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Assessment of the Human Health Risks Associated with Heavy Metals in Surface Water Near Gold Mining Sites in Côte d'Ivoire

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Abstract

Heavy metals are a major cause for concern in relation to water systems, due to their high toxicity at elevated levels. The metals can originate from both natural processes, including geological weathering and volcanic activity, as well as anthropogenic activi-ties such as industrial discharges, agricultural runoff, mining, and urbanization, which sig-nificantly contribute to water pollution and environmental degradation. The as-sessment of these risks is crucial for protecting public health, especially in populations reliant on contaminated water sources. Exposure to such contaminants can result in severe health con-sequences, including neurological impairments, organ deterioration, and an elevated risk of cancer. To conduct this assessment study, six surface water sampling sites were selected (i.e., S1 (Gobia), S2 (Kouamefla), S3 (Benkro), S4 (Dou-kouya), S5 (Doka), and S6 (Zengue)) due to their proximity to mining activities. We used the hazard quotient (HQ) and hazard index (HI) methods to estimate the levels of non-carcinogenic health risk associated with heavy metals. Then, the assessment of carcinogenic health risk was carried out using the Incremental Lifetime Cancer Risk (ILCR) methods. First, the highest ILCR total values were observed in the Doya locality (i.e., 0.4237 for the children and 0.5650 for the adults) and during the great dry season (i.e., 0.4333 for the children and 0.5743 for the adults). These findings highlight that populations in this locale experience heightened exposure during the period of the Great Rainy Season. The results indicated that the population exposed to Cd and Hg may experience health concerns irrespective of season and locality. For As and Pb, risks are present in both seasons (i.e., Short Dry Season (SDS) and Short Rainy Season (SRS)). On the other hand, the HIs are well above 1, indicating that the population may be exposed to non-carcinogenic diseases associated with the metals, regardless of the season or locality. To further explore the results, the assessment by ILCR was em-ployed, which demonstrated that for all the designated localities, the ILCRs of As and Cd are well above 10^{-4} for the entire population, indicating that the population con-suming this water may develop major carcinogenic risks. In addition, the highest ILCR values were obtained for Cd, regardless of the age group. It should be noted that sea-sonal variation had no significant effect on the trend in ILCRs determined for the en-tire population.

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1. Introduction

Human risk assessment of heavy metals from surface water involves evaluating the potential health hazards posed by the presence of toxic metals, such as lead (Pb), mercury (Hg), cadmium (Cd), and arsenic (As) in aquatic environments [1]. Once released, heavy metals pose significant environmental and health concerns due to their toxicity and persistence within ecosystems [2]. These contaminants can enter the environment naturally, for example, when rock is worn away by wind and water. However, they are mainly introduced into aquatic systems by anthropogenic activities, including mining, industrial effluents, and the excessive use of pesticides and fertilizers [2–4]. Likewise, the World Health Organization (WHO) has listed As, Pb, Cd, and Hg as some of the most dangerous chemicals for public health [5]. Unlike other pollutants, these heavy metals such as cadmium (Cd), lead (Pb), and mercury (Hg) exhibit unique characteristics. They do not degrade and instead accumulate in sediments, plants, aquatic animals, and ultimately in the human food chain [6]. The risks associated with skin contact, inhalation, and ingestion have been assessed in soils contaminated with heavy metals [7–9]. In developing countries, untreated or inadequately treated industrial wastewater and mining represent primary sources of metal pollution in freshwater systems [6]. Furthermore, atmospheric deposition has also been identified as a potential pathway for the entry of heavy metals into water [10]. The consumption of animal and plant products contaminated with heavy metals has the potential to pose a heightened risk to human health [11]. In West Africa, research has been conducted on surface waters in Togo, specifically in the Bangeli canton. The findings indicate that the carcinogenic risk for cadmium (Cd), lead (Pb), and arsenic (As) is below the established limit value (10^{-4}). This observation suggests that there is no significant cancer risk associated with these elements in the environment [12]. Some authors have also revealed that human exposure to groundwater across mining areas can cause serious health problems in adults, with ILCRs ranging from 1.72×10^{-4} to 1.27×10^{-3}. They also showed that children are less likely to be affected by cancer, with an ILCR ranging from 5.35×10^{-5} to 3.98×10^{-4} and arsenic was the main cause of risks [13]. In Côte d'Ivoire, there is a high level of mining activity in the Oume department, leading to heavy metal contamination of river water. The local populations, who use the water from these rivers for domestic consumption, irrigation, livestock farming, and fishing, are thus increasing their exposure to toxic metals. This can result in significant health implications, including kidney failure, cancer, and cardiovascular disease, due to prolonged exposure [12]. Otherwise, regulations pertaining to discharges and effluents from facilities classified for environmental protection date back to 2008 [14], yet there has been a notable increase in industry, particularly in the mining sector. Consequently, a necessity arises to undertake a comprehensive review of discharge standards and limit values for industrial effluents, with the objective of ensuring the population's health and well-being. The present study aims to assess the level of carcinogenic and non-carcinogenic risks associated with heavy metals present in Oume surface water consumed by the exposed population. Specifically, the objectives of the study are threefold: first, to determine the concentrations of metals in the water; second, to statistically process the data according to the spatio-temporal variation of the data; and finally, to assess the carcinogenic and non-carcinogenic risks associated with heavy metals.

