

Assessment of Mercury (Hg) and Cyanide (CN) Pollution in Surfacewaters, Groundwaters and Sediments around Industrial Mining Sites in the Department of Divo (Ivory Coast)

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How to cite this paper: Aristide, Y.K.S. and Ernest, A.K. (2021) Assessment of Mercury (Hg) and Cyanide (CN) Pollution in Surfacewaters, Groundwaters and Sediments around Industrial Mining Sites in the Department of Divo (Ivory Coast). *Journal of Water Resource and Protection*, **13**, 75-91.
<https://doi.org/10.4236/jwarp.2021.132005>

Received: November 26, 2020

Accepted: February 1, 2021

Published: February 4, 2021

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Abstract

Contamination of water and sediments by trace metal elements constitutes a risk to water, living species and for human health. The objective of this study is to assess the level of contamination of water and sediments in the Divo mining area with trace elements. Trace elements (CN and Hg) were determined in water and sediments using an Inductive Coupled Plasma Atomic Emission Spectrometer (ICP-AES). The intensity of sediment contamination was estimated from the calculation of several indices, including the Contamination Factor (FC), the Modified Contamination Degree (DC_m) and the Sediment Pollution Index (SPI). The results of the monitoring of the seasonal evolution of TME (CN and Hg), during the months of September 2018 and February 2020 are as follows: In surface water, the metallic concentrations vary from 0 to 4.98 $\mu\text{g/L}$ for mercury and 0 to 95 $\mu\text{g/l}$ for cyanide. All surface water samples have mercury concentrations lower than the average reference concentration of 6 $\mu\text{g/L}$. 7% of surface water samples have cyanide concentrations above the average concentration of 70 $\mu\text{g/L}$. Concerning groundwater, the cyanide concentrations remained below the standards for drinking water over the two seasons. Mercury recorded high concentrations in wells in the department. The sediments were found to be polluted with CN (uncontaminated to low contamination/very heavily contaminated) and Hg (uncontaminated to moderately contaminated/very heavily contaminated). The IPS values show that the surface sediments are moderately polluted except at the HR6 stations (0.07); ZR3 (0.22); AR1 (1.15); R3 (0.96); BRR (0); DRV (0.07) where the sediments are healthy. The inhabitants of mining areas are exposed to the risk of contracting various diseases by consuming this water contami-

nated with these trace elements.

Keywords

Mercury, Cyanide, Sediments, Contamination, Source Apportionment

1. Introduction

Extractive industries are essential for the development of national economies. The mining sector plays an important role in the growth of many countries around the world and continues to make an important contribution to national and regional economies [1]. Mercury and cyanide, however are toxic metals, recognized nowadays significant and harmful pollutants for man and the environment [2]. They are naturally present in water but at very low concentrations [3]. However, through industrialization, the industrial mining of gold and silver, man contributes to the increase in the amount of these trace elements in the environment [4]. Recent studies have shown that the amount of mercury in water has increased since the industrial age [5]. Few studies have been conducted on potential contamination of hydrosystems by the use of mercury and cyanide in mining activities, to understand the extent and the depth of the problems associated with industrial mining [6]. It is important to study the levels of mercury and cyanide the sites of industrial min. Most of the communities in the department get their domestic water supplies from boreholes, rivers and streams. Therefore, it is imperative that the levels of mercury and cyanide in these sources are known. Fishing is also a phenomenon running in these rivers and streams. The knowledge of the levels of mercury and cyanide will also inform corrective measures to take before this water is used for any purpose. The objective of this study is to determine the levels of total mercury and cyanide in the rivers, streams, sediments and drillings. Then compare them with [7] guideline values.

2. Materials and Methods

2.1. Study Area

The study area is located at the western part of Ivory Coast in the department of Divo, about 187 km from Abidjan, the economic capital. It covers an area of approximately 3577 km² and is located between the latitudes 05°40'N and 06°10'N and longitudes 05°30'W and 04°40'W. The department has (07) sub-prefectures including: sub-prefecture of Chiepo, Hiré, Zégo, Didoko, Nébo, Ogoudou and Divo. It is limited by Oumé department to the north, Lakota department to the west, Grand Lahou department to the southeast, Guitry department to the southwest, and Tiassalé department to the east. It is made up of three sub-watersheds: the Bandama and Gô watershed and the Boubo watershed, with the presence of two large mining areas in Hiré and Agbaou. The department consists mostly of old basement rocks and a small portion of coastal sedimentary rocks. The for-

mations of the basement rocks are Archaean formations (compound gneisses), the bast formations (granitoid) and the formations birimiennes (conglomerates, sandstone and schists). The basement formations are grouped into three main groups, which are the Archean formations (migmatites), the Liberian formations (granitoids) and the Birimian formations (conglomerates, sandstones and schists). The Liberian and Birimian formations were the dominant rock types (Figure 1).

2.2. Mining Activities in the Department of Divo

The department has an enormous amount of mineral resources, especially in the commune of Hiré and the locality of Agbaou. These resources are exploited by multinational companies such as: NEWCREST, ANDEAVOR and also in an artisanal way called gold panning (Figure 2). The industrial exploitation of gold in Côte d'Ivoire is carried out through an exploitation with open mines. This mode of exploitation generates major environmental problems, in particular the destruction of the soil, the pollution of waterways, the drying up of underground water tables, and the destruction of plants amongst others.

