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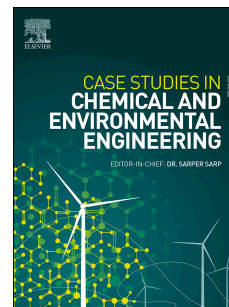
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Waters of the Djouzamigold mining site (Adamawa, Cameroon): physicochemical characterization and treatment test by Banasmectite (West, Cameroon).

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Abstract

This paperfirstly evaluates the influence of semi-mechanized artisanal gold mining in Djouzami (Adamawa, Cameroon) on the water quality of the site.Samples of runoff, stagnant water and sediments are collected in the study area. These waters are characterized from a physical (pH, electrical conductivity, turbidity and suspended solids) and chemical point of views. The results obtained show that the waters of the semi-mechanized artisanal gold mining site of Djouzami are slightly acid to neutral ($5.93 < pH < 7.02$), turbid ($46 mg.L^{-1} < SS < 200 mg.L^{-1}$) and polluted by inorganic substances. These include heavy metals such as Cd, Pb and Fe, which exceed the World Health Organization (WHO) standard. The correlation matrix is used to determinerelationshipexistingbetween the differentphysicochemicalparameters and heavymetals in water and sedimentsamples. Finally, this paper investigates the ability of Banasmectite (West, Cameroon) denoted BN 61to remove lead in aqueous medium. It appears that all the lead is adsorbed after adding 0.5 g of clay.

Keywords: Semi-mechanized artisanal gold mining, heavy metals, water, sediments, pollution, smectic clay, adsorption.

1. INTRODUCTION

In Cameroon, there has been more than a decade of increased expansion in small and medium-scale gold mining, particularly in the eastern and Adamawa regions, because of the rising price of the raw material on the world market and the discovery of many deposits.These exploitations are mainly concentrated in the placer and affect the water basins. However, these waters are often too mineralized to be directly usable for drinking water, and in some extreme cases, it is a source of important contamination of the environment [1]. James Lyon said "Water, the victim of mining" thus, the protection of water resources in mining areas becomes imperative for sustainable development. The respect and application of the standards, rules and laws governing the protection of water during mining activities would make it possible not to consider the exploitation of mineral substances as a nightmare for rivers.Physicochemical characterization works has been carried out around the world toevaluate the water quality [2] and specifically show the impact of mining on water resources. These studies weare investigated in Morocco in the abandoned Kettara mine [3] and the Zeida mine [4], in Bolivia in the Val Milluni [5], in Ivory Coast in the Bonikro gold mine [6] or in Ghana [7].They show that this activity also has (during or after) environmental consequences and can become a problem for the human and economic development of society living in this environment.Very few physicochemical characterization studies of water from mining operations have been investigated in Cameroon. Recently, a study was conducted on the assessment of the surface water quality of the Betare-Oya gold zone in the east region of Cameroon [8]. In the region of Adamawa, no study has been doneto the best of the authors knowledge.In rivers, the greatest risk of pollution is related to the presence of heavy metals. Metals are omnipresent in surface waters. However, their concentrations are generally very low, which explains why they are called "trace metals" or "metallic trace elements" (TM). TM are commonly found in the earth's crust. The alteration and erosion of rocks naturally feed surface water into TM [9]. At high concentrations, TM cause adverse effects in humans. As a result, the search for technologies to eliminate these metals in water requires a primordial issue.

During the last decades many researches have focused on adsorption techniques. This technology has already shown its potential in the treatment of inorganic pollutants (heavy metals as Pb (II) and Zn (II)) on water [10]. The adsorption has also the potential to remove toxic organic compounds, natural organic materials and volatile organic compounds. Compared to other technologies, it is an economical technology to remove heavy metals in water. Thus, the research is increasingly oriented towards treatment processes using natural materials less expensive and widely available [11] such as natural zeolites, volcanic ash and especially clays [12,

13].The application of natural and abundant adsorbents such as clay for the treatment of water is a legitimate way to preserve water capital. Clays remain to this day the natural adsorbent materials which have a high adsorption capacity [14] thanks to their high specific surface, their size and the presence of charge on their surface.For nearly three decades, many research projects have been conducted on clay materials from Cameroon and their potential for recovery. Some authors focused on talc [15], halloysite [16], smectites [17] and kaolinic clays, which nowadays have been the largest clay deposit in Cameroon [18-21]. In the context of valorization of local materials, this study is focus on the use of BanaSmectite (West, Cameroon) as an adsorbent in the process of elimination of heavy metals in aqueous medium.

The main objective of this study is to characterize physically and chemically the waters of the semi-mechanized artisanal gold mining site of Djouzami (Adamawa, Cameroon) and to carry out a test of elimination of lead by adsorption on the smectite of Bana (West, Cameroon).This work is organized as follows: the second section presents materials and methods. The third section presents results and discussions. The last section gives the conclusion which recalls the original results and the main contributions of this study.

2. MATERIALS AND METHODS

The study area is located in Djouzami in the region of Adamawa (Cameroon), Mbere department and the district of Meiganga at around 40 km from the city of Meiganga going to the east of Cameroon. It is precisely located at the east of Djouzami village and bounded by geographical coordinates A (6°14'31.91"N, 14°24'15.00"E), B (6°14'33.53"N, 14°26'22.43"E), C (6°12'36.16"N, 14 ° 24'15.41"E) and D (6°12'36.54"N, 14°26'22.02 "E). This locality belongs to the Mbere ditch. The study area is crossed by the Lom River. The location map of the study area is presented in figure 1.
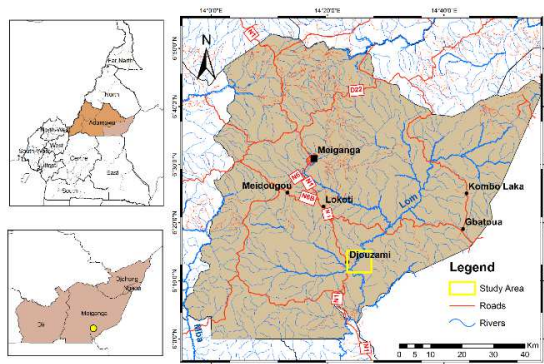

Figure 1: Location map of the study area.