2. Materials and Methods

2.1. Study Area Presentation

The Department of Oumé is located in the south-central part of Côte d'Ivoire in the Gôsh region, between latitude 6°30′ North and longitude 5°25′ West, approximately 250 km north-west of Abidjan (Figure 1). It covers a total area of about 4600 km^2 with a humid equatorial climate characterized by four seasons: a long rainy season (April–July), a short dry season (August–September), a short rainy season (September–November), and a long dry season (December–March). [15]. Annual rainfall and temperature range between 1.200 and 1.800 mm and between 25 °C and 30 °C, respectively. The data show that the Department of Oumé enjoys a climate that is conducive to agriculture, particularly for crops such as cocoa, coffee, and rubber. The Téné River is the main tributary of the Bandama River, which flows through the Department of Oumé. Several smaller streams complete the hydrographic network. Granitic, metamorphic, and volcanic rocks from Precambrian formations dominate the geology of this department, which is renowned for its gold resources, although mining remains predominantly artisanal [16,17]. As illustrated in Figure 1, the specific points from which samples were obtained within the designated study area are indicated.

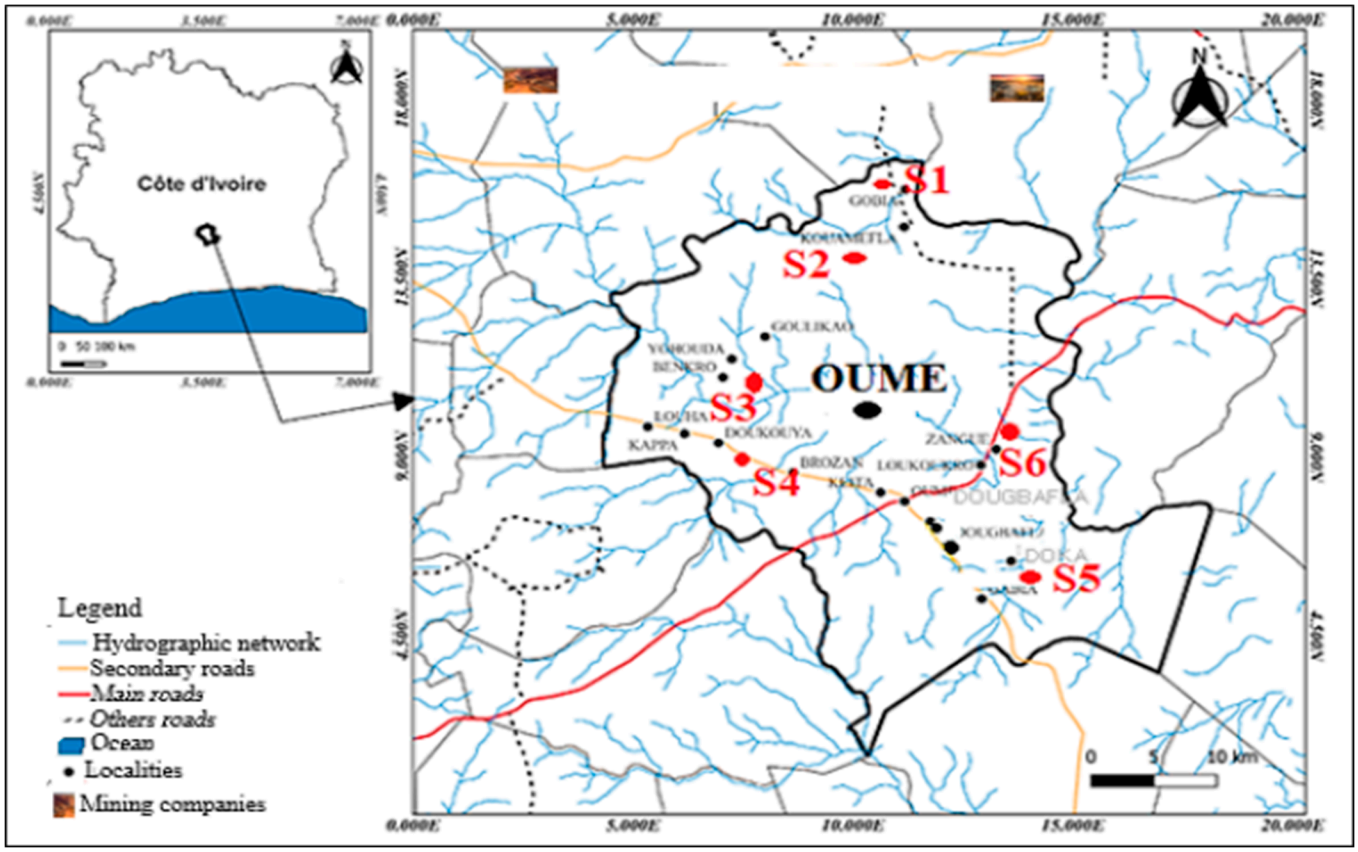


Figure 1. Different sampling points in the study area.

2.2. Water Sampling and Physico-Chemical Analysis

The surface water sampling sites were selected based on their accessibility, usage, spatial distribution, and the anthropogenic pressures exerted on them. On this basis, six (6) surface water sampling sites were selected (S1 (Gobia), S2 (Kouamefla), S3 (Benkro), S4 (Doukouya), S5 (Doka), and S6 (Zengue)), for which the geographical coordinates were recorded using an MLR SP 12X GPS (MLR Electronics (HK) Ltd., Guangzhou, China) (Figure 1). Since 2023 and 2024, a series of surface water sampling campaigns were

conducted during January (long dry season), June (long rainy season), August (short dry season), and October (short rainy season). Surface water from each site was sampled twice per campaign during two years, giving a total of four samples per site. The samples were taken in the middle of the river, 50 cm from the surface. The water samples were taken in 500 mL polyethylene bottles, which were pre-washed and labelled, then acidified with concentrated nitric acid (98% purity) and sent to the laboratory for analysis. Concentrations of As, Cd, Hg, and Pb were analyzed using an X-ray fluorescence spectrophotometer (MESA-50) (Hitachi, Tokyo, Japan). Prior to analysis, the water samples were subjected to filtration using a 100 mm Whatman filter (Whatman, Maidstone, United Kingdom). The HORIBA MESA-50 X-ray fluorescence (XRF) analyzer attains detection limits in the parts per million (ppm) range for the metals under scrutiny.

2.3. Data Processing and Statistical Analysis

2.3.1. Spatio-Temporal Variation in Heavy Metals

