



HAL
open science

Capacity of Two Clays to Clean Up Water from An Illegal Gold Mining Site

Lucas Moses Kouadio, Zié Coulibaly, Atolé Brice Bienvenu Kedi, Vamoussa
Coulibaly, Joseph Sei

► **To cite this version:**

Lucas Moses Kouadio, Zié Coulibaly, Atolé Brice Bienvenu Kedi, Vamoussa Coulibaly, Joseph Sei.
Capacity of Two Clays to Clean Up Water from An Illegal Gold Mining Site. *European Journal of
Applied Sciences*, In press, 12 (3), pp.266-277. 10.14738/aivp.123.16868 . hal-04624511

HAL Id: hal-04624511

<https://hal.science/hal-04624511>

Submitted on 2 Jul 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Capacity of Two Clays to Clean Up Water from An Illegal Gold Mining Site

Kouadio, Lucas Moses

Nangui Abrogoua University, Abidjan, Côte d'Ivoire

Coulibaly, Zié

Felix Houphouët Boigny University, Abidjan, Côte d'Ivoire

Kedi, Atolé Brice Bienvenu

Jean Lorougnon Guédé University, Daloa, Côte d'Ivoire

Coulibaly, Vamoussa

Felix Houphouët Boigny University, Abidjan, Côte d'Ivoire

Sei, Joseph

Felix Houphouët Boigny University, Abidjan, Côte d'Ivoire

ABSTRACT

The intensive development of illegal gold mining, with the uncontrolled use of chemicals, has a strong impact on the environment in Côte d'Ivoire. This study aims to clean up contaminated water from the illegal gold mining site of Angamankro in the Daoukro department using two clays from Ivory Coast. To achieve this goal, physicochemical parameters such as pH, conductivity, turbidity and metal contents in water were measured. The levels of most of the metals studied in wastewater are higher than their various limit values recommended by the WHO. In order to depollute the water, adsorption treatment on Bingerville (BIN) and Katiola (KAT) clays were used. The treatment of wastewater with clays showed a significant reduction in metal contents. The elimination of different metals in water has decreased in the direction $Cu > Hg > Zn > Mn > Ni > Co > Cd > Cr > As > Pb$. KAT clay adsorbs metals better than BIN clay. This greater adsorption capacity that KAT clay possesses is due to its mineralogical composition (20.14% smectite) and its greater surface properties.

Keywords: Illegal gold mining, adsorption, metals, clay

INTRODUCTION

Pollution is a major problem for the environment and public health that attracts the attention of the scientific community. This pollution is very often caused by different anthropogenic sources such as mining activity, the metallurgical and steel industry, fertilizers and pesticides applied in soil cultivation, incinerators and waste incineration ashes, medical waste, city recycling centers, emissions from factories and internal combustion engines, sewer effluents and sewage sludge, etc. These different activities are responsible for the release of certain dangerous chemical compounds that are poorly or non-biodegradable such as hydrocarbons,

phenolic compounds, heavy metals, dyes, insecticides, etc. Among these anthropogenic sources, it appears that the mining industry is the main source of heavy metals in the environment [1]. Côte d'Ivoire is not on the fringes of the phenomenon of environmental pollution. Illegal gold mining, which has grown and affects most regions of Côte d'Ivoire, is the one that pollutes the most [2, 3]. Localities housing illegal gold mining sites such as Kong 2 (Yakassé Attobrou department), Degbézéré (Bouaflé department) and Aboisso are contaminated by heavy metals. Most of the rivers of Côte d'Ivoire are polluted due to gold panning, these are the Cavally, the Sassandra, the Bandama and the N'zi [4, 5]. Numerous studies have found metal levels above the limit values set by the WHO in the surface waters of several localities hosting illegal gold panning sites in Côte d'Ivoire [6, 7]. Consequently, this surface water is unfit for consumption due to this contamination. However, the populations of these localities impacted by illegal gold panning very often use this contaminated water for their various needs. In this context, it is necessary to depollute these waters. Among the decontamination techniques, the adsorption of pollutants by less expensive adsorbents, available and easily used such as clays, constitutes a great interest [8]. Due to their sheet structure and their interesting adsorbent properties linked to their large specific surface area and their cation exchange capacities, clays are used in the depollution of contaminated solutions as adsorbents [9, 10]. In addition, several studies have shown that Côte d'Ivoire has numerous clay sites with interesting adsorbent properties [11]. Following the above, the objective of this work is to depollute water from a gold panning site using two clays from Ivory Coast.

MATERIALS AND METHODS

Materials

Water Sample:

The water sample for this study comes from the illegal gold panning site of Angamankro at 7°29'54" north longitude and 5°10'30" west latitude in the Daoukro department (Fig. 1).