2.1. Sampling, physicochemical parameters of waters and correlation matrix

Four samples of water are taken at different points of the site. **EAM** corresponds to the sampling upstream of the site on the Lom River; **ES** is the stagnant water; **EMS**corresponds to a sample taken in the middle of the site on the LomRiver and **EAV** corresponds to the sample taken downstream of the site.The sampling campaign was done on a sunny day and the flow of the Lom River was relatively average. Water samples are taken from plastic bottles at 30cm below the surface.Sampling of sediment is done at two points on the site. **SMS** corresponds to the sample taken in the middle of the site near Lom and **SES** corresponds to the sediment taken from a pit containing stagnant water. The map sampling of waters and
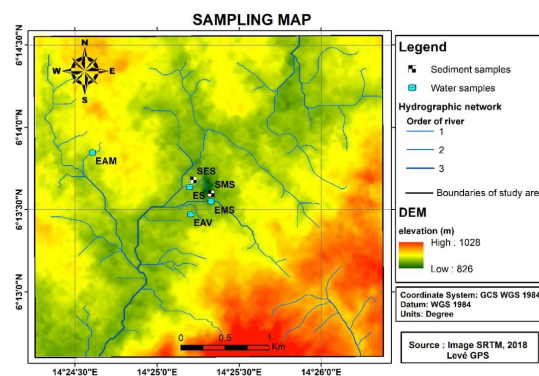
sediments is presented in figure 2.

Figure 2: Waters and sediments sampling map.

To characterize physically the water samples taken from the mining site, many parameters are determined among which are the pH, the electrical conductivity (EC), the turbidity (Tu) and suspended solids (SS). The pH analysis is carried out in the chemistry LaboratorySchool of Geology and Mining Engineering ofthe University of Ngaoundere, Cameroon. Conductivity, turbidity and SS are measured using the analytical protocols of the Chemical Engineering Laboratory of the University Institute of Technology of the University of Ngaoundere, Cameroon.The analysis of heavy metals is carried out at the International Institute of Tropical Agriculture Laboratory of Analysis of Yaounde by using atomic absorption spectrometry (AAS). The apparatus used is the Buck Scientific Atomic Adsorption Spectrometer 205. The analysed metals are copper, zinc, nickel, cadmium, lead and iron.Sediment samples (02) are analysed by portable XRF (Gemius 7000) to determine metal and trace element concentrations.

The correlation matrix used in the work is Pearson's correlation [22].

$$r = \frac{\sum(X-\bar{X})(Y-\bar{Y})}{\sqrt{\sum(X-\bar{X})^2}\sqrt{\sum(Y-\bar{Y})^2}}, \qquad (1)$$

where, $\bar{X}$ = mean of X variable and $\bar{Y}$ = mean of Y variable.

2.2. Characterization of smectite and its adsorption properties

In this study, the smectic clay is denoted **BN 61**. The analyzes techniques are used to define the physical properties ofsmecticclay are: Nitrogen adsorption

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volumetric analysis to determine the specific surface; determination of the cation exchange capacity (CEC) to estimate the theoretical cation binding power and determination of potential hydrogen (pH) to measure the acidity of a substance. It isdeterminedfrom the amount of hydrogen ions (H$^+$) or hydroxide ions (OH-) contained in the substance.The specific surface area and total pore volume of the sample aredeterminedfromnitrogen adsorption and desorptionisothermsat 77 K, obtainedfrom a Carlo Erba Sorptomatic 1990 volumetricdevice, afteroutgassing the samplesovernightat ambianttemperatureat a pressure lowerthan 10^{-4} Pa [23]. Thespecific surface area (SSA) iscalculatedfrom adsorption data by applying the Brunauer-Emmet-Teller (B.E.T) method. Cation exchange capacities (CEC) aremeasuredusingcobaltihexamine $[Co(NH_3)_6Cl_3]$ as exchangeable ions. The amount of cobaltihexaminefixed by the solid phase isdeterminedusing UV-visible spectroscopy. The displaced cations aredetermined by atomic absorption spectrometry (Perkin-Elmer 1100B). The equilibrium pH of clay suspensions are measuredusing an analyticalradiometer TIM 845.These parameters are measured following the laboratory protocol of the Research Unit Clays, Geochemistry and Sediment Environment (AGEs) of the University of Liege.

The XRD analysisisdone on a Bruker AXS model D8 Advancediffractometer, with Cu-Kα radiation, under 40 kV and 30 mA operating conditions, to identify the mineralogical phases of the bulkclaysample. The XRD patterns on the < 63 μm fraction arerecordedbetween 2° and 70° using a step scan 0.02° and a step time of 3 seconds. The test consists of saturating the < 2μm clay fractions with 2 M LiCl solution overnight. The Li-exchanged fractions arethenrinsedwithdemineralized water, and orientedaggregates have been prepared on glass slides. The XRD analyses on orientedclay fractions areconducted in sequence on the air-driedslide (N), heatedat 300°C (H300, 2H), and finallyovernightglycerolsolvated (Gl). A d spacing (001) reflectionat 9.6 to 10 Å, is indicative of montmorillonite (octahedralnegative layer charge), while a spacingat 16.7 to 17.7Å indicates beidellite (tetrahedralnegative layer charge).

