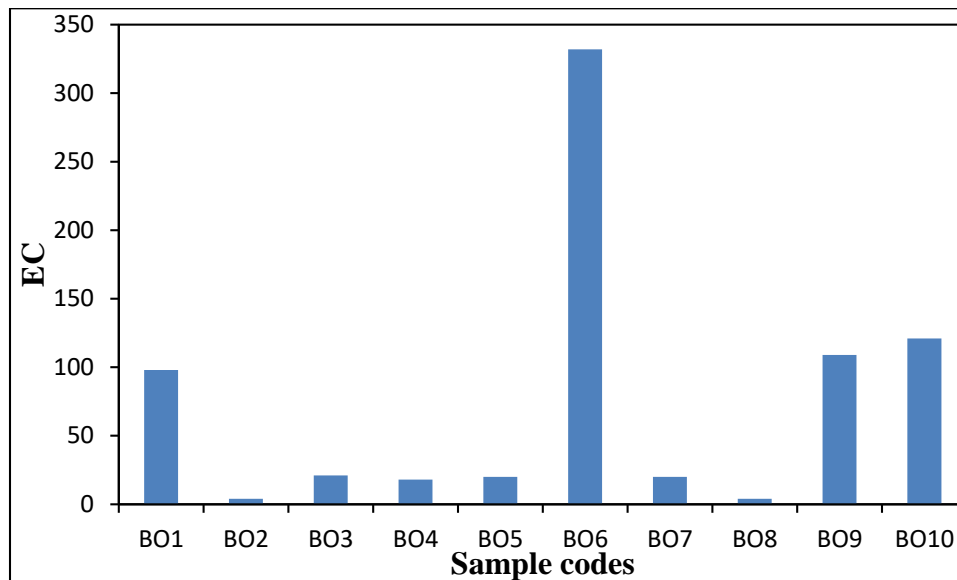Figure 5: Spatial variation of TDS in surface water of Betare Oya

Figure 6: Spatial variation of EC in surface water of Betare Oya

3.3 Pollution Indices

3.3.1 Degree of Contamination (DC)

The degree of contamination (DC) was used as reference of estimating the extent of metal pollution. The DC values in the study area ranged from 38.38 to 46.63 (Table 3). The surface waters from Betare Oya were characterized by DC as considerable degree to very high degree of contamination.

Table 3: Summary classification of Betare Oya surface water based on degree of contamination

Sampling	Cfi														DC
	Au	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Sr	Cd	Ba	Pb	
BO1	49	-0.79	-0.56	2.56	-0.999	-0.55	-1	-0.9914	-0.9842	-0.99	-0.999	-0.99	-0.691	3.68	45.73
BO2	49	-0.82	-0.48	2.78	-0.999	-0.56	-1	-0.9941	-0.9858	-0.99	-0.999	-0.987	-0.647	2.18	44.55
BO3	49	-0.72	-0.5	2.88	-0.999	-0.57	-1	-0.9938	-0.9852	-0.99	-0.999	-0.963	-0.504	2.89	45.59
BO4	49	-0.9	-0.76	-0.036	-1	-0.89	-1	-0.9966	-0.9931	-0.99	-0.999	-0.99	-0.814	-0.29	38.38
BO5	49	-0.91	-0.82	-0.098	-1	-0.87	-1	-0.9973	-0.9935	-0.99	-0.999	-0.993	-0.864	-0.08	38.41
BO6	49	-0.93	-0.84	0.136	-1	-0.87	-1	-0.9962	-0.9933	-0.99	-1	-0.993	-0.859	0.64	39.33
BO7	49	-0.92	-0.84	-0.42	-1	-0.89	-1	-0.9973	-0.9947	-0.99	-0.999	-0.997	-0.829	0.51	38.66
BO8	49	-0.79	-0.52	3.14	-0.999	-0.66	-1	-0.996	-0.9858	-0.99	-0.999	-0.997	-0.769	2.96	45.43
BO9	49	-0.88	-0.58	2.96	-0.999	-0.6	-1	-0.9948	-0.9845	-0.99	-0.999	-0.993	-0.69	2.38	44.66
BO10	49	-0.76	-0.34	3.26	-0.999	-0.63	-1	-0.9943	-0.9855	-0.99	-0.999	-0.963	-0.637	3.62	46.63

3.3.2 Pollution load index (PLI)

Pollution load index is a quick tool in order to compare the pollution status of different places [31]. The PLI values ranged from -6.33 to 0.407 as in table 4. The values of pollution load index are <1 which is indicative that there is no risk of pollution in Betare Oya. According to classification of [25] all of the samples have PLI<1 indicating that there is no pollution. According to [32], PLI > 1

indicates the need of immediate intervention to prevent pollution. The results showed that trace element show no pollution risk.

