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Human Risk Assessment of Trace Metals in Surface Water from Bandama, Bia and Comoé Rivers, Southeast Côte d’Ivoire

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Authors’ contributions

This work was carried out in collaboration among all authors. Author AAO participated in the sampling campaigns, in the laboratory analyzes, in the interpretation of the results and in the writing of this manuscript. Author HK participated in the sampling campaigns, in the laboratory analyzes and in the drafting of this manuscript. Author GVA participated in the sampling campaigns, the laboratory analyzes and the writing of this manuscript. Author AT participated in the interpretation of the results and the writing of this manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Water pollution is a global environmental problem. Trace metals present in polluted water can have harmful effects on human health. In Côte d'Ivoire, Little data is available to assess human health risk associated with exposure to trace metals from rivers. This paper presents an assessment of the

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human health risks associated with exposure to trace metals from Bandama, Comoé and Bia Rivers, three main rivers in Côte d'Ivoire.
The chronic daily intake (CDI), hazard quotient (HQ), hazard index (HI), non-carcinogenic risk and carcinogenic risk of metals through oral and dermal routes were determined to assess the human health risk.
The hazard quotient (HQ) values for arsenic are >1 in the Bia River and close to 1 in the other rivers during the dry and flood seasons. The Hazard Index (HI) values are <1 at all stations during the dry and flood seasons, indicating is a likelihood of the local population contracting non-carcinogenic diseases from trace metals through ingestion of surface water. Arsenic represents a high cancer risk in the rivers during the dry and wet seasons (1.00E-04 > C < 1.00E-03).
Consequently, governmental environmental monitoring agencies should carry out continuous and increased monitoring of trace metals in the rivers to make appropriate decisions for the safety of human health.

Keywords: Rivers; surface water; trace metals; health risk assessment; chronic daily intake; hazard quotient; cancer risk.

1. INTRODUCTION

“Trace metal contamination of surface waters is a major concern worldwide” [1,2]. “Trace metals in the environment originate from both natural processes (such as atmospheric deposition, erosion and mineral weathering) and anthropogenic activities (such as urban and industrial development and agriculture)” [3–6]. “Trace metals like copper (Cu) and zinc (Zn) are trace elements and are essential for the body to function properly, whereas arsenic (As), cadmium (Cd), and lead (Pb) are toxic metals that play no role. These metals can cause biological toxicity and pose a serious threat to aquatic ecosystems and human health at certain concentrations. A study of the total concentration of trace metals in surface water can provide information on the state of contamination of rivers, but not enough on the health risks” [7-9].

In Côte d'Ivoire, most of the studies carried out have focused on metallic contamination of sediments and few studies have focused on contamination of river surface waters, given the complexity of the fate of metals in water. In addition, most studies have focused on assessing river water quality, particularly in terms of physical, chemical and organic parameters. To our knowledge, there are no studies assessing the health risks of trace metals in rivers in the Côte d'Ivoire region to provide advice on environmental management [6–12].

“The Bandama, Comoé and Bia rivers are among the main rivers in Côte d'Ivoire. The water from these rivers is used by the local population for their daily needs and above all as drinking and bathing water. Local people living near the rivers do not have access to tap water” [2]. The use of this surface water contaminated by trace metals exposes the local population to illness and the risk of cancer. It is therefore important to assess the carcinogenic and non-carcinogenic risks to raise public awareness and attract the attention of governors.

The objective of this study is to assess the human health risks associated with the surface waters of the Bandama, Bia, and Comoé rivers, by calculating the hazard quotient (HQ) and carcinogenic risk (CR), based on methods established by the United States Environmental Protection Agency (USEPA) [5,13].

2. MATERIALS AND METHODS

2.1 Study Area and Data Collection

The study area encompasses the lower reaches of the Bandama and Comoé rivers in the south and the coastal Bia River in the southeast of Côte d'Ivoire. Five sampling stations were selected per river.

The study area has four seasons (a long rainy season, a short rainy season corresponding to the river flooding season, a long dry season and a short dry season). Fig. 1 shows the study area and the sampling sites.

