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Post-Mining Impact Assessment of the Kiniéro Gold Mine (Semafo) on Groundwater and Surface Water in Guinea

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Bintou Konate[1*], Narcisse Eboua Wandan[1], Koffi René Dongo[2], Mory Kourouma[3], Soumaila Alassane Boukari [2]

[1]Laboratory Science, Society & Environment, Institut National Polytechnic - Houphouët Boigny, B.P. 1093, Yamoussoukro, Ivory Coast

[2]Laboratory for Industrial Processes, Environmental Synthesis and New Energies, Institut National Polytechnic - Houphouët Boigny, B.P. 1093, Yamoussoukro, Ivory Coast. [3]Laboratory of Applied Research in Geoscience & Environment, Institut Superior of Mines and Geology of Boké B.P.84 Boké (Guinea).

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ABSTRACT

In Guinea, gold mining provides positive income conditions for the population. However, it is a source of pollution of water resources with chemicals. The objective of the study is to assess the impact of Semafo mining activity on the ground and surface water of Kiniéro after eight years of closure. To achieve this, water samples were taken between january and february 2021. 21 water samples were taken and 20 physico-chemical parameters were determined for each sample. The results of the analyses were processed using the multivariate statistical analysis method. These results showed that the groundwater and surface water are alkaline with respective pH values of 9.12 and 9.16. They have average temperatures of 27.86°C and 21.4°C respectively. The surface waters are weakly mineralized, whereas the groundwater is highly mineralised with respective maximum electrical conductivities of 149 µS/cm and 1107 µS/cm. The groundwater is less turbid, but the surface water is more turbid with maximum turbidities of 19.2 NTU and 47.20 NTU respectively. Groundwater is bicarbonated calcic magnesian and sulphated potassic, whereas surface water is chlorinated sodic sulphated potassic. The values of the physico-chemical parameters determined are below the WHO standard values. Overall, the quality of the water of Kiniéro is good, but requires further study during the next mining operation. To limit the high mineralization and turbidity of the wells, the following measures are recommended: improving their depth, cementing the walls and using appropriate covers.

INTRODUCTION

Water is an essential element for life, but its availability is not guaranteed everywhere and its quality often does not meet drinking water standards, which poses a risk to human health. The problem of drinking water is acute in most West African countries [1]. Water resources are threatened today by pollution from domestic, industrial and agricultural wastewater disposal, climate change, natural mineralization and acid rain. Surface pollutants can seep through the soil into groundwater. The danger of pollution depends on the types and concentrations of pollutants [2]. In recent decades, many African countries have faced challenges in the availability and use of water resources. This is due to climatic variations, anthropogenic pressures (especially mining), poorly controlled urbanization and high population growth [3]. Mining, agricultural inputs and domestic waste are the main sources of pollution of water resources.

Most people in the world use groundwater for a variety of purposes such as agriculture, industry, home, recreation and environmental activities [4].

At the end of the last century, the number of people without access to safe drinking water was estimated at 1.1 billion, or 1/6 of the world's population [5]. Access to water by rural populations has become a crucial issue due to environmental pollution and natural resources [6] . The Republic of Guinea is a mining country. In 2019, it ranked eighth among the largest gold-producing countries in Africa and thirtieth in the world with a production of 27.5 tonnes [7]. Gold deposits are located in Upper Guinea and in some localities in Lower and Middle Guinea. In Guinea, mining takes place in rural areas where the population lives mainly from agriculture and livestock.

Throughout the world, gold mining contributes to the economic development of countries by alleviating unemployment and creating jobs [8] . In Guinea, gold mining also contributes to the income of the population. Indeed, the mining sector accounted for 35 % of GDP in 1998 [9]. However, it is not without negative effects on the environment, including the pollution of water resources. Indeed, gold mining influences the quality and availability of water (cyanide leaching techniques and tailings ponds) and poses enormous pollution risks (infiltration and contamination of water resources [10].

Metallic pollution is a current problem that worries regions of the world concerned with maintaining their water heritage at a quality level [11]. This concern affects the sub-prefecture of Kiniéro, located 650 km east of Conakry, where numerous mining activities have been developed since 2002. These mining activities take the form of various gold panning sites and a gold mine (Sémafo) which is located 5 km from Kiniéro-centre and 7 km from Balan. This gold mine is an open-pit mine where the gold ore was processed by hydrometallurgical extraction (CIL) [12].

The current challenge for the mining sector is to find a balance between preserving the quality of the environment (groundwater and surface water) and meeting the water needs of society [13]. For the past eight years, no post-mining impact assessment of this mine has been conducted. However, the population of Kiniéro is supplied with drinking water from groundwater and surface water. It is therefore necessary to know and monitor the quality of these waters. It is in this context that this study is being carried out to assess the impact of Semafo mining activity on the groundwater and surface water of Kiniéro.

To address these concerns, we will follow the following methodology: determine the physics-chemistry parameters of groundwater and surface water and characterize the quality of these waters.