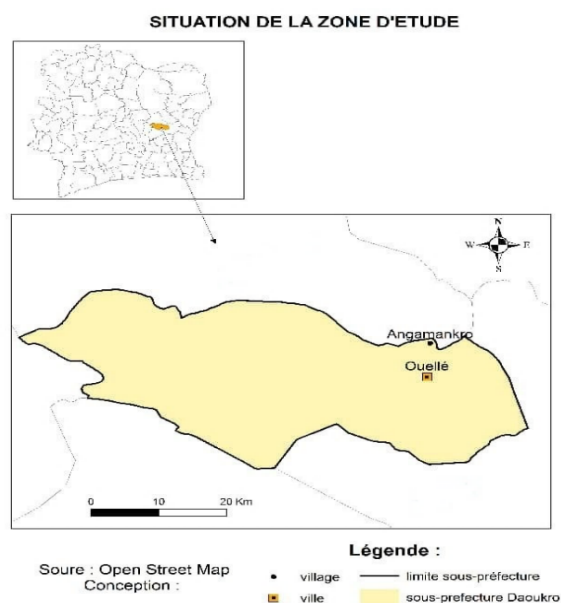


Fig1: Location of the illegal gold panning site of Angamankro

Clay Materials

The clays used in this study are referenced BIN and KAT (Fig. 2). BIN clay was extracted at 5°18' north latitude and 3°50' west longitude in Bregbo in the town of Bingerville belonging to the Autonomous District of Abidjan. As for KAT clay, it comes from the town of Katiola in the Hambol region in the north of Ivory Coast at 8°08' north latitude and 5°06' west longitude. The main characteristics of these clays are grouped in Table 1 (Mineralogical composition, specific surface area and cation exchange capacity) below.



Fig2: Images of BIN (a) and KAT (b) clay samples

Table 1: Mineralogical composition and physicochemical properties of BIN and KAT clays [11]

Sample	% Kaolinite	% Illite	% Smectite	% Quartz	% Goethite	CEC (meq/100g)	S _{BET} (m ² /g)
BIN	52.21	6.23	-	17.50	15.71	6.2	31.7
KAT	48.08	3.55	20.14	6.11	16.86	35.47	48.5

Methods

Sampling:

Water sampling was carried out using half-liter (500mL) capacity glass bottles. These bottles were first rinsed well with 10% hydrochloric acid, then twice with distilled water. The samples were taken with hands protected by sterile gloves to avoid any contamination. A composite water sample was formed from the same volume of three water samples from different points in the watercourse (Fig. 3).



Fig3: Water sample from the Angamankro gold panning site

The formed sample was collected in a glass bottle labeled A_{E1}. The sample taken was immediately stored in a cooler with ice and taken to the laboratory. Before analysis, the water sample was stored at 4°C in a refrigerator to avoid any damage.

Analysis of the Water Sample:

Parameters measured include pH, conductivity, turbidity and trace metal element concentrations. The pH of the water was measured using a HANNA HI 2211 type pH meter. The conductivity was determined using a HANNA HI98192 “EC/TDS/NaCl/Resistivity” conductivity meter. A HANNA HI98713 type turbidimeter was used to determine the turbidity. The metals in the water were measured using an optical emission spectrometer coupled to an inductively coupled plasma (ICP-OES) of the Perkin Elmer Optima 2100 DV type. The metals analyzed are: mercury (Hg), lead (Pb), cadmium (Cd), arsenic (As), copper (Cu), nickel (Ni), zinc (Zn), chromium (Cr), cobalt (Co) and manganese (Mn).

Adsorption Reaction:

Part of the water sample taken from the gold panning site was treated with each of the two clays (BIN and KAT). A mass of 1.25 g of clay is brought into contact with 125 mL of liquid samples from the gold panning site in a beaker with a capacity of 250 mL. The clay to liquid ratio is 10g per liter. The mixtures were stirred for 90 minutes at 600 rpm using a DWB MS-PB type magnetic stirrer. After stirring, the mixture is centrifuged at 5000 rpm for 15 min and the supernatant is taken for the determination of chemical species at ICP-OES in order to determine the residual contents of metallic trace elements. The elimination of chemical species by clays is evaluated by calculating the adsorption capacity Q ($Q = \frac{C_0 - C_t}{m} V$) and the elimination percentage R ($R = \frac{C_0 - C_t}{C_0} * 100$). Figure 4 summarizes the metal adsorption protocol.

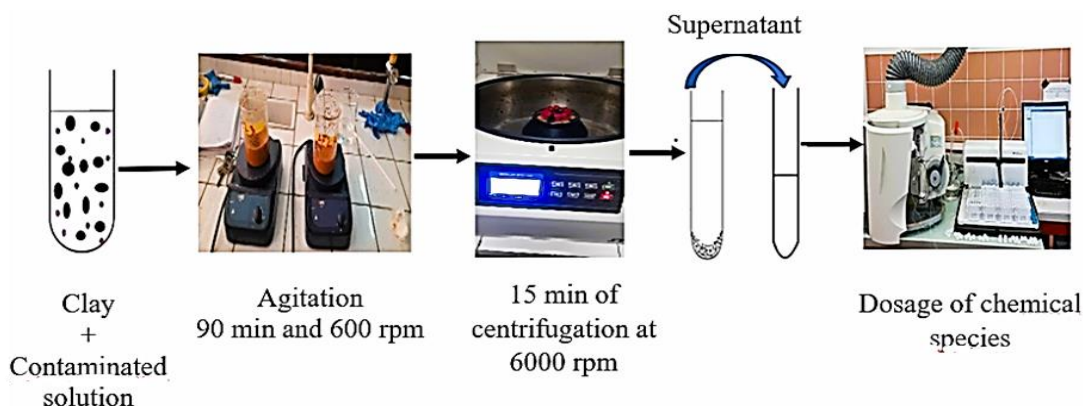


Fig4: Metal adsorption protocol

RESULTS

Hydrogen Potential (pH); Conductivity and Turbidity

The results of pH, conductivity and turbidity measurements, before and after treatment with clays are shown in Figure 5. The pH of the raw sample (A₁) is 6.1. After the clay treatment, the pH increased slightly. This value increased to 6.8 after treatment with BIN clay (A_{1BIN}) and to 7.3 for KAT clay (A_{1KAT}). The pH of the raw sample is below the WHO standard (comprised of