Table 4: Summary Classification of Betare Oya surface water based on pollution load index

Sampling	Cfi														PLI
	Au	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Sr	Cd	Ba	Pb	
BO1	49	-0.79	-0.56	2.56	-1	-0.55	-0.964	-0.99	-0.98	-0.99	-1	-0.99	-0.7	3.68	-5.104
BO2	49	-0.82	-0.48	2.78	-1	-0.56	-0.95	-0.99	-0.99	-0.99	-1	-0.99	-0.6	2.18	-2.747
BO3	49	-0.72	-0.5	2.88	-1	-0.57	-0.959	-0.99	-0.99	-0.99	-1	-0.96	-0.5	2.89	-2.693
BO4	49	-0.9	-0.76	-0.036	-1	-0.89	-0.964	-1	-0.99	-0.99	-1	-0.99	-0.8	-0.3	-0.017
BO5	49	-0.91	-0.82	-0.098	-1	-0.87	-0.976	-1	-0.99	-0.99	-1	-0.99	-0.9	-0.1	-0.015
BO6	49	-0.93	-0.84	0.136	-1	-0.87	-0.971	-1	-0.99	-0.99	-1	-0.99	-0.9	0.64	-0.168
BO7	49	-0.92	-0.84	-0.42	-1	-0.89	-0.974	-1	-0.99	-0.99	-1	-1	-0.8	0.51	0.407
BO8	49	-0.79	-0.52	3.14	-1	-0.66	-0.966	-1	-0.99	-0.99	-1	-1	-0.8	2.96	-6.333
BO9	49	-0.88	-0.58	2.96	-1	-0.6	-0.964	-0.99	-0.98	-0.99	-1	-0.99	-0.7	2.38	-4.832
BO10	49	-0.76	-0.34	3.26	-1	-0.63	-0.95	-0.99	-0.99	-0.99	-1	-0.96	-0.6	3.62	-3.798

3.3.3 Geo-accumulation Index

The geo-accumulation index (Igeo) is a quantitative measure of the degree of pollution in surface water (Singh *et al.,* 1997) [33]. Table 5 presents the geo-accumulation index for the quantification of trace elements accumulation in Betare Oya. The Igeo values ranged from 1.01 to 10.87 which are indicative that the water is moderately to extremely polluted as in table 6.

Table 5: Classification of Betare Oya surface water based on geo-accumulation index

Sampling	Cfi														Igeo
	Au	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Sr	Cd	Ba	Pb	
BO1	10	0.02	0.02	1.78	0.0034	0.005	0.003	0.017	0.08	1E-04	0.006	0.00003	0.02	0.05	1.179
BO2	10	0.02	0.03	1.89	0.0036	0.004	0.004	0.012	0.07	1E-04	0.004	0.00004	0.02	0.03	1.008
BO3	10	0.03	0.03	1.94	0.0037	0.004	0.003	0.012	0.07	1E-04	0.005	0.00011	0.03	0.04	10.865
BO4	10	0.01	0.01	0.48	0.0008	0.001	0.003	0.007	0.03	1E-04	0.002	0.00003	0.01	0.01	10.700
BO5	10	0.01	0.01	0.45	0.0007	0.001	0.002	0.006	0.03	1E-04	0.002	0.00002	0.01	0.01	10.636
BO6	10	0.01	0.01	0.57	0.001	0.001	0.002	0.008	0.03	1E-04	0.002	0.00002	0.01	0.02	10.577
BO7	10	0.01	0.01	0.29	0.0007	0.001	0.002	0.006	0.03	1E-04	0.005	0.00001	0.01	0.02	10.508
BO8	10	0.02	0.02	2.07	0.0034	0.003	0.002	0.008	0.07	1E-04	0.003	0.00001	0.02	0.04	10.444
BO9	10	0.01	0.02	1.98	0.0034	0.004	0.003	0.011	0.08	1E-04	0.003	0.00002	0.02	0.03	10.306
BO10	10	0.02	0.03	2.13	0.0034	0.004	0.004	0.012	0.07	1E-04	0.003	0.00011	0.03	0.05	10.161

Table 6: Classification of Betare Oya surface water based on pollution evaluation indices.