MATERIAL AND METHODS

Study area

The study area is located in the sub-prefecture of Kiniéro between 10° 30' north latitude and 9° 50' west longitude, 25 km south of Kouroussa-centre in the Upper Guinea region. It is bordered to the north by Kouroussa-centre, to the north-east by Babila and Baro, to the south-east by Gbrédou-Baranama, to the east by Karifamoriah, to the south by Banfélé, to the west by Beindou and to the north-west by Sanguiana. Our study focuses on two villages in the sub-prefecture of Kiniéro. These are Kiniéro-centre and the village of Balan. The climate is equatorial, with two alternating seasons: a dry season from november to may and a rainy season from june to october. The average rainfall is about 1600 mm; the average temperature is 27.6 °C [12] (Fig.1).

The river consists of two catchments: the main Niandan catchment and the Balankoba. The study area is mainly drained by a marigot called Badiko, which flows for about 4.5 km northwards to join the Sinkè River. This river flows further into the Balankoba. And other rivers named Kéléko, Tabako and Farabalan drain to the south of the project area.

In the study area, there are two types of aquifers. The upper aquifer, which oscillates between the surface and a depth of around ten meters, and the deep rock aquifer, which varies from 25 to 35 meters in depth. From a geological point of view, the area consists of a volcanic basement and a small sedimentary cover located in the south-eastern part of the Siguiri volcano-sedimentary basin within the Paleo-Proterozoic formations of the birimian. This basin is filled with volcanics and meta-sediments. The host rocks of the area consist of basalts, andesites and oxidised saprolites that were formed as a result of intense meteorite alteration on the surface [12].

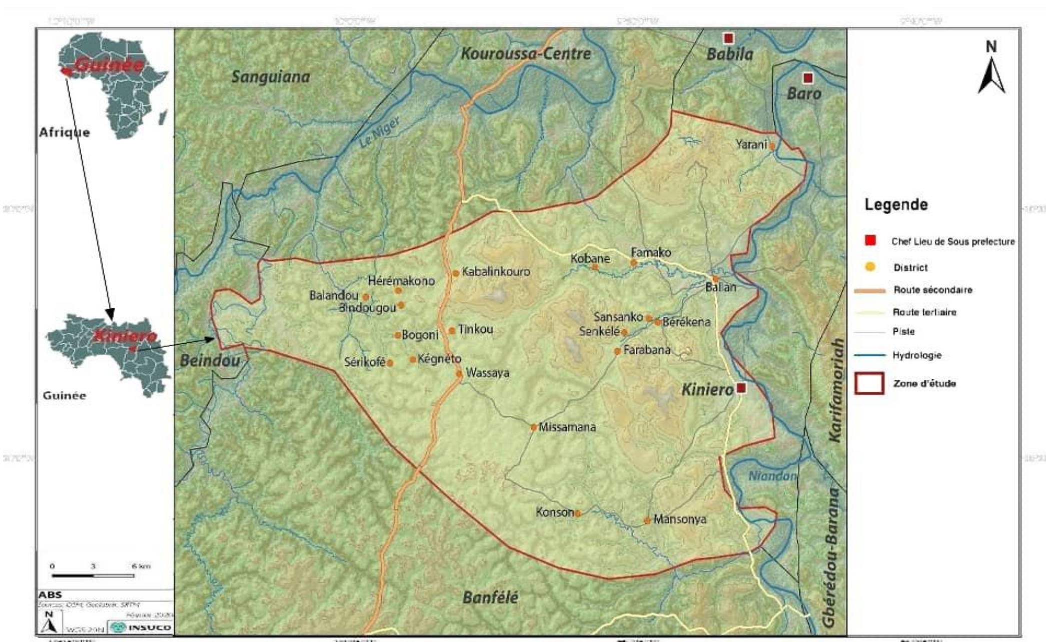

Fig.1. Location of the study area adopted from [14]

Materials

Sampling material

The material used in the study are listed in Table 1:

Table 1: material used

Material	Type	Usefulness
Sampling material	Garmin Map 64S GPS	to take the coordinates of the sampling points
	5 L bucket	for water withdrawal
	250 mL polyethylene bottles	for the sampling of water for the determination of heavy metals
	500 mL polyethylene bottles	for the collection of water for the determination of major ions
	a multi-parameter probe type WTW 3420	for in situ measurements of physical parameters
	a cooler	for storing the samples
	nitric acid	for parameter stabilisation
	distilled water	for rinsing the multi-parameter electrodes and laboratory vessels
	a tape	for measuring the depth of well
Analysis material	a Palintest 7100 photometer	for the determination of major ions
	a Spectrophotometer type DR2800 HACH	for the determination of cyanide ions
	a Plasma Atomic Absorption Spectrometer (PAS) type MP-AES 4210	for the determination of heavy metals
Data processing material	XLSTAT 2019.2.2	for the statistical treatment of the variables
	Arcgis 10.5 et Qgis 3.16	to draw up the maps
	WHO 2017 Standard	to compare the results

Methods

Method of sampling

The sampling campaign was carried out between fanuary and february 2021, which corresponded to the beginning of the dry season. A total of 21 water samples were collected, including 5 borehole water samples, 5 well water samples and 11 river water samples (Fig. 2). The coordinates and information of the collected waters are presented in Table 2.

