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Quality Of Drinking Water In An Area With High Gold Panning Activity In Côte d'Ivoire (Daloa, Centre-West)

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Abstract
Background*: Gold panning has experienced remarkable growth in recent decades in Côte d'Ivoire. This activity contributes substantially to local economies. However, the use of toxic chemicals has an impact on human health and the environment, particularly water resources. The aim of this study was to evaluate the level of contamination of drinking water by metallic trace elements, cyanide and pesticides in an area with high gold panning activity in Côte d'Ivoire.*
Materials and Methods*: Five (5) surface water samples and 5 well water samples were collected in the area of the gold panning sites and then analyzed. The metallic trace elements were measured by atomic absorption spectrometry. Total cyanides were measured according to the NF EN ISO 14403-1 standard and the pesticides were analyzed using a UV-visible HPLC chain.*
Results*:The average concentrations of the metallic trace elements found were 0.125; 0.002; 0.046; 0.036 and 0.009 µg/L respectively for arsenic, Cadmium, Iron, Lead and mercury in surface waters. In the well water, the concentrations of arsenic, cadmium, iron, lead and mercury were respectively 0.025; 0.001; 0.009; 0.007 and 0.002 µg/L. The average concentration of arsenic in all surface water samples and three well water samples was higher than the standard set by WHO (0.01 mg/Kg) for drinking water. Lead and mercury levels in surface water were also higher than recommended standards for drinking water. Cyanide has been found in surface and well waters at relatively low concentrations. Twenty-five pesticides belonging to the chemical families of organochlorines, organophosphates, carbamates and other compounds derived from urea and atrazine were found in the water samples analyzed. Farmer's well water was qualitatively the most contaminated with the simultaneous presence of several pesticides. The sum of the measured pesticide concentrations for each sample complied with the recommendations for drinking water, set at 0.50 µg/L.*
Conclusion: *Drinking water in this locality is contaminated by metallic trace elements, cyanide and pesticides. The quality of drinking water in this locality must be subject to permanent monitoring in order to protect the health of the population.*
Keywords: *gold panning, mercury, arsenic, cyanide, pesticide, Côte d'Ivoire.*

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I. Introduction

The Ivorian mining industry has experienced significant growth in recent decades with the discovery of numerous deposits across the country. This sector, which contributes 5% of the national gross domestic product (GDP)[1], is still largely dominated by gold mining activity, which is subject to industrial and artisanal exploitation. Artisanal gold mining activities affect almost all regions of Côte d'Ivoire and substantially contribute to local economies[2]**.** Furthermore, in addition to its significant socio-economic impacts, this activity has harmful effects on human health and the environment, particularly water resources, due to the use of numerous harmful chemicals such as mercury and cyanide [3,4,5]**.** Artisanal and small-scale gold mining is the largest emitter of mercury globally[6]**.** In Côte d'Ivoire, according to the Ministry of Environment and Sustainable Development, about 13 tons of mercury are used each year in artisanal and small-scale gold mining[7]**.** Anthropogenic water pollution is a major environmental and health problem for contries where this vital resource is becoming increasingly scarce due to demographic pressures[8]**.** This concern affects the Daloa region in the Center-West of Côte d'Ivoire where surface and groundwater, the main sources of drinking water for the population are constantly polluted by gold panning to which agricultural practices are added[9,10]. Located in a forest area, this large cash crop and food growing region occupies the first and second place respectively in the production of coffee and cocoa in Côte d'Ivoire[11]**.** It is also home to several artisanal gold mining sites, including the one in the Zoukougbeu sub-prefecture, which has been exploited in the open pit since the 2010s. This area is crossed by the *Lobo* river, which provides drinking water to the people of the region[9,12]. Also, the farmers, to ensure their drinking water needs, have erected wells not far from the gold panning sites. The chemicals from these mining and agricultural activities, which are often not very degradable, are dispersed in the environment and contaminate surface water or infiltrate the soil to reach groundwater. The impacts of these human activities on health and different ecosystems are not always studied. The aim of this study was to assess the quality of drinking water in Zoukougbeu, a town located in the department of Daloa where gold panning activities are important.

II. Material And Methods

Description of the study area

The gold panning area that is the subject of this study is located in the central-western part of Côte d'Ivoire, precisely between 746,000 and 757,000 west longitude and between 751,000 and 770,000 north latitude. From an administrative point of view, its geographical area straddles the sub-prefectures of Zoukougbeu, Zaïbo and Gregbeu (Figure 1). The capital of the region is the city of Daloa. The area belongs to the Sassandra River watershed, which is one of the 4 main rivers in Côte d'Ivoire. In the study area, there are large cocoa, coffee and rubber plantations and other crops such as rice and some market gardeners belonging to the villagers.