The non-parametric Kruskal–Wallis and Mann–Whitney tests were used to compare the heavy metal concentrations in river waters across different seasons and sites. These tests were used at a significance level of p of 95% ($p < 0.05$). R studio software (2025.05.1+513), which is a product of Posit PBC (Boston, MA, USA), was used to perform the analyses.

2.3.2. Assessment of Carcinogenic and Non-Carcinogenic Health Risks Associated with Heavy Metals

The levels of non-carcinogenic and carcinogenic health risk associated with heavy metals were estimated using the hazard quotient (HQ) and incremental lifetime cancer risk (ILCR) methods [18–22]. The assessment included hazard identification, exposure assessment, dose-response assessment, and risk characterization.

Identification and Characterization of the Hazard

Arsenic (As), cadmium (Cd), mercury (Hg), and lead (Pb) are among the most toxic heavy metals for humans. In Côte d'Ivoire, their elevated presence in surface water has been demonstrated by numerous studies [23–25]. The carcinogenic and non-carcinogenic diseases caused by the selected metals are shown in Table 1.

Table 1. Hazard characteristics.

Heavy Metals	Toxicities	References
Arsenic	Arsenic Skin manifestations, visceral cancers, vascular diseases in 5–10 years.	[26,27]
Cadmium	Kidney damage, kidney disorders, carcinogenic to humans in 30 years.	[26,27]
Mercury	Rheumatoid arthritis and diseases of the kidneys, circulatory, and nervous systems in 69 days to 27 years.	[26,27]
Lead	Damage to the brain of the fetus, diseases of the kidneys, circulatory system, and nervous system, prostate cancer, and reduced fertility in men in 20 years.	[26,27]

Exposure Assessment

The scenario developed considered the direct ingestion of river water by the population. Children and adults were exposed to concentrations of arsenic, cadmium, mercury, and lead during the sampling periods in the studied river water. Ingestion of river water

was the only exposure route. Exposure was assessed by determining the quantity (Q) of water consumed per day, the toxic chemical (mg L^{-1}) ingested by an individual per day, and the frequency of consumption (F). In practice, the quantification of exposure levels was calculated by multiplying the concentration (C) of metals (As, Cd, Hg, and Pb) (mg L^{-1}) obtained in the water by the quantity (Q) of water consumed and the frequency (F), and dividing by the body mass of the individual. The scenario was used to determine the probable intake of the hazard known as the DED (the Daily Exposure Dose) as shown in Equation (1):

$$\mathrm{DED}\left(\mathrm{mgkg^{-1}day^{-1}}\right) = \sum \mathrm{C} \times \mathrm{Q} \times \mathrm{F/MC} \quad (1)$$

where C is the concentration of metals; Q is the quantity of water consumed; F is the frequency; and M is the body mass of the individual. Data on the quantity of water ingested per person per day and the body weight of children and adults are given in Table 2 [28,29]. The average body weight of children aged 0–15 years is 28 kg, and that of an adult is conventionally set at 70 kg according to the US Environmental Protection Agency (USEPA) [30].