The groundwater sampling protocol was that recommended by [15] . This involved letting the first quantity of water flow, then rinsing the sampling and measuring equipment (electrode of the multi-parameter) with distilled water, and three times in a row with water to be sampled, and filling the bottles directly with the pump. Then, a first sample is taken for the in situ measurements and a second sample is used for the analyses in the laboratory.

The samples for the determination of heavy metals were acidified with three drops of nitric acid (HNO_3) to stabilise the parameters. The sample vials were filled to capacity and then recapped immediately to avoid contact with the atmosphere. Finally, the samples were stored in a cooler containing ice at a temperature of - 4°C.

As for surface water, the sampling protocol was that recommended by [16]. This involved standing in the direction of water flow while waiting for the sediment lifted from the bottom to be carried downstream. The 500 mL bottles were filled underwater, rinsed and then emptied out of the water. The bottles were quickly resealed and immersed in the water to a depth of 30 cm (0.3 m) for water sampling. Sampling was carried out upstream and downstream of the rivers. The samples for heavy metal analysis were then acidified with nitric acid. Finally, the caps were quickly resealed and the samples were stored at a temperature of -4°C in a cooler. All groundwater and surface water samples were transported to the laboratory where the analyses were carried out the day after collection.

Analysis method

The analysis method concerned firstly the in situ measurements of physical parameters through operating modes and finally the chemical parameters (major ions and heavy metals) in the laboratory.

In-situ measuring

The in situ measurement concerned the determination of physical parameters such as: hydrogen potential (pH), temperature (T), electrical conductivity (EC), dissolved oxygen (O_2) which were measured using a multi-parameter probe type WTW 3420 with an accuracy of ± 0.01 and turbidity (Turb) which was measured using a ‟Lovibond″ turbidimeter type TB210IR of Russian brand with an accuracy of ± 0.001.

- **Calibration**

Calibration is the use of the measuring instrument on a standard, after which the measurement taken corresponds to the expected value. If this is not the case, the instrument's setting is corrected.

- For pH: the pH meter is calibrated with three standard solutions (pH: 4, pH: 7 and pH: 10). For calibrate, the pH probe is connected to the multi-parameter, after switching on the instrument, the pH probe is immersed in the three standard solutions; then the calibrate button is pressed and the instrument starts to calibrate the pH probe. The calibration ends when the reading stabilises around the value of the pH standards (± 1 pH).

- For electrical conductivity (EC): the conductivity meter is calibrated following the same procedure, except that with the conductivity meter, there is only one standard solution of 1412 µS/cm.

- For dissolved oxygen (O_2): unlike the first two, no standard solution was used, instead it was sufficient to keep the probe in the open air until saturation (100 % O_2) was achieved. Instead, it was sufficient to keep the probe in the open air until saturation was reached (100 % O_2).

- The temperature (T °C) is automatically calibrated with the other parameters.

- For turbidity, we used the ″Lovibond‟ turbidimeter type TB210IR.

- **Determination of parameters**

Once the device was calibrated, the parameters were measured in surface and groundwater.

✓ Surface water

To measure the pH in surface water, the probe was placed in the watercourse (river) and waited for the value to stabilise on the screen, and then the value read on the screen was noted.

The same principle is applied to determine the other parameters (EC and O_2).

For turbidity, we filled the tube with 10 mL of sample to be analysed, then we placed the tube in the apparatus, then we pressed the read button and, we waited 30s for the stabilisation of the values, on the screen to make the reading.

✓ Ground water

To measure the parameters in groundwater, water was taken from a previously prepared (sterilised) bottle and the same procedures were applied as for surface water.