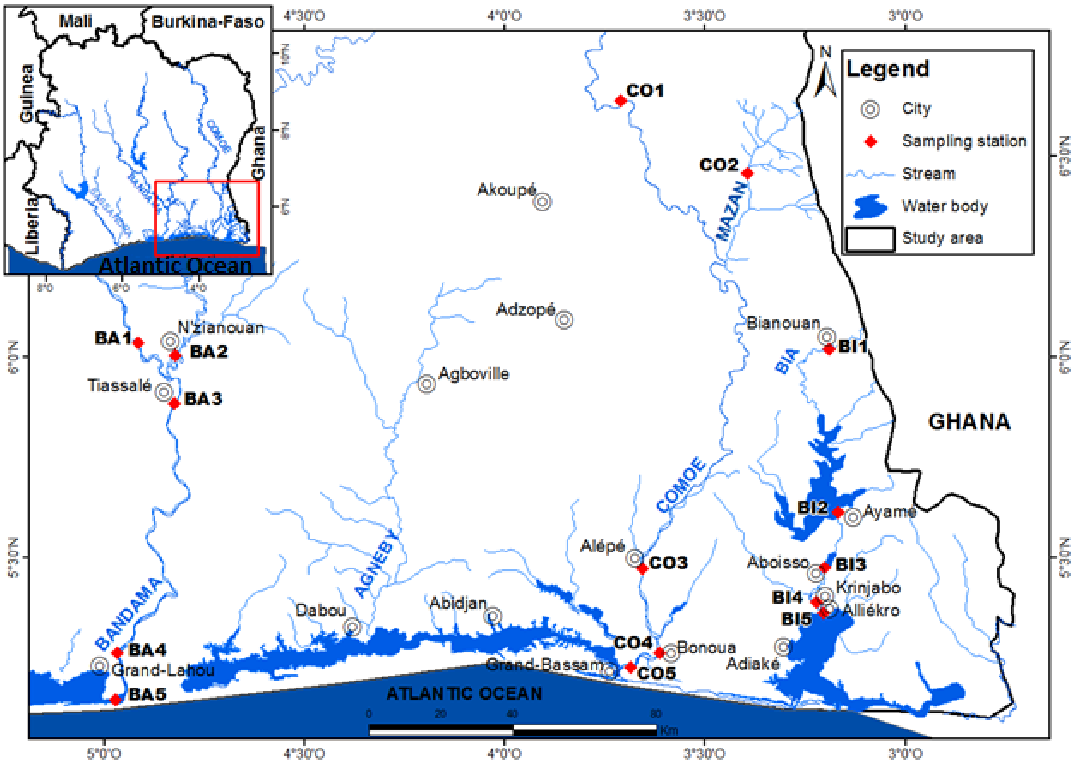

Fig. 1. Sampling locations of surface sediments collected from Bandama, Comoé and Bia River (Côte d'Ivoire) [2]

The total concentrations of trace metal reported by Ouattara et al., [2] were used for human risk quantification. The methodologies used for sampling and metal analysis are detailed in the studies of Ouattara et al., [2].

2.2 Health Risk Assessment

Trace metals can enter the human body through various routes, including direct ingestion, inhalation, skin absorption [14] and through the food chain. However, there are two main exposure routes of exposure to water: ingestion of metals through water consumption and dermal absorption through swimming [15,16].

2.3 Chronic Daily Intake (CDI)

The chronic daily intake (CDI) (µg/kg/day) by water ingestion and skin absorption defines the quantity of trace metals ingested and absorbed by a human being per day through the use of water. It can be calculated using equations (1) and (2), respectively [5,17]. The definitions and values of the parameters and variables are presented in Table 1 [18–20].

$$CDI_i = \frac{C \times IngR \times EF \times ED}{BW \times AT} \quad (1)$$

$$CDI_d = \frac{C \times SA \times K_p \times ET \times EF \times ED \times CF}{BW \times AT} \quad (2)$$

Where: CDIi is the chronic daily dose by ingestion (oral) and CDId, the chronic daily dose by dermal route (skin).

2.4 Non-carcinogenic Risk

Non-carcinogenic risks are assessed by determining the hazard quotient (HQ). The contaminant hazard quotient is defined as the quotient of the chronic daily intake (CDI) by the toxicity threshold value or reference dose (RfD) for each chemical element according to each exposure route (ingestion of water and cutaneous absorption) as indicated by equation 3.

$$HQ = CDI / RfD \quad (3)$$

where CDI is the chronic daily dose ($\mu g.kg^{-1}.day^{-1}$) and RfD is the reference dose of metals in a given condition ($\mu g.kg^{-1}.day^{-1}$). The reference dose by ingestion of water (RfD in) was obtained from the [1]. "RfD by dermal absorption (RfD dermal) was obtained from RfDin multiplied by a gastrointestinal absorption factor" [22].