Table 2. Chemical risk assessment criteria for the metals studied.

Heavy Metals	Quantity of Water Ingested per Day (Q) (L/Day) [31]		Body Weight (BW) (kg) [32]		Guide Value (mg L^{-1}) [33]	RfD (mg $kg^{-1}Day^{-1}$) [31,34]
	Children	Adults	Children	Adults		
As	1.5	2	28	70	0.01	3×10^{-4}
Cd	1.5	2	28	70	0.003	1×10^{-4}
Hg	1.5	2	28	70	0.006	3×10^{-4}
Pb	1.5	2	28	70	0.01	3.6×10^{-3}

Assessment of the Dose-Response Relationship

The objective is to find a link between the dose administered or absorbed and the resulting effect, so that the Toxicological Reference Values (TRV) or Reference Dose (RfD) can be estimated. The RfD values recommended by the United States Environmental Protection Agency (USEPA) and the World Health Organization (WHO) were used for the risk assessment [31,34] (Table 2).

Characterization of the Health Risks Associated with Heavy Metals

1. Non-carcinogenic risk

- Hazard quotient

The Hazard Quotient (HQ) is the ratio of the Daily Exposure Dose (DED), previously determined in Equation (1), to the reference dose (RfD) [3,4,7] in Table 2:

$$\mathrm{HQ} = \mathrm{DED/RfD} \quad (2)$$

If HQ < 1, the occurrence of a health risk is very unlikely; if HQ > 1, populations exposed to metals may experience health problems.

- Hazard index

The hazard index (HI) has been shown to be a valuable tool in determining the potential non-carcinogenic risk resulting from exposure to a mixture of several metals [35,36]. HI is determined by the sum of all the hazard quotients for individual heavy metals [37,38]. The HI value is calculated using the following equation:

$$\mathrm{HI} = \mathrm{HQ_{As}} + \mathrm{HQ_{Cd}} + \mathrm{HQ_{Hg}} + \mathrm{HQ_{Pb}} \quad (3)$$

The presence of an HI value greater than 1 suggests the possibility of a non-carcinogenic effect.

2. Estimation of carcinogenic risk

- Incremental Lifetime Cancer Risk

The Incremental Lifetime Carcinogenic Risk (ILCR) is a metric used to estimate the probability of an individual developing any cancer following exposure to a specified daily amount of a carcinogenic element over a period of years. The ILCR is determined by the following equation:

$$\text{ILCR} = \text{DED} \times \text{CSF} \quad (4)$$

CSF, or the carcinogenic slope factor, is defined as the risk generated by an average quantity of a chemical over a lifetime and is specific for a particular contaminant. The total risk is estimated excluding Hg. According to the USEPA [39], CSF values as a function of metals are CSF (As) = 1.5; CSF (Pb) = 0.0085; CSF (Cd) = 1.5. If the ILCR value is less than 10^{-6}, the carcinogenic risk is considered negligible. On the other hand, if the ILCR value is greater than 10^{-4}, there is a high risk of developing cancer in humans. The range between 10^{-6} and 10^{-4} is widely accepted as constituting an acceptable risk to humans (USEPA, [40–45]).

3. Cumulative carcinogenic risk

The assumption was made that the cumulative cancer risk from exposure to multiple carcinogenic heavy metals due to water consumption would be the sum of the individual heavy metal exposure risks. The following calculation was made to determine this risk [44]:

$$\text{ILCR}_{\text{total}} = \text{ILCR}_{\text{As}} + \text{ILCR}_{\text{Cd}} + \text{ILCR}_{\text{Pb}} \quad (5)$$

where, $\text{ILCR}_{\text{total}}$ represents the total Incremental Lifetime Carcinogenic Risk.