Index	Range	Classification	Samples	%
DC	20- 40	considerable degree of contamination	4	40
	>40	Very degree of contamination	6	60
PLI	<1	No pollution risk	10	100
Igeo	1-2	Moderately polluted	2	20
	>5	Extremely pollution	8	80

3.4. Trace elements in Water Samples

The concentration of trace elements is presented in Table 7, the concentrations of copper at sampling points are below the [34] standard. The presence of copper in water samples may also be due to soil leaching and the weathering of the chacopyrite.

Zinc concentrations are below the [34] standard. Sphalerite mineral is the main source of zinc. The dissolution of this mineral can contaminate surface water. Zinc concentrations are not elevated in gold zones [35].

Manganese concentrations are between 0.29 and 2.13 mg/L. This value is much higher than the [34] standard (0.05 mg/L).

The iron concentrations of the water samples vary from 0.001 to 0.003 mg/L. These values are below the [34] standard (0.3 mg/L). Iron is the most abundant element in the various water samples, as well as in the sediments and the geochemical bottom. Therefore, it has greater bioavailability. The presence of iron is due to the hydrolysis of the pyrite. Higher concentrations of iron are also observed in other gold zones [18].

Chromium concentrations are equal to 0.008 to 0.033 mg/L. These results are very far from the maximum admissible value set by [34] at 0.05 mg/L. The chromium is contained in most soils and rocks.

Arsenic levels are below the [34] standard at certain points as in table 7. The presence of arsenic in the waters of the study area could be due to leaching of the soil. The soils contain arsenic primary minerals resulting directly from the alteration of the bedrock in the subsoil where the most frequent species of primary mineralization are not only arsenopyrite (FeAsS), realgar (AsS), and orpiment (As_2S_3) but also niccolite (NiAs), cobaltite (CoAsS), tennantite ($Cu_{12}As_4S_{13}$), enargite (Cu_3AsS_4), proustite (Ag_3AsS_3), and native arsenic.

The lead concentrations are above the [34] standard. This indicates pollution. The main source of lead in nature is galena (PbS). The presence of lead in water samples mainly can also be due to the leaching of discharges from the farm. Lead fuels from mining machinery are a secondary source.

Table 7: Concentration of the trace elements analyzed.

Parameter	Concentration		WHO
	Min	Max	
Cu	0.0055	0.0173	2
Zn	0.0267	0.0792	3

Ni	0.0017	0.0035	0.02
Mn	0.29	2.13	0.05
Fe	0.00072	0.00371	0.3
Cr	0.008	0.033	0.05
As	0.0001	0.0001	0.01
Pb	0.0071	0.0468	0.01
Li	0.0001	0.0057	0.2
V	0.007	0.028	0.2
Co	0.0011	0.0045	0.01
Sr	0.0018	0.006	4
Cd	0.00001	0.00011	0.003
Ba	0.0095	0.0347	0.07
Au	0.00025	1	0.5

Conclusion

The objective of this paper was to carry out the environmental impact of mine tailings from the Betare-Oya Gold Area (East Cameroon) on surface water Sources. Results of the physicochemical parameters showed that the surface waters are slightly acidic to alkaline, and contained dissolved solids.

Trace element analyses of water samples revealed that copper, zinc, nickel, chromium, iron, Asenic, Lithium, vanadium, cobalt, strontium, cadmium and barium are below the thresholds defined by the World Health Organization standards. Trace elements such as manganese, gold, and lead particularly, were attracting attention because their concentrations that is above the thresholds admissible by the World Health Organization standards.

The presence of these metals can be due to the weathering of minerals and rocks present in the study area.

From the pollution indices, the surface waters from Betare Oya were characterized by DC as considerable degree to very high degree of contamination, PLI<1 indicating that there is no pollution and Igeo indicates moderate to extreme pollution.

References

[1] J. Brodie, A. Wenger, T. Morrison, R. Pressey, J. Day, A. Dale, A. Grech, "The Future of the Great Barrier Reef": the Water Quality Imperative 2019.