Table 1. Parameters characterising chronic daily intake (CDI) values

Parameters	Units	Values	Source
Concentration of trace metal in water (C)	µg/L	-	[2]
Ingestion rate (IR)	L/day	2	[18]
Exposure frequency (EF)	day/year	365	[5]
Exposure duration (ED)	year	51	[1]
Body weight (BW)	kg	60.7	[1]
Average time (AT)	day	18615	[1,18,21]
Skin-surface area (SA)	cm^2	18	
Exposure time (ET)	h/day	0.6	
Conversion factor (CF)	L/cm^3	0.001	
Permeability coefficient (Kp)	cm/h		
Zn		0.0006	
Cu		0.001	
As		0.001	
Cd		0.001	
Pb		0.004	

"If the HQ value is close to or equal to unity, this indicates potentially harmful effects on human health or the need for further investigation. HQ values > 1 suggest even higher probabilities of adverse health effects" [22–24].

2.5 Hazardous Index (HI)

The hazardous index (HI) is used to assess the health risk due to combined effect of all trace metals present in water. Indeed, recent studies on the health risks due to metal contamination have shown that contamination by two or more metals could lead to an interaction between the latter and result in an addition of their toxicity [25,26]. In this way, the hazard quotient (HQ) of the various metals can be added together by the oral or dermal route (HIi and HId, respectively) [25,27] to produce an even higher risk. The hazardous index generated by the daily use of water was calculated using the following equation:

$$\mathrm{HI} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{HQ_i} \quad (4)$$

HDi is the exposure quotient for element i. When HI < 1, it would have no adverse effects while for HI > 1 adverse effects could occur.

2.6 Carcinogenic Risk (CR)

Carcinogenic risks (CR) for metals have been estimated to assess the likelihood of an individual developing cancer during their lifetime following exposure to a potential carcinogen [28–30]. The CR is obtained using the Cancer Slope Factor (CSF) for the metal established by the US EPA [21,5,13]. The carcinogenic risk is determined by the following relationship:

$$CR = CDI \times SF \quad (5)$$

where SF is the carcinogenic slope factor ($\mu g.kg^{-1}.day^{-1}$); the SF by water ingestion (SFin) was provided by the US EPA [21] and SF by skin absorption was calculated by SFd = SFin / ABSg.

The slope factor (SF) is a toxicity value that quantitatively defines the relationship between dose and response. The probabilities of potential carcinogenic effects that an individual will develop cancer over a lifetime of exposure are estimated from the projected intakes and the slope factor. Table 2 gives the values of the slope factor and RfD.

The different levels of risk according to the values of carcinogenic risk are shown in Table 3.

Table 2. Reference doses (RfD) and carcinogenicity factors (CSF) [1]

Elements	As	Cd	Pb
SF (mg/kg/j)	1.5	260	8.5
RfD (µg/kg/j)	0.3	0.5	1.4

Table 3. Risk according to cancer risk level [5]

Cancer risk level	Risk
< 1.00E-06	Very low
1.00E-06 to 1.00E-05	Low
1.00E-05 to 1.00E-04	Medium
1.00E-04 to 1.00E-03	High
>1.00E-03	Very high

3. RESULTS AND DISCUSSION

3.1 Total Concentration of Trace Metal

The total concentrations of trace metals in the surface water from Bandama, Bia and Comoé Rivers, are presented in [2]. The total concentration of the trace metals ranged between 0.02 and 360.49 µg/l.

3.2 Health Risk Assessment

The chronic daily intake (CDI): Table 4 presents the values of the chronic daily intake calculated for the metals studied. CDI values of arsenic, cadmium, copper, lead and zinc in the three rivers varied between 0.05 and 0.46 µg/kg.day, 0.001 and 0.033 µg/kg.day, 0.29 and 7.23 µg/kg.day, 0.04 and 0.53 µg/kg.day and 0.02 and 11.88 µg/kg.day respectively. The mean values of CDI of trace metals concentrations were found in the order of Zn > Cu > As > Pb > Cd in Bandama River and in the order of Zn > As > Cu > Pb > Cd in Comoé and Bia River. CDI values were higher in the oral route compared to the dermal route.