3. Results and Discussion

3.1. Spatial Distribution of Heavy Metals

As illustrated in Figure 2, the concentrations of heavy metals and their limit values are presented at various sampling points along the rivers in the Oume department. As demonstrated in Figure 2, the concentrations of cadmium (Cd) in each locality exceed the limit value (i.e., 0.005 mg L^{-1}), with the exception of the value obtained at Benko River. However, the highest concentrations were obtained in the Doukouya (0.478 mg L^{-1}), Doka (0.525 mg L^{-1}), and Zengue (0.504 mg L^{-1}) water bodies. The concentrations of Hg also exceeded the limit value (i.e., 0.006 mg L^{-1}) in all cases, except those at Kouamefla (0.0023 mg L^{-1}) and Benko (0.0049 mg L^{-1}). Conversely, the concentrations of Pb and As remained below their respective limit values (i.e., 0.05 mg L^{-1} for Pb and 0.01 mg L^{-1} for As), regardless of the watercourse.

The elevated concentrations of Cd and Hg in certain watercourses are attributed to anthropogenic activities in the vicinity, including gold panning and mining industries [4,10]. According to Wang et al. [4], the expansion of urban areas and industrial development near rivers exacerbate heavy metal contamination in surface water. Urbanization leads to increased stress on water bodies, resulting in higher levels of pollution and environmental degradation. In view of the toxicity of certain elements, their bioaccumulation, and the long-term effects they exert on consumers, it is imperative to conduct regular monitoring of HM concentrations in water resources and the associated risks. Statistical analysis revealed significant correlations between elevated concentrations of Cd, Hg, and Pb in the Doukouya, Doka, and Zengue rivers.

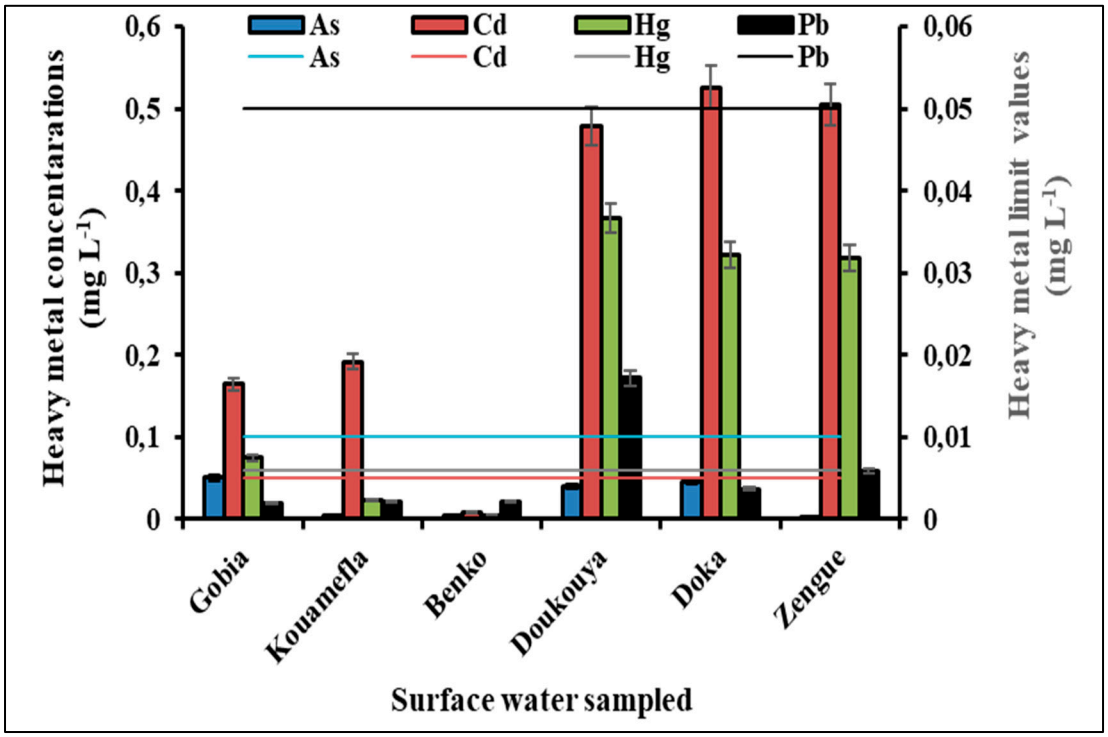


Figure 2. Concentrations of heavy metals and their limit values at different sampling points: The lines represent the limit values according to national Ivorian standards, while the rectangles indicate the measured metal concentrations.