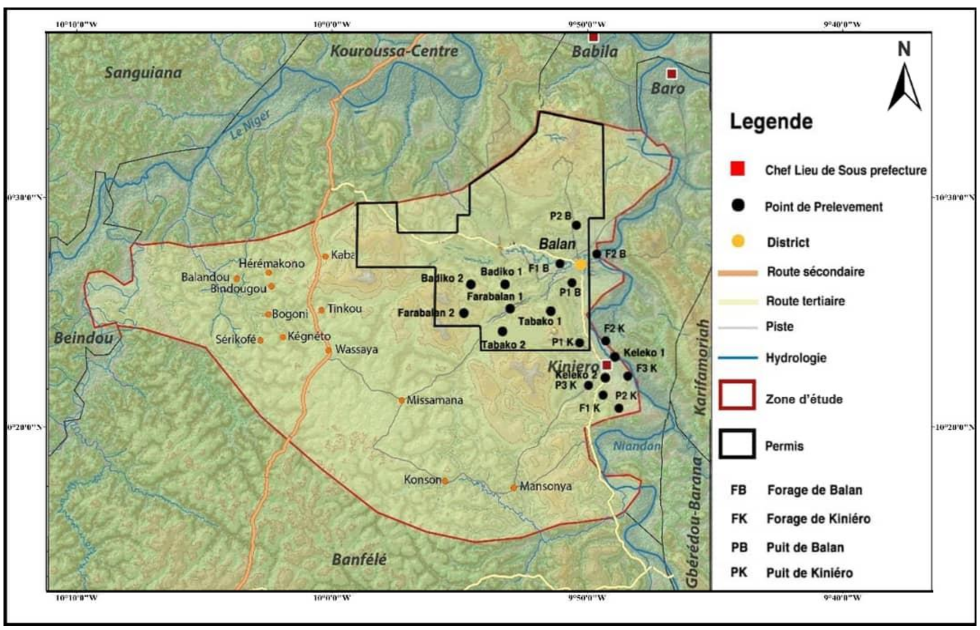

Fig.2. Map of sampling points

Table 2. Characteristic of groundwater and surface water sampling points

No	Localities	Sampled waters	Symbols	W (X) (m)	N (Y) (m)	Altitude (m)	Depth (m)	Distance from locality to mine (Km)
Groundwater								
E1	Kiniéro	Drilling 1 Kiniéro	F1K	417180	1149253	171	35	5
E2	Kiniéro	Drilling 2 Kiniéro	F2K	417275	1149307	257	35	5
E3	Kiniéro	Drilling 3 Kiniéro	F3K	417640	1149431	377	35	5
E4	Balan	Drilling 4 Balan	F4 B	415318	1157696	375	35	7
E5	Balan	Drilling 5 Balan	F5 B	415486	1157588	373	35	7
E6	Kiniéro	Well 1 Kiniéro	P1 K	417645	1149439	378	8	5
E7	Kiniéro	Well 2 Kiniéro	P2 K	417615	1149399	372	8	5
E8	Kiniéro	Well 3 Kiniéro	P3 K	417527	1149387	372	6	5
E9	Balan	Well 4 Balan	P4 B	415265	1157771	374	10	7
E10	Balan	Well 5 Balan	P5 B	415230	1157836	371	10	7
Surface water								
E1	Kiniéro	Tabako Upstream	Tab 1	417082	1149603	369	0,3	5
E2	Kiniéro	Tabako Downstream	Tab 2	417080	1149721	367	0,3	5
E3	Kiniéro	Kélèko Upstream	Kél 1	416637	1150392	371	0,3	5
E4	Kiniéro	Kélèko Downstream	Kél 2	416617	1150420	370	0,3	5
E5	Balan	BalankobaUpstream	BK 1	414730	1157933	378	0,3	7
E6	Balan	BalankobaDownstream	BK 2	414521	1157997	366	0,3	7
E7	Mining site	Small Dam	SD	412263	1152215	431	0,3	on the site
E8	Kiniéro	Badiko Upstream	Bad 1	411567	1153375	406	0,3	5
E9	Kiniéro	Badiko Downstream	Bad 2	411483	1153505	405	0,3	5
E10	Balan	Farabalan Upstream	Farab 1	409013	1152101	416	0,3	7
E11	Balan	Farabalan Downstream	Farab 2	407982	1153663	408	0,3	7

W (X) : West   N (Y) : North

Laboratory analysis

The analyses of the samples were carried out at the water quality control laboratory of the direction régionale de l'hydraulique in Kankan (Guinea). Major ions were measured using a palintest 7100 photometer and CN- ions were measured using a DR 2800 HACH spectrophotometer. Metals were determined using a Russian MP-AES 4210 plasma atomic absorption spectrometer (SAAP).

Data processing

The results of the physico-chemical analyses were processed using the multivariate statistical analysis method for the statistical treatment of variables. The statistical approach is based on the use of XLSTAT 2019.2.2 software. The maps were produced using arcgis 10.5 and qgis 3.16.

Finally, the values of the parameters obtained were compared with the standards of the World Health Organisation (WHO 2017).

RESULTS AND DISCUSSION

The results of the physical-chemical analyses of groundwater and surface water are recorded in tables. 3 and 4.

Physical analysis of groundwater and surface water

- In groundwater, low values of pH, T, EC, Turb, Suspended matter and O_2 are recorded in: Well 4 Balan (pH: 7.8; EC: 96.2 µS/cm); Well 1 Kiniéro (T: 25.7 °C); Well 3 Kiniéro (Turb: 0.87 NTU); Well 5 Balan (Suspended matter: 1.13 mg/L) and in all groundwater samples (O_2: 0 mg/L). High values are recorded in: Drilling 3 Kiniéro (pH: 10.36); Well 3 Kiniéro (T: 29.3 °C; EC: 1107 µS/cm) and in Well 1 Kiniéro (Turb: 19.2 NTU; Suspended matter: 4.84 mg/L; O_2: 0.03 mg/L).

- In surface waters, low values of pH, T, EC, Turb, Suspended matter and O_2 are recorded in: Badiko 1 (pH: 8.8; Suspended matter: 0.07 mg/L); Farabalan 1 and 2 (T: 18.5 °C); Balankoba 2 (EC: 35.7 µS/cm) and in Small Dam (Turb: 1.83 NTU; O_2: 0 mg/L). High values are recorded in: Balankoba 2 (pH: 9.58); Tabako 1 and Keleko 1 (T: 23.9 °C); Tabako 2 (EC: 149 µS/cm; Suspended matter: 4.74 mg/L); Balankoba 1 (Turb: 47.2 NTU) and in Badiko 2 (O_2: 0.06 mg/L).