The department has many rivers and streams. The gold mining areas where the study was conducted are drained by the Gnouzalé, Gnénessi, Zessié and Lélébiabarivers. Out of these, several rivers were selected because of their strategic locations in relation to mining activities and their potential impact on the domestic water supply in the area. Twelve boreholes and nine sampled wells are

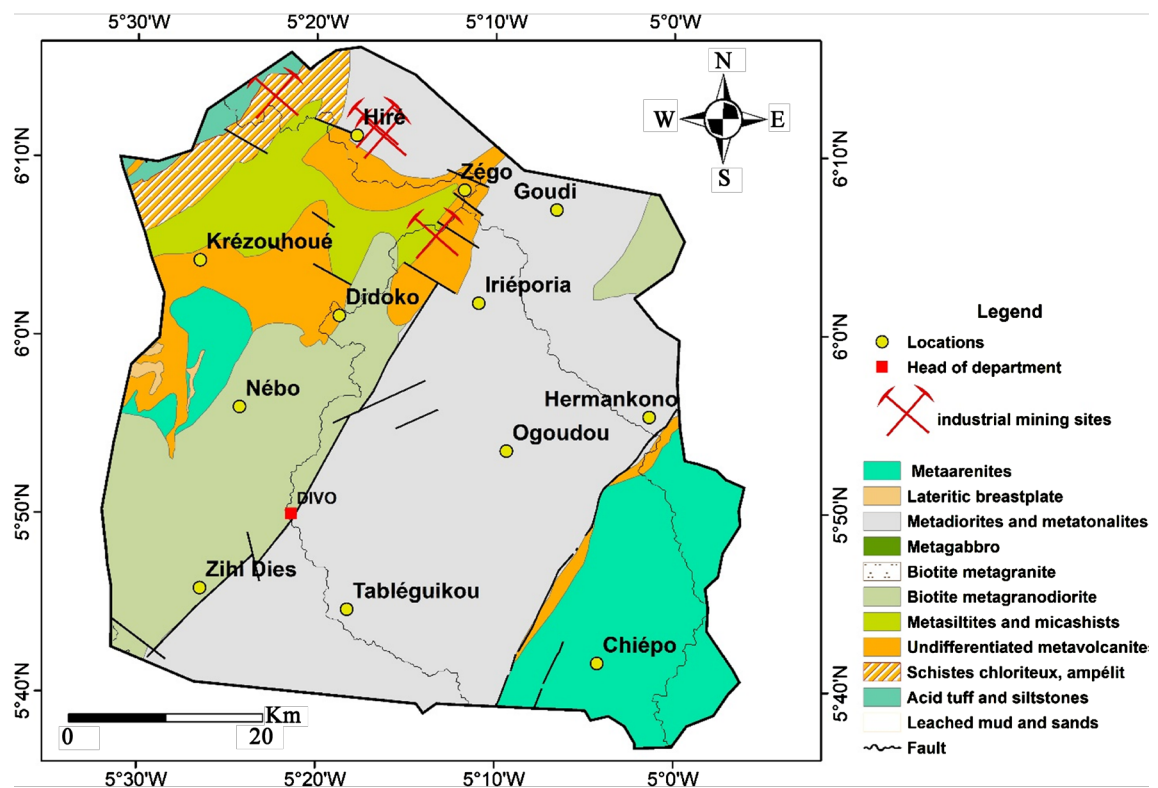


Figure 1. Geological map of the study area.



Figure 2. Open-cast mine to AGBAOU (a) and HIRE (b) (Source: Newrest Mining, April 2012; Google map, 2016).