3.2. Seasonal Distribution of Heavy Metals

As demonstrated in Figure 3, the average concentrations of each heavy metal in each locality are presented by season. It is evident from the data that higher metal concentrations are observed during the dry season compared to the rainy season for all metals. As posited by Bhaga et al. [46], anthropogenic disturbances to surface water resources are amplified in the dry season due to the limited availability of alternative surface water sources. As a result, there is an increased accumulation of heavy metals in surface water bodies during the dry season. Otherwise, the Hg concentration recorded during the peak rainy season is slightly higher than that observed during the main dry season. This finding highlights the importance of seasonal variations in metal concentrations within water bodies. Wang et al. [4] demonstrated that the levels of heavy metals in Luoma Lake vary with the seasons. In the wet season (July), increased rainfall and runoff transport more pollutants into the lake, causing heavy metal levels to rise. In contrast, during the dry season (December), the lake's self-purification processes significantly reduce concentrations of Mn and Zn, as less pollution enters the lake. However, in another area of the lake that is not influenced by human activity, the presence of certain metals during the dry season can be attributed to human practices, such as adding fish food. In the inlet and outlet areas, frequent water exchange prevents the accumulation of heavy metals. In the retreating polder area, there are minimal seasonal fluctuations, which indicates effective control of heavy metal pollution and improvement in water quality following the removal of aquaculture enclosures. The presence of heavy metals, including As, Cu, and Pb, in water samples can serve as a reliable indicator of water quality, particularly in contexts where anthropogenic activities and seasonal variations are significant factors [46]. Although these heavy metals may enter surface water resources through natural processes, industrial activities must also be considered as a potential source. The key anthropogenic sources of concern include

industrial activities and waste, pesticides and agro-wastes, smelting of copper and lead, metal plating, mining, and mineral leaching [47,48].

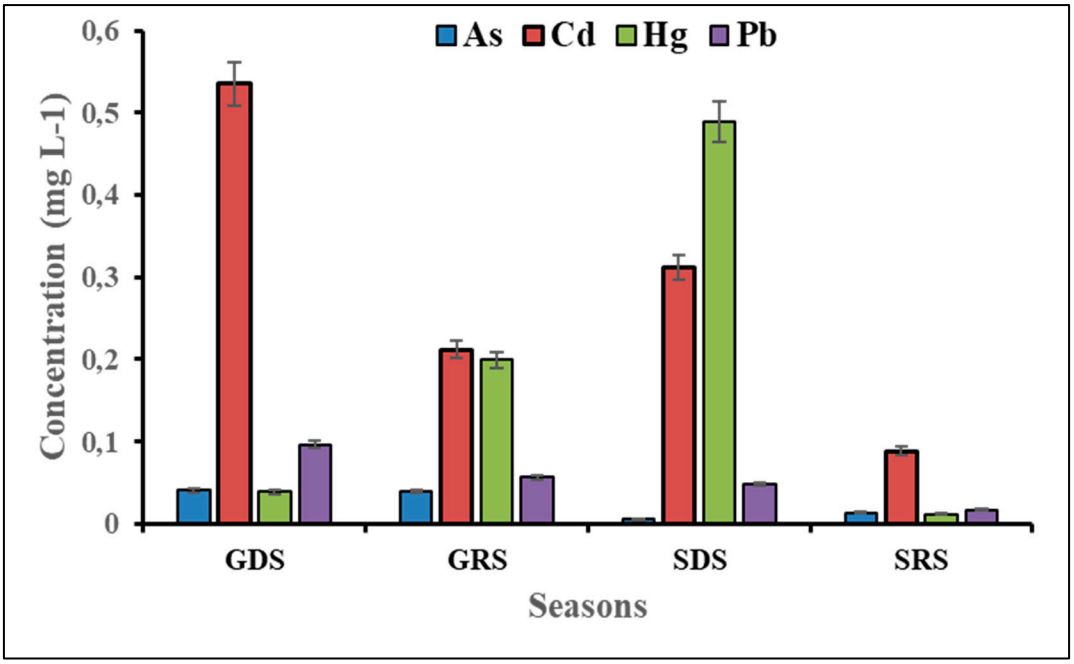


Figure 3. Heavy metal concentrations by season: GDS (Great Dry Season); GRS (Great Rainy Season); SDS (Short Dry Season); SRS (Short Rainy Season).

3.3. Non-Carcinogenic Health Risks Associated with Metals

Tables 3 and 4 present the HQ and HI values for heavy metals (i.e., Cd, As, Hg, and Pb) detected in different places and at different times of the year. The HQs for Cd and Hg for children are well above 1 in all locations, except for Hg at Benko (i.e., 0.88 < 1). This indicates that children in all areas are exposed to contamination from these metals. Furthermore, elevated concentrations of As were observed in the Gobia, Doukouya, and Doka streams. In contrast, the Doukouya stream has shown higher concentrations of Pb, indicating that children consuming water from these streams are exposed to elevated levels of this metal. Conversely, the waters of Zengue, Benko, and Kouamefla do not exhibit such contamination levels. However, the HIs obtained for children were well above 1, suggesting a potential risk of non-carcinogenic health effects of these metals in children. The HQs of metals determined for adults are generally greater than 1, with the exception of As in the Zengue stream and Pb in the Gobia, Kouamefla, Benko, and Doka streams. It should be noted that rivers with HQ > 1 indicate potential health risks to exposed populations [49]. According to Preonty et al. [50], it is possible that this area poses a health risk, whether through ingestion or dermal exposure. Similarly, the HI values determined in all rivers were greater than 1, underlining the same results as above for adults. (See Table 3).