The results showed that the local population using surface water from the River Bia absorbs more metals orally and dermally than the populations using water from the other two rivers. The average CDI values for the Bia river were higher than those for the other rivers for all metals. The CDI values show that the local population living near the river Bia is more exposed to the harmful effects of trace metals.

Hazard Quotient (HQ): Variations in the non-carcinogenic risk of trace metals through the ingestion route (HQi) and by dermatological (HQd) in the waters of the Bandama, Comoé and Bia rivers are depicted in Table 5 and Table 6.

Assessing the non-carcinogenic risks of heavy metals involves evaluating the potential adverse health consequences, other than cancer, of exposure to these metals. According to Karki et al., (2024), its main objective is to understand the hazards that heavy metals pose to different organs and systems in the human body, such as the nervous system, liver, kidneys and respiratory system.

The HQi values for the trace metals Cd, Cu, Pb and Zn are less than 1 in all samples for the three rivers. For arsenic, the HQi values obtained are greater than 1 during the dry and flood seasons in all samples from the Bia, while in the Comoé river, only 20% of samples have HQi values greater than 1.

These results show that arsenic can cause adverse effects through ingestion of contaminated water and that there is no health risk from dermatological exposure of the population for all the trace metals studied [31–33].

In addition, the HQi in the study area were found in the following order: As> Pb> Cu> Zn> Cd.

The HQd values calculated are all well below 1 for all elements.

Hazard Index (HI): Figs. 2 and 3 show the HI values for oral intake and the dermal route of trace metals through the use of river water.

The HI values by ingestion are higher than the limit suggested by USEPA (HI = 1) for all samples during the dry season, the flood season and for 6.67% of samples during the rainy season. This suggests a risk of chronic contamination, and hence health problems for the population. Arsenic is the major contributor to the non-carcinogenic risk of water ingestion by residents, with percentages ranging from 41.39% to 77.94%.

The dermatological HI values for all the trace metals are less than 1 for all the samples (Fig. 3). This result indicates that there is no health risk to the population from prolonged skin contact with river water.

As arsenic, cadmium and lead are carcinogenic, we assessed the carcinogenic risk associated with these elements by oral route.

Table 4. CDI values of trace metals in the river water

		As		Cd		Pb		Cu		Zn	
		CDI_i	**CDI_d**	**CDI_i**	**CDI_d**	**CDI_i**	**CDI_d**	**CDI_i**	**CDI_d**	**CDI_i**	**CDI_d**
Bandama	**Min**	0.161	8.42E-04	0.001	6.82E-06	0.097	2.03E-03	1.822	9.51E-03	1.907	5.97E-03
	Max	0.223	1.16E-03	0.003	1.59E-05	0.198	4.13E-03	4.117	2.15E-02	4.187	1.31E-02
	Moy	0.195	1.02E-03	0.002	1.22E-05	0.162	3.39E-03	2.942	1.54E-02	3.223	1.01E-02
	SD	0.025	0	0.001	0	0.042	0.001	0.938	0.005	1	0.003
Comoé	**Min**	0.217	1.13E-03	0.001	3.44E-06	0.115	2.41E-03	2.339	1.22E-02	2.188	6.85E-03
	Max	0.286	1.49E-03	0.002	1.29E-05	0.271	5.67E-03	2.585	1.35E-02	4.181	1.31E-02
	Moy	0.248	1.30E-03	0.001	7.71E-06	0.174	3.63E-03	2.44	1.27E-02	3.444	1.08E-02
	SD	0.026	0	0.001	0	0.066	0.001	0.099	0.001	0.791	0.002
Bia	**Min**	0.28	1.46E-03	0.001	3.44E-06	0.157	3.28E-03	2.007	1.05E-02	2.28	7.14E-03
	Max	0.35	1.83E-03	0.013	6.53E-05	0.302	6.30E-03	3.588	1.87E-02	3.816	1.20E-02
	Moy	0.325	1.70E-03	0.004	2.26E-05	0.208	4.33E-03	2.683	1.40E-02	3.089	9.68E-03
	SD	0.028	0	0.005	0	0.061	0.001	0.67	0.003	0.583	0.002