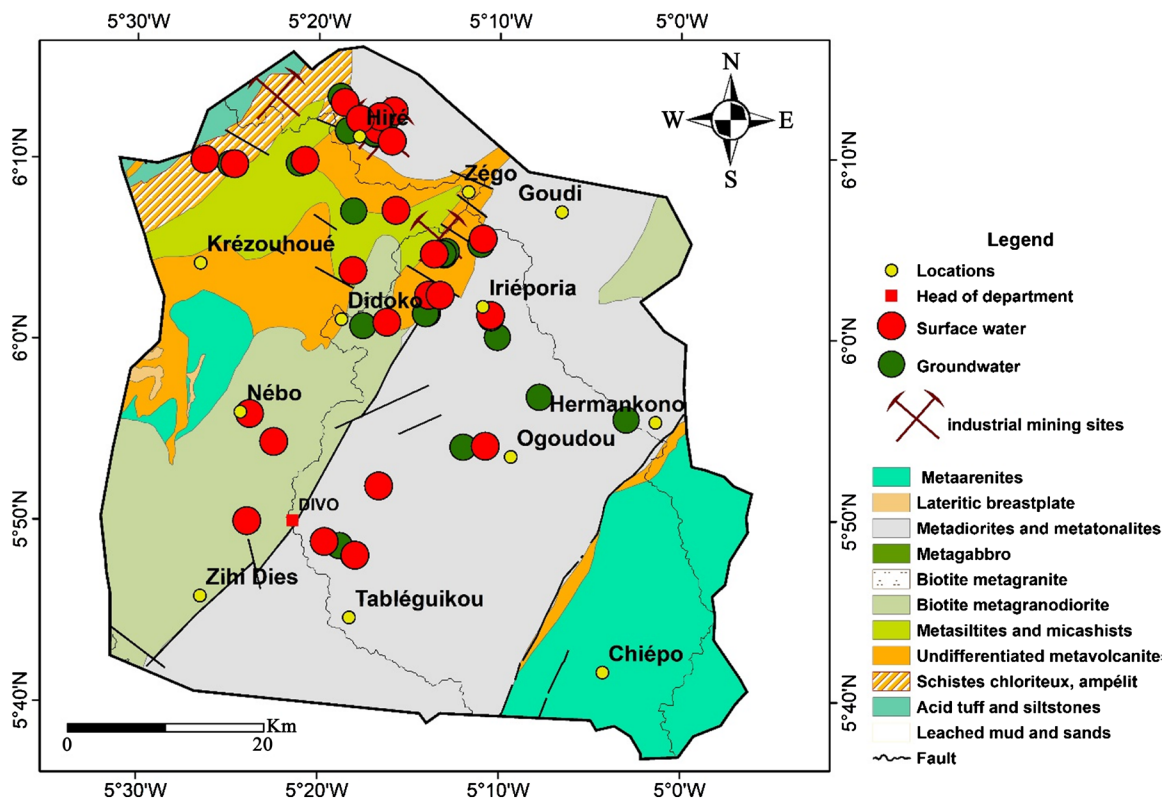


Figure 3. Location of study sites and sampling stations.

located in areas mainly affected by mining activities and outside mining areas (Figure 3).

3. Sampling Methodology

3.1. Environmental Data Sampling

Sampling was conducted to cover a period of 18 months. Samples were taken between September, 2018 and February 2020. September is the wet period while February is considered the dry period. Water and sediment sampling points

were located immediately upstream of areas near mining areas. Sampling points up stream of industrial gold mining areas are located at least 2 km from gold mining to prevent any possible contamination, while the sampling points located close the mining areas are also about 100 m away. In the case of the Zéhi River, samples were taken about 200 m downstream from a site of gold washing. Drilling waters were selected in each mining town/village. At each river and stream sampling point, approximately 1.5 ml of water was taken from the center of the stream/river to a depth of approximately 10 to 20 cm below the water surface. Sediment samples weighing about 300 grams were also below the water surface from the center of the stream/river. The drilling water samples were taken directly from the well heads. The drill pipe was pumped out before taking the sample, the samples were taken directly. The water samples were stored in polypropylene bottles which were rinsed with 10% HNO₃. Approximately 3 cm³ of concentrated HNO₃ was added to the water samples to stabilize the mercury and cyanide content. The sediment samples were collected in pre-labeled transparent polythene bags. All samples were stored in an ice chest with ice to maintain a low temperature (4°C) during transport to the CIAPOL Laboratory, Cote d'Ivoire.

3.2. Laboratory Analyses

Laboratory analyses were carried out according to procedures defined by [8]. Total mercury analysis was carried out at the CIAPOL Laboratory by Atomic Emission Spectrometer Inductively Plasma Coupled (ICP-AES).

3.2.1. Analyses of TME in Water Samples

The analysis of mercury and cyanide was by Inductive Coupled Plasma Atomic Emission Spectrometer (ICP-AES), which consist of the measurement of light radiation from a given element after artificial excitation. Indeed, fine amounts of the water samples will be absorbed by a tube and sprayed onto the optical path of the spectrometer. By emission of light at wavelengths specific to the TME being assayed, they are excited. Their return to a stable state will be preceded by an emission of light radiation which was picked up by a detector which will allow the concentration reading of the measured TMEs. The results of the analysis of the samples will be compared to the standards proposed by the water quality [7].

3.2.2. Analyses for Trace Metal Elements (TME) in Sediments

After drying of the sediments in an oven at a temperature of 50°C for 24 hours, the samples were sieved on 2 mm mesh size sieve to eliminate the coarse elements. They are then ground using an agate mortar and sifted to obtain a powder with particle diameter of less than 63 µm. The powder is then subjected to digestion. The digestion method used in this study is that of total decomposition recommended by [9]. The concentration of TMEs (Hg and CN) was determined by atomic emission spectrometry using an argon plasma source generated by inductive coupling (ICP-AES) (C).

3.2.3. Calculation of Metal Enrichment Indices

The evaluation of the degree of metallic contamination and of the toxicity of surface sediments was based on the calculation of the metallic and polymetallic enrichment indices, in particular: the contamination factor (CF), the modified degree of contamination (DC_m), the sediment toxicity index or sediment pollution index (SPI).

1) Calculation of the Contamination Factor

The contamination factor is used to show the existence or absence of contamination of sediments by trace elements. It also makes it possible to give the level of contamination if it exists [10] [11]. This contamination factor is expressed by the following formula:

$$CF = \frac{C_{\text{metal}}}{C_{\text{reference}}} \quad (1)$$

C_{metal} : Concentration measured for a metal

$C_{\text{reference}}$: Reference concentration of the metal

[12] defined CF contamination classes (Table 1).

2) Determination of the degree of contamination (DC)

The degree of contamination (DC) is the sum of the CFs [12].

According to [13], it allows the estimation of the a priori polymetallic contamination for each sampling point. This degree of contamination is expressed by the following formula:

$$DC_i = \sum CF \quad (2)$$

The use of this formula requires consideration of metallic and organic pollutants. In order to generalize the formula, [14] modified it and adapted it to the number of analyzed pollutants. The modified contamination degree (DC_m) is determined at each site by the sum of the contamination factors (CF) divided by the number of analyzed pollutants. It is expressed by the following formula:

$$DC_m = \frac{\sum CF}{n} \quad (3)$$

where n: number of analyzed pollutants.

The DC_m is associated with seven (07) classes according to [14] (Table 2).