6.5 and 8.5). Untreated water (A_1) has a conductivity of $186.4 \mu\text{S}/\text{Cm}$. After treatment, the conductivity of A_1 increased from $186.4 \mu\text{S}/\text{cm}$ to $142 \mu\text{S}/\text{cm}$ and $115.9 \mu\text{S}/\text{cm}$ respectively with Bingerville and Katiola clays, a reduction of 24% and 38%. Before or after treatment with clays, the conductivity values comply with the WHO standard ($500 \mu\text{S}/\text{cm}$ in drinking water) [12].

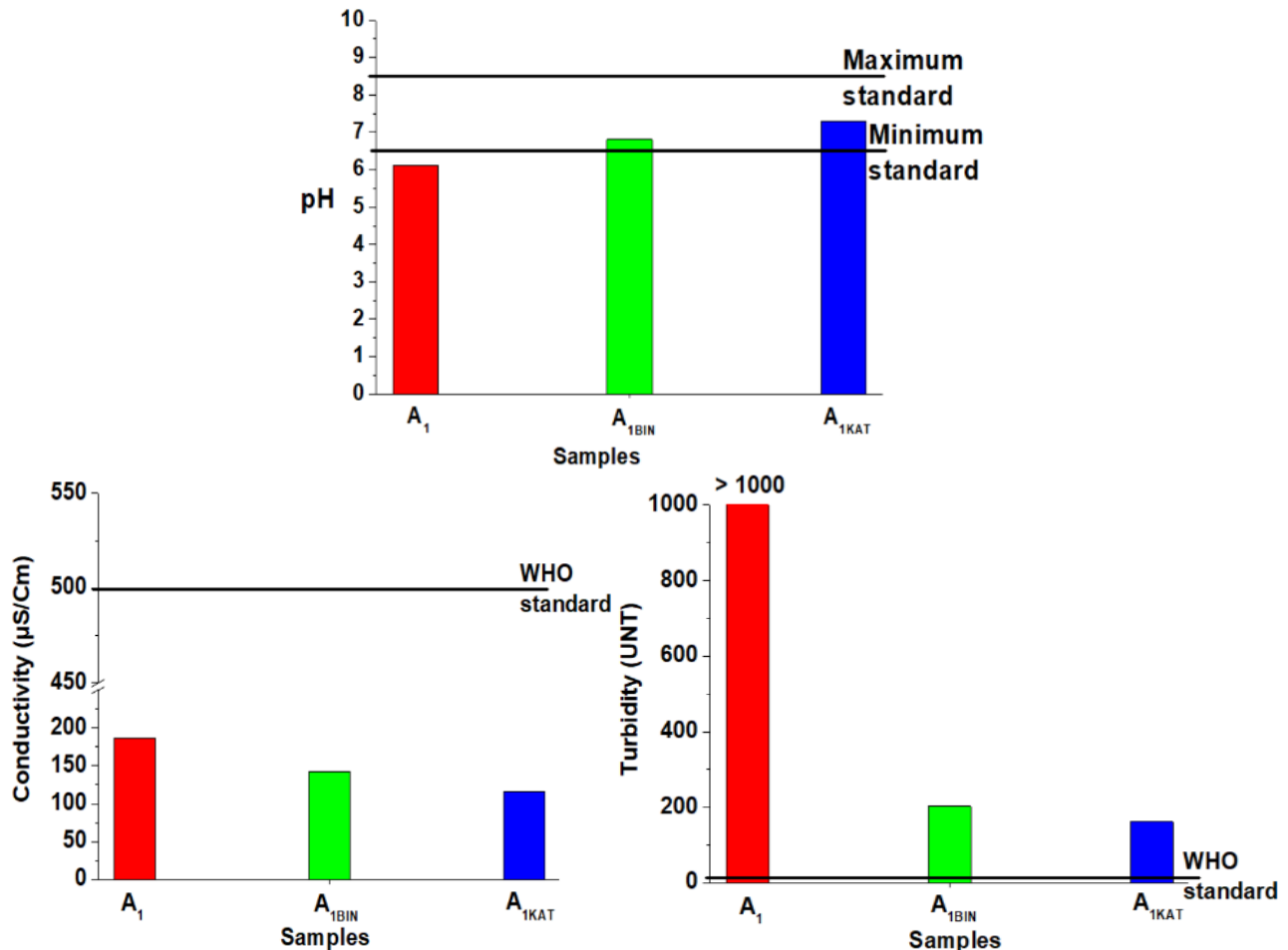


Fig5. pH, Conductivity and Turbidity of the water sample before (A_1) and after treatment with clays ($A_{1\text{BIN}}$ and $A_{1\text{KAT}}$)

As for turbidity, the raw sample (A_1) has a value greater than 1000 UNT. Clay treatment significantly reduced the turbidity value. The turbidity increased to 202 UNT after treatment with BIN clay and to 162 UNT with KAT clay, a reduction of more than 80% for both clays. Despite the sharp reduction in turbidity, the values still remain above the WHO standard (5 UNT in drinking water) [12]. The reduction in turbidity is visible in Figure 6 with a darker color for the untreated water (A_1) and lighter colors for the clay-treated samples ($A_{1\text{BIN}}$ and $A_{1\text{KAT}}$).