With regard to the health risks associated with metals due to seasonal variation, the HQs determined for children and adults are mostly greater than 1, with the exception of that of As for children at the SDS level and those of Pb in the short seasons (i.e., SDS, SRS) for adults and GRS, SDS, and SRS for children. The results indicate that individuals exposed to Cd and Hg may experience health complications regardless of the season, while this is not the case for As and Pb in the SDS and SRS. The phenomenon of Cd accumulation within the kidneys has been proven to result in renal dysfunction and the onset of osteoporosis [49]. However, the HI values were found to exceed 1, indicating that the metals pose a non-carcinogenic health risk, regardless of the season. This finding

suggests that greater emphasis should be placed on the public health risks associated with Cd and Hg.

Table 3. Spatial variation in non-carcinogenic health risk associated with heavy metals in surface water in Oumé.

Localities	Heavy Metals																Children	Adults
	As				Cd				Hg				Pb					
	Children		Adults		Children		Adults		Children		Adults		Children		Adults			
	DED (mg/kg/day)	HQ	DED (mg/kg/day)	HQ	DED (mg/kg/day)	HQ	DED (mg/kg/day)	HQ	DED (mg/kg/day)	HQ	DED (mg/kg/day)	HQ	DED (mg/kg/day)	HQ	DED (mg/kg/day)	HQ	HI	HI
GOBIA	0.0027	8.98	0.0036	11.98	0.0088	87.96	0.0117	117.29	0.0040	13.34	0.0053	17.79	0.0010	0.28	0.0013	0.37	110.56	147.43
KOUAMEFLA	0.0002	0.78	0.0003	1.04	0.0103	102.59	0.0137	136.79	0.0012	4.05	0.0016	5.40	0.0012	0.32	0.0016	0.43	107.74	143.66
BENKO	0.0003	0.89	0.0004	1.18	0.0004	4.29	0.0006	5.71	0.0003	0.88	0.0004	1.17	0.0011	0.32	0.0015	0.42	6.38	8.48
DOUKOUYA	0.0021	7.10	0.0028	9.47	0.0256	256.29	0.0342	341.71	0.0196	65.42	0.0262	87.22	0.0092	2.55	0.0123	3.40	331.36	441.8
DOKA	0.0025	8.29	0.0033	11.05	0.0282	281.63	0.0376	375.50	0.0172	57.48	0.0230	76.64	0.0020	0.55	0.0026	0.73	347.95	463.92
ZENGUE	0.0001	0.35	0.0001	0.47	0.0270	270.01	0.0360	360.02	0.0170	56.71	0.0227	75.62	0.0031	0.86	0.0041	1.15	327.93	437.26

Table 4. Seasonal variation in the non-carcinogenic health risk associated with heavy metals in Oume river water.

SEASONS	Heavy Metals																Children	Adults
	As				Cd				Hg				Pb					
	Children		Adults		Children		Adults		Children		Adults		Children		Adults			
	DED (mg/kg/day)	HQ	DED (mg/kg/day)	HQ	DED (mg/kg/day)	HQ	DED (mg/kg/day)	HQ	DED (mg/kg/day)	HQ	DED (mg/kg/day)	HQ	DED (mg/kg/day)	HQ	DED (mg/kg/day)	HQ	HI	HI
GDS	0.0022	7.23	0.0029	9.64	0.0287	286.65	0.0382	382.20	0.0021	6.93	0.0028	9.23	0.0052	1.43	0.0069	1.91	302.24	402.98
GRS	0.0002	7.02	0.0028	9.37	0.0167	167.13	0.0223	222.83	0.0107	35.57	0.0142	47.42	0.0030	0.85	0.0041	1.13	210.57	280.75
SDS	0.0003	0.96	0.0004	1.28	0.0167	167.13	0.0223	222.83	0.0262	87.26	0.0349	116.35	0.0026	0.72	0.0035	0.96	256.07	341.42
SRS	0.0021	2.38	0.0010	3.18	0.0048	47.61	0.0063	63.48	0.0006	2.16	0.0009	2.88	0.0009	0.25	0.0012	0.34	52.4	69.88

Notes: GDS: Great Dry Season; GRS: Great Rainy Season; SDS: Short Dry Season; SRS: Short Rainy Season.