3) Calculation of the Sediment Pollution Index (SPI)

The calculation of the enrichment factors makes it possible to obtain information on the contamination of the sediments but does not take into account the concept of toxicity linked to each metal.

Table 1. Contamination factor classes [8].

Class	Value	Sediment pollution intensity
1	$CF < 1$	Goes away with weak
2	$1 \leq CF < 3$	Moderated
3	$3 \leq CF < 6$	Considerable
4	$6 \leq CF$	Very strong

Table 2. Classes of the degree of contamination modified according to [14].

Class	Value	Sediment pollution intensity
1	$DC_m < 1.5$	Zero degree of contamination to very low level
2	$1.5 < DC_m < 2$	Low degree of contamination
3	$2 < DC_m < 4$	Moderate degree of contamination
4	$4 < DC_m < 8$	High degree of contamination
5	$8 < DC_m < 16$	Very high degree of contamination
6	$16 < DC_m < 32$	Extremely high degree of contamination
7	$DC_m \geq 32$	Ultra-high degree of contamination

Table 3. Sediment pollution index (SPI) classes.

Class	Value	Sediment pollution intensity
1	$0 \leq IPS < 2$	Healthy sediment
2	$2 \leq IPS < 5$	Slightly polluted sediment
3	$5 \leq IPS < 10$	Moderately polluted sediment
4	$10 \leq IPS < 20$	Very polluted sediment
5	$20 \leq IPS$	Dangerous sediment

Thus, [15] introduced the sediment pollution index (SPI). This index is defined as a linear sum of the CF and takes into account the relative toxicity of the TME by a weighting factor (W). A weight of 1 is assigned to Zn because it is the least toxic; Cr the value 2; Pb and Cu are assigned the value 5 and Cd the value 30 [12]. The SPI can be expressed by the following equation:

$$SPI_n = \left(\frac{\sum FC_n \times W_n}{\sum W_n} \right) \quad (4)$$

FC_n : metal contamination factor n

W_n : weight assigned to the metal considered

SPI is associated with five (05) quality classes [16] (Table 3).

4. Results

Comparisons were made between the waters, then the sediments. Comparisons were also made between wet and dry season averages [1] for surface water, boreholes and sediment samples.

In addition, the results of the water samples were compared with the [7] guideline value (6 µg/L) for mercury and (70 µg/L) for cyanide for drinking water and that of sediments samples were compared to the [17] guideline value (0.2 mg/kg for mercury and 0.07 mg/kg for cyanide). Finally, comparisons were made with the results of studies conducted elsewhere with similar characteristics. The results of the total mercury and cyanide analysis for the study periods are presented in Table 4 and Figures 4-6. Concentrations that fall above safe limits are identified and discussed.

Table 4. Comparison of Mean Concentrations of Total Mercury and Cyanide ($\mu\text{g/L}$) in Stream/River Water Samples.

Localités	Mercure			Cyanide		
	Wet saeson	Dry season	Mean	Wet saeson	Dry season	Mean
HR5	-0.0126	4.98	2.3137	0.002	<0.06	0.002
HR4	-0.003	0	-0.0015	<0.002	<0.06	0
HR1	0.498	0	0.249	<0.002	<0.06	0
HR6	-0.0277	0	-0.01385	<0.002	<0.06	0
HR7	-0.0013	0	-0.00065	75	80	77.5
HR2	-0.0094	0	-0.0047	<0.002	<0.06	0
HR8	-0.0197	0	-0.00985	<0.002	<0.06	0
HR3	-0.012	0	-0.006	<0.002	<0.06	0
AR2	-0.0116	0	-0.0058	<0.002	<0.06	0
ZR3	-0.011	0	-0.0055	<0.002	<0.06	0
R3	-0.008	0	-0.004	0.003	<0.06	0.003
IR	0.0051	2.64	1.32255	0.003	<0.06	0.003
R2	0.0137	1.67	0.84185	<0.002	<0.06	0
ZR2	-0.0119	0	-0.00595	0.006	<0.06	0.006
ZR1	-0.0132	4.64	2.4834	<0.002	<0.06	0
AR1	-0.0074	2.34	1.1663	95	50	72.5
BRR	-0.0162	0	-0.0081	0.007	<0.06	0.007
GR	-0.0095	1.56	0.77525	0.003	<0.06	0.003
NR1	-0.0128	0	-0.0064	<0.002	<0.06	0
NR2	-0.0029	0	-0.00145	0.005	<0.06	0.005
BR1	-0.0174	0	-0.0087	<0.002	<0.06	0
DVR	0.0301	0	0.01505	<0.002	<0.06	0
KGR1	-0.0113	0	-0.00565	<0.002	<0.06	0
DOR	-0.0099	3.391	1.69055	<0.002	<0.06	0
KGR2	-0.0088	0	-0.0044	<0.002	<0.06	0
BR2	-0.0076	2.64	1.3162	<0.002	<0.06	0
MR	-0.0112	3.31	1.6494	0.006	<0.06	0.006

4.1. Mercury and Cyanide in River/Stream Water

All mercury concentrations recorded during the rainy season are lower than the corresponding concentrations during the dry season **Table 4**. The difference in mercury concentration between seasons is significant at 5%. As for the cyanide concentrations, they are approximately equal over the two seasons.