Fig6: Water samples from gold panning site before (A₁) and after clay treatment (A_{1BIN}; A_{1KAT})

Trace Metal Element Content in The Raw Sample

The ICP analysis of the water sample from the gold panning site revealed the presence of heavy metals such as mercury, lead, cadmium, arsenic, copper, nickel, zinc, chromium, cobalt and manganese. Table 2 groups the metal concentrations in sample A₁.

The concentrations of lead, cadmium, arsenic, chromium, manganese, nickel and mercury in sample A₁ are respectively 47.4 µg/L; 44.1 µg/L; 27.8 µg/L; 61.6 µg/L; 314 µg/L; 71.8 µg/L and 11.6 µg/L. These different contents are significantly higher than their limit recommended by the WHO for surface water, which is 10 µg/L for lead, 3 µg/L for cadmium, 10 µg/L for arsenic, 50 µg/L for L for chromium, 100 µg/L for manganese, 70 µg/L for nickel and 6 µg/L for mercury. Concerning the zinc, copper and cobalt contents in sample A₁, they are respectively 220 µg/L, 412 µg/L and 19.5 µg/L. As for these contents, they are lower than their different threshold concentrations in surface water which are 5000 µg/L for zinc, 2000 µg/L for copper and 20 µg/L for cobalt [13].

Table 2: Concentration of metals (Pb, Cd, As, Cr, Mn, Ni, Zn, Cu, Hg and Co) in µg/L in raw sample A₁

Pb	Cd	As	Cr	Mn	Ni	Zn	Cu	Hg	Co	Total
47.4	44.1	27.8	61.6	314	71.8	220	412	1.9	19.5	1229.8

Trace Metal Element Content After Treatment with Clays

The treatment of sample A₁ with clays reduced the concentration of pollutants. Table 3 groups the metal concentrations in the A₁ samples before and after treatment with BIN and KAT clays as well as the adsorption capacity (Q_{BIN} and Q_{KAT}) and the elimination percentages (R_{BIN} and R_{KAT}). The results of the metal contents are also shown in Figures 7 and 8.

Table 3: Concentration of metals (Pb, Cd, As, Cr, Mn, Ni, Zn, Cu, Hg and Co) in µg/L in the sample before (A₁) and after treatment with clays (A_{1BIN} and A_{1KAT})

	A1	A1BIN	RBIN(%)	QBIN(µg/g)	A1KAT	RKAT(%)	QKAT(µg/g)
Pb	47.4	30.1	36.5	1.7	25.9	45.4	2.2
Cd	44.1	24.6	44.2	2	13.6	69.2	3.1
As	27.8	19.6	29.5	0.8	8.9	68	1.9
Cr	61.6	50.6	17.9	1.1	7.8	87.3	5.4

Mn	314	103	67.2	21.1	10.8	96.6	30.3
Ni	71.8	34.5	51.9	3.7	5.4	92.5	6.6
Zn	220	54.8	75.1	16.5	5.4	97.5	21.5
Cu	412	41.5	89.9	37.1	11.3	97.3	40.1
Hg	11.6	1.9	83.6	1	0.1	99.6	1.2
Co	19.5	7.9	59.5	1.2	3.2	83.4	1.6
Total	1229.8	368.5	70	86.1	92.5	92.5	113.7

The lead content increased to 30.1 $\mu\text{g/L}$ with BIN clay, compared to 25.9 $\mu\text{g/L}$ for KAT, a drop of 36.5 and 45.4% respectively. The adsorption capacity is 1.7 $\mu\text{g/g}$ for BIN compared to 2.2 $\mu\text{g/g}$ for KAT relative to the elimination of lead. The cadmium concentration decreased by 44.2% for BIN, representing an adsorption capacity of 2 $\mu\text{g/g}$. However, for KAT clay, a reduction of 69.2% in the cadmium content is observed, giving adsorption capacity of 3.1 $\mu\text{g/g}$. This content increased from 44.1 $\mu\text{g/L}$ to 24.6 with BIN clay and to 13.6 $\mu\text{g/g}$ after treatment with KAT clay. Concerning the arsenic content, its initial concentration decreased by 29.5% (from 27.8 $\mu\text{g/g}$ to 19.6 $\mu\text{g/g}$) after treatment with BIN clay and by 68% (from 27.8 $\mu\text{g/g}$ to 8.9 $\mu\text{g/g}$) after treatment with KAT, giving adsorption capacities of 0.8 and 1.9 $\mu\text{g/g}$ respectively.

Treatment of A₁ with BIN and KAT reduced the chromium concentration by 17.9% (from 61.6 $\mu\text{g/g}$ to 50.6 $\mu\text{g/L}$) and by 87.3% (from 61.6 to 7.8 $\mu\text{g/g}$) respectively. The adsorption capacity is 1.1 $\mu\text{g/g}$ for BIN and 5.4 $\mu\text{g/g}$ for KAT relative to the elimination of chromium.