3.4. Carcinogenic Health Risks Associated with Heavy Metals

Tables 5 and 6 show the ILCR values for heavy metals in children and adults by locality and season. To assess the carcinogenic risk, three metals for which there were indications of carcinogenicity, namely As, Cd, and Pb were selected for analysis. The determination of carcinogenic risk was therefore conducted according to the specific locality and season. For all the localities, the ILCRs for the various metals (i.e., As and Cd) were well above 10^{-4}, regardless of the age group, indicating that the population consuming these waters may face significant carcinogenic risks. In addition, the highest ILCR values were observed for Cd across all age groups. In contrast, the ILCR values for Pb ranged between 10^{-6} and 10^{-4} for all age groups, indicating acceptable levels and therefore not posing significant carcinogenic risks [50–54]. Finally, the total ILRCs exceeded 10^{-4} in all locations (see Table 5), indicating the combined presence of these metals poses a high cancer risk to the population. It is important to note that children were found to have higher estimated carcinogenic hazards than adults. Some studies have indicated that children who consume greater quantities of water relative to their body weight are more susceptible to health risks [50–52]. It is also noteworthy that seasonal fluctuations did not substantially influence the observed trends in ILCRs for the entire population, as shown in Table 6.

Table 5. Spatial variation in the carcinogenic health risk associated with heavy metals in river water in Oume.

Localities	Heavy Metals							
	$ILCR_{As}$		$ILCR_{Cd}$		$ILCR_{Pb}$		$ILCR_{TOTAL}$	
	Children	**Adults**	**Children**	**Adults**	**Children**	**Adults**	**Children**	**Adults**
Gobia	0.0040	0.0054	0.13	0.18	8.5×10^{-6}	11.1×10^{-6}	0.134	0.1854
Kouamefla	0.0004	0.0005	0.15	0.21	10.2×10^{-6}	13.6×10^{-6}	0.1504	0.2105
Benko	0.0004	0.0005	0.01	0.01	9.4×10^{-6}	12.8×10^{-6}	0.0104	0.0105
Doukouya	0.0032	0.0043	0.38	0.51	7.8×10^{-5}	10.5×10^{-5}	0.3832	0.5143
Doka	0.0037	0.0050	0.42	0.56	17×10^{-6}	22.1×10^{-6}	0.4237	0.5650
Zengue	0.0002	0.0002	0.41	0.54	2.6×10^{-5}	3.5×10^{-5}	0.4102	0.5402

Table 6. Seasonal variation in the carcinogenic health risk associated with heavy metals in the river water of Oume.

Seasons	Heavy Metals							
	$ILCR_{As}$		$ILCR_{Cd}$		$ILCR_{Pb}$		$ILCR_{TOTAL}$	
	Children	**Adults**	**Children**	**Adults**	**Children**	**Adults**	**Children**	**Adults**
GDS	0.0033	0.0043	0.43	0.57	4.39×10^{-5}	5.85×10^{-5}	0.4333	0.5743
GRS	0.0032	0.0042	0.25	0.33	2.58×10^{-5}	3.45×10^{-5}	0.2532	0.3342
SDS	0.0004	0.0006	0.25	0.33	2.20×10^{-5}	2.94×10^{-5}	0.2504	0.3306
SRS	0.0011	0.0014	0.07	0.10	7.77×10^{-6}	1.03×10^{-5}	0.0711	0.1014

Notes: GDS: Great Dry Season; GRS: Great Rainy Season; SDS: Short Dry Season; SRS: Short Rainy Season.

4. Conclusions

The comprehensive evaluation of heavy metal contamination in surface water near gold mining facilities has revealed a significant environmental predicament with serious direct consequences for public health. The assessment of these risks is imperative for safeguarding public health, particularly among populations dependent on contaminated water sources, as exposure can result in severe health consequences, including neurological disorders, organ damage, and an elevated risk of cancer. The present study was undertaken in order to assess the quality of surface water samples. The results indicate that individuals exposed to Cd and Hg are at risk of health concerns regardless of season and location, while exposure to As and Pb during the Short Dry Season (SDS) and Short Rainy Season (SRS) is associated with specific health risks. Conversely, the HIs are consistently above 1, suggesting that the population may be exposed to diseases associated with metals, irrespective of season or geographical location. To further explore the results, the ILCR assessment was employed, demonstrating that for all designated localities, the ILCRs of As and Cd were well above 10^{-4} for the entire population, indicating a major carcinogenic risk for those consuming this water. Furthermore, the highest ILCR values were observed for Cd, irrespective of age group. It is important to acknowledge that seasonal variation exerted no substantial influence on the observed trend in ILCRs for the entire population. The effective management of water resources is of paramount importance for the present and future well-being of the population, as well as for the region's ecological and socio-economic stability. After this study showed that the population could be contaminated in the long term, we are asking local leaders to allow more drilling sites in the Oumé

department. This is to stop the population from using river water. We are also asking national leaders to strengthen regulations applicable to mining companies.

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