About 80 camps and villages, all equipped with village wells, are located in the study area. The main watercourse is the Lobo River, the main tributary on the left bank of the Sassandra River.

This river has its source in the Séguéla region (north-west of Côte d'Ivoire). It drains an area of 12,722 km^2 and covers 355 km with a perimeter of 530 km. The tributaries of the Lobo River in the study area are the *Glêglê* and *Kodo* rivers.

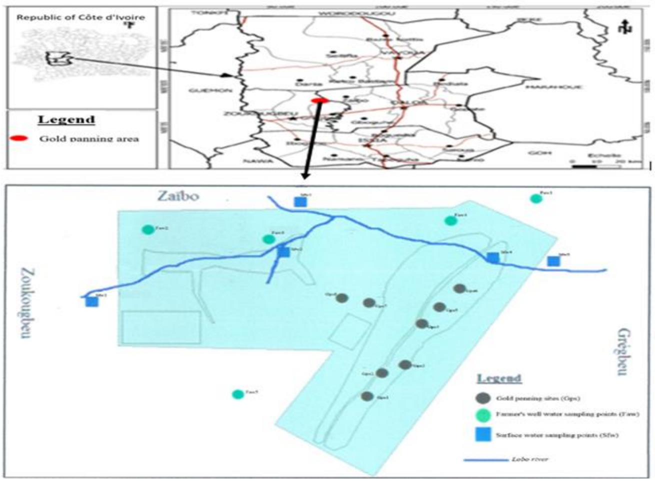

Figure 1 : *Study area*

Sampling sites

A total of ten (10) water samples were collected in the study area. These samples consisted of 5 samples of surface water (Sfw) and 5 samples of water from farmers' wells (Faw). Concerning surface water, 3 samples were taken from the *Lobo* River and the other two came from its tributaries *Kodo* and *Glêglê* located upstream of the gold panning site (Table 1). Groundwater was taken from 5 functional wells located in the camps around the gold panning sites (Figure 2).

Table 1: Surface and farmers' well water sampling points

Reference		Location of the sampling site	Geographic coordinates	
			UTM easting	UTM northing
Surface water	Sfw1	*Kodo* river (upstream)	748170	766123
	Sfw2	*Glêglê* river (upstream)	750926	767034
	Sfw3	*Lobo river* (upstream of the study area)	751161	767962
	Sfw4	*Lobo river* (North end of study area)	753942	766954
	Sfw5	*Lobo river* (downstream of the study area)	754806	766881
Well water	Faw1	Camp Djibo	754556	768032
	Faw2	Camp *Adama*	748980	767439
	Faw3	Camp *Aboulaye*	750716	767269
	Faw4	Mine warehouse	753328	767617
	Faw5	Camp *Djaha*	750287	764420

Sampling method

Surface and well water sampling was conducted according to the method described by Rodier[13] Water samples were taken in plastic vials and treated with nitric acid to stabilize metllic trace elements. For each sampling point identified, the GPS coordinates were recorded with a margin of error of approximately ± 3 m (**Figure 2).** The water samples collected were stored in coolers and transported to the laboratory for analysis.

Figure 2: Water withdrawal from farmers' wells

Methods for the analysis of chemical compounds

Metallic trace elements such as arsenic, cadmium, iron and lead were analyzed by inductively coupled plasma mass spectrometry (ICP-MS) according to the method described by the Quebec Centre of Expertise in Environmental Analysis[14]. The mercury was analysed by cold vapour atomic absorption spectrometry according to the EN 1483 standard[15]. Total cyanides were determined according to ISO 14403-1[16]**.** Pesticides were analyzed using a UV-visible HPLC chain (SHIMADZU) according to the protocol described by Al-Rimawi [17]

III. Results

Metallic trace elements and cyanide in water

Analysis of samples from surface water and farmers' wells revealed the presence of several trace metals including arsenic (As), cadmium (Cd), mercury (Hg), lead (Pb), and iron (Fe) in these two types of water. The mean concentrations were 0.125; 0.002 ; 0.046 ; 0.036 and 0.009 µg/L respectively for As, Cd, Fe, Pb, and Hg in surface waters. In the water of farmers' wells, the concentrations of arsenic, cadmium, iron, lead and mercury were respectively 0.025; 0.001 ; 0.009 ; 0.007 and 0.002 µg/L. Arsenic was the most abundant metal in the waters. The mean concentration of this compound in all surface water samples and three well water samples (Faw1, Faw4, Faw5) was above the WHO standard (0.01 mg/Kg) for drinking water[18]. The average levels of lead and mercury in surface water were also above the recommended standards (Table 4). The mean concentrations of total cyanides in surface and groundwater were 0.009 and 0.007 mg/L, respectively. These values were all below the regulatory limit of 0.07 mg/L.