Manganese was removed from A₁ at 67.2% (from 314 $\mu\text{g/L}$ to 103 $\mu\text{g/L}$) after treatment by BIN and at 96.6% (from 314 $\mu\text{g/L}$ to 10.8 $\mu\text{g/L}$) for KAT. The adsorption capacities of BIN and KAT are 21.1 and 30.3 $\mu\text{g/g}$, respectively. The nickel reduction percentage is 51.9% (from 71.8 $\mu\text{g/L}$ to 34.5 $\mu\text{g/L}$) after treatment by BIN and 92.5% (from 71.8 $\mu\text{g/L}$ to 5.4 $\mu\text{g/L}$) for KAT. The adsorption capacities of BIN and KAT are 3.7 and 6.6 $\mu\text{g/g}$, respectively. BIN and KAT clays adsorbed respectively 75.1% (from 220 $\mu\text{g/L}$ to 54.8 $\mu\text{g/L}$) and 97.5% (220 $\mu\text{g/L}$ to 5.4 $\mu\text{g/L}$) of the initial zinc content in sample A₁. The adsorption capacities are 16.5 $\mu\text{g/g}$ for BIN clay and 21.5 $\mu\text{g/g}$ for KAT.

The rate of reduction in copper concentration is 89.9% (from 412 $\mu\text{g/L}$ to 41.5 $\mu\text{g/L}$) after treatment with BIN compared to 97.3% (from 412 $\mu\text{g/L}$ to 11.3 $\mu\text{g/L}$) for KAT, giving adsorption capacities of 37.1 and 40.1 $\mu\text{g/g}$ respectively. The adsorption capacities of BIN and KAT clays relative to the elimination of mercury in A₁ are respectively 1 $\mu\text{g/g}$ (representing 83.6% of reduction) and 1.2 $\mu\text{g/g}$ (giving 99.6% of reduction). The mercury content decreased from 11.6 $\mu\text{g/L}$ to 1.9 $\mu\text{g/L}$ after treatment with BIN and to 0.1 $\mu\text{g/L}$ for KAT.

As for the cobalt concentration, the initial content was reduced by 59.5% (from 19.5 $\mu\text{g/L}$ to 7.9 $\mu\text{g/L}$) by BIN clay and by 83.4% (from 19.5 $\mu\text{g/L}$ to 3.2 $\mu\text{g/L}$) by KAT clay. The adsorption capacities of BIN and KAT clays in sample A₁ are 1.2 and 1.6 $\mu\text{g/g}$ respectively.

Relative to all the metals studied, the total content in the water sample went from 1229.8 $\mu\text{g/L}$ to 368.5 $\mu\text{g/L}$ after treatment with BIN clay, a reduction of 13.1 %. On the other hand, after treatment with KAT clay, the total content increased to 92.5 $\mu\text{g/L}$, a reduction of 92.5%. With the exception of lead, cadmium and arsenic, the metal contents in the water sample generally fell below their various limit values after treatment with clays.

