Risks assessment of heavy metals (Cd, Pb, Cu, Fe and Al) linked to the consumption of drilling water by local populations: case of the city of Bouaké (Cote d’Ivoire)

Abstract

Drilling water consumption in the city of Bouaké, the second largest city in Cote d’Ivoire, could potentially expose the population to carcinogenic and non-carcinogenic risks linked to heavy metals (Cd, Pb, Cu, Fe, Al). In order to assess these risks, heavy metals analyzed by graphite furnace atomic absorption spectroscopy (GFAAS) were carried out in 16 samples of drilling water collected in the dry season (March 2024) and in the rainy season (May 2024) in several neighborhoods of the city of Bouaké. The hazard quotient (HQ) method and the additional lifetime cancer risk (ILCR) method made it possible to assess the health risks linked to the studied metals. Aluminum-related HQ values greater than 1 indicate that, in the long term, the risk of brain disorders is high for children and adults. The ILCR values obtained by ingestion varied between 10^{-4} and 10^{-5} for cadmium and between 10^{-3} et 10^{-4} for lead. ILCR values indicate low risks from cadmium and high risks from lead.

Keywords: Heavy metals; Drilling water; Hazard quotient; Carcinogenic and non-carcinogenic risk; Bouaké

1. Introduction

The rapid growth of the Ivorian population in recent decades resulted in rapid urbanization of most cities in Côte d'Ivoire. However, having access to quality water has become a major concern for most of them [1-2]. Thus, groundwaters, often perceived as pure and natural, has become a source of drinking water for many populations in Côte d'Ivoire [3]. The city of Bouaké, second city in Côte d'Ivoire, which is located in the center of the country, is experiencing an evolution resulted in significant demographic growth and rapid spatial growth. The demand for housing has increased significantly. So, the city has expanded to more than 29,250 ha. Thus, many new neighborhoods, such as Cité des Impôts, CIDT, Agamblé, d’Amabo, Angamblé, Fêtêkro Extension, Assoumankro, Banco, Soussoroubougou, etc., have emerged in recent years. Unfortunately, the development of these neighborhoods does not always follow the population growth curve. Thus, several neighborhoods have suffered for years from a lack of drinking water supply [3-4]. This major drinking water crisis has revealed a structural problem in access to drinking water throughout the region. Only the urbanized areas are served by the distribution network managed by SODECI (Cote d’Ivoire Water Distribution Company). As a result, the population resorts to alternative sources on a daily basis: wells or boreholes [5]. Indeed, many households in the city of Bouaké have equipped themselves with boreholes to secure their supplies, or even develop a commercial activity [5]. However, is the borehole water of good quality?

Indeed, the contamination of these waters by heavy metals remains today to be one of the most important environmental problems in the world due to their impact on human health [6]. The aim of this research work is to assess the carcinogenic and non-carcinogenic risks linked to the consumption of drilling water by local populations in the city of Bouaké. This work will consist, specifically, to determine the contents of heavy metals (Cu, Fe, Al, Pb, Cd) in samples of drilling water and to assess the carcinogenic and non-carcinogenic risks linked to heavy metals present in the waters of some households of the city of Bouaké.

2. Materials and methods

2.1. Description of the sampling area

The sampling area of our study in the city of Bouaké includes the neighborhoods of Nanaville (cité des impôts) and CIDT, where SODECI provides partially or not at all drinking water. These neighborhoods were selected because of their wealthy or middle-income population, able to finance alternative water supply systems such as boreholes. We studied 8 households with 8 boreholes. The different sampling points selected are indicated in Figure 1 below.