Table 5. Hazard quotient ingestion of trace metals in water from the rivers

		Bandama			Comoé			Bia		
		Dry	**Wet**	**Flood**	**Dry**	**Wet**	**Flood**	**Dry**	**Wet**	**Flood**
As	Min	0.60	0.25	0.67	0.55	0.15	1.03	1.00	0.39	1.38
	Max	0.77	0.54	0.98	1.19	0.59	1.35	1.25	0.88	1.53
	Mean	0.72	0.40	0.83	0.90	0.41	1.18	1.12	0.65	1.48
	SD	0.08	0.12	0.13	0.23	0.18	0.12	0.11	0.18	0.06
Cd	Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Max	0.01	0.01	0.01	0.01	0.00	0.00	0.02	0.00	0.07
	Mean	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.02
	SD	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.03
Cu	Min	0.09	0.01	0.02	0.13	0.01	0.01	0.09	0.02	0.04
	Max	0.18	0.04	0.12	0.16	0.02	0.03	0.17	0.04	0.07
	Mean	0.13	0.02	0.07	0.14	0.02	0.02	0.12	0.03	0.05
	SD	0.04	0.02	0.04	0.01	0.00	0.01	0.04	0.01	0.01
Pb	Min	0.04	0.04	0.13	0.07	0.04	0.12	0.08	0.03	0.20
	Max	0.19	0.08	0.23	0.26	0.11	0.22	0.24	0.06	0.38
	Mean	0.11	0.06	0.18	0.15	0.06	0.16	0.13	0.04	0.27
	SD	0.07	0.02	0.04	0.07	0.03	0.04	0.07	0.02	0.07
Zn	Min	0.02	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00
	Max	0.04	0.00	0.00	0.04	0.00	0.00	0.04	0.00	0.00
	Mean	0.03	0.00	0.00	0.03	0.00	0.00	0.03	0.00	0.00
	SD	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00

Table 6. Hazard quotient dermal of trace metals in water from the rivers

		Bandama			Comoé			Bia		
		Dry	**Wet**	**Flood**	**Dry**	**Wet**	**Flood**	**Dry**	**Wet**	**Flood**
As	Min	3.12E-03	1.33E-03	3.49E-03	2.87E-03	7.98E-04	5.37E-03	5.22E-03	2.04E-03	7.20E-03
	Max	4.04E-03	2.84E-03	5.11E-03	6.20E-03	3.08E-03	7.06E-03	6.52E-03	4.61E-03	7.98E-03
	Mean	3.75E-03	2.11E-03	4.34E-03	4.68E-03	2.14E-03	6.14E-03	5.83E-03	3.40E-03	7.75E-03
	SD	3.92E-04	6.32E-04	6.76E-04	1.21E-03	9.63E-04	6.41E-04	5.53E-04	9.23E-04	3.17E-04
Cd	Min	1.38E-04	1.38E-04	1.38E-04	1.38E-04	1.38E-04	1.38E-04	1.38E-04	1.38E-04	1.38E-04
	Max	1.05E-03	7.84E-04	1.06E-03	1.05E-03	3.65E-04	1.38E-04	2.59E-03	4.06E-04	6.92E-03
	Mean	7.19E-04	4.21E-04	3.21E-04	6.05E-04	1.83E-04	1.38E-04	7.94E-04	1.91E-04	1.72E-03
	SD	3.49E-04	2.80E-04	4.11E-04	4.37E-04	1.02E-04	0.00E+00	1.03E-03	1.20E-04	2.92E-03
Cu	Min	2.36E-03	1.89E-04	5.14E-04	3.35E-03	3.31E-04	2.57E-04	2.29E-03	5.43E-04	1.03E-03
	Max	4.72E-03	1.11E-03	3.00E-03	4.08E-03	5.70E-04	8.58E-04	4.46E-03	1.00E-03	1.74E-03
	Mean	3.44E-03	6.19E-04	1.70E-03	3.68E-03	4.78E-04	6.17E-04	3.17E-03	7.00E-04	1.38E-03
	SD	9.24E-04	4.15E-04	1.10E-03	2.66E-04	9.02E-05	2.53E-04	1.08E-03	2.03E-04	2.55E-04
Pb	Min	8.47E-04	7.41E-04	2.76E-03	1.38E-03	7.78E-04	2.46E-03	1.66E-03	5.37E-04	4.22E-03
	Max	3.91E-03	1.74E-03	4.80E-03	5.33E-03	2.29E-03	4.52E-03	5.06E-03	1.34E-03	7.90E-03
	Mean	2.25E-03	1.16E-03	3.85E-03	3.11E-03	1.30E-03	3.36E-03	2.72E-03	8.44E-04	5.72E-03
	SD	1.43E-03	4.18E-04	7.55E-04	1.56E-03	6.26E-04	8.70E-04	1.49E-03	3.49E-04	1.48E-03
Zn	Min	2.76E-04	2.06E-05	1.12E-06	3.04E-04	1.86E-05	1.07E-06	3.37E-04	1.85E-05	1.48E-06
	Max	6.20E-04	4.00E-05	1.62E-06	6.13E-04	4.02E-05	1.32E-06	5.55E-04	4.06E-05	1.67E-06
	Mean	4.72E-04	3.10E-05	1.30E-06	5.07E-04	3.12E-05	1.19E-06	4.50E-04	3.18E-05	1.56E-06
	SD	1.50E-04	8.40E-06	2.00E-07	1.23E-04	9.48E-06	9.49E-08	8.48E-05	9.95E-06	7.02E-08