Chemical analysis of groundwater and surface water

✓ **Anions**

- In the groundwater analysed, bicarbonates (HCO_{3^-}) remain the dominant ions.

The low value of 10 mg/L is recorded in Well 5 Balan, the high value of 195 mg/L is recorded in Drilling 1 Kiniéro with an average of 117.8 ± 52 mg/L. The low value of chlorides (Cl^-) 24.5

mg/L is recorded in Well 1 Kiniéro, the high value 50 mg/L is recorded in Drilling 4 and 5 Balan with an average of 34.7 ± 10.59 mg/L. The low value of sulphates (SO_4^{2-}) 9 mg/L is recorded in Drilling 5 Balan, the high value 32 mg/L is recorded in Well 3 Kiniéro with an average of 17.4 ± 6.84 mg/L. Nitrate (NO_{3-}) content is not significant with an average of 0.34 ± 0.20 mg/L.

- As for surface waters, chlorides (Cl^-) are the dominant anions, representing 97 % of the samples.

The low value of 34 mg/L is recorded in Small Dam, the high value of 58 mg/L is recorded in Balankoba 2 with an average of 46.91 ± 6.22 mg/L. Bicarbonates (HCO_{3-}) vary from 11 mg/L in Badiko 1 to 55 mg/L in Tabako 1 and 2 and in Small Dam with an average of 32.18 ± 15.77 mg/L. Sulphates (SO_4^{2-}) vary from 9 mg/L in Farabalan 2 to 23 mg/L in Farabalan 1 with an average of 17 ± 5.08 mg/L. The content of nitrates (NO_{3-}) is not as significant in surface waters but compared to the control value (0.62 mg/L) there is a slight increase in the mean value (0.78 ± 1.36 mg/L).

✓ **Cations**

- In groundwater, calcium (Ca^{2+}) remains the dominant cation. The low value of 10 mg/L is recorded in Well 5 Balan, the high value 52 mg/L is recorded in Drilling 1 Kiniéro with an average of 24.1 ± 11.00 mg/L. The low value of magnesium (Mg^{2+}) 3 mg/L is recorded in Well 5 Balan, the high value 25 mg/L is recorded in Well 3 Kiniéro with an average of 15.55 ± 5.80 mg/L. The low value of sodium (Na^+) 15.87 mg/L is recorded in Well 1 Kiniéro, the high value 32.39 mg/L is recorded in Drilling 4 and 5 Balan with an average of 22.48 ± 6.86 mg/L. Potassium (K^+) values vary from 0.35 mg/L in Well 5 Balan to 12 mg/L in Well 2 Kiniéro with an average of 7.51 ± 3.85 mg/L.

- In surface waters, sodium (Na^+) remains the dominant cation. The low value of 22.02 mg/L is recorded in Small Dam. The high value of 37.49 mg/L is recorded in Balankoba 2 with an average of 30.38 ± 4.02 mg/L. As for calcium (Ca^{2+}), the values are not significant enough in groundwater. They vary from 7 mg/L in Farabalan 2 to 16 mg/L in Tabako 1 and 2 with an average of 11.73 ± 2.72 mg/L. Mg^{2+} is also less significant than Ca^{2+}. They vary from 3 mg/L in Balankoba 2 to 15 mg/L in Tabako 1 and 2 with an average of 6.77 ± 4.29 mg/L. Potassium (K^+)

values are very low, they vary from 0.01 mg/L in Small Dam to 4.15 mg/L in Keleko 1 with an average of 2.09 ± 1.47 mg/L.

Table 3. Statistical variables and extreme values for groundwater

Parameters	**Units**	**WHO (2017)**	**Witness** [17]	**Mini**	**Maxi**	**Average ± σ**
Physical parameters						
T	°C	**25**	–	25.7	29.3	**27.86 ± 0.97**
pH	–	**6.5 – 8.5**	6.6	7.8	10.36	**9.16 ± 0.80**
Electric cnductivity	µS/cm	**≤ 500**	5.06	96.2	1107	**456.3 ±312.54**
Turbidity	NTU	**≤ 5**	33.5	0.87	19.2	4.65 ± 5.43
Suspended matter	mg/L	–	7.1	1.13	4.84	2.52 ± 1.22
Dissolved oxygen	mg/L	**≤ 8**	–	0	0.03	0.003 ± 0.01
Chemical parameters						
Magnesium	mg/L	**≤ 150**	10.33	3	25	**15.55 ± 5.80**
Calcium	mg/L	**≤ 100**	20.7	10	52	**24.1 ± 11.00**
Sodium	mg/L	**≤ 200**	12.63	15.87	32.39	**22.48 ± 6.86**
Potassium	mg/L	**≤ 12**	0.93	0.35	12	**7.51 ± 3.85**
Chlorides	mg/L	**≤ 250**	0.77	24.5	50	**34.7 ± 10.59**
Sulphates	mg/L	**≤ 250**	4.47	9	32	**17.4 ± 6.84**
Bicarbonates	mg/L	–	–	10	195	**117.8 ± 52.00**
Nitrates	mg/L	**≤ 50**	0.62	0.04	0.8	0.34 ± 0.20
Heavy metals						
Cadmium	mg/L	**≤ 0.003**	0.01	0.000	0.001	0.001 ± 0.001
Arsenic	mg/L	**≤ 0.01**	0.002	0.001	0.01	0.002 ± 0.003
Chromium	mg/L	**≤ 0.05**	0.01	0.000	0.001	0.001 ± 0.00
Mercury	mg/L	**≤ 0.006**	0.001	0.001	0.001	0.001 ± 0.00
Cyanide	mg/L	**≤ 0.07**	–	0.01	0.01	0.01 ± 0.00
Lead	mg/L	**≤ 0.01**	0.01	0.001	0.001	0.001 ± 0.00