Chemical analyses arecarried out usingemissionspectrometry. The samples aremolded in fused lithium borate (LiBO$_2$) and dissolved in nitricacid. The major elements aredetermined by Inductive Coupled Plasma by Atomic Emission Spectrometry (ICP-AES), while trace and rare earthelements Inductive Coupled Plasma by Mass Spectrometry (ICP-MS). Relative analyticaluncertainties areestimatedat 1-5% for major elementsexcept for P$_2$O$_5$ (10%). They are up to 5% for most of the trace element concentrations except for Cu (10%). However, uncertaintyis high (>10%) for any trace elementdisplaying a low concentration (<0.1ppm). This

analyses iscarried out atat the *Service d'Analyse des Roches et des Minéraux* (SARM Nancy-France).

The adsorption of lead is studied as a function of the adsorbent mass. The experiments are performed at ambient temperature. In a 125mL beaker, amount 0.1 to 0.5g of smecticclay are brought into contact with 50 mL of water containing lead of concentrations 0.089mg.L^{-1} and 0.2mg.L^{-1}. The samples are agitated for 1 hour using an IKA RT 5 magnetic stirrer at a temperature of 25°C and a speed of 800rpm.

3. RESULTS AND DISCUSSIONS

The physical analyses of the sampling waters are summarized in Table 1.

Table 1: Physical characteristics of the waters of the artisanal semi-mechanized gold mining site of Djouzami.

Parameters	Samples				WHO standard
	EAM	EMS	ES	EAV	
pH	6.59	6.73	5.93	7.02	6.5 < pH < 8.5
EC (μs.cm^{-1})	23.3	24.9	7.42	22.4	14μs.cm^{-1}
Tu (NTU)	38.23 ± 2.31	235.33 ± 4.73	265 ± 4.36	167 ± 5.29	5 NTU
SS (mg.L^{-1})	46	282	318	200	50 mg.L^{-1}

The water samples taken from the mining site have a pH ranging from slightly acidic to neutral. Table 1 shows that the samples EAM, EMS and EAV have a pH which is in agreement with the standard for a surface water in particular 6.5 < pH < 8.5 [24]. Sample ES has a slightly acidic pH which would indicate the presence of sulfates in this stagnant water. These values are similar to those observed at the mining sites in the Pra basin in Ghana and in south-eastern of Senegal [7, 25]. The conductivity values are above the standard value of the WHO (see Table 5) for the EAM, EMS and EAV samples. This indicates that waters are mineralized [26]. The different turbidity values (see Table 1) of the samples taken at the site are high compared to the WHO standard (5 NTU). This has been also observed in the auriferous zones and the mining sites of Bonikro, Betare-Oya and Amazonia [6, 8, 27]. The waters of the site have a trouble state. At the upstream of the site, turbidity is low (38.23 NTU), because that there is no exploitation activity. Turbidity increases at the points in the site (EMS and ES) and downstream (EAV) due to excavation, river diversion and ore washing. Suspended solids are related to turbidity. It is noted that upstream EAM, the value of the SS is relatively low and below the standard WHO (50 mg.L^{-1}) as shown in Table 1. For the samples in the mining activity area, the SS values are well above the WHO standard (see Table 1). This is due to deforestation, the

diversion of rivers and the washing of gold [28]. Thus, this reinforces the influence of mining activity.

3.1. Heavy metals in waters

The order of the average content of heavy metals concentrations in the waters of the exploitation site is: Cu < Zn < Ni < Cd <Pb< Fe.Figure 3 presents the spatial variation of copper concentration in the water samples.
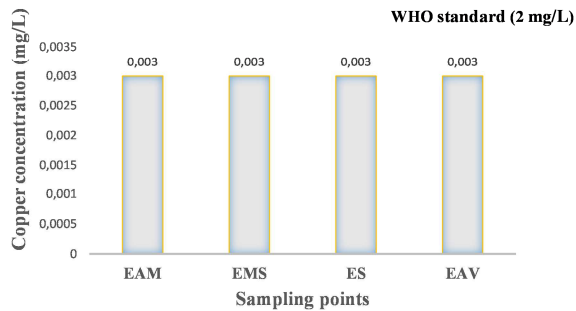
WHO standard (2 mg/L)

Figure 3: Spatial variation of copper concentration.

In figure 3, the concentrations do not vary according to the sampling points. They are below the WHO standard (2 mg.L^{-1}). The presence of copper in the water samples may also be due to soil leaching. The analysis of the sediment samples near the sampling points shows fairly high concentrations of copper (see Tables 2 and 3). The spatial variation of zinc concentration is presented in
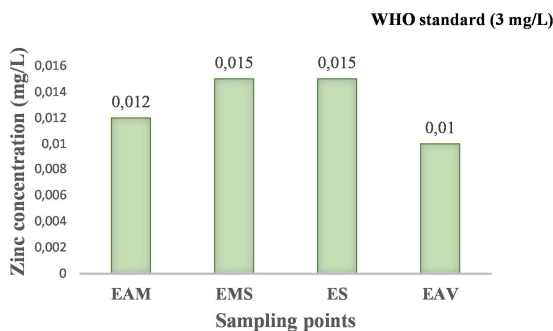
WHO standard (3 mg/L)

figure 4.

Figure 4: Spatial variation of zinc concentration.