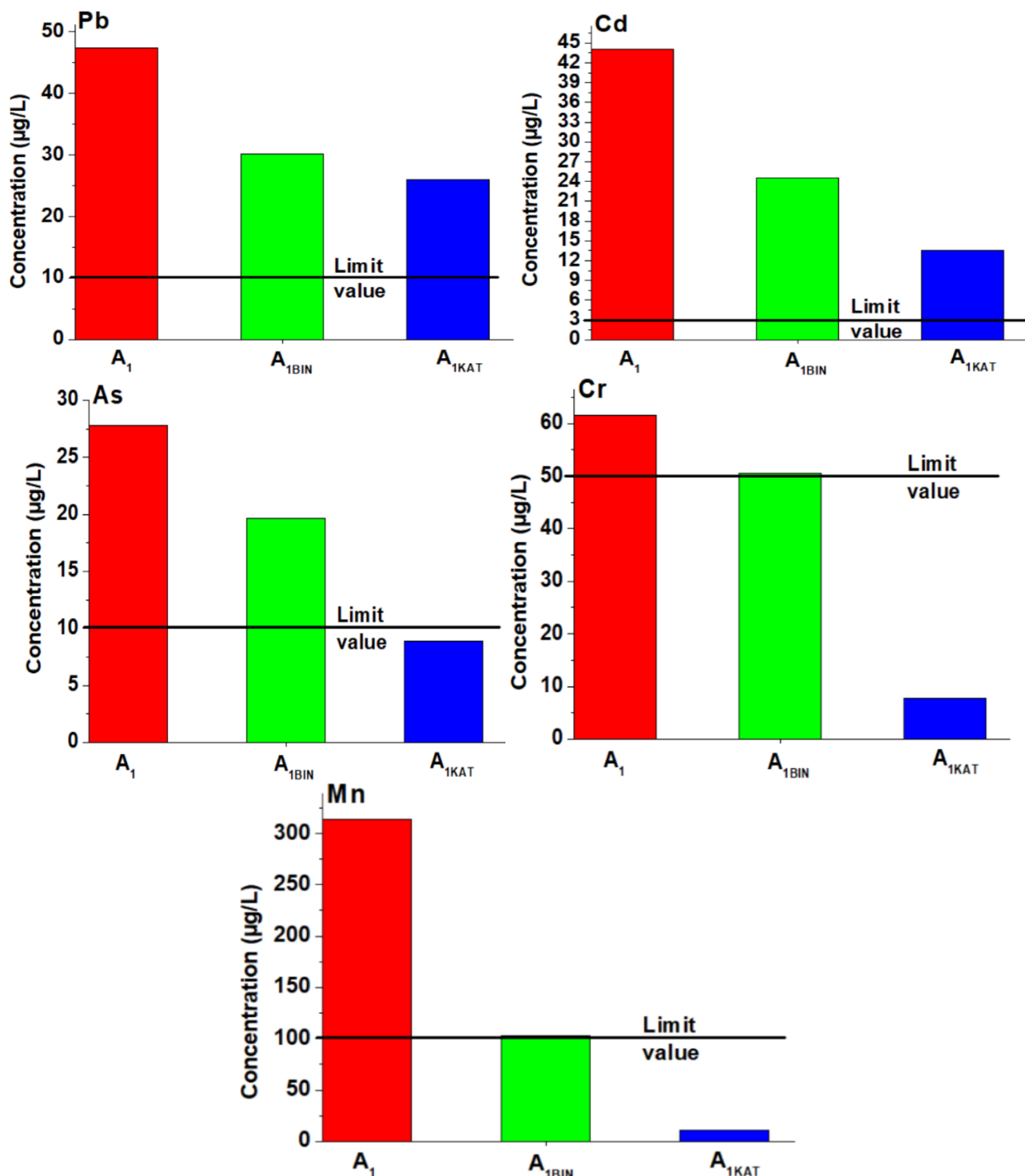


Fig7: Pb, Cd, As, Cr and Mn contents in the water sample before (A_1) and after treatment with clays (A_{1BIN} and A_{1KAT})

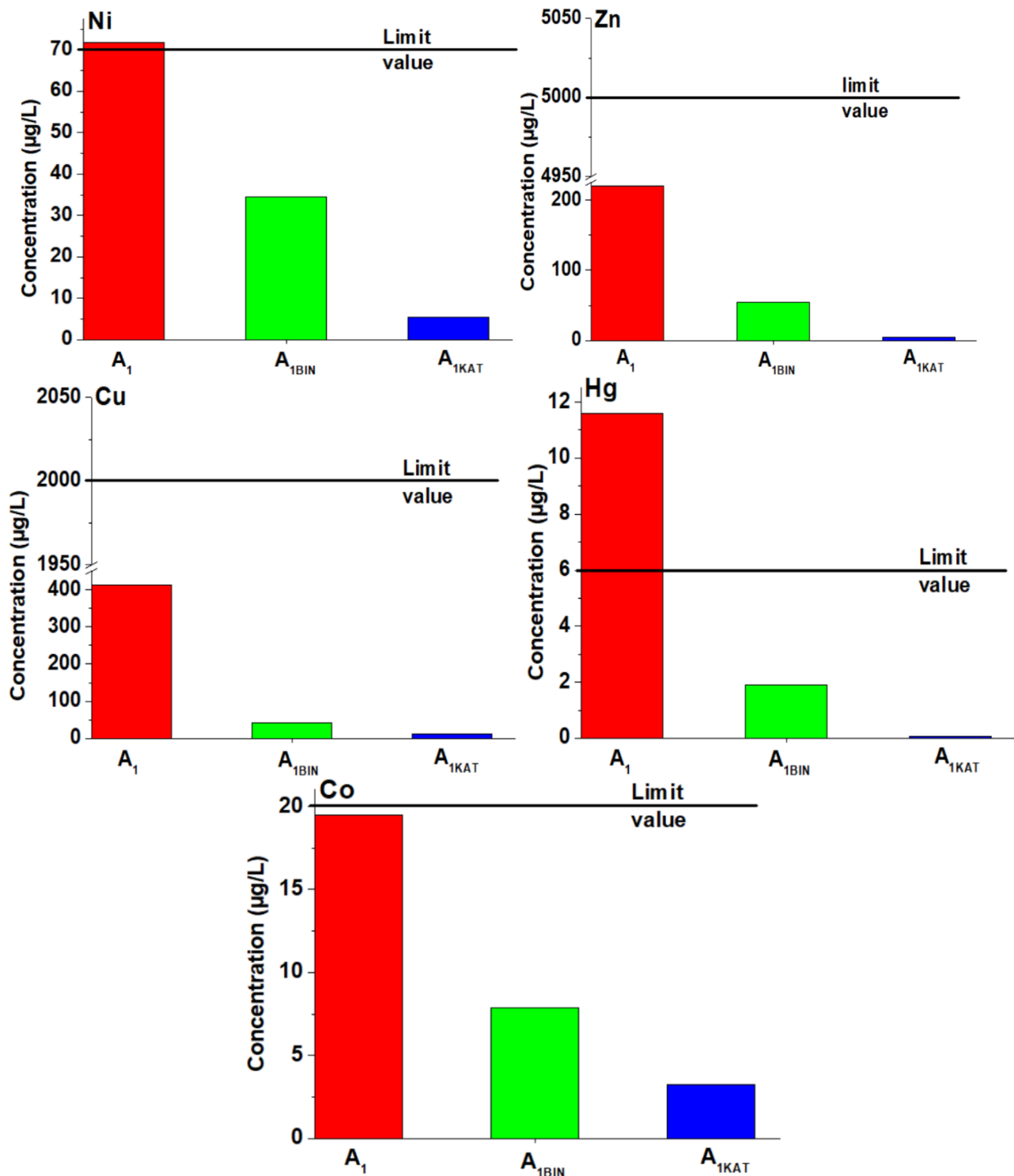


Fig8: Ni, Zn, Cu, Hg and Co contents in the water sample before (A_1) and after treatment with clays ($A_{1\text{BIN}}$ and $A_{1\text{KAT}}$)