The concentrations of mercury in the rainy season do not exceed the [7] guideline value ($6 \mu\text{g/L}$) for drinking water. These results show that all mercury

concentrations obtained in rivers and streams are in line with [7] guide values for drinking water. The highest concentration is recorded at the HR1 site (0.498 µg/L). The Hg concentrations recorded in dry season vary between 0 and 4.98 µg/L respectively at the level of ZHR3 (outside mining sites) and HR5 (near mining sites). High concentrations of cyanide were recorded on the HR7 (80 µg/L in the dry season) and AR1 (95 µg/L in the wet season). These stations are located respectively near a gold mining site in Hiré and downstream from the Agbaou industrial mining site (Figure 4 and Figure 5).

This reveals systematic seasonal variations in mercury concentrations and the increase in total mercury.

The spatial distribution map of the cyanide content is presented by the Figure 6. On this map, the highest cyanide values are located in the mining area, hence the direct effect of this metal in the surface waters.

4.2. Mercury and Cyanide in Groundwater

These results show that all mercury and cyanide concentrations in wells and drills are in line with [7] guide values for drinking water. During wet and dry seasons, cyanide concentrations remained lower than [7] standards for drinking water. Trends in mercury concentrations showed maximum values at AGPU

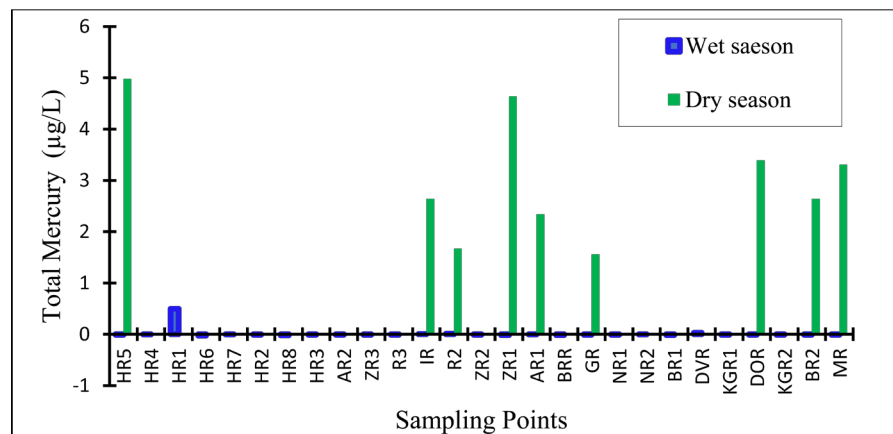


Figure 4. Total mercury analysis of stream/river water samples.

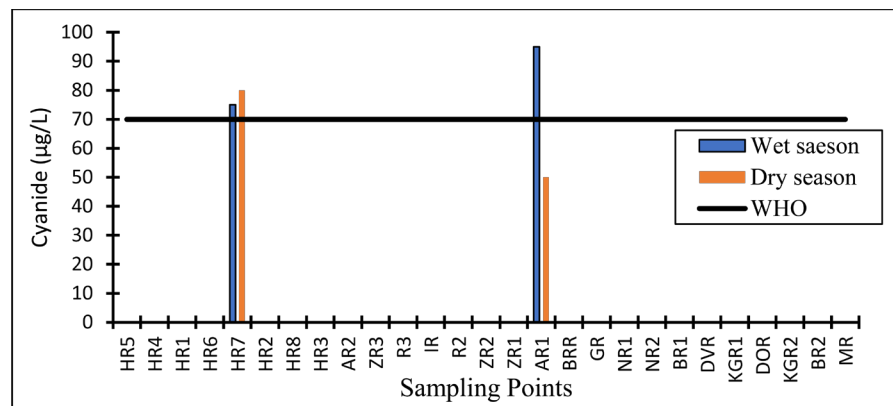


Figure 5. Cyanide analysis of stream/river water samples.

(3.67 µg/L). This well water is located in the village of Agbaou downstream of the site of treatment of gold. The average mercury values for the two seasons are 0.0087 µg/L (wet season) and 1.05 µg/L (dry season). The mercury levels measured during the rainy season are lower than the corresponding dry season. The concentrations of mercury during the wet season are lower than the standards of 6 µg/L (Figure 7 and Table 5).