✓ **Heavy metals**

In groundwater as well as in surface water, metal elements are present in trace amounts with values that are within the WHO standard.

- In groundwater, the average values for cadmium (Cd), chromium (Cr), mercury (Hg) and lead (Pb) are 0.001 mg/L. (Hg) and (Pb) are 0.001 mg/L. This value is within the WHO limits (Cd ≤ 0.003 mg/L; Cr ≤ 0.05 mg/L; Hg ≤ 0.006 mg/L and Pb ≤ 0.01 mg/L). The mean values for arsenic (As) and cyanide (CN-) are 0.01 mg/L, this value is also within the WHO limits (As ≤ 0.01 mg/L and CN- ≤ 0.07mg/L).).

- In surface waters, the average value of cadmium (Cd) is 0.001 mg/L, which is within the WHO limit (Cd ≤ 0.003 mg/L). This value is within the WHO limit (Cd ≤ 0.003 mg/L). The mean values of arsenic (As) and Pb are 0.01 mg/L, which is equal to the WHO limit value (As ≤ 0.01 mg/L and Pb ≤ 0.01 mg/L). The mean values of (Cr), (Hg) and (CN-) are at 0.004 mg/L, it is also within the WHO limits (Cr ≤ 0.05 mg/L; Hg ≤ 0.006 mg/L and CN- ≤ 0.07mg/L). The average value for (Hg) is 0.004 mg/L. This value is within the WHO limit (Hg ≤ 0.006 mg/L) but is higher than the control value (0.001 mg/L).

Table 4. Statistical variables and extreme values for surface waters

Parameters	**Units**	**WHO (2017)**	**Witness** [17]	**Mini**	**Maxi**	**Average ± σ**
Physical parameters						
T	°C	**25**	–	18.5	23.9	21.4 ± 2.14
pH	–	**6.5 – 8.5**	**6.6**	8.8	9.58	**9.24 ± 0.33**
Electric cnductivity	µS/cm	**≤ 500**	**5.06**	35.7	149	**70.191 ± 41.20**
Turbidity	NTU	**≤ 5**	**33.5**	1.83	47.20	18 ± 14.77
Suspended matter	mg/L	–	**7.1**	0.07	4.74	2.360 ± 1.53
Dissolved oxygen	mg/L	**≤ 8**	–	0	0.06	0.029 ± 0.02
Chemical parameters						
Magnesium	mg/L	**≤ 150**	**10.33**	3	15.00	6.773 ± 4.29
Calcium	mg/L	**≤ 100**	**20.7**	7	16.00	11.727 ± 2.72
Sodium	mg/L	**≤ 200**	**12.63**	22.02	37.49	**30.38 ± 4.02**
Potassium	mg/L	**≤ 12**	**0.93**	0.01	4.150	**2.087 ± 1.47**
Chlorides	mg/L	**≤ 250**	**0.77**	34	58	**46.91 ± 6.22**
Sulphates	mg/L	**≤ 250**	**4.47**	9	23	**17 ± 5.08**
Bicarbonates	mg/L	–	–	11	55	32.182 ± 15.77
Nitrates	mg/L	**≤ 50**	**0.62**	0.00	4.50	**0.78 ± 1.36**
Heavy metals						
Cadmium	mg/L	**≤ 0.003**	**0.01**	0.001	0.002	0.001 ± 0.001
Arsenic	mg/L	**≤ 0.01**	**0.002**	0.01	0.02	0.01 ± 0.00
Chromium	mg/L	**≤ 0.05**	**0.01**	0.003	0.005	0.004 ± 0.00
Mercury	mg/L	**≤ 0.006**	**0.001**	0.003	0.004	**0.004 ± 0.00**
Cyanide	mg/L	**≤ 0.07**	–	0.003	0.005	0.004 ± 0.001
Lead	mg/L	**≤ 0.01**	**0.01**	0.01	0.02	0.01 ± 0.001

The results obtained showed that the average T of the groundwater was 27.86 ± 0.97 °C. This corresponds to the average temperature of the study area. This temperature is characteristic of groundwater in West Africa under a humid equatorial climate with high rainfall [13]. This result confirms the work of [18]–[21] in Côte d'Ivoire.