Table 2: Metallic trace elements and cyanide content of surface and well water

		Arsenic (mg/L)	Cadmium (mg/L)	Iron (mg/L)	Lead (mg/L	Mercury (mg/L)	Total cyanide (mg/L)
Surface water	Sfw1	0.150	0.003	0.055	0.04	0.011	0.012
	Sfw2	0.129	0.002	0.047	0.04	0.010	0.006
	Sfw3	0.099	0.002	0.036	0.03	0.007	0.014
	Sfw4	0.183	0.003	0.067	0.05	0.014	0.007
	Sfw5	0.063	0.001	0.023	0.02	0.005	0.007
	Min	0.063	0.001	0.023	0.02	0.005	0.006
	Max	0.183	0.003	0.067	0.05	0.014	0.014
	average	**0.125**	**0.002**	**0.046**	**0.036**	**0.009**	**0.009**
	Standard deviation	0.046	0.001	0.017	0.011	0.004	0.004
well water	Faw1	0.029	0.001	0.010	0.008	0.002	0.005
	Faw2	0.007	-	0.003	0.002	0.001	0.009
	Faw3	0.005	-	0.002	0.001	-	0.005
	Faw4	0.036	0.001	0.013	0.010	0.003	0.009
	Faw5	0.049	0.001	0.018	0.013	0.004	0.005
	Min.	0.005	0.000	0.002	0.002	0.000	0.005
	Max.	0.049	0.001	0.018	0.013	0.004	0.009
	average	**0.025**	**0.001**	**0.009**	**0.007**	**0.002**	**0.007**
	Standard deviation	0.019	0.001	0.007	0.005	0.002	0.002
WHO Guidance Value (2017) (mg/L)		**0.01**	**0.003**	**0.3**	**0.01**	**0.006**	**0.07**

Pesticide content of water

Of the thirty pesticides tested, twenty-five (25) were found in the water samples analyzed. These pesticides belonged to the chemical families of organochlorines, organophosphates, carbamates and other compounds derived from urea and atrazine. The pesticides found were mainly herbicides derived from urea and atrazine. Cyanazine, isoproturon, propazine were the most frequent pesticides found in 80 % of all water samples analyzed. Well water was qualitatively the most contaminated with the simultaneous presence of several pesticides. This is the case for the wells water Faw2, Faw3 and the surface water Sfw1, which respectively concentrated 18, 18 and 17 of the 25 pesticides detected. The sum of the measured concentrations of pesticides for each sample was in accordance with the drinking water guidelines of 0.50 µg/L[19].

Table 3: Pesticides content in water (ng/L)

		Pesticide content of surface water (ng/L)					Pesticide content of well water (ng/L)					number of positive samples	
		Sfw1	Sfw2	Sfw3	Sfw4	Sfw5	Faw1	Faw2	Faw3	Faw4	Faw5	N	%
Organophosphorus	Methyl Parathion **				7.22		3.52	1.25	14.82	11.26		5	50
	Chlorfenvinphos**						2.14	14.82	3.33	6.86	3.51	5	50
	Vinclozolin***	11.7			11.29		2.27	3.33	2.43	7.27	9.71	7	**70**
	Parathion ethyl**	10.2			12.83		60.16	2.43	14.82	19.51	1.02	7	70
Organochlorine	Metolachlor *										33.95	1	10
	Metazachlor *	15.6					21.70	33.86		69.43	1.53	5	50
	Endosulfan**				0.088							1	10
Carbamates	Aldicarb**								22.98			1	10
	Metoxuron*	7.21	2.88	12.70	2.70	2.17		22.98	10.46			7	**70**
Derivatives of Urea	Monuron*	0.99		11.33	14.24			10.46	107.0		22.43	6	60
	Méthabenzthiazuron*	1.05	39.12		34.92	4.28		107	2.53		5.04	7	**70**
	Chlortoluron*	13.9						2.53	2.50			3	30
	Monolinuron*	12.3					31.68	2.50		101.4	35.30	5	50
	Isoproturon*		13.08	13.14	23.35	22.4	2.34		26.59	7.48	1.54	8	80
	Diuron*	15.5						26.59			1.86	3	30
	Métobromuron*	12.9					32.00		33.86	102.4	13.82	5	50
	Buturon*								26,24			1	10
	Linuron*	18.5	5.41	11.12	10.49	3.25		26.24	57.54			7	**70**
Triazine and Metabolites	Simazine*	21.7			22.26		84.58	57.54	5.34	270.6	22.90	7	**70**
	Cyanazine*	0.88	2.05	3.12	0.52	1.83	2.88	5.35		9.22		8	80
	Atrazine*	12.1						.	21.73		13.00	3	30
	Propazine*	4.93	8.15	17.92	15.64	12.33		21.73	2.53		25.40	8	80
	Terbuthylazine*							2.53	19.04		19.23	3	30
	Prometryne*	13.7			18.76		3.30	19.04	1.25	10.55	32.59	7	**70**
	Terbutryn*	0.35	16.51	13.47	12.73			1.25				5	50
Number of pesticides present in each sample		**17**	**7**	**7**	**14**	**6**	**11**	**18**	**18**	**11**	**16**		
Guide Value of Pesticides (ng/L)		500					500						