Figure 4 shows that zinc concentrations are below the WHO standard which indicated a slight zinc contamination of the site water. Zinc concentrations are not elevated in gold zones [6, 8]. Natural sources of zinc in the environment are rock alteration, volcanism and vegetation [29]. In gold mining areas, zinc from sphalerite is most often associated with PbS galena [5]. The spatial variation of the concentration of nickel concentration is presented in figure 5.
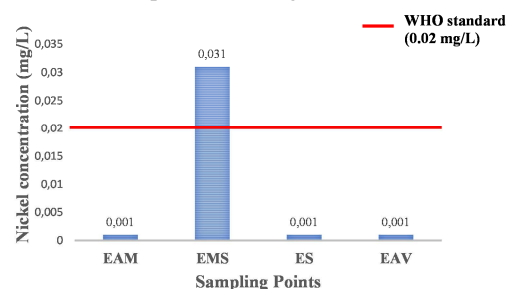
WHO standard (0.02 mg/L)

Figure 5: Spatial variationof nickelconcentration.

Figure 5 shows a peak in nickel concentration at the EMS sample. This concentration is higher than the standard of WHO (0.02 mg.L^{-1}) [24]. The presence of nickel in water samples may be due to soil leaching. The analysis of the sediment sample near the sampling points shows fairly

WHO standard (0.003 mg/L)
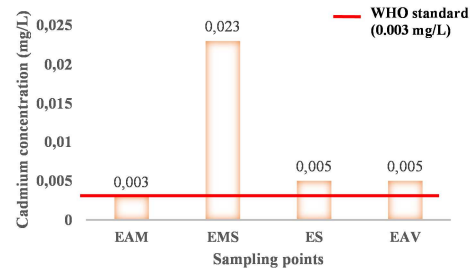
high concentrations of nickel (see Tables 2 and 3). Figure 6 presents the spatial variation of cadmium concentration in the sampling waters.

Figure 6: Spatial variation of cadmium concentration.

In figure 6, the cadmium concentrations are above the WHO standard (0.003 mg.L^{-1}) except for the upstream sampling point. Studies at Betare-Oya on the Lomriver (East, Cameroon) has also shown that concentrations are above the standard [8].Sphalerite is the main source of zinc and cadmium. Zinc is a trace element in sphalerite [30]. Cadmium is the most feared element because it is toxic, mobile, easily bioavailable and could either pass through the food chain through plants. Cd could come from Ni-Cd batteries used in gold mine sites [31, 32].The spatial variation of lead concentration is presented in figure 7

WHO standard (0.01 mg/L)
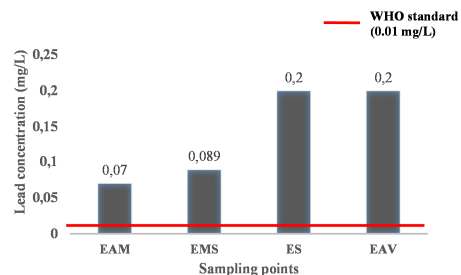
Figure 7: Spatial variationof lead concentration.

In figure 7, the lead concentrations are above the WHO standard at all the sampling points. This indicatesthe pollution. They are also higher than lead concentrations in the two gold zones of Bonikro and Betare-Oya [6, 8]. The main source of lead in nature is galena (PbS). The lead could be from the dissolution of this ore. In the presence of oxygen, galena can produce Pb^{2+} ions according to the equation: $PbS + 2O_2 \rightarrow Pb^{2+} + SO_4^{2-}$

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.Another source of lead is the leaching of lead in equipment used for ore washing and gold mining. Lead could come from the exhaust pipes of excavators or vehicles used at mining sites [32].

In figure 8, iron concentrations are above the WHO standard (0.3 mg.L^{-1}) at all sampling points indicating the pollution. They are higher than those obtained in the Bonikro gold mine in Ivory Coast [6] and in the Betare-Oya gold zone [8].Two origins may justify the presence of iron in the waters of the mining site. The first could be the dissolution of pyrite (FeS). In this type of mining, placer deposits come from a gold-bearing bedrock and most often this rock is accompanied by satellite minerals such as pyrite. Thus, during the deposit of gold quantities of pyrite (FeS) are present and the dissolution of this rock can contaminate the waters of the exploitation. During panning, the presence of iron oxide in the bottom of the panes is also observed.The second is the leaching of lateritic ferralitic soils with strong complexation with humic acids. Two types of soils are present in the study area, particularly ferruginous tropical soils (the majority) and ferralitic soils [33]. Studies have also shown that iron content is generally high in West African waters due to leaching of lateritic soils [34].The spatial variation of iron concentration is presented in figure 8.

Figure 8: Spatial variation of iron concentration.
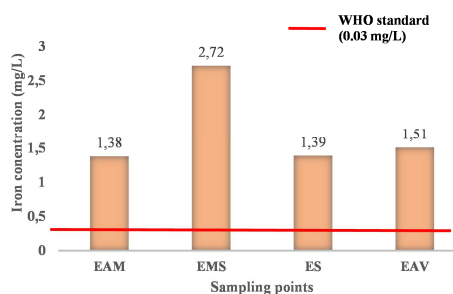
3.2. Heavy metals in the sediments

The concentrations of heavy metals determined in sedimentsare compared to the WHO standard (Tables 2 and 3).

Table 2: Heavy metals content (ppm) in the sediment collected in the middle of the site (Lom).

Elements	Cu	Zn	Ni	Cd	Pb	Fe
Concentration (ppm)	8	27	39	0	17	31384
WHO standard (ppm)	30	90	50	0.35	35	/

Table 3: Heavy metal content (ppm) in the sediment taken from the stagnant water pit.