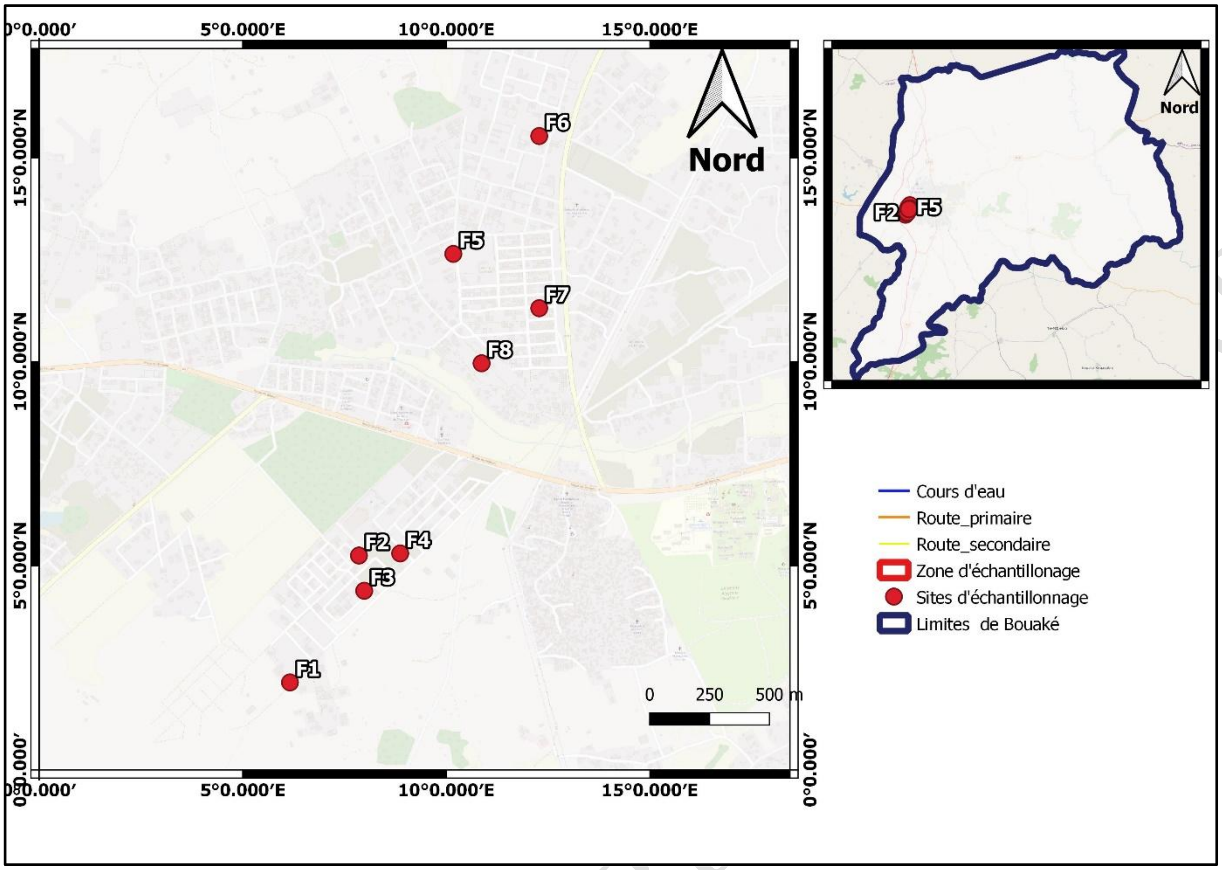

Figure 1: Location of sampling points

2.2. Sampling

As part of our study, two sampling campaigns were carried out, one campaign in the dry season (March 2024) and the other in the rainy season (May 2024). A total of 16 borehole water samples were collected directly from the tap, in 500 ml polyethylene bottles, from 8 households for analysis. After filling, the samples were acidified using ultra-pure nitric acid (HNO3). After sampling, all samples were stored in a cooler at around 4°C in order to limit chemical or biological reactions. Then, they were transported to the Geoscience and Environment Laboratory at NANGUI Abrogoua University (Abidjan-Cote d'Ivoire) for the analyses.

2.3. Analysis of heavy Metals (Fe, Al, Pb, As, Cd, Cu, Al)

The determination of heavy metals in the drilling water samples was carried out by graphite furnace atomic absorption spectroscopy (GFAAS) according to AOAC method 999.10 [7]. For heavy Metals (Fe, Al, Pb, As, Cd, Cu, Al) analysis, an aliquot of 0.5 g of water was digested in a microwave digester (Milestone Ethos), with 5 mL of nitric acid (65%) and 2 mL of hydrogen peroxide (30%). The mineral was then transferred into a 25-mL volumetric flask and completed to the mark with ultrapure water and kept refrigerated prior to analysis [7].

2.4. Assessment of carcinogenic and non-carcinogenic risks linked to heavy metals

Identification or characterization of hazards

Cadmium, lead and arsenic are the most toxic heavy metals for humans. In addition to these metals, aluminum, iron and copper have been reported in waters by several studies carried out in Cote d'Ivoire due to their strong presence in the environment.