The average pH of the groundwater is 9.16 ± 0.80. Compared to the control value, it increased from 6.6 to 9.16. The average EC is 456.3 ± 312.54 µS/cm, with the highest values recorded in the three Wells of Kiniéro (Well 1 Kiniéro, EC: 614 µS/cm; Well 2 Kiniéro, EC: 815 µS/cm and Well 3 Kiniéro, EC: 1107 µS/cm) The average EC of the Well water is 615.04 µS/cm and that of the Borehole water is 297.56 µS/cm. While the average EC of the Kiniéro Wells is 845.33 µS/cm, that of the Balan Wells is 269.6 µS/cm. The average EC of the Kiniéro Boreholes is 330.93 µS/cm, while that of the Balan Boreholes is 247.5 µS/cm.

The electrical conductivity of a water is its capacity to move electrical charges, and its measurement allows us to determine the mineralization of this water [22]. When we compare the EC value of the groundwater to the control value, we find that it has increased from 5.06 µS/cm to 456.3 µS/cm.

The average Turb of the groundwater is 4.65 ± 5.43 NTU, the highest value (19.2 NTU) is determined in Well 1 Kiniéro. The average Turb of the Well water is 7.22 NTU, that of the Borehole water is 2.07 NTU. The average turbidity of the Kiniéro Wells is 9.24 NTU, while that of the Balan Wells is 4.20 NTU. The average Turb of the Kiniéro Boreholes is 2.77 NTU, while that of the Balan Boreholes is 1.03 NTU. From the above, the Kiniéro Wells and Boreholes are more mineralized than the Balan Wells and Boreholes. In addition, the Kiniéro Wells are more turbid than the Balan Wells. This high mineralization and turbidity is justified by the shallow depth of the Wells in Kiniéro and the distance between this village and the mine (Table.2). When we compare the Well water to the Borehole water overall, it is clear that the Well water is more mineralized and turbid. On the other hand, the Borehole water has the best characteristics, it is less mineralised and less turbid.

This difference depends on the depth of the Wells and the geology of the area. The Boreholes are located in the bedrock aquifer, which is basalt and andesite. The depth is 35 m, which is a medium permeable zone for infiltration water. The Wells are located in the upper aquifer, which oscillates between the surface and about ten metres in a permeable saprolitic zone. In addition, the Well walls are not watertight and the covers are not suitable. In fact, the Wells are exposed to the infiltration of water and contaminated soil from the leaching of mine tailings. The superficial position of the reservoirs captured by the Wells is also reflected in the high turbidity values that are a global measure [23].

The temperature of the surface water was 21.4 ± 2.14 °C. It remains within the WHO standard (25 °C). The average pH is 9.24 ± 0.33. The pH values indicate that the waters of Kiniéro are on the whole alkaline. This alkalinity is thought to be related to the gold ore treatment process. Compared to the control value, it has increased from 6.6 to 9.16 in the groundwater and 6.6 to 9.24 in the surface water. This explains the impact of the mining activity on the groundwater and surface water of Kiniéro. Indeed, gold extraction in the area is done by cyanidation, the gold present in the ore is treated with a dilute solution of sodium cyanide in an alkaline medium at a pH higher than 10 (pH > 10) in the presence of oxygen according to eq.1[24].

$$4\ Au + 8\ CN- + O_2 + 2H_2O \longrightarrow 4\ Au(CN)_{2-} + 4\ OH \qquad (1)$$

The mean EC of the surface water was 70.191 ± 41.20 µS/cm, the high value 149 µS/cm was recorded in Tabako 2. Compared to the control value, it increased from 5.06 µS/cm to 70.191 µS/cm. The increase in EC is likely to be related to leaching and runoff of contaminated water and soil from mine tailings that carry minerals into surface waters. Mineralization is strongly dependent on transit time and the rocks in contact with the water, but also on possible anthropogenic impacts [22] .

The average turbidity is 18 ± 14.77 NTU, the highest value is determined in Balankoba 1 (47.20 NTU). The turbidity of a water determines the rate of suspended solids in that water, which means that the surface water is highly loaded in places with suspended elements. This high turbidity is probably related to the leaching and runoff of contaminated water and soil from the mine tailings, which also transports solids to the surface water. The high turbidity of water is related to runoff to the water and to the flow of Well walls that bring suspended matter [25]. When we compare groundwater to surface water, groundwater is more mineralized and less turbid, whereas surface water is less mineralized and more turbid, with average values of 456.3 ±

312.54 µS/cm and 4.65 ± 5.43 NTU respectively, compared to 70.191 ± 41.20 µS/cm and 18 ± 14.77 NTU.

The high concentration of HCO_{3-} ions is linked to the hydrolysis of aluminosilicate minerals (anorthite) present in the rocks. The hydrolysis of aluminosilicate minerals produces HCO_{3-} ions and Ca^{2+} ions according to eq.2 [26] :

$$2CaAl_2SiO_8 + 4CO_2 + 6H_2O = 2Ca^{2+} + 4HCO_{3-} + Si_2O_{10}Al_4(OH)_8 \quad (2)$$

This phenomenon of hydrolysis has been demonstrated by the studies of [20], [27], [28]. In our case, the presence of the Ca^{2+} ion would be related to the use of calcium hydroxide $Ca(OH)_2$ for pH control in cyanidation. According to [29], in a cyanidation process, the in-leach carbon circuit/CIL consists of several reactors. The oxidised concentrate in the circuit is subjected to pH control by $Ca(OH)_2$ to avoid the formation of the deadly hydrogen cyanide gas.