Elements	Cu	Zn	Ni	Cd	Pb	Fe
Concentration (ppm)	13	38	38	0	0	37357
WHO standard (ppm)	30	90	50	0.35	35	/

In Table 2, the concentrations are below the limits set by WHO.The concentrations of Cu, Zn and Niare below the WHO standard are shown in Table 3. There is no lead and cadmium in the sample taken from the stagnant water pit.

3.3. Correlation matrix

The correlation between elements determined in water are presented in Table 4.

Table 4: Correlation matrix between parameters determined in water.

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Variables	pH	EC	Tu	SS	Zn	Ni	Cd	Pb	Fe
pH	1	0.788	0.151	0.153	0.473	0.055	0.049	0.047	0.090
EC	0.788	1	0.282	0.283	0.188	0.196	0.153	0.410	0.224
Tu	0.151	0.282	1	1.000	0.388	0.152	0.222	0.291	0.160
SS	0.153	0.283	1.000	1	0.389	0.151	0.221	0.291	0.159
Zn	0.473	0.188	0.388	0.389	1	0.296	0.304	0.032	0.234
Ni	0.055	0.196	0.152	0.151	0.296	1	0.990	0.234	0.992
Cd	0.049	0.153	0.222	0.221	0.304	0.990	1	0.154	0.992
Pb	0.047	0.410	0.291	0.291	0.032	0.234	0.154	1	0.191
Fe	0.090	0.224	0.160	0.159	0.234	0.992	0.992	0.191	1

The relationship between heavy metals in water and sediment samples are illustrated in Table 5.

Variables	Cu	Zn	Ni	Cd	Pb	Fe
Cu	1	0.994	0.913	0.268	0.147	0.969
Zn	0.994	1	0.952	0.278	0.207	0.990
Ni	0.913	0.952	1	0.290	0.408	0.985
Cd	0.268	0.278	0.290	1	0.116	0.287
Pb	0.147	0.207	0.408	0.116	1	0.291
Fe	0.969	0.990	0.985	0.287	0.291	1

Table 5: Correlation matrix between heavy metals present in water and sediment.

In Table 4, high correlations are obtained between physical parameter, such as pH and EC (0.788). Turbidity also has a high correlation with SS (1). This correlation is attributed to physical pollution, which probably originated from the erosion of mining wastes (tailings) and discharge of wastewater from gold washing into the rivers. The values of Tu and SS are above the WHO Standard (see Table 1). For the heavy metals, the matrix correlation obtain indicated high correlations between Ni/Cd (0.990). Ni and Cd come from Ni-Cd batteries used in this gold mine site. They are also high correlations between Ni/Fe (0.992) and Cd/Fe (0.992). These elements can sometimes be derived from geological units, for example Cd exists in spharelite (ZnS) accompanied by Zn; iron is linked to the oxidation of sulfide minerals (FeS_2 pyrite, arsenopyrite$FeAsS$) or rocks containing gold bearing ores [35].

The correlations are also observed between heavy metals in water and sediment samples (see Table 5). High correlations is obtained between Cu/Zn (0.994), Cu/Ni (0.913) and Cu/Fe (0.965). The origincanbefrommining tailingsdepositedalong the Lom river. Table 5 shows high correlationsbetween Zn/Ni (0.952), Zn/Fe (0.990) and Ni/Fe (0.985). Theseelements are present in the composition of the sediments (see Tables 2 and 3). In the water samples, the presence of theseelementscanbe due to soilleaching. The significantcorrelation observe betweentheseparameterssuggestthat the origincanbe the miningactivity or fromgeological formations.

3.4. Lead adsorption by smectite

The physical characteristics of Banasmectic clay are presented in Table 6.The choice is focused on the adsorption of lead because it is the most dangerous between all heavy metals analyzed. In addition, it is a not essential metal for living organisms and its concentrations are above the WHO standard at all the sampling points compared to cadmium.

Table 6: Physical characteristics of Bana clay (smectite).

Parameters	Surface of micropores ($m^2.g^{-1}$)	Surface off micropores ($m^2.g^{-1}$)	Total specific surface area ($m^2.g^{-1}$)	Cation Exchange Capacity(CEC)	pH

BN 61	38.2	49.4	82.3 ± 2.8	49	5.1

In Table 6, the claysample has acidicequilibrium pH.Thecobalitihexane method revealed CEC value 49 meq/100 g. The specific surface area of the sample is 49.4 m^2.g^{-1}. This high specific surface areaconfirms the high smectite mineral content in this clay [17]. It is an important factor when the clay is used as adsorbent. Tables 5 and 6 show the amounts of lead adsorbed by BanaSmectite.

Electrokinetic

The electrophoretic mobility is measured by micro-electrophoresis using a Zetaphoremeter V by CAD Instrumentation (LEM), in 10^{-3} M NaNO$_3$ background in a pH range from 2 to 10. The result of the electrophoretic mobility of the smectite clay is presented in figure 9.
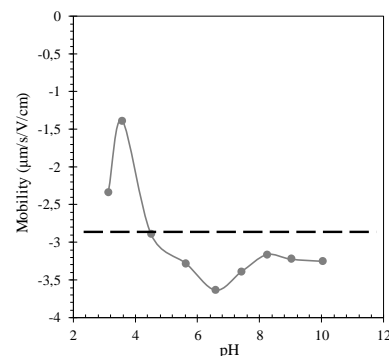

Figure 10: **Figure X-ray patterns of BN 61 sample.**

The mineralogical composition of fraction samplelessthan 63 μm,whichisfoundfrom X-ray diffractograms, isdetermined by usingitscharacteristicreflections (001). It consists of predominantly montmorillonite (70-77%) and substantialamounts of mica (5-9%), kaolinite (2-9%), quartz (1-4%), anatase (2%) and K-feldspars (1-6%) (Table 8).