DISCUSSION

The relatively high metal contents (above the limit values) in the sample studied show that this water is polluted and should not be in contact with surface water (lagoons, rivers, etc.)

without prior treatment. The raw water sample being acidic ($\text{pH} < 7$), there are more H^+ ions in the solution. Consequently, on contact with the clay, the silanol ($-\text{SiOH}$) and aluminol ($-\text{AlOH}$) groups at the edge of the sheets capture the H^+ ions ($-\text{SiOH} + \text{H}^+ \rightleftharpoons -\text{Si-OH}_2^+$ and $-\text{Al-OH} + \text{H}^+ \rightleftharpoons -\text{Al-OH}_2^+$) [14], thereby reducing the acidity of the water sample. This phenomenon could justify the slight increase in the pH of the water.

The reduction in conductivity, turbidity and metal contents in wastewater after treatment is due to the fixation of pollutants on the surface of the clays. Indeed, clays are known for their ability to remove toxic metals and other pollutants from wastewater [15]. This power is linked to their large specific surface area, their cation exchange capacity and their negative charge which give them a strong adsorption capacity [16]. In the same direction as this work, Dos Andjos and colleagues found high percentages of metal adsorption (varying from 59% to 100%) [17]. Katiola clay has higher adsorption capacities than Bingerville clay. Indeed, KAT clay is rich in type 2/1 minerals such as smectites (20.14%) unlike Bingerville clay which does not contain any and is mainly made up of kaolinite (52.21%) which is a type 1/1 mineral. The mineralogical composition of the two clays gives the KAT sample ($\text{SBET} = 48.5 \text{ m}^2/\text{g}$ and $\text{CEC} = 35.5 \text{ meq}/100\text{g}$) greater adsorbent properties than BIN ($31.7 \text{ m}^2/\text{g}$ and $\text{CEC} = 6.2 \text{ meq}/100\text{g}$) [11]. The mineralogical and physicochemical characteristics of these two clays explain their difference with respect to the elimination of metals. The best elimination efficiencies are obtained for copper, followed by mercury then zinc, manganese, nickel, cobalt, cadmium, chromium, arsenic and lead. Among the ten metals, copper is the metal which adsorbs preferentially on clays ahead of the nine others. Lead is the least adsorbed among the metals studied. Several research studies have reported cases of preferential adsorption. For example, Kajeiou and colleagues found in their study that in multi-metallic systems, competition between various metals caused preferential adsorption [18]. The preference of certain metal cations for adsorption could be explained by their various affinity with clays. Indeed, certain metal cations are adsorbed on the edges of clay particles, forming either monodentate or bidentate complexes [19].

CONCLUSION

The objective of this study was to clean up water from an illegal gold panning site using clay from Ivory Coast (Bingerville and Katiola). Firstly, this work consisted of analyzing water from an illegal gold mining site in Angamankro in the Daoukro department. The analyzes consisted of determining physicochemical parameters such as pH, conductivity, turbidity and the contents of metallic trace elements (Hg, Pb, Cd, As, Cr, Mn, Cu, Zn, Co, Ni). Secondly, the sample taken was treated by adsorption on Bingerville (BIN) and Katiola (KAT) clays. The analyzes carried out showed that the water sampled had a pH below the standard, with relatively low conductivity and very high turbidity. This water is polluted by metals. With the exception of zinc, copper and cobalt, the concentrations of metals studied in wastewater are higher than their various limit values in surface water recommended by the WHO. Treatment of wastewater with clays slightly increased pH and reduced conductivity and turbidity. In addition, the treatment of this water showed a reduction in metal contents due to the adsorption of these chemical species on the clay surfaces. Copper and mercury are the most adsorbed metals with reduction rates reaching 97.3% and 99.6% respectively. The percentage of metal removal is higher after treatment with Katiola clay. The strong adsorption capacity of KAT clay is linked to its mineralogical composition (20.14% smectite),

its larger specific surface area and its large cation exchange capacity. For all metals, the reduction rate reaches 70% with BIN clay and 92% with KAT clay. Consequently, the clays used and the protocol applied are effective in depolluting contaminated water. This work is intended to be a contribution to the depollution of large quantities of water contaminated by metals.

References

- [1] Oursel, B., Transferts et dynamique des contaminants métalliques en zone côtière : Impact d'une grande agglomération méditerranéenne. Thèse, Université de Toulon, France, 2013
- [2] Yobo, J., et Nassa, D.D.A., L'exploitation minière, facteur de récession de l'activité agricole à Hiré Watta en Côte d'Ivoire. *Revue de Géographie Tropicale et d'Environnement*, 2018. 1: p. 91-101.
- [3] Goh, D., L'exploitation artisanale de l'or En Côte d'Ivoire: La persistance d'une activité illégale. *European Scientific Journal*, 2016. 12: p. 18-36. <https://doi.org/10.19044/esj.2016.v12n3p18>
- [4] Konan, K.S., Kouamé, K.B., Konan, F.K., Boussou, K.C., et Kouakou, K.L., Pollution des eaux à usages domestiques par les éléments traces métalliques des activités anthropiques : cas du sous bassin versant du fleuve Sassandra en amont du barrage de Buyo, Côte d'Ivoire. *Proc. IAHS*, 2021. 384: p. 85-92. <https://doi.org/10.5194/piahs-384-85-2021>
- [5] Kouakou, Y.C., Touré, A., Fall, A., et Bredou, K.S., 456-Impact de l'orpaillage sur la Comoé et la santé humaine dans le district de Bettié, Côte d'Ivoire. *Revue d'Épidémiologie et de Santé Publique*, 2022. 70: S181. <https://doi.org/10.1016/j.respe.2022.06.141>
- [6] Kouadio, L.M., Tillous, K.E.N., Coulibaly, V., Sei, J., Martinez, H., et Pannier, F., Assessment of metallic pollution of water and soil from illegal gold mining sites in Kong 2, Hiré and Degbézéré (Ivory Coast). *J. Mater. Environ. Sci*, 2023. 14: p. 41-61
- [7] Yapi, Y.H.A., Dongui, B.K., Trokourey, A., Barima, Y.S.S., Essis, Y., et Atheba, P., Evaluation de la pollution métallique des eaux souterraines et de surface dans un environnement minier aurifère à Hiré (Côte d'Ivoire). *International Journal of Biological and Chemical Sciences*, 2014. 8: p. 1281-1289. <http://dx.doi.org/10.4314/ijbcs.v8i3.41>
- [8] Mockovčiaková, A., Orolínová, Z., et Škvarla, J., Enhancement of the bentonite sorption properties. *Journal of Hazardous Materials*, 2010. 180: p. 274-281. <https://doi.org/10.1016/j.jhazmat.2010.04.027>
- [9] Ouakouak, A., et Youcef, L., Adsorption of Cu²⁺ ions on powder activated carbon and a sodique bentonite. *Larhyss Journal*, 2016. 27: p. 39-61
- [10] Mimanne, G., Benhabib, K., Benghalem, A., et Taleb, S., Etude de l'adsorption des métaux lourds (Pb et Cd) en solution aqueuse sur charbon actif et montmorillonite sodée de l'ouest Algérien. *Journal of Materials and Environmental Science*, 2014. 5: p. 1298-1307
- [11] Kouadio, L.M., El Islam Lebouachera, S., Blanc, S., Sei, J., Miqueu, C., Pannier, F., et Martinez, H., Characterization of clay materials from Ivory Coast for their use as adsorbents for wastewater treatment. *Journal of Minerals and Materials Characterization and Engineering*, 2022. 10: p. 319-337. <https://doi.org/10.4236/jmmce.2022.104023>
- [12] Hadzi, G.Y., Essumang, D.K., et Adjei, J.K., Distribution and risk assessment of heavy metals in surface water from pristine environments and major mining areas in Ghana. *Journal of Health & Pollution*, 2015. 5: p. 86-99. <https://doi.org/10.5696/2156-9614-5-9.86>

- [13] Bempah, C.K., et Ewusi, A., Heavy metals contamination and human health risk assessment around Obuasi gold mine in Ghana. *Environmental Monitoring and Assessment*, 2016. 188:13p. <https://doi.org/10.1007/s10661-016-5241-3>
- [14] Kouadio, L.M., Contribution à l'évaluation des niveaux de contamination des eaux et des sols des sites d'orpaillage clandestin et élimination des métaux (Hg, Pb, Cd) et de l'arsenic des eaux polluées, à l'aide des argiles de Côte d'Ivoire. Thèse, Université Félix Houphouët-Boigny, Côte d'Ivoire, 2023
- [15] Bhattacharyya, K.G., et Gupta S.S., Adsorptive accumulation of Cd(II), Co(II), Cu(II), Pb(II), and Ni(II) from water on montmorillonite: Influence of acid activation. *Journal of Colloid and Interface Science*, 2007. 310: p. 411-424
- [16] Yuan, G.D, Theng, B.K.G., Churchman, G.J., et Gates, W.P., Clays and clay minerals for pollution control. *Developments in Clay Science*, 2013. 5B: p. 587-644. <http://dx.doi.org/10.1016/B978-0-08-098259-5.00021-4>
- [17] Dos Anjos, V.E., Rohwedder, J.R., Cadore, S., Abate, G., et Grassi, M.T., Montmorillonite and vermiculite as solid phases for the preconcentration of trace elements in natural waters: Adsorption and desorption studies of As, Ba, Cu, Cd, Co, Cr, Mn, Ni, Pb, Sr, V, and Zn. *Applied Clay Science*, 2014. 99: p. 289–296. <https://doi.org/10.1016/j.jcis.2007.01.080>
- [18] Kajeiou, M., Alem, A., Mezghich, S., et Pantet, A., Adsorption compétitive des ions de zinc, cuivre et plomb sur les fibres de lin. *AJCE*, 2019. 37: p. 9-12. <https://doi.org/10.33557/ajce.37.1.3>
- [19] Srivastava, P., Singh, B., Angove, M., Competitive adsorption behavior of heavy metals on kaolinite. *Journal of Colloid and Interface Science*, 2005. 290: p. 28–38. <https://doi.org/10.1016/j.jcis.2005.04.036>