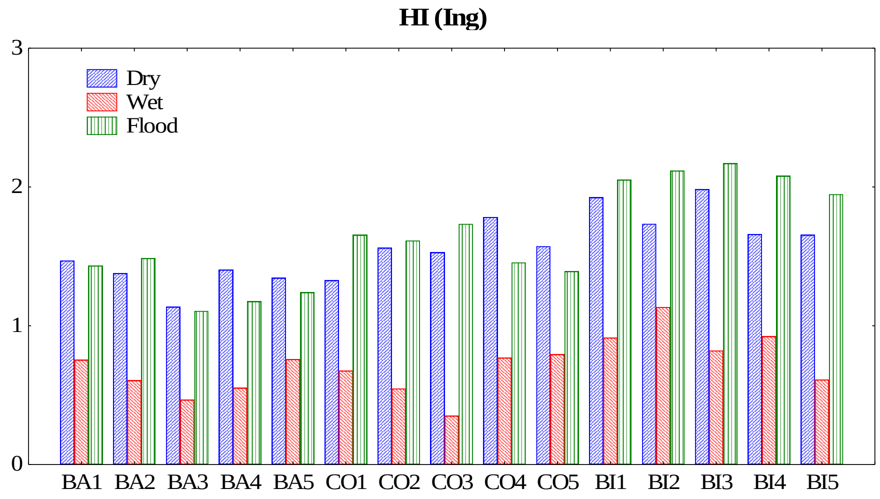

Fig. 2. Hazard index ingestion (HIing) in the Bandama, Comoé and Bia rivers

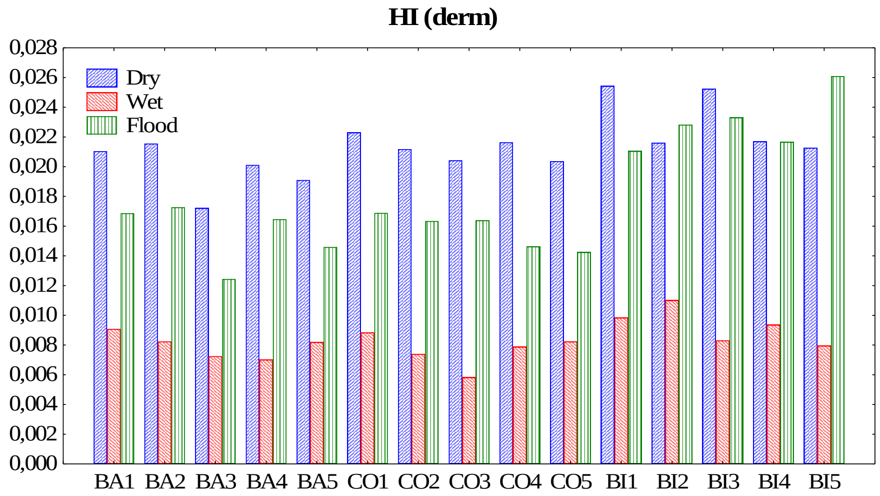

Fig. 3. Hazard index dermal route (HId) in the Bandama, Comoé and Bia rivers

Table 7. Carcinogenic risk of trace metals in the Bandama, Comoé and Bia rivers.

	As			Cd			Pb		
	Dry	Wet	Flood	Dry	Wet	Flood	Dry	Wet	Flood
BA1	1.5E-04	1.0E-04	1.9E-04	1.0E-10	4.0E-10	1.0E-10	2.9E-05	1.0E-05	2.8E-05
BA2	1.4E-04	7.2E-05	2.0E-04	7.7E-10	3.7E-10	1.0E-10	1.2E-05	1.4E-05	3.8E-05
BA3	1.2E-04	5.1E-05	1.5E-04	5.8E-10	5.8E-10	1.0E-10	6.7E-06	5.8E-06	2.2E-05
BA4	1.5E-04	7.0E-05	1.3E-04	5.2E-10	1.0E-10	7.8E-10	3.1E-05	6.0E-06	3.3E-05
BA5	1.5E-04	1.1E-04	1.6E-04	6.7E-10	1.0E-10	1.0E-10	1.0E-05	1.0E-05	3.1E-05
CO1	1.1E-04	8.1E-05	2.4E-04	7.7E-10	2.7E-10	1.0E-10	4.2E-05	1.8E-05	3.6E-05
CO2	1.8E-04	6.3E-05	2.4E-04	1.0E-10	1.0E-10	1.0E-10	2.9E-05	1.2E-05	3.2E-05
CO3	1.8E-04	3.1E-05	2.7E-04	1.0E-10	1.0E-10	1.0E-10	2.6E-05	7.1E-06	2.4E-05
CO4	2.4E-04	1.2E-04	2.2E-04	5.8E-10	1.0E-10	1.0E-10	1.5E-05	6.1E-06	1.9E-05
CO5	2.0E-04	1.2E-04	2.1E-04	6.8E-10	1.0E-10	1.0E-10	1.1E-05	7.8E-06	2.2E-05
BI1	2.5E-04	1.3E-04	3.1E-04	1.9E-09	1.0E-10	4.5E-10	1.3E-05	1.1E-05	3.3E-05
BI2	2.2E-04	1.8E-04	3.0E-04	1.0E-10	1.0E-10	6.0E-10	1.3E-05	8.6E-06	4.3E-05
BI3	2.4E-04	1.3E-04	3.0E-04	1.0E-10	1.0E-10	1.0E-10	4.0E-05	4.2E-06	6.2E-05
BI4	2.0E-04	1.4E-04	3.0E-04	4.4E-10	1.0E-10	1.0E-10	2.7E-05	5.1E-06	5.1E-05
BI5	2.1E-04	7.8E-05	2.8E-04	3.8E-10	3.0E-10	5.1E-09	1.4E-05	4.9E-06	3.6E-05

Carcinogenic risk assessment (CR): Carcinogenic substances are those that have a high probability of causing cancer, particularly in humans, in the event of prolonged or significant exposure [18]. The CR results are given in Table 7.

The CR values calculated for cadmium (CR < 1.00E-06) showed that there is no carcinogenic risk in all surface water samples. For lead, the values (10^{-6} < CR < 10^{-4}) found show average risks of contracting cancer in all seasons. Whereas the values observed for arsenic are higher than 10^{-4} during the dry season and the flood season in the three rivers, and in general are lower than 10^{-4} during the rainy season in the Bandama and Comoé rivers and higher than 10^{-4} for the Bia river. There is therefore a high probability that an individual will develop cancer by ingesting water after a certain length of time at these stations.

4. CONCLUSION

In the present study, the hazard quotient (HQ) and carcinogenic risk (CR), based on USEPA methods were used to assess the non-cancer and cancer risks of arsenic, copper, cadmium, lead and zinc in surface water from Bandama, Bia and Comoé River. The results of the risk assessment showed that, among the trace metals studied, As could cause harmful effects by oral ingestion and long-term cancer through consumption of river water, particularly from the Bia. Indeed, the high values of hazard quotient and cancer risk were observed in the Bia River for arsenic. The health risks are higher during dry and flood seasons. The results showed that concentrations of As and Pb in the Comoé and Bia rivers posed a threat to the local population. Monitoring of trace metal pollution in these rivers should therefore be implemented by decision-makers. It is also recommended that the water from these rivers be treated and a remedy established to eliminate trace metals to guarantee the health of the local population.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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