Chemicalanalyzes

The FTIR spectra of the < 63 μm fractionsampleisshowed in figure 11. The spectra for BN 61 sample shows a band at 3621 cm^{-1}, corresponding to stretching vibrations of AlAlOH or AlMgOH in smectite.

Figure 9: Electrophoretic mobility of the clay fraction in 10^{-3} M NaNO$_3$ as function of pH.

In the range of investigated pH (2 to 10), the mobility is negative as observed by the electrophoretic mobilities (EM) (See figure 9). This negative mobility indicates that the clay surface is negatively charged. A relative constant mobility between pH = 4.5 and pH = 10 is observed for an EM average value of 3.3 μm.s^{-1}.V^{-1}.cm^{-1}. No isoelectric point is observed within 4.3-10 pH range. The constant behavior between pH 4.5 and 10 is concordant with the montmorillonite behavior due to the permanent charge of this clay. The absence of an isoelectric point is usual in clays with permanent crystalline charge like smectites.

Mineralogical composition

The XRD patterns are recorded in the range 3-63°2θ. The result of XRD pattern of BN 61 sample clay is presented in figure 10.
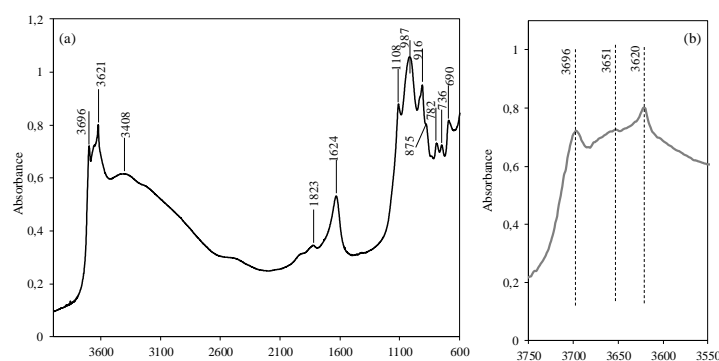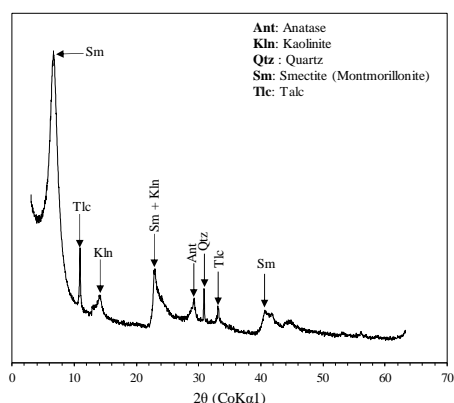

Figure 11: Infrared spectra of the clay sample (a) complete spectrum (b) OH stretching domain.

The absorbencyat 3621 and 916 cm^{-1} confirms the dominant presence of dioctahedralsmectitewith (Al-Al-OH and Mg-OH-Al) stretching and bending bands. The weak band at 3696 cm^{-1} corresponds to Al-OH stretching vibration of kaolinite [36].The chemical compositions of the < 63 μm fractions are analyzed for the major elements and the results are presented in Tables 7 and 8.

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Table 7: Composition in oxides (wt. %) of Banasmectic clay.

Samples	Elements											
	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	L.O.I	Total
BN 61	50.11	23.41	7.25	0.01	2.88	0.08	0.01	0.13	2.10	0.19	13.48	99.62

L.O.I: Loss on ignition.

Table 8: Mineral composition (wt. %) of Banasmectic clay.

Samples	Elements						
	Smectite	Mica	Kaolinite	Quartz	Anatase	K-feldspars	Iron oxide
BN 61	70.5	9.0	7.2	1.5	2.1	0.8	7.3

The most abundant oxides in this sample are SiO_2, Al_2O_3 and Fe_2O_3 (See Table 7) because their mineralogy is dominated by smectite. The sample exhibited a similar TiO2 content 2.10%. The presence of this oxide is coherent with the presence ofanatase. This sample is characterized by high amounts of SiO_2 (52.11%) and relative amounts of Al_2O_3 (23.41%). The Al_2O_3 content within the clay depends on the intensity of kaolinization. A higher Al_2O_3 content indicates more kaolinization of a clay sample [37]. In addition the SiO_2/Al_2O_3 is equal to 2.14. It is indicative of smectite clay with a ratio ~2.36. Bana clay are made essentially of clays such as smectite or mica (See Table 8). The Fe_2O_3 contents for this sample vary is 7.25%, indicate that the iron cation are present in the interlayer of smectite or associated with another minerals like hematite. The loss on ignition for the sample is ranged from 13.48%.