The different water hazards identified in the case of this study are presented in Table I.

Table I: Hazard identification and characterization

Heavy Metals	**Hazard characterization**		
	Source	**Acceptable daily intake/tolerance (ADI or TDI) in mg/kg/day**	**Diseases**
Copper		0.01	Insuffisance rénale
Iron	Rock weathering, corrosion	0.02	Risk of significant gastrointestinal bleeding if: ADI = 250 mg/kg/d
Aluminum		0.7	Brain disorders
Cadmium	Sedimentary rocks, manufacturing of pigments, stabilization of plastics.	0.001	Renal failure, osteoporosis, prostate cancer [8]
Lead	Earth's crust, anthropogenic activity (piping, painting)	0.0036	Saturnism (anemia, lowered intelligence quotient and neurodevelopmental disorders)

Estimation of chemical exposure

The exposure assessment consisted of determining the quantity (Q) of water consumed per day, the toxic chemical substance (mg/L) ingested by an individual per day and the frequency of consumption (F). The quantification of exposure levels was obtained by evaluating the Daily Exposure Dose (DED) which is given by the expression:

$$\mathbf{DED} = \mathbf{\Sigma C} \times \mathbf{Q} \times \frac{\mathbf{F}}{\mathbf{MC}} \quad \textbf{(mg/Kg/day)} \quad \textbf{(1)} \quad [9]$$

Table II: Criteria for assessing chemical risk linked to the metals studied

Metals	**Amount of water ingested per day (Q) L/D) [10]**		**Body weight (W) (Kg) [11]**		**Guideline value (mg/L) [12]**	**ADI (mg/kg/d) [10, 13]**
	Child	**Adult**	**Child**	**Adult**		
Copper	1.5	2	28	70	1	0.01
Iron	1.5	2	28	70	0.3	0.02
Aluminum	1.5	2	28	70	0.2	0.7
Cadmium	1.5	2	28	70	0.003	0.001
Lead	1.5	2	28	70	0.01	0.0036

Characterization of non-carcinogenic risk (Cu, Fe, Al, Pb, Cd)

The probability of a non-carcinogenic risk for Cu, Fe, Al, Pb and Cd to which populations could be exposed through the consumption of Drilling water is assessed by the hazard quotient (HQ) factor. This factor corresponds to the ratio of the daily exposure dose (DED) to the reference dose (RFD).

$$\mathbf{HQ = \frac{DED}{RFD}} \quad \mathbf{(2)}$$

If HQ > 1, populations exposed to pollutants may have non-carcinogenic health problems;

If HQ < 1 the occurrence of a health risk is very unlikely.

The reference doses (RFD) for Cd, Pb, Cu, Fe and Al are respectively 0.001; 0.0035; 0.04; 0.7 and 0.06 mg/kg body weight/day [14-15].

Hazard Index (HI)

The Hazard Index (HI) determines the potential of non-carcinogenic risk induced by exposure to a mixture of several metals. It results from the sum of all the hazard quotients linked to each heavy metals [16]. Equation (3) shows the mathematical representation of this parameter according to USEPA (United States Environmental Protection Agency) [17] and Storelli et al. [18] :

$$\mathbf{HI = (HQ)_{Cu} + (HQ)_{Fe} + \cdots + (HQ)_{Pb}} \quad \mathbf{(3)}$$

When the HI value is greater than 1, there is the possibility of having a non-carcinogenic effect.

Characterization of carcinogenic risk (Pb, Cd)

The risk of developing any cancer during life was estimated using the Incremental Lifetime Cancer Risk (ILCR). The ILCR makes it possible to estimate the probability that a person will develop any cancer following exposure to a specified daily quantity of a carcinogenic element over years. The ILCR is calculated as follows:

$$\mathbf{ILCR = DDE \times CSF} \quad \mathbf{(4)}$$

CSF is the Cancer Slope Factor, it is defined as the risk generated by an average amount of a chemical over a lifetime and is explicit for a particular contaminant.

For the ingestion route of metals considered in mg/kg/day, we have: CSF (Pb) = 0.0085 and CSF (Cd) = 15 [13].

For the cutaneous route of metals considered in mg/kg/day, we have: CSF (Pb) = 8.5 and CSF (Cd) = 6.1 [19].