4.3. Mercury and Cyanide in Surface Sediments

The results of the determination of mercury and cyanide in surface sediments

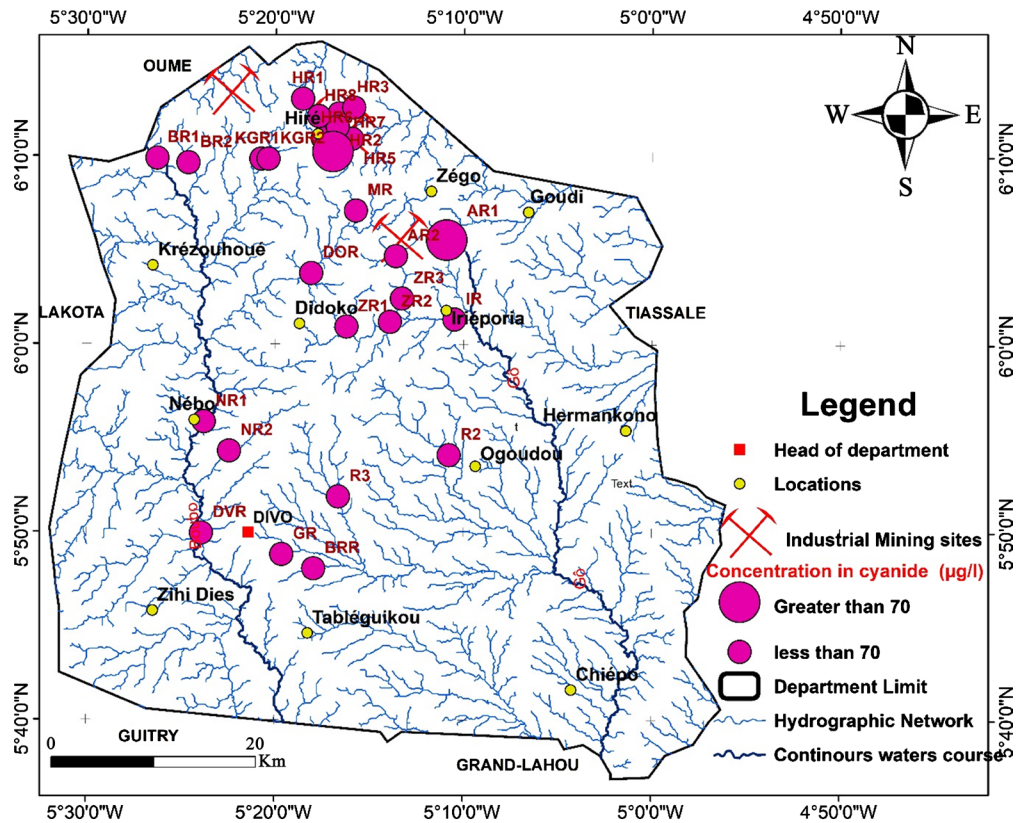


Figure 6. Space distribution of cyanide content in the surface waters of the diver.

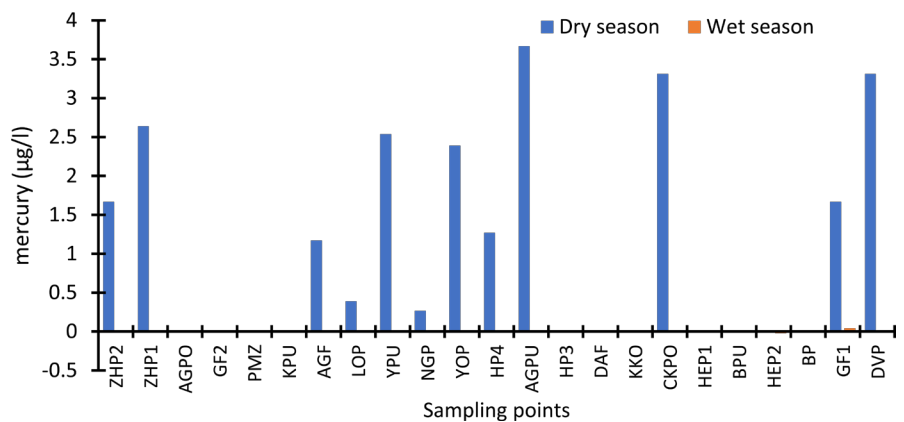


Figure 7. Total mercury analysis of groundwater water samples.

Table 5. Comparison of mean concentrations of total mercury and cyanide ($\mu\text{g/L}$) in groundwater water samples.

Localités	Cyanide			Mercury		
	Dry season	Wet season	Mean	Dry season	Wet season	Mean
ZHP2	<0.06	<0.002	<0.002	1.67	-0.007	0.8315
ZHP1	<0.06	<0.002	<0.002	2.64	-0.0136	1.31
AGPO	<0.06	<0.002	<0.002	<1	-0.0022	-0.0022
GF2	<0.06	0.016	<0.002	<1	-0.0093	-0.0093
PMZ	<0.06	<0.002	<0.002	<1	0	0
KPU	<0.06	0.009	<0.002	<1	-0.0067	-0.0067
AGF	<0.06	<0.002	<0.002	1.17	-0.0032	0.5834
LOP	<0.06	<0.002	<0.002	0.39	-0.0078	0.1911
YPU	<0.06	<0.002	<0.002	2.539	0	1.27
NGP	<0.06	<0.002	<0.002	0.268	0	0.268
YOP	<0.06	<0.002	<0.002	2.391	-0.011	1.19
HP4	<0.06	<0.002	<0.002	1.268	0	1.27
AGPU	<0.06	<0.002	<0.002	3.67	0.0087	1.83
HP3	<0.06	<0.002	<0.002	<1	0	0
DAF	<0.06	<0.002	<0.002	<1	-0.0162	-0.0162
KKO	<0.06	<0.002	<0.002	<1	-0.007	-0.0068
CKPO	<0.06	<0.002	<0.002	3.31	-0.0059	1.65
HEP1	<0.06	<0.002	<0.002	<1	-0.009	-0.0087
BPU	<0.06	<0.002	<0.002	<1	0	0
HEP2	<0.06	<0.002	<0.002	<1	-0.023	-0.02314
BP	<0.06	<0.002	<0.002	<1	-0.0074	-0.0074
GF1	<0.06	0	<0.002	1.67	0.045	0.8575
DVP	<0.06	0	<0.002	3.31	-0.0161	1.65

are presented in the table. All mercury concentrations measured in the dry season are higher than the corresponding concentrations in the wet season, with the exception of a few points (**Table 6**).

In the case of rivers near mining sites, the mercury concentration in the rainy season of the HR5 (0.7 mg/kg), HR1 (0.5 mg/kg) and HR2 (0.3 mg/kg) sites are higher than the dry season mercury concentrations with respective values 0.002 mg/kg; 0.041 mg/kg and 0.033 mg/kg. The difference in total mercury concentration between wet and dry seasons is significant.

Like mercury, the cyanide concentrations of the different samples in the dry season are higher than the corresponding concentrations in the rainy seasons, with the exception of the sites HR7 (0.80 mg/kg), R3 (0.65 mg/kg) and R2 (0.75 mg/kg). Mercury concentrations in sediment samples collected near mining

Table 6. Comparison of the mean concentrations of total Mercury and cyanide (mg/kg).

Localités	Cyanide			Mercury		
	Dry season	Wet season	Mean	Dry season	Wet season	Mean
HR1	0.032	0.08	0.0545	0.41	0.50	0.1409
HR2	0.039	0.00	0.0205	0.33	0.30	0.0789
HR3	0	0.04	0.0215	0	0.00	0.0129
HR4	0.125	0.04	0.08	0.053	0.00	0.0586
HR5	0.026	0.00	0.014	0.002	0.70	0.1488
HR6	0.005	0.00	0.0035	0.21	0.00	0.0063
HR7	0.02	0.80	0.41	0.011	0.00	0.2482
HR8	0	0.10	0.049	0	0.00	0.0294
ZR1	0.125	0.00	0.0625	0.027	0.03	0.0489
ZR2	0.02	0.10	0.06	0.005	0.00	0.037
ZR3	0.01	0.01	0.009	0.005	0.01	0.0084
R3	0.017	0.65	0.3335	0.004	0.03	0.2069
IR	0.024	0.07	0.0485	0.003	0.00	0.0297
AR2	0.178	0.00	0.089	0.034	0.04	0.0682
AR1	0.074	0.01	0.0435	0.008	0.04	0.0357
R2	0.379	0.75	0.5625	0.045	0.00	0.3465
GR	0.159	0.06	0.1075	0.026	0.00	0.0697
BRR	0	0.00	0	0	0.00	0
DOR	0.19	0.06	0.126	0	0.00	0.0756
DVR	0.041	0.00	0.0215	0.011	0.00	0.0151
KGR1	0.157	0.01	0.0845	0.027	0.00	0.0561
BR1	0.041	0.00	0.0215	0.007	0.00	0.0143
BR2	0.047	0.05	0.0495	0.008	0.00	0.0313
NR1	0.059	0.05	0.0555	0.007	0.00	0.0347
NR2	0.118	0.01	0.0655	0.028	0.00	0.0449
MR	0.134	0.07	0.1035	0.067	0.00	0.0755
KGR2	0.111	0.09	0.1015	0.016	0.03	0.0701

areas during wet and dry seasons exceed the [17] guideline value of 0.2 mg/kg with the exception of HR4 sites (0.053 mg/kg) and HR3 (00 mg/kg) during the rainy season. The highest mercury concentration of 0.7 mg/kg was recorded about 200 km from a gold mining site during the wet season while the lowest (0 mg/kg) was recorded in several samples outside mining areas during the rainy and dry season. The highest cyanide concentration of 0.80 mg/kg was recorded in a sample located near a gold mining site during the rainy season and the lowest (0 mg/kg) was also recorded in several samples outside mining areas during both seasons.

The high concentrations recorded in the sediments during the dry season are due to the increase in mining activities during the dry season with a corresponding increase in the use of mercury. The other reason is the evaporation of surface water resulting from increased concentrations of mercury in water and sediment. As for the high concentrations recorded during the wet season is due to the phenomenon of erosion, with the flow of surface water from mining sites to surrounding waterways.

4.4. Assessment of Sediment Contamination

The results of the calculations of the metal enrichment indices during the two seasons are presented in **Table 7**. The results of the table show often very high

Table 7. CF, DC_m and IPS values of surface sediments.

Localités	Wet season				Dry season			
	FC (CN)	FC (Hg)	DC _m	IPS	FC (CN)	FC (Hg)	DC _m	IPS
HR1	2.57	8.93	5.75	11.50	0.62	0.82	0.72	2.16
HR2	0.07	5.36	2.71	5.42	0.73	0.98	0.86	2.57
HR3	1.43	0.00	0.72	1.43	0.00	0.00	0.00	0.00
HR4	1.17	0.00	0.58	1.17	1.96	2.62	2.29	6.87
HR5	0.07	12.50	6.28	12.57	0.39	0.52	0.45	1.35
HR6	0.07	0.00	0.03	0.07	0.23	0.31	0.27	0.81
HR7	2.67	0.00	1.33	2.67	0.37	0.49	0.43	1.29
HR8	3.27	0.00	1.63	3.27	0.00	0.00	0.00	0.00
ZR1	0.00	0.54	0.27	0.54	1.99	2.66	2.32	6.97
ZR2	3.33	0.00	1.67	3.33	0.32	0.43	0.38	1.13
ZR3	0.27	0.18	0.22	0.45	0.18	0.24	0.21	0.63
R3	21.67	0.54	11.10	22.20	0.27	0.36	0.32	0.96
IR	2.43	0.00	1.22	2.43	0.37	0.49	0.43	1.28
AR2	0.00	0.71	0.36	0.71	1.12	1.49	1.30	3.91
AR1	0.43	0.71	0.57	1.15	2.71	3.62	3.17	9.50
R2	24.87	0.00	12.43	24.87	1.31	1.75	1.53	4.60
GR	1.87	0.00	0.93	1.87	2.80	3.74	3.27	9.81
BRR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DOR	2.07	0.00	1.03	2.07	0.67	0.89	0.78	2.34
DVR	0.07	0.00	0.03	0.07	5.76	7.68	6.72	20.16
KGR1	0.40	0.00	0.20	0.40	2.45	3.27	2.86	8.57
BR1	0.07	0.00	0.03	0.07	0.64	0.85	0.75	2.24
BR2	1.73	0.00	0.87	1.73	0.59	0.79	0.69	2.08
NR1	1.73	0.00	0.87	1.73	0.90	1.20	1.05	3.14
NR2	0.43	0.00	0.22	0.43	1.90	2.53	2.22	6.65
MR	2.43	0.00	1.22	2.43	2.12	2.83	2.47	7.42
KGR2	3.07	0.54	1.80	3.60	1.71	2.28	1.99	5.98