The presence of the K^+ ion in water is thought to be due to the hydrolysis of aluminosilicate minerals (orthoclase or potassium feldspar) [25] . The origin of Mg^{2+} ions in water is thought to be related to the dissolution of magnesium carbonate ($MgCO_3$) in the gold leaching process. During the leaching process, the ($MgCO_3$) dissolves to release the Mg^{2+} ion into the water [29]. The Na^+ ions would come from the gold ore extraction process by using sodium cyanide and sodium hydroxide in cyanidation. Compared to the control value, the Na+ concentration increased from 12.63 mg/L to 22.48 mg/L in groundwater and from 12.63 mg/L to 30.38 mg/L in surface water.

The origin of the chloride ions is believed to be related to the use of chloridic acid in the cyanidation process. Compared to the control value, the concentration increased from 0.77 mg/L to 34.7 mg/L in the groundwater and from 0.77 mg/L to 46.91 mg/L in the surface water. The SO_4^{2-} ions are believed to be a result of the oxidation of the sulphide minerals in the study area (pyrite and arsenopyrite) as a result of the cyanidation process. Due to the oxidising conditions of cyanidation, the S^{2-} formed can further oxidise to sulphate [30]. According to [31], when pyrite and arsenopyrite are exposed to air and water, as in alteration reactions, sulphates are formed according to eq. 3 and 4:

$$FeS_2 + 7/2(O)_2 + H_2O = Fe^{2+} + 2SO_4^{2-} + 2H^+ \quad (3)$$

$$Fe\ AsS + 7/2\ (O_2) + H_2O = Fe^{2+} + AsO_4^{3-} + SO_4^{2-} + 2H^+ \qquad (4)$$

Two types of hydrofacies are encountered in groundwater. These are the waters: bicarbonated calcic magnesian and chlorinated sodic sulphated potassic. Whereas in surface waters, only one type of hydrofacies is encountered. This is the water: chlorinated sodic sulphated potassic.

The average NO_{3-} value of 0.78 mg/L in surface water is slightly higher than the control value of 0.62 mg/L. This would be related to the use of ammonium nitrate in mining. Heavy metals remain within the WHO 2017 standard. The low value of metals in the water is probably linked to the closure of the mine 8 years ago. Except for Hg, which has a mean value of 0.004 mg/L, slightly higher than the control value of 0.001 mg/L in surface waters (see Table 4). It is thought to be linked to the use of mercury by gold miners.

CONCLUSION

The results of this study were used to assess the post-exploitation impact of Semafo on the groundwater and surface water of Kiniéro. The physical-chemical characteristics and types of water were determined. Groundwater is bicarbonated calcic magnesian and chlorinated sodic sulphated potassic and surface water is chlorinated sodic sulphated potassic. Of the twenty (20) parameters, only the temperature (27.86 °C) of the groundwater is above the WHO standard (25 °C), but it corresponds to the average temperature of the study area.

The pH values of the waters are between ($7 < pH < 14$), indicating that the waters are overall alkaline. The concentrations of electrical conductivity, turbidity, sodium, chlorine, magnesium, sulphate and nitrate are above the control values but still within the WHO 2017 standard. To limit the high mineralization and turbidity of the Wells, the following measures are recommended:

- improving the depth of the Wells ;
- cement the walls;
- and use appropriate covers.

Overall, the quality of the water in Kiniéro is good as all measured values are below the WHO standard. However, we are considering a more in-depth study necessary for the next mining operation.

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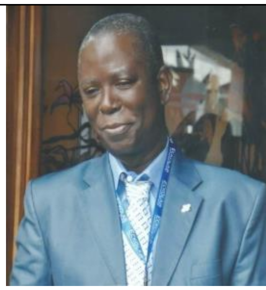
	*Bintou KONATE – **Corresponding Author*** [1]Science, Society & Environment Laboratory Institute National Polytechnique – Félix Houphouët Boigny. BP : 1093
	***Author Name*** Narcisse Eboua WANDAN [1]Science, Society & Environment Laboratory Institute National Polytechnique – Félix Houphouët Boigny. BP: 1093.
	Koffi René DONGO [2]Laboratory for Industrial Processes, Environmental Synthesis and New Energies. Institute National Polytechnique – Félix Houphouët Boigny. BP: 1093.
	***Author Name*** Mory KOUROUMA [3]Laboratory for Applied Research in Geoscience & Environment Institute Superior of Mines and Geology of Boké. BP: 84.
	Soumaila ALASSANE BOUKARI [2]Laboratory for Industrial Processes, Environmental Synthesis and New Energies. Institute National Polytechnic- Félix Houphouët Boigny. BP : 1093.