If the ILCR < 10-6 the carcinogenic risk is considered negligible, if ILCR > 10-4 there is a high risk for humans to develop cancer and when 10-6 < ILCR < 10-4 there is a acceptable risk for humans [11, 20-22].

Cumulative risk of cancer

The cumulative cancer risk from exposure to multiple carcinogenic heavy metals from water consumption was assumed to be the sum of individual heavy metal exposure risks and was calculated as follows [23] :

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

2.5 Statistical analysis

The software QGIS version 3.14.0, STATISTICA version 7.1 and Excel version 2016 were used, respectively, for the creation of maps, for statistical analyzes and for database creation and automated calculations.

3. Results and discussion

Spatial variation of metals studied in Bouaké drilling waters

The results of the heavy metal concentrations measured in the different drilling waters are recorded in Table III. It indicates for each heavy metal, the values of the mean and the standard deviations. The mean concentrations of heavy metals obtained range between 0.00035 ± 0.00049 (F3) and 0.0013 ± 0.0015 mg.L^{-1} (F5) for Cadmium, between 0.0006 ± 0.0008 (F2) and 0.0260 ± 0.0019 mg.L-1 (F7) for Lead, between 0.0005 ± 0.00014 (F2) and 0. 0139 ± 0.0009 mg.L^{-1} (F7) for Copper, between 0.51 ± 0.72 (F4) and 2.27 ± 0.49 mg.L^{-1} (F7) for iron and between 0.58 ± 0.70 (F8) and 6.90 ± 2.48 mg.L^{-1} (F3) for Aluminum.
The concentrations of cadmium and copper recorded in these waters are lower than the threshold values recommended by the WHO (2017) which are respectively 0.003 and 1 mg/L. For lead, all the concentrations obtained are lower than the threshold value, of 0.01 mg/L, set by the WHO [12] with the exception of stations F7 and F8 with a respectively concentration of 0.026 and 0.0105 mg/L which are higher. This exception for lead concentrations could be due to volcanic rocks such as basalts or andesites which may contain lead minerals in variable concentrations [24]. These results are consistent with those of Demir et al. [25] who reported levels of lead (0.13 to 3 µg/L) and cadmium (0.51 to 2 mg/L) in the drinking water of the town of Tunceli in Turkey. Also, the concentrations of iron and aluminum which varied respectively from 0.51 to 2.27 mg/L and from 0.58 to 6.90 mg/L are for the most part above the threshold values. The high concentration of iron and aluminum is probably due to seepage, corrosion of water supply pipes. Acidic soils promote the dissolution of aluminum in water, thereby increasing its concentration [26].
Moreover, the Kruskal-Wallis statistical test carried out on the parameters indicates no significant difference between the different stations ($p > 0.05$).

Table III: Spatial variation of physico-chemical parameters

Parameters		F1	F2	F3	F4	F5	F6	F7	F8	Kruskal-Wallis (P-value)
Cd	Mean ± SD	0.00045 ± 7.07.10^{-05}	0.00045 ± 0.00021	0.00035 ±0.00049	0.0004 ± 0.00042	0.0013 ± 0.0015	0.0012 ± 0.0007	0.001± 7.07.10^{-05}	0.0002 ± 0.00014	0.41
	Min - Max	0.0004 - 0.0005	0.0003 - 0.0006	0 - 0.0007	0.0001 - 0.0007	0.0002 - 0.0024	0.0007 - 0.0017	0.001 - 0.0011	0.0001 - 0.0003	
Pb	Mean ± SD	0.00065 ± 0.00091	0.0006 ± 0.0008	0.026 ± 0.0019	0.0007 ± 0.0007	0.0027 ± 0.0014	0.00065 ± 7.07.10^{-05}	0.0162 ± 0.0077	0.0103 ± 0.00028	0.098
	Min - Max	0 - 0.0013	0 -0.0012	0.0012 - 0.004	0.0002 - 0.0012	0.0017 - 0.0037	0.0006 - 0.0007	0.0107 - 0.0217	0.0101 - 0.0105	
Cu	Mean ± SD	0.0009 ± 0.007	0.0005 ±0.00014	0.0046 ± 0.0007	0.0015 ± 0.00042	0.001 ± 0.0007	0.0034 ± 0.0007	0.0139 ± 0.0009	0.00085 ± 7.07.10^{-05}	0.075
	Min - Max	0.0004 - 0.0014	0.0004 - 0.0006	0.0041 - 0.0051	0.0012 - 0.0018	0.0005 - 0.0015	0.0029 - 0.0039	0.0132 - 0.0146	0.0008 - 0.0009	
Fe	Mean ± SD	0.78 ± 0.069	0.63 ± 0.14	1.21 ± 0.07	0.51 ± 0.72	1.57 ± 0.35	1.34 ± 0.42	2.27 ± 0.49	1.38 ± 0.018	0.067
	Min - Max	0.73 - 0.83	0.53 -0.73	1.16 - 1.26	0.0065 - 1.03	1.32 - 1.82	1.04 - 1.64	1.92 - 2.62	1.37 - 1.39	
Al	Mean ± SD	3.90 ± 0.44	3.61 ± 2.26	6.90 ± 2.48	2.45 ± 2.19	2.85 ± 0.23	1.46 ± 0.70	0.58 ± 0.70	083 ± 0.13	0.129
	Min - Max	3.58 - 4.21	2.01 -5.21	5.15 - 8.65	0.90 - 4.00	2.69 - 3.01	0.96 - 1.96	0.089 - 1.08	0.73 - 0.93	

Health risk assessment

- Non-carcinogenic risks linked to metals

The hazard index (HI) for the ingestion of drinking water by populations calculated for each sampling point is presented in Figure 2 below. The values obtained range between 1.01 and 6.32 for children and between 0.50 and 1.90 for adults. For each site, the risk index is greater than 1 whether for children or adults. Only the risk index for sampling points F6, F7 and F8 for adults are less than 1.
The hazard index (HI), which is the combined action of all studied metals, is greater than 1 for all drilling waters, whether for children or adults; with the exception of sampling station F6 (HI=0.79), F7 (HI=0.50) and F8 (HI=0.52). This means that frequent consumption of these waters would expose the population to gastrointestinal disorders, breathing disorders, possible alteration of DNA [27]. These results agree with those of Roghayeh and Majid [28] who determined values of HI of 2.78 and 0.31 in drilling waters from Kerman, Iran.

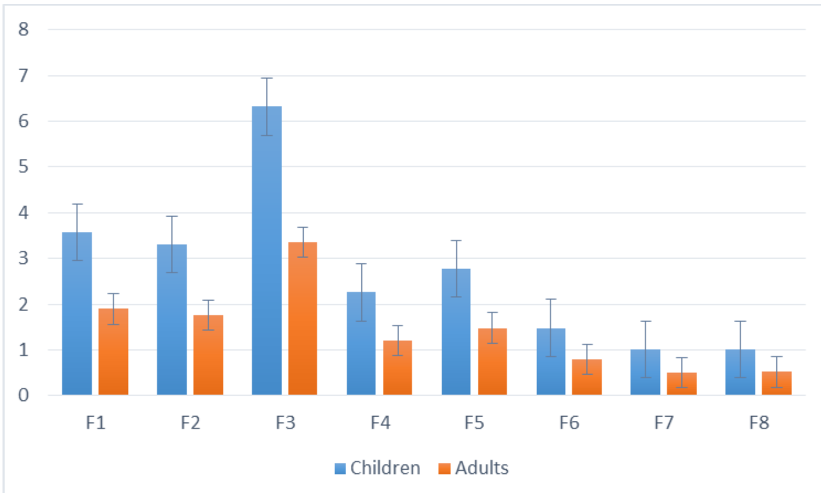

Figure 2: Metal risk index calculated for each point

- Carcinogenic risks (ILCR) linked to Cadmium and Lead

The carcinogenic risks for cadmium and lead are represented in Figure 3 and 4 respectively for the ingestion and the cutaneous route. These values concern both children and adults. The Incremental Lifetime Cancer Risk (ILCR) have been estimated for ingestion and dermal exposure for cadmium and lead. For ingestion, the ILCR for cadmium and for children were above 10^{-4} at all stations except for sampling station F8 (ILCR= 6.53E-5). For adults, the ILCR is above 10^{-4} for sampling stations F5, F6 and F7 and arround 10^{-5} for boreholes F1, F2, F3, F4 and F8. This results mean that there is a real risk of developing prostate and testicular cancers or other diseases linked to cadmium (Akesson, 2008). For lead, the ILCR through ingestