POLLUTION AND HEALTH RISKS RELATED TO HEAVY METAL CONTAMINATION OF WATER RESOURCES IN THE KOKO RIVER WATERSHED IN THE CITY OF KORHOGO (NORTH OF CÔTE D'IVOIRE).

Abstract

The present study aimed to evaluate the distribution of Hg, As, Cd, Cr, Cu, Ni, Pb and Zn as well as the health risks in surface water in northern Côte d'Ivoire. The pollution of the waters was determined by pollution indices. The human health risks were assessed using non carcinogenic and carcinogenic risks indices.In surface waters, concentrations of trace metals (Hg, As, Cd, Cr, Cu, Ni, and Zn) in groundwater respected the guideline values. However, the total concentrations of Pb in surface waters exceeded the guideline values. The pollution indices HPI, HEI, and WQI revealed very low pollution in the surface waters. The total non-carcinogenic risk values for Hg, As, Cd, Cr, Cu, and Ni in surface waters varied from 1.02×10^{-3} to 8.22×10^{-1}, indicating low adverse on human healtheffects. In contrast, the total non-carcinogenic risk values for Pb and Zn suggest adverse on human healtheffects. The total carcinogenic risk (CR) values for Ni, Cd, and Cr in all surface waters varied from 3.11×10^{-4} to 2.36×10^{-1} for children. Concerning adults, these values ranged between 1.88×10^{-3} and 4.80×10^{-2} for Ni and Cr. These results indicate that possible carcinogenic effects may occur for humans exposed to these waters. The values of CRing (carcinogenic risk by ingestion) of Pb vary between 1.93×10^{-3} and 10^{-2}, showed potentially significant carcinogenic effects for all surface waters. However, the CRing values for As for children and Cd for adults indicate possible carcinogenic effects by ingestion for these two metals. Therefore, it is essential to treat water to remove trace metals before any domestic or agricultural use.

Keywords: Trace metals, Pollution assessment, Risk assessment, Surface waters.

1. Introduction

The town of Korhogo (Figure.1) located in the Poro region (northern Côte d’Ivoire) is experiencingindustrial, tourist and agricultural development, which is increasing the pressure on water resources already threatened by climate change. The KOKO river is affected by this economic dynamic. The massive and sustainable intensification of urban agriculture poses a several challenges for the quality of the river water resources. The use of chemical and biological inputs as well asmaintenance chemicals (pesticides) in this type of agricultural practice pollutes surface water (1). The development of urban agriculture may compromise, in the long term, the availability of potable water. In addition, the entire northern zone has become in recent years the cradle of many illegal gold miners from here and the sub-region who extract minerals through artisanal mining practices (gold, diamonds, etc.). This expose water resources to various metallic pollutions resulting from mining activities. Generally, these metal pollutants end up in runoff water, which contaminates surface water and groundwater, ending up in the food chain with all the harmful consequences this represents for our health (2,3). Surface waters are known to be the ultimate reservoirs of heavy metals released into the environment (4). However, in those city, the drinking water supply relies mainly on surface water reservoirs. It is in this perspective that the Koko dam has been the subject of many. The studies (5) showned that the metal elements analyzed do not present a risk of toxicity for consumers, according to the guidelines (6). Conversely, studies (7) showed that the KOKO dam is polluted by trace metal elements (Lead and Zinc). This dam is fed by four water sources in addition to rainwater. To date, no study on the evolution of metals in these effluents has been carried out to diagnose their pollution and their impacts on humans. Although no outbreaks of illness attributable to heavy metal poisoning have been reported in the city, it is known that increased concentrations of heavy metals in drinking water can cause immediate and chronic health problems for residents (8).The common approach to evaluate health risks consists of directly compare directly compare the values determined with the permissible limits. This system, although acceptable, does not correctly represent the levels of danger and does not allow differentiate of the risk agents of greatest concern (9). By assessing the potential risk involved, it is possible to estimate the likely health consequences of many pollutants present in an environment (10). Thus, the objective of the study is to assess pollution by heavy metals and the health risks linked to exposure to pollutants from water samples collected inside and around the KOKO river, in the town of Korhogo,

2. Materials and Methods

2.1. Description of the Study Area

The KOKO river is located in the Koko district of the city of Korhogo in northern Côte d'Ivoire. The city has two climates: hot and humid. The year is divided into two main seasons: the rainy season (May to October), with average precipitation of 1300 to 1400 mm per year, and the dry season (November to April), with average annual temperatures of 20ºc and 37ºc

(8). The dam is located between longitudes 5°38'45" W and latitudes 9°28'05"N (Figure.1). It has an area of 62 hectares (9). Four streams dissect the plateau on which the basin of this body of water is located. They constitute canals for collecting rainwater runoff and wastewater from commercial and domestic activities. We have canal to the south (the Koko district), to west another marks the boundary between Mongaha and Koko. We also have tcanal to the north (between the Sonzoribougou and Mongaha district) and finally, still to the north, an artificial stream created by the inhabitants to facilitate the passage of their wastewater (9).

2-2. Sampling Methods

The waters sampling was carried out in July 2019 from the tributaries and within the KOKO river. Preliminary measures have been taken in accordance with standard guidelines (10) to avoid contamination. Surface waters were sampled with a Niskin bottle (5 L) at 15 cm depht. To prevent metal precipitation, water samples were acidified with 1 mL of nitric acid (65% suprapur, E. Merck, Germany) and stored at 4°C until analysis(11).

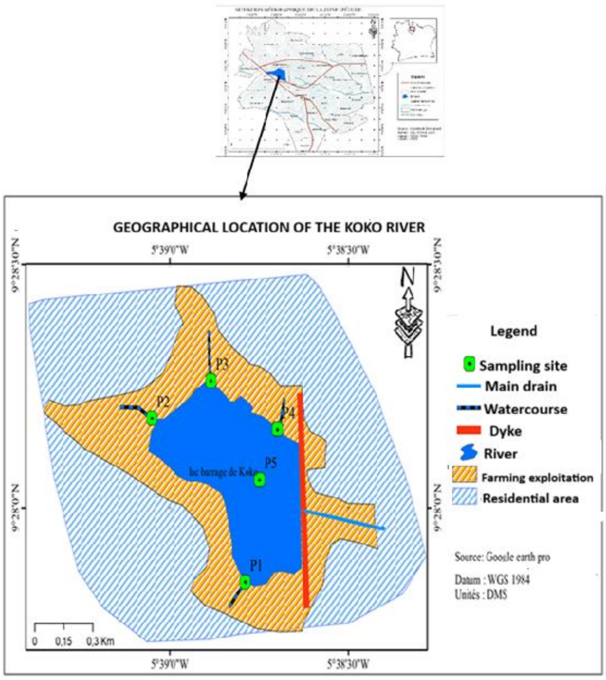

Figure 1: **Geographic location of the study area**

2-3-2. Assessment of the degree of metal contamination in surface water

Standard solutions were prepared for calibration, and the total concentrations of Hg, AS, Cd, Cr, Cu, Ni, Pb, and Zn in the samples were determined using an atomic absorption spectrophotometer HACH DR 6000. The determination of heavy metals were applied in accordance with standard guidelines (12). The detection limit for trace metals were 0.0001 ppm for Cd and As, 0.0005 mg/L for Hg and Pb, 0.001 ppm for Cu and Ni, and finally 0.005 mg/L for Zn.

2-3-3. Assessment of the pollution level

2-3-3.2. Metal Pollution Index

The heavy metal pollution index (HPI) is an index proposed by (13). The index is a global indicator used to assess the level of contamination of water (surface or groundwater) by many heavy metals simultaneously. It is used by many authors (12; 13) in the context of their studies to evaluate the metal pollution of surface waters. This method is based on weighted arithmetic quality. HPI is calculated from equation below :

$$HPI = \frac{\sum_{i=0}^{n} Qi * Wi}{\sum_{i=0}^{n} Wi}$$ **Equation 1**

$$W_i = \frac{k}{S_i}$$ **Equation 2**

$$Q_i = \left(\frac{Vi}{Si}\right) * 100$$ **Equation 3**

Qi is the sub-index for ith trace metal. The unit weighting of ith metal is defined by wi. n is the number of metals analysed. Vi was the determined concentration of the pollutant i. K is the proportionality constantwhich is equal to 1, while Si is the standard value of the parameter ((as a reference the limit established by (6)).

The pollution risk based on the HPI value can be classified into three categories. HPI < 100 indicates low pollution of heavy metal. HPI =100 indicates that harmful health effects are probable. HPI > 100 suggests that the water is not suitable for drinking (14).

2-3-3.3. Heavy Metal Evaluation Index (HEI)

The HEI is an indicator used to assess the overall quality of an aquatic environment (surface water, groundwater, etc.) based on the presence of heavy metals.It is used to determine whether the cumulative concentration of many metals exceeds the limit values established by reference organizations (6). The HEI index is calculated as follows (14, 15).

$$HEI = \sum_{i=1}^{n} \frac{C_i}{H_{MAC_i}}$$ **Equation 4**

Where Ci is the measured concentration of the ith heavy metal. MACi is the maximum admissible concentration of metal i. The HEI value below 10 indicates low pollution level.

The water is moderately polluted when HEI is between 10 and 20. HEI higher than 20 indicates high pollution level (14).

2-3-3.4. Water Quality Indices (WQI)

The water quality index (WQI) was proposed by (16) with the following equation:Where Ci was the determined value of ith parameter. Si was the standard value according to WHO.

$$IQE = \sum (PRi \times Ci/Si \times 100)$$ **Equation 5**

$$PRi = Pui / \sum Pui$$ **Equation 6**

Where :

PRi and Pui : PRi and Pui were the relative weight and the weight attributed to the element i, respectively.

Ci : Concentration of element i

Si : was the standard value according to WHO

WQI value below 50 indicates excellent quality; water quality is good when 50 ≤ WQI < 1; when 100 ≤ WQI < 200, water quality is poor; if 200 ≤ WQI < 300, water quality is very poor; WQI ≥ 300 indicates that water is not drinkable (17; 18).

2-3-3.4. Health Risk Assessment

This study used the CDI to calculate the non-carcinogenic and carcinogenic risks associated with ingestion and dermal exposure to trace elements present in water samples (19, 20).

$$CDI_{ing} = \frac{C_i \times IR \times EF \times ED}{BW \times AT_{nc}}$$ **Equation 7**

$$CDI_{der} = \frac{C_i \times SA \times K_p \times ET \times EF \times ED \times CF}{BW \times AT_{nc}}$$ **Equation 8**

Where CDIing (µg/Kg.day) indicates the chronic daily intake through ingestion. CDIder(µg/Kg.day) expresses the chronic daily intake through dermal contact.

2-3-3.4.1. Non-carcinogenic risks

The hazard quotient (HQ) was used to assess the non carcinogenic risk The hazard index (HI) expresses the total non-carcinogenic risk. HI is computed as follows (21)

$$HQ_{ing} = \frac{CDI_{ing}}{RFD_{ing}}$$ **Equation 9**

$$HD_{der} = \frac{CDI_{der}}{RFD_{der}}$$ **Equation 10**

$$RFD_{der} = RFD_{ing} \times ABS_g$$ **Equation 11**

$$HI = \Sigma(HQ_{ing} + HQ_{der})$$ **Equation 12**

The HI value below 1 indicates low adverse effects. When HI ≥ 1, adverse effects can occur on human health (21).

2-3-3.4.2. Carcinogenic risks

Trace metals AS, Cd, Cr, Ni et Pb were used to assess the carcinogenic risk. The carcinogenic risk is calculated as follows (22, 23) :

$$CRing = CDIing \times SFing$$ **Equation 13**

$$CRder = CDIder \times SFder$$ **Equation 14**

Where SF represents the carcinogenicity factor. The dermal carcinogenicity factor is calculated using the following formula:

$$SF_{der} = \frac{SF_{ing}}{ABS_g}$$ **Equation 15**

The total carcinogenic risk is determined by the equation:

$$CR = \sum (CR_{ing} + CR_{der})$$ **Equation 16**

The range of acceptable carcinogenic risk is 10^{-6} to 10^{-4}. CR value ≤ 10^{-6}indicates no significant risk. When CR value ≥ 10^{-4}, humans can develop a cancer (22).The other exposure parameters were reported in Table 1.

Table 1 :Exposure assessment parameters.

Parameter	Meaning	Adult	Child	Unit	Références
IR	Ingestion rate	2,2	1	L/jour	(23)
EF	Exposure frequency	365	365	Jour/an	(23)

ED	Exposure duration	30	10	An	(22)
BW	Body weight	70	15	Kg	(23)
ATnc	Average time for non-carcinogenic	DE x 365=25550	DE x 365= 3650		(25)
ATc	Average time for carcinogenic	EDV x 365=21170	EDV x 365=21170		(25)
SA	Skin-surface area	5700	2800	Cm^2	(23)
Kp	Permeability coefficient	As, Hg, Cu, et Cd :0,001 Cr :0,002 ; Ni :0,0002 ; Zn, Pb : 0,0001		Cm /h	(23)
ET	Exposure time	0,58	1	h/jour	(23).
CF	Conversion factor	0,001			(23)
RfDing	Reference dose of heavy metals through ingestion	As et Hg :0,3 ; Pb: 0,001 ; Zn: 0,0006 ; Cd :0,5 ; Cr :3, Ni :20 ; Cu : 20		µg/Kg/Jour	(23)
SFing	Slop factor of metal through ingestion	Cd : 0,38 ; Ni :0,91 ; Cr : 0,42, As : 0,0015 ; Pb : 0,0085		µg /Kg/Jour	(23)
ABSg	Gastrointestinal absorption factor	As :1,5 et Cu :1 ; Hg : 0,07 ; Cd : 0,05 ; Ni :0,04 ; Cr : 0,025 ; Pb : 0.3 ; Zn : 0.02			(24)

3. Results and Discussion

3-1. Characteristics of trace metal elements in water

The distributions of total concentrations of Hg, As, Cd, Cr, Cu, Ni, Pb, and Zn in the tributaries and the Koko River are shown in Table 2. Hg concentrations varied between 0,37 and 0.11 µg/L. The Hg values were more concentrated of 0,37 µg/L, 0.31 µg/L, 0,27 µg/L, 0.24 µg/L, and 0.11 µg/L, in the river and tributaries 1, 4, 2, and 3, respectively. As concentrations varied between 0.9 µg/L and 3.69 µg/L. The values were 0.9 µg/L in tributary 1 ; 1.5 in tributary 3 ; 2.43 µg/L in tributary 4 ; 2.68 in the river, and 3.69 µg/L in tributary 2. As shown in Table 1, Cd concentrations varied between 0.19 and 0.40 µg/L. Cd concentrations were 0.219 µg/L; 0.258 µg/L; 0.304 µg/L; 0.322 µg/L, and 0.40 µg/L in tributaries 2, 4, 3, the river, and tributary 1, respectively. Concentrations of Cr varied between 1,16 µg/L to 4.61 µg/L. The values were 1.16 µg/L in tributary 1; 1.81 µg/L in tributary 3; 2.77 µg/L in tributary 2; 4.15 µg/L in tributary 4; and 4.61 µg/L in the river. Cu Concentrations varied between 2.57 and 4.81 µg/L. The values Cu were 2.57 µg/L, 3.03 µg/L, 3.77 µg/L, 4.21 µg/L, and 4.81 µg/L in tributaries 1, 3, 2, the river, and tributary 4, respectively. Trace metal Nickel concentrations varied between 1.42 and 3.89 mg/L.

Concentrations were 1.42 µg/L, 2.18 µg/L, 2.83 µg/L, 3.37 µg/L, and 3.89 µg/L in tributaries 1, 3, 2, 4, and the river,respectively. Trace metal Pb concentrations varied between 16.90 µg/L to 25.2 µg/L. The values were 22.1 µg/L in tributary 1; 25.2 µg/L in tributary 3; 16.90 µg/L in tributary 2; 24.5 µg/L in tributary 4; and 17.7 µg/L in the river. Zn concentrations varied between 15.21 µg/L and 43.11 µg/L. The values were 15.21 µg/L in tributary 1, 19.67 µg/L in tributary 3, 39.41 µg/L in tributary 4, 43.11 in the river, and 28.44 µg/L in tributary 2.The trace metal concentrations measured in the tributaries and River varied between 0.11 and 43.11 µg/L. These values generally respect the standards recommended by (6), with the exception of Pb, which has high values in the sampling areas.These results corroborate those of (7), which had monstrated a particularly high concentration of Pb in the water of the Koko River. The high concentrations of Pb observed could be attributed to significant anthropogenic pressure on the city of Korhogo, particularly due to agricultural, and agro-industrial activities (26). (27) have reported that vehicular exhausts from leaded gasoline are a source of Pb in the environment. Therefore, proximity of the study area to the road, may also explain the high concentration of Pb.Pesticides and fertilizers used on surrounding farms contain heavy metals (Cd, Hg, Pb, Al, As, Cr, Cu, Mn, Ni et Zn etc.). These heavy metals may be introduced the river through natural processes. (28, 29, 30). According to (31), their persistence in the environment (water, soil, air) can lead to the accumulation of these molecules in the food chain. Surface water pollution is influenced by anthropogenic activities (32).

Table 2. Concentrations of trace metals (µg/L) in the tributaries and the KOKO River.

Stations	Hg(µg/L)	AS(µg/L)	Cd(µg/L)	Cr(µg/L)	Cu(µg/L)	Ni(µg/L)	Pb(µg/L)	Zn(µg/L)
River	0.37	2.68	0.322	4.61	4.21	3.89	17.7	43.11
Tributary 1	0.31	0.9	0.40	1.16	2.57	1.42	22.1	15.21
Tributary 2	0.24	3.69	0.219	2.77	3.77	2.83	16.90	28.44
Tributary 3	0.11	1.5	0.304	1.81	3.03	2.18	25.2	19.67
Tributary 4	0.27	2.43	0.258	4.15	4.81	3.37	24.5	39.41

3.2. Pollution indices and water quality assessment

The pollution indices HPI, HEI, and WQI values are shown in Table 3. The HPI values obtained in tributaries 1, 2, 3, 4, and the river are 57.50 ; 52.50 ; 65.01 ; 67.49 and 34.32, respectively. According to the HPI scale, the HPI values obtained in surface waters indicate low pollution of heavy metal. The HEI values in tributaries 1, 2, 3, 4, and the river are 2.62 ; 2.36 ; 2.90 ; 3.06 and 2.49, respectively, which indicated a low pollution. For the WQI, tributaries 1, 2, 3, 4, and the river have respective values of 38.6 ; 32.45 ; 41.48 ; 41.86, and 34.34. These results showed that the quality of the groundwater was excellent. Whatever the index, we noted that these values are significantly higher of tributaries 3 and 4. The high pollution level of surface waters may be due to Domestic wastewaterand waste residues from agricultural activities discharge in the surface waters. Therefore, environmental management and reduced surface waters pollution by trace metals are highly crucial.

Table 3: values of WQI, HPI, and HEI.

Water	**WQI**	**HPI**	**HEI**
River	34.34	34.32	2.49
Tributary 1	38.60	57.50	2.64
Tributary 2	32.45	51.78	2.36
Tributary 3	41.48	65.01	2.90
Tributary 4	41.86	67.49	3.06

3.3. Health risk assessment

3.3.1. Assessment of non-carcinogenic risks in adults and children

The HQder, HQing, and HI values were reported in Table 4. The values of the HQder, HQing and HI indices of Hg, As, Cd, Cr, Cu and Ni were lower than 1 for adults and children in the various tributaries and the KOKO River. The results showed that these trace metals have no adverse effects on humans. However, the HQing, HQder, and HI values for Pb and Zn in all of these surface waters varied between 1.05 and 1.68×10^{3}. the values were higher 1 for adults and children.All values suggested that adverse effects could occur on human health through ingestion or dermal contact with these metals (Pb and Zn).According to (33), Pb was reported as a major contributor to non-carcinogenic risk. In this study, the values of HQing were higher than those of HQder. Tributaries 3 and 4 showed high HQing and HI index values compared to other surface waters. It can therefore be inferred that the population living around these surface waters could develop non-carcinogenic risks related to Pb and Zn through water ingestion. It is therefore important to prohibit this population to swim in these waters.

Table 4: Values of non-carcinogenic risk indices for dermal contact (HQder), ingestion (HQing), and total non-carcinogenic risk (HI) related to trace metals.

Children

Water	Indice	Hg (ug/L)	AS(ug/L)	Cd(ug/L)	Cr(ug/L)	Cu(ug/L)	Ni(ug/L)	Pb(ug/L)	Zn(ug/L)
	HQing	$8,22\times10^{-2}$	$5,97\times10^{-1}$	$4,29\times10^{-2}$	$1,02\times10^{-1}$	$1,40\times10^{-2}$	$1,30\times10^{-2}$	$1,18\times10^{3}$	$4,79\times10^{3}$
River	HQder	$3,29\times10^{-3}$	$1,11\times10^{-3}$	$2,40\times10^{-3}$	$2,29\times10^{-2}$	$3,93\times10^{-5}$	$1,82\times10^{-4}$	1,10	$6,71\times10^{1}$
	HI	$8,55\times10^{-2}$	$5,98\times10^{-1}$	$4,53\times10^{-2}$	$1,25\times10^{-1}$	$1,41\times10^{-2}$	$1,31\times10^{-2}$	$1,18\times10^{3}$	$4,86\times10^{3}$
	HQing	$7,00\times10^{-2}$	$2,00\times10^{-1}$	$6,00\times10^{-2}$	$2,58\times10^{-2}$	$8,57\times10^{-3}$	$4,73\times10^{-3}$	$1,47\times10^{3}$	$1,69\times10^{3}$
Tributary 1	HQder	$2,76\times10^{-3}$	$3,73\times10^{-4}$	$2,99\times10^{-3}$	$5,77\times10^{-3}$	$2,40\times10^{-5}$	$6,63\times10^{-5}$	1,38	$2,37\times10^{1}$
	HI	$7,28\times10^{-2}$	$2,00\times10^{-1}$	$6,30\times10^{-2}$	$3,16\times10^{-2}$	$8,59\times10^{-3}$	$4,80\times10^{-3}$	$1,47\times10^{3}$	$1,71\times10^{3}$
	HQing	$5,30\times10^{-2}$	$8,20\times10^{-1}$	$3,00\times10^{-2}$	$6,16\times10^{-2}$	$1,26\times10^{-2}$	$9,43\times10^{-3}$	$1,13\times10^{3}$	$3,16\times10^{3}$
Tributary 2	HQder	$2,13\times10^{-3}$	$1,53\times10^{-3}$	$1,64\times10^{-3}$	$1,38\times10^{-2}$	$3,52\times10^{-5}$	$1,32\times10^{-4}$	1,05	$4,42\times10^{1}$
	HI	$5,51\times10^{-2}$	$8,22\times10^{-1}$	$3,16\times10^{-2}$	$7,53\times10^{-2}$	$1,26\times10^{-2}$	$9,57\times10^{-3}$	$1,13\times10^{3}$	$3,20\times10^{3}$
	HQing	$2,00\times10^{-3}$	$3,30\times10^{-1}$	$4,00\times10^{-2}$	$4,02\times10^{-2}$	$1,01\times10^{-2}$	$7,27\times10^{-3}$	$1,68\times10^{3}$	$2,19\times10^{3}$
Tributary 3	HQder	$9,78\times10^{-4}$	$6,22\times10^{-4}$	$2,27\times10^{-3}$	$9,01\times10^{-3}$	$2,83\times10^{-5}$	$1,02\times10^{-4}$	1,57	$3,06\times10^{1}$
	HI	$2,98\times10^{-3}$	$3,31\times10^{-1}$	$4,23\times10^{-2}$	$4,92\times10^{-2}$	$1,01\times10^{-2}$	$7,37\times10^{-3}$	$1,68\times10^{3}$	$2,22\times10^{3}$
	HQing	$6,00\times10^{-2}$	$5,40\times10^{-1}$	$3,40\times10^{-2}$	$9,22\times10^{-2}$	$1,60\times10^{-2}$	$1,12\times10^{-2}$	$1,63\times10^{3}$	$4,38\times10^{3}$
Tributary 4	HQder	$2,40\times10^{-3}$	$1,01\times10^{-3}$	$1,93\times10^{-3}$	$2,07\times10^{-2}$	$4,49\times10^{-5}$	$1,57\times10^{-4}$	1,52	$6,13\times10^{1}$
	HI	$6,24\times10^{-2}$	$5,41\times10^{-1}$	$3,59\times10^{-2}$	$1,13\times10^{-1}$	$1,61\times10^{-2}$	$1,14\times10^{-2}$	$1,63\times10^{3}$	$4,44\times10^{3}$
					Adults				
		Hg (ug/L)	**AS (ug/L)**	**Cd(ug/L)**	**Cr(ug/L)**	**Cu(ug/L)**	**Ni(ug/L)**	**Pb(ug/L)**	**Zn(ug/L)**
	HQing	$1,67\times10^{-2}$	$1,20\times10^{-1}$	$8,67\times10^{-3}$	$2,07\times10^{-2}$	$2,84\times10^{-3}$	$2,62\times10^{-3}$	$2,38\times10^{2}$	$9,68\times10^{2}$
River	HQder	$3,29\times10^{-3}$	$1,11\times10^{-3}$	$2,40\times10^{-3}$	$2,29\times10^{-2}$	$3,93\times10^{-5}$	$1,82\times10^{-4}$	1,10	$6,71\times10^{1}$
	HI	$2,00\times10^{-2}$	$1,21\times10^{-1}$	$1,11\times10^{-2}$	$4,36\times10^{-2}$	$2,87\times10^{-3}$	$2,80\times10^{-3}$	$2,40\times10^{2}$	$1,03\times10^{3}$
	HQing	$1,39\times10^{-2}$	$4,04\times10^{-2}$	$1,08\times10^{-2}$	$5,21\times10^{-3}$	$1,73\times10^{-3}$	$9,56\times10^{-4}$	$2,98\times10^{2}$	$3,41\times10^{2}$
Tributary 1	HQder	$2,76\times10^{-3}$	$3,73\times10^{-4}$	$2,99\times10^{-3}$	$5,77\times10^{-3}$	$2,40\times10^{-5}$	$6,63\times10^{-5}$	1,38	$2,37\times10^{1}$
	HI	$1,67\times10^{-2}$	$4,08\times10^{-2}$	$1,38\times10^{-2}$	$1,10\times10^{-2}$	$1,75\times10^{-3}$	$1,02\times10^{-3}$	$2,99\times10^{2}$	$3,65\times10^{2}$
	HQing	$1,08\times10^{-2}$	$1,66\times10^{-1}$	$5,90\times10^{-3}$	$1,24\times10^{-2}$	$2,54\times10^{-3}$	$1,91\times10^{-3}$	$2,28\times10^{2}$	$6,38\times10^{2}$
Tributary 2	HQder	$2,13\times10^{-2}$	$1,53\times10^{-3}$	$1,64\times10^{-3}$	$1,38\times10^{-2}$	$3,52\times10^{-5}$	$1,32\times10^{-4}$	1,05	$4,42\times10^{1}$
	HI	$1,29\times10^{-2}$	$1,67\times10^{-1}$	$7,53\times10^{-3}$	$2,62\times10^{-2}$	$2,57\times10^{-3}$	$2,04\times10^{-3}$	$2,29\times10^{2}$	$6,83\times10^{2}$
	HQing	$4,94\times10^{-3}$	$6,73\times10^{-2}$	$8,19\times10^{-3}$	$8,13\times10^{-3}$	$2,04\times10^{-3}$	$1,47\times10^{-3}$	$3,39\times10^{2}$	$4,42\times10^{2}$
Tributary 3	HQder	$9,78\times10^{-4}$	$6,22\times10^{-4}$	$2,27\times10^{-3}$	$9,01\times10^{-3}$	$2,83\times10^{-5}$	$1,02\times10^{-4}$	1,57	$3,06\times10^{1}$
	HI	$5,92\times10^{-3}$	$6,80\times10^{-2}$	$1,05\times10^{-2}$	$1,71\times10^{-2}$	$2,07\times10^{-3}$	$1,57\times10^{-3}$	$3,41\times10^{2}$	$4,72\times10^{2}$
	HQing	$1,21\times10^{-2}$	$1,09\times10^{-1}$	$6,95\times10^{-3}$	$1,86\times10^{-2}$	$3,24\times10^{-3}$	$2,27\times10^{-3}$	$3,30\times10^{2}$	$8,84\times10^{2}$
Tributary 4	HQder	$2,40\times10^{-3}$	$1,01\times10^{-3}$	$1,93\times10^{-3}$	$2,07\times10^{-2}$	$4,49\times10^{-5}$	$1,57\times10^{-4}$	1,52	$6,13\times10^{1}$
	HI	$1,45\times10^{-2}$	$1,10\times10^{-1}$	$8,88\times10^{-3}$	$3,93\times10^{-2}$	$3,28\times10^{-3}$	$2,43\times10^{-3}$	$3,32\times10^{2}$	$9,46\times10^{2}$

3.3.2. Carcinogenic risk assessment

The carcinogenic risk was assessed using these trace metals : As, Pb, Cr, Ni, and Cd (34). The CRing, CRder, and total risk (CR) values are reported inTable5 The total carcinogenic risk (CR) values for Ni, Cd, and Cr in all surface waters ranged between 3.11×10^{-4} and 2.36×10^{-1} for children. For adults, they ranged between 1.88×10^{-3} and 4.80×10^{-2} for Ni and Cr. These results indicate that possible carcinogenic effects can occur for humans who will be in contact with these waters. The CRing values of As ranged between 1.5×10^{-4} and 3.70×10^{-4}, indicating possible great carcinogenic effects for children. In contrast, for adults, ingestion would present a high risk related to Cd ($1.12\times10^{-3} \leq$ CRing $\leq 12.11\times10^{-3}$), while no significant risk ($3.04\times10^{-8} \leq$ CRder $\leq 7.47\times10^{-8}$ or $1.82\times10^{-5} \leq$ CRing $\leq 7.46\times10^{-5}$) would be observed for As in adults. Possible carcinogenic effects through ingestion are also observed in adults ($1.93\times10^{-3} \leq$ CRing $\leq 2.89\times10^{-3}$) and children ($9.58\times10^{-3} \leq$ CRing $\leq 10^{-2}$) for Pb.In this study, the CRing values were higher than those of CRder. All tributaries and rivers showed high values of CRing and CRder for Cd, Cr, and Ni. Pb and As showed significant values for the CRing index for all surface waters. Similar results were obtained by (35, 36, and 37), who indicated that these trace metals posed a possible carcinogenic risk. In addition, previous studies have revealed that human exposure to low concentrations of these trace metals over long-term can have toxic and carcinogenic effects (38). (39) also reported that these trace metals in the soil posed a significant carcinogenic risk to adults and children. Particular attention should caused therefore be paid to the pollution of these elements.

Table 5: Values of carcinogenic risk indices for dermal contact (CRder), ingestion (CRing), and total carcinogenic risk (TCR) related to trace metals.

Children						
Water	Indices	AS(ug/L)	Cd(ug/L)	Cr(ug/L)	Ni(ug/L)	Pb(ug/L)
River	CRing	$2,70\times10^{-4}$	$7,60\times10^{-3}$	$1,29\times10^{-1}$	$2,36\times10^{-1}$	$1,00\times10^{-2}$
	CRder	$5,00\times10^{-7}$	$4,57\times10^{-4}$	$2,89\times10^{-2}$	$3,30\times10^{-3}$	$9,36\times10^{-6}$
	CR	$2,71\times10^{-4}$	$8,06\times10^{-3}$	$1,58\times10^{-1}$	$2,39\times10^{-1}$	$1,00\times10^{-2}$
Tributary1	CRing	$9,00\times10^{-5}$	$1,01\times10^{-2}$	$3,25\times10^{-2}$	$8,61\times10^{-2}$	$1,25\times10^{-2}$
	CRder	$1,68\times10^{-7}$	$5,67\times10^{-4}$	$7,28\times10^{-3}$	$1,21\times10^{-3}$	$1,17\times10^{-5}$
	CR	$9,02\times10^{-5}$	$1,07\times10^{-2}$	$3,98\times10^{-2}$	$8,74\times10^{-2}$	$1,25\times10^{-2}$
Tributary2	CRing	$3,69\times10^{-4}$	$5,55\times10^{-3}$	$7,76\times10^{-2}$	$1,72\times10^{-1}$	$9,58\times10^{-3}$
	CRder	$6,89\times10^{-7}$	$3,11\times10^{-4}$	$1,74\times10^{-2}$	$2,40\times10^{-3}$	$8,94\times10^{-6}$
	CR	$3,70\times10^{-4}$	$5,86\times10^{-3}$	$9,49\times10^{-2}$	$1,74\times10^{-1}$	$9,59\times10^{-3}$
Tributary3	CRing	$1,50\times10^{-4}$	$7,70\times10^{-3}$	$5,07\times10^{-2}$	$1,32\times10^{-1}$	$1,43\times10^{-2}$
	CRder	$2,80\times10^{-7}$	$4,31\times10^{-4}$	$1,14\times10^{-2}$	$1,85\times10^{-3}$	$1,33\times10^{-5}$
	CR	$1,50\times10^{-4}$	$8,13\times10^{-3}$	$6,20\times10^{-2}$	$1,34\times10^{-1}$	$1,43\times10^{-2}$
Tributary4	CRing	$2,43\times10^{-4}$	$6,54\times10^{-3}$	$1,16\times10^{-1}$	$2,04\times10^{-1}$	$1,39\times10^{-2}$
	CRder	$4,54\times10^{-7}$	$3,66\times10^{-4}$	$2,60\times10^{-2}$	$2,86\times10^{-3}$	$1,30\times10^{-5}$
	CR	$2,43\times10^{-4}$	$6,90\times10^{-3}$	$1,42\times10^{-1}$	$2,07\times10^{-1}$	$1,39\times10^{-2}$
Adults						
River	CRing	$5,41\times10^{-5}$	$1,65\times10^{-3}$	$2,61\times10^{-2}$	$4,77\times10^{-2}$	$2,03\times10^{-3}$
	CRder	$5,42\times10^{-8}$	$4,95\times10^{-5}$	$3,14\times10^{-3}$	$3,58\times10^{-4}$	$1,02\times10^{-6}$
	CR	$5,42\times10^{-5}$	$1,70\times10^{-3}$	$2,92\times10^{-2}$	$4,80\times10^{-2}$	$2,03\times10^{-3}$
Tributary1	CRing	$1,82\times10^{-5}$	$2,05\times10^{-3}$	$6,56\times10^{-3}$	$1,74\times10^{-2}$	$2,53\times10^{-3}$
	CRder	$1,82\times10^{-8}$	$6,15\times10^{-5}$	$7,89\times10^{-4}$	$1,31\times10^{-4}$	$1,27\times10^{-6}$

	CR	$1,82\times10^{-5}$	$2,11\times10^{-3}$	$7,35\times10^{-3}$	$1,75\times10^{-2}$	$2,53\times10^{-3}$
	CRing	$7,46\times10^{-5}$	$1,12\times10^{-3}$	$1,57\times10^{-2}$	$3,47\times10^{-2}$	$1,93\times10^{-3}$
Tributary2	CRder	$7,47\times10^{-8}$	$3,37\times10^{-5}$	$1,88\times10^{-3}$	$2,61\times10^{-4}$	$9,69\times10^{-7}$
	CR	$7,46\times10^{-5}$	$1,15\times10^{-3}$	$1,76\times10^{-2}$	$3,49\times10^{-2}$	$1,94\times10^{-3}$
	CRing	$3,03\times10^{-5}$	$1,56\times10^{-3}$	$1,02\times10^{-2}$	$2,67\times10^{-2}$	$2,89\times10^{-3}$
Tributary3	CRder	$3,04\times10^{-8}$	$4,68\times10^{-5}$	$1,23\times10^{-3}$	$2,01\times10^{-4}$	$1,45\times10^{-6}$
	CR	$3,03\times10^{-5}$	$1,60\times10^{-3}$	$1,15\times10^{-2}$	$2,69\times10^{-2}$	$2,89\times10^{-3}$
	CRing	$4,91\times10^{-5}$	$1,32\times10^{-3}$	$2,35\times10^{-2}$	$4,13\times10^{-2}$	$2,81\times10^{-3}$
Tributary4	CRder	$4,92\times10^{-8}$	$3,97\times10^{-5}$	$2,82\times10^{-3}$	$3,10\times10^{-4}$	$1,41\times10^{-6}$
	CR	$4,91\times10^{-5}$	$1,36\times10^{-3}$	$2,63\times10^{-2}$	$4,16\times10^{-2}$	$2,81\times10^{-3}$

5. Conclusion

The objective of the study is to assess heavy metal concentrations and health risks in surface waters around and within the KOKO River in the city of Korhogo, Côte d'Ivoire. The results showed that concentrations of Hg, As, Cd, Cr, Cu, Ni, and Zn in surface water were below WHO guidelines, while Pb values exceeded WHO guideline values. The pollution indices HPI and HEI indicated low pollution of surface water. In addition, WQI Index indicated that surface water quality was excellent. The non-carcinogenic risk assessment showed that, for surface water, the HQder, HQing, and HI values were below 1 for trace metals such as mercury (Hg), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), and nickel (Ni) in adults and children, indicating low adverse effects. However, the HQing, HQder, and HI values for Pb and Zn in all of these surface waters exceeded 1 for adults and children, indicating potential adverse effects on human health. The assessment of the carcinogenic risk of Ni, Cd, and Cr in children showed CR values for Ni, Cd, and Cr in surface water exceeding 10^{-4}. These indicate a possible carcinogenic risk for children. In contrast, in adults only the CR values of Ni and Cr indicate a potential gread carcinogenic risk. The CRing values of As showed potentially significant carcinogenic effects for children. However, for adults, ingestion would present a high risk related to Cd. Possible carcinogenic effects through ingestion also observed in adults and children for Pd. It is therefore essential to treat water in order to remove trace metals before before using them for irrigation or domestic purposes. In addition, Complementary studies including Hg, As, Cd, Cr, Cu, Ni, Pb, and Zn accumulation in the blood, urine, and hair of population should be investigated to better understand the risks related to trace metals.

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