values of the indices at certain points.

In the rainy season, the Contamination Factor (CF) values vary from 0 at station ZR1 and 24.87 at station R2 for CN. As for mercury, the Contamination Factor (CF) values vary from 0 at the IR station and 12.50 at the HR5 station. The sediments of the stations studied show a low contamination absent ($CF \geq 1$) for the TME studied and very strong contaminations ($6 \leq CF$) are observed at some stations. The modified Degree of Contamination (DC_m) values vary from 0 at station BRR to 12.43 at station R2. These values indicate the presence of considerable contamination ($DC_m = 12.43$) at station R2 and low contamination ($DC_m < 6$) at the other stations of studies.

Regarding the Sediment Pollution Index (SPI), the values vary between 0.07 at station HR6 and 24.87 at station R2. Overall, the SPI values show that the surface sediments are moderately polluted except those at stations HR1, HR5, R2 and R3 which are heavily polluted sediments. These stations have SPI values ≥ 10 .

In the dry season, the Contamination Factor (CF) values vary from 0 at the HR3 station and 5.76 at the DVR station for CN. As for mercury, the values of the Contamination Factor (CF) vary from 0 at station HR3 and 3.74 at station GR. The sediments of the stations studied show an absent to low contamination ($CF \geq 1$) for the TME studied and considerable contamination ($3 \leq CF < 6$) is observed on some stations. Modified Contamination Degree (DC_m) values vary from 0 at the BRR station to 6.72 at the DVR station. These values indicate the presence of a moderate contamination ($DC_m = 6.72$) to station DVR and of a weak contamination ($DC_m < 6$) at the other. These values indicate the presence of moderate contamination ($DC_m = 6.72$) at the DVR station and low contamination ($DC_m < 6$) at the other stations of studies. Regarding the Sediment Pollution Index (SPI), the values vary between 0 at the BRR station and 20.16 at the DVR station.

Overall, the SPI values show that the surface sediment is moderately polluted except from the DVR station, which is a heavily polluted sediment with a value of SPI ≥ 10 .

5. Discussion

The high concentration of mercury recorded at the HR5 station (4.98 $\mu\text{g/L}$), as well as in other stations, is lower than the average reference concentration of the study area set to 6 $\mu\text{g/L}$ [7]. Cyanide and mercury are present in the natural water of the department, but at concentrations that meet the standards for drinking water. These elements are strongly present in water, when they are of anthropic origin, originating respectively from cyanide leaching and mercury amalgamation used to separate gold from waste rock during ore processing.

According to [18], with the phenomenon of pluviolessivage, the metallic elements are entrained in the water. According to [17], people who drink water containing Hg well above the maximum contaminant level for many years could experience kidney damage. Our results work with those of [19] in the mining area of Zouan-Hounien (West Coast of Ivory Coast).

The results of analyses of mercury and cyanide in the surface sediments of the department show that stations (R2, HR5, GR, DVR and HR7) are subjected to anthropic pressures. These stations present higher average concentrations of Hg and CN than the other study stations. The concentrations of the studied ETM are higher than the average values of reference defined by directive EPA of the United States.

The concentrations of the TME studied are higher than the average reference values defined by the United States EPA directive. This trend is confirmed by the results of the various calculated indices (DC_m and IPS). Variations in TME concentrations are affected by multiple factors such as natural and anthropic sources. These same observations were made by [20] in the mining field in Ghana.

6. Conclusion

Mining has for some time been highly developed in Ivory Coast. The Department of Divo is one of the main metallogenic provinces of the country. There are several industrial mining sites in operation, more specifically in Hiré and Agbaou. Several gold-bearing lenses have been identified, some of which are in operation by mining companies such as: Endeavour Mining and Agbaou Gold mine. The present study made it possible to highlight the level of contamination of water and surface sediments by mercury and cyanide. It should be noted that the waters and sediments in the study area are contaminated with CN and Hg in some cases and not contaminated at other sites. This contamination is expressed by the high contamination factor and high IPS values. These results reflect an enrichment of elements of anthropic origin compared to the average levels of the UCC. Enrichment would be linked to mining activity. More detailed studies on the water and types of fertilizers, then the products used in general during mining activities in the department will support these presumptions. While waiting for, it is obvious that this water is not appropriate for human consumption. Their consumption without prior treatment exposes the population to health risks.

Acknowledgements

The authors thank the international joint laboratory LMI MINERWA, the international network AMEDEE, the Laboratory of Soil, Water and Geomaterials Sciences (LSSEG) of the Félix Houphouët Boigny University of Abidjan and the analysis laboratory of the IRD of Nangui Abrogoua University for data analyses.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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