Adsorption test

The analysis is performed on the EMS and ES samples with respective lead concentrations of 0.089 mg.L^{-1} and 0.2 mg.L^{-1}. The mass of the adsorbent is amount 0.1 to 0.5g.Experimental conditions are: volume of water = 50 mL, speed = 800 rpm, time = 1 hour and temperature = 25°C.The results of this adsorption test are presented in figure 12.
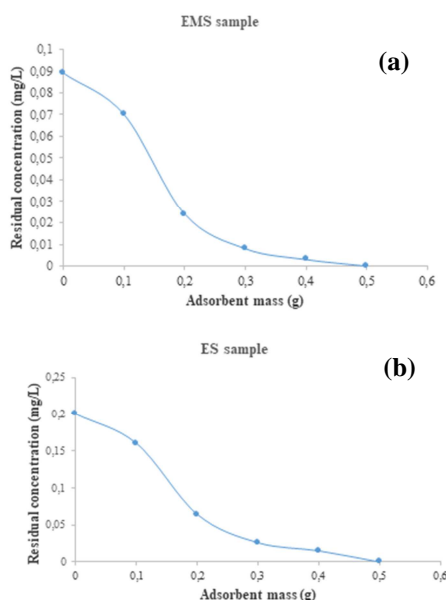

Figure 12: Residual concentrations after adsorption by Banasmectite: (a) – EMS sample; (b)- ES sample.

Samples of waters polluted with lead are subjected to adsorption in the presence of Bana clay (Ambient temperature of 26°C, agitation time 1 hour and 800turns.min^{-1} of stirring). The quantities of lead in water samples are adsorbed. This elimination of lead by Bana clay (West, Cameroon) shows that the adsorption sites present on the surface of this material are favorable for the fixation of lead. It is also noted that 0.5g of Bana clay is sufficient for the removal of all the lead contained in 50mL of water.

4. CONCLUSION

The aim of this paper was to characterize physically and chemically the waters of the artisanal semi-mechanized gold mining site of Djouzami in order to identify probably sources of pollution and to realize a lead removal test with Bana(West, Cameroon) smectic clay. The physical parameters then the heavy metals and the test of the capacity of the clay of Bana to eliminate the lead in an aqueous medium were highlighted.The measured values of hydrogen potential,electrical conductivity, turbidity, and the suspended solids were above the World Health Organization standard for sampling points in the site and downstream of the site of operation. This pollution is mainly due to the excavation work for the extraction of gold. Zinc and copper contamination were found with very low values compared to the World Health Organization standard. At the upstream of the site, there was no pollution of heavy metals such as nickel and cadmium but higher than the standard for the sample taken in the middle of the site (Lom). For iron and lead, pollution at all sampling points was observed. The physical and chemical analyzes shown that the adsorbent material is a semctic clay. The ability of Bana clay (smectite) to remove the lead determined in the water samples was carried out.After introduction of 0.5g of Banasmectite, all lead was completely removed. Thus, the smectite of Bana which is a local material

having within it sites favourable to the fixation of the lead in aqueous medium.In the future works, itwillinteresting: (i) to investigate the mechanism of adsorption thatmayoccur in lead adsoprtion; (ii)usingBanasmectite as adsorbent and all the correlationbetween the phenomenathatoccurduring adsorption to determine the adsorption kinetics and isotherms.

REFERENCES

1. N. Dorfliger, J. Perrin. Une gestion nécessairement locale dans une approche globale. Revue du Bureau de Recherches Géologique et Minière pour une terre durable. Géoscience. 2011.

2. Z. Salem, M. Ghobara, A.A. El Nahrawy, Spatio-temporalevaluation of the surface water quality in the middle Nile Delta usingPalmer's algal pollution index. Egyptian Journal of Basic and Applied Sciences. 2017; 4: 219-226.

3. Hakkou R, Benzaazoua M, Bussière B. Evaluation de la qualité des eaux de ruissellement dans la mine abandonnée de Kettara (Maroc). 2005.

4. S. Chakraoui. Caractérisation de la pollution métallique des sédiments de l'Oued Moulouya et Oued Ansegmir au voisinage de la Mine de Zeida. Risques de transfert vers le barrage d'Hassan II (Haute Moulouya, Maroc). Mémoire de Master. 2015; 76.

5. M.M.S. Aranguren. Contamination en métaux lourds des eaux de surface et des sédiments du Val de Milluni (Andes Boliviennes) par des déchets miniers Approches géochimique, minéralogique et hydrochimique. Planète et Univers [physics]. Université Paul Sabatier – Toulouse III. 2008.

6. Y. Bamba, Evaluation des impacts de la mine d'or de Bonikro (Côte d'Ivoire) sur les ressources en eau. Mémoire de Master, 2012; 55.

7. E.K. Ahialey, Y. Serfoh-Armah, B.K. Kortatsi.Hydrochemical analysis of groundwater in the lower Pra Basin of Ghana.Journal of Water Resource and Protection. 2010; 2:864–871.

8. F. Rakotondrabe, J.R.N, Ngoupayou, Z. Mfonka, E.H. Rasolomana, A.J.N. Abolo, B.L. Asone,A.A. Ako and Rakotondrabe.Assessment of Surface Water Quality of Bétaré-Oya Gold Mining Area (East-Cameroon).Journal of Water Resource and Protection. 2017. 9: 960-984.

9. J.F. Elder.Metal Biogeochemistry in Surface-Water system- A review of Principles andConcepts. 1013, United States Geological Survey. 1988: 50.

10. S.A. Chaudhry, T.A. Khan, I. Ali, adsorptive removal of Pb(II) and Zn(II) from water onto manganese oxide-coated sand: Isotherm, thermodynamic and kinetic studies, Egyptian Journal of Basic and Applied Sciences. 2016; 3: 287-300.

11. S.E. Bailey, T.J. Olin, R.M.Bricka,D.D. Adrian. A Review of potentially low- cost sorbent for heavy metals. Water Resource. 1999; 33: 2469-2479.

12. K. James, G.D. Guenzi.Pesticides in soil and water,Soil Science Society of America. Madison WI. Environnemental Engineering Ressources. 1986; 5: 47-67.

13. M.A. Etoh, D.J.D. Dina,H.M. Ngomo,J.M. Ketcha. Adsorption of Pb^{2+} Ions on two clays: Smectite and kaolin the role of their textural and some physicochemical properties.International Journal of AppliedResearch. 2015; 13: 793-803.

14. E. Errais.Réactivité de surface d'argiles naturelles: Etude de l'adsorption de colorants anioniques.Thèse de doctorat, UniversitéStrasbourg. 2011.

15. C. Nkoumbou, D. Njopwouo, F. Villiéras, A. Njoya, G.C. Yonta, N.L. Ngo, J. Yvon,F.M. Tchoua. Geological study and physico-chemical Characteristics of Talc of Boumnyebel (Centre-Cameroon).Journal of AfricanEarth Sciences. 2006; 54: 61-73.

16. D. Njopwouo,R. Wandji. Minéralogie de l'argile kaolinitiqueBomkoul (Cameroun). Revue Scientifique et Technique, Série Science de la Terre. 1985; 1: 71-81.

17. J.R. Mache. Minéralogie et propriétés physico-chimiques des smectites de Bana et Sabga (Cameroun) : Utilisation dans la décoloration d'une huile végétale alimentaire. Thèse de doctorat, Université de Liège. 2013.

18. D. Njopwouo,R. Wandj. Minéralogie et comportement de quelques argiles camerounaises au renforcement du coutchouc naturel par voie humide. Annales de la faculté des Sciences, Université de Yaoundé I, Série Chimie. 1988a; 2: 187-199.

19. A. Elimbi, E. Yeugouo,J. Nenwa, Liboum,D. Njopwouo. Caractérisations chimiques et minéralogiques de deux matériaux du gisement argileux de Bakong (Cameroun).African Journal of Material and Minerals. 2003; 6: 13-19.

20. A. Njoya,C. Nkoumbou,C. Grosbois, D. Njopwouo, D. Njoya, A.N. Courtin, J. Yvon, F. Martin. Genesis of Mayouomkaolin deposit (Western Cameroon). Applied Clay Science. 2006; 32: 125-140.

21. D. Njoya, A. Elimbi,C. Nkoumbou, A. Njoya, D. Njopwouo, G. Lecomte,J. Yvon. Contribution à l'EtudePhysico-Chimique et Minéralogique de quelques Echantillons d'Argiles de Mayouom (Cameroun).Annales de Chimie Science des Matériaux. 2007; 32: 55-688.

22. E. Obilor, E.C. Amadi. Test for Significance of Pearson's Correlation Coefficient. Department of Educational Foundations, Rivers State University, Port Harcourt, Nigeria, 2018.

23. S.J. Gregg, K.S.W. Sing. Adsorption, Surface Area and Porosity, AcademicPress. 1982.

24. World Health Organization. Guidelines for Drinking-Water Quality. Recommandations. 4th Edition, World Health Organization, Geneva.2011.

25. M. Ibrahima, D. Moctar, D.N. Maguette, M.H. Diakher, N.P. Malick, F. Serigne.Evaluation of water resources quality in Sabodala gold mining region and its surrounding area (Senegal).Journal ofWater Resource and Protection. 2015; 7:247–263.

26. M. Detay.Le forage d'eau, réalisation, entretien, réhabilitation.Masson, Paris. 1993: 375.

27.J.H. Mol, P.E.Ouboter, Downstream effects of erosion from small-scale gold. Conservation Biology. 2004; 18:201–214.

28. O. Betancourt, A. Narvaez and M. Roulet.Southern Ecuador: a study of environmental impacts and human exposures.EcoHealth. 2005; 2:323–332.

29.A. Horowitz.A primer on Trace Metal Sediment Chemistry, United States Geological Survey.1985.

30.H.K. Wedepohl.The composition of the continental crust.Geochimica andCosmochimicaActa. 1995; 59: 1217-1232.

31. S.M.M. Aranguren, A. Probst,M. Roulet,M.P. Isaure. Contamination of Surface Waters by Mining Wastes in the Milluni Valley (Cordillera Real, Bolivia): Mineralogical and Hydrological Influences.Applied Geochemistry. 2008; 23:1299-1324.

32. H. Pahimi, C.R. Panda, M.B. Ngassoum, R. Tchameni. Environmental Impacts of Mining in the Volcano-Sedimentary Basins of Cameroon: Case Study of Artisanal Gold Mine Tailings (BetareOya, East-Cameroon).International Journal of Energy, Sustainability and Environmental Engineering. 2015. 2: 5-15.

33.G.B. Deffo.Prospection du minerai de scheelite (tungstène) de la région de Djouzami (Adamaoua) par la lumière ultra-violette et l'analyseur XRF portable. Mémoire de Master. Ecole de Géologie et d'Exploitation Minière, Université de Ngaoundéré. 2016;21-23.

34.L.M. Hernandez.Dynamique des éléments traces métalliques dans les sols dedifférents écosystèmes français. Thèse de doctorat, Université Paul Sabatier, Toulouse. 2003: 280.

35. P.L. Younger. Mine water pollution in Scotland: nature, extent and preventativestrategies. Science of the Total Environment, 2001; 309-326.

36. V.C. Farmer, F. Palmieri. The characterization of soilminerals by infraredspectroscopy. In: Gieseking, E.J. Soil Components. 2, Springer-Verlag, NewYork. 1975; 573-670.

37 G. Yanik. Mineralogical, crystallographic and technologicalcharacteristics of Yaylayolu kaolin (Kütahya, Turkey). Clay Minerals. 2011; 397-410.

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