* : Herbicide
** : Insecticide
*** : Fungicide

IV. Discussion

The results of the analyses revealed a strong contamination of surface and well water by Metallic trace elements (Hg; Cd; Fe; Pb; As), cyanide and pesticides. Among these various chemical substances found, mercury and cyanide are known for their regular use in gold panning and are used respectively for the amalgamation and cyanidation of gold[3,20,21]**.** As artisanal gold mining processes are carried out in the *Lobo* river watershed, the discharge of untreated effluent was the cause of contamination of surface and groundwater. Unlike cyanide, which was below standards, the concentration of mercury in surface water was higher than the WHO guideline values for drinking water[18]**.** This high concentration of mercury was related to its increased use in this activity and its persistence in the environment. Indeed, artisanal gold mining is considered to be the largest emitter of mercury with 38 % of emissions and releases of this trace metals into the environment worldwide[22]**.** Its release and accumulation in the environment leads to heavy water pollution. The wells sampled are located outside the gold panning sites. Their contamination with mercury and cyanide is due to horizontal infiltration of these pollutants into the soil, thus reaching the surrounding surface wells.This phenomenon is generally observed in the dry season when water infiltration is low [23] **.** Other metals such as cadmium, iron, lead and arsenic were found in the water in various concentrations. Arsenic is the most abundant compound found in 80 % of all samples analyzed. Its average concentration in both water sources and that of lead only in surface waters were higher than drinking water standards [18]. The high content of metallic trace elements in the water is linked to the geological nature of the region's soils[10,24]. Moreover, the great richness in ETM of soils in various localities in western Côte d'Ivoire has been highlighted in several studies[4,21,25]**.** In the soil, arsenic binds to many metals including gold and is used as an indicator for gold prospecting[26,27]**.** Gold mining has led to its dispersion in the environment, thus exacerbating the contamination of surface and well waters. The presence of metals in water can also be linked to the use of used batteries, used oil, and certain solid waste on gold panning sites. The various pesticides found in water belong to the chemical families of organochlorines, organophosphates, carbamates, urea derivatives and atrazine and its metabolites. These pesticides, mainly herbicides, come from the cultivation of cocoa, coffee, rubber but also from food crops, which are the main products of the region. The area studied is located in a forest region with significant rainfall all year round[28]**.** These climatic conditions favour large-scale agriculture with an increased use of phytosanitary products. Some of these pesticides, which are frequently found in water samples, are not approved in Côte d'Ivoire (endosulfan, metolachlor). The waters in which pesticides, metals and cyanide were found are intended for the food of the populations of this region. The Lobo River from which the surface water samples were taken is used for the distribution of drinking water in the Department of Daloa. Also, the wells very often erected in the heart of plantations treated with pesticides are used directly to feed the farmers. Metals found in the water and cyanide are all known for their harmful and carcinogenic effects. Also, the presence of many pesticides in each sample can increase the health and environmental risk. Indeed, simultaneous exposure to several substances, even at regulatory doses, can have a deleterious effect on the exposed organism [29,30,31].

V. Conclusion

This study highlighted the poor quality of the water consumed by the population in the department of Daloa. Many pollutants identified in these waters, such as mercury, cyanide and pesticides, come mainly from gold panning activities and intensive agriculture. In addition to these anthropogenic activities, there is a natural presence of these water compounds linked to the great richness of the soil. The high concentration of certain pollutants in water is all the more worrying as they are substances with toxic and carcinogenic potential. Simultaneous exposure to this multitude of toxic molecules exacerbates the risk to consumers' health. The quality of drinking water in this locality must be constantly monitored in order to protect the health of the population. Côte d'Ivoire's ratification of the Minamata Convention on Mercury in 2019 and many other international agreements should allow it to tighten regulations on the use of chemicals in gold panning activities and agriculture in order to limit their impact on human health and the environment.

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