[2] J.A. Nathanson, "Water Supply System", Encyclopedia Britannica 2020.

[3] A. Fahad, R. Alan, E.E. Collins, "Drinking water quality impacts on health care expenditures in the United States". Water Resour. Econom. 32, 2212–4284 2020.

[4] E. Braune, S. Mutheiwana, "Towards sustainable utilization of the basement aquifers of the Southern Africa". WRC Report No.TT42809. In: Basement Aquifers of Southern Africa, pp. 104–113, 2009.

[5] B. Adelodun, F.O. Ajibade, J.O. Ighalo, et al. "Assessment of socioeconomic inequality based on virus-contaminated water usage in developing countries: a review". Environ Res.;192:110309, 2021.

[6] J.O. Ighalo, A.G. Adeniyi, G. Marques, "Artificial intelligence for surface water quality monitoring and assessment: a systematic literature analysis". Model Earth Syst Environ, 7:669-681, 2021.

[7] T. Behailu, T. Badessa, B. Tewodros, "Analysis of physical and chemical parameters in ground water used for drinking around Konso Area, Southwestern Ethiopia". J Anal Bioanal Tech. 2017;08:379.

[8] R. Shyam, G. Kalwania, "Groundwater chemistry: A case study of eastern part of Sikar city (Rajasthan), India". Int J Appl Eng Res. 2011;2:367-378.

[9] D. Marghade, D.B. Malpe, N. Subba Rao, "Applications of geochemical and multivariate statistical approaches for the evaluation of groundwater quality and human health risks in a semi-arid region of eastern Maharashtra, India". Environ Geochem Health. 2021;43: 683-70

[10] A. Cazenave and S. Nerem, "Geophysics: redistributing Earth's mass," Science, vol. 297, no. 5582, pp. 783-784, 2002.

[11] A. I. Tsafe, L. G. Hassan, D. M. Sahabi, Y. Alhassan, and B. M. Bala, "Assessment of heavy metals and mineral compositions in some solid minerals deposit and water from a gold mining area of Northern Nigeria," International Journal of Geology and Mining, vol. 2, no. 9, pp. 254–260, 2012.

[12] F. Rakotondrabe, J. R. N. Ngoupayou, Z. Mfonka et al., "Assessment of surface water quality of betar ´e-oya gold ´ mining area (East-Cameroon)," Journal of Water Resource and Protection, vol. 9, no. 8, pp. 960–984, 2017.

[13] N. J. R. Ngoupayou, J. G. Dzana, A Kpoumie et al., "Presentday sediment dynamics of the Sanaga catchment (Cameroon): from the total suspended sediment (TSS) to erosion balance," Hydrological Sciences Journal, vol. 61, pp. 1080–1093, 2016.

[14] M. K. Dorleku, D. Nukpezah, and D. Carboo, "Effects of small-scale gold mining on heavy metals levels in groundwater in the Lower Pra Basin of Ghana," Applied Water Science, vol. 8, p. 126, 2018.

[15] N. Gafur, M. Sakakibara, S. Sano, and K. Sera, "A case study of heavy metal pollution in water of bone river by artisanal small-scale gold mine activities in eastern part of gorontalo, Indonesia," Water, vol. 10, no. 11, p. 1507, 2018.

[16] C. B. Kofi, A. Ewusi, S Obiri-Yeboah et al., "Distribution of arsenic and heavy metals from mine tailings dams at obuasi municipality of Ghana," American Journal of Engineering Research (AJER), vol. 2, pp. 61–70, 2013.

[17] N. M. Ayiwouo, L. L. N. Mambou, J. R. Mache, S. T. Kingni, and I. Ngounouno, "Waters of the Djouzami gold mining site (Adamawa, Cameroon): physicochemical characterization and treatment test by Bana smectite (West, Cameroon)," Case Studies in Chemical and Environmental Engineering, 2020, In press.

[18] F. Rakotondrabe, J. R. N. Ngoupayou, Z. Mfonka, E. H. Rasolomanana, A. J. N. Abolo, and A. Ako, "Water quality assessment in the Betare-Oya gold mining area (EastCameroon): multivariate Statistical Analysis approach," Science of the Total Environment, vol. 611, pp. 831–844, 2017

[19] S.F. Toteu, W.R. Van Schmus, J. Penaye, and J.B. Nyobé, "U-Pb and Sm-Nd Evidence for Eburnean and Pan-African High-Grade Metamorphism in Cratonic Rocks of Southern Cameroon", Precambrian Research, 108, 45-73, 1994.

[20] S.F. Toteu, J. Penaye, and Y. Poudjom Djomani, "Geodynamic Evolution of the Pan-African Belt in Central Africa with Special Reference to Cameroon". Canadian Journal of Earth Sciences, 41, 73-85, 2004.

[21] S.F. Toteu, J. Penaye, E. Deloule, W.R. Van Schmus, & R. Tchameni, "Diachronous evolution of volcanosedimentary basins north of the Congo craton: Insights from U–Pb ion microprobe dating of zircons from the Poli, Lom and Yaoundé Groups (Cameroon) ", Journal of African Earth Sciences, 44, 428–442, 2006.

[22] V. Ngako, P. Affaton, J.M. Nnange, T. Njanko, "Pan African tectonic evolution in central and southern Cameroon: transpression and transtension during sinistral shear movements", Journal of African Earth Sciences, 36, 207–214, 2003.

[23] B. Deruelle, and J.M. Regnoult, "Carte Tele-interpretative des linéaments de la République Unie du Cameroun au nord du 4e parallele (1/1,000,000) ", Interpretation Map of Lineaments of United Republic of Cameroon at 4th Parallel (1/1 000,000).] Ministry of Mines and Energy Resources, DMG, Yaoundé, 1983.

[24] J. Gazel, V. Hourcq, and M. Nickles, Reference Notice on 1/1,000,000 Geologic Map of Cameroon. Service Bulletin of Mines and Geology, 2, Yaoundé, 1956.

[25] A.E. Edet, and O.E. Offiong, "Evaluation of water quality pollution indices for heavy metal contamination monitoring, A study case from Akpabuyo- Odukpani Area Lower Cross River Basin (Southeastern Nigeria) ", *Geo. J*. 57:295-304, 2002.

[26] P.S. Harikumar, U.P. Nasir, M.M. Rahman, Distribution of heavy metals in the core sediments of a tropical wetland system. International Journal of Environmental Science & Technology;6(2):225-232, 2009.

[27] Y. Ji, Y. Feng, J. Wu, T. Zhu, Z. Bai, and C. Duan, "Using geo-accumulation index to study source profiles of soil dust in China", Journal of Environmental Sciences, 20(5), 571– 578, 2008.

[28] World Health Organization Guidelines for Drinking-Water Quality. 4th Edition, Incorporating the First Addendum, Geneva, 2017

[29] J.K. Nduka, O.E. Orisakwe, "Water-quality issues in the Niger Delta of Nigeria: a look at heavy metal levels and some physicochemical properties". Environ. Sci. Pollut. Res.18:237-246 2011.

[30] M. Detay, Le Forage D'eau, R´ealisation, Entretien, R´ehabilitation, Masson, Paris, France, 1993.

[31] K.O. Adebowale, F.O. Agunbide, B. OluOwolabi, "Trace metal concentration, site variations and partitioning pattern in water and bottom sediments from coastal area: A case study of Ondo Coast, Nigeria", Environmental Research Journal; 3(2):46-59, 2009.

[32] T. Liaghati, M. Preda, M. Cox, "Heavy metal distribution and controlling factors within coastal plain sediments, Bells Creek Catchment, southeast Queensland, Australia", Environment International; 29:935–948. DOI: 10.1016/S0160-4120(03)00060-6, 2003.

[33] M. Singh, A.A. Ansari, G. I.B. Müller, Singh, "Heavy metals in freshly deposited sediments of the Gomati River (a tributary of the Ganga River): Effects of human activities", Environmental Geology; 29(3-4):246-252, 1997.

[34] World Health Organization, World Health Organization Guidelines for Drinking-Water Quality. Recommandations, World Health Organization, Geneva, Switzerland, 4th edition, 2011.

[35] Y. H. Yapi, B. K. Dongui, A. B.Y. S. S. Trokourey, Y. Essis, and P. Atheba, "Evaluation de la pollution m´etallique des eaux souterraines et de surface dans un environnement minier aurifere ` a Hir ` e (C ´ ote d'Ivoire)," ˆ International Journal of Biology Chemistry and Science, vol. 8, no. 3, pp. 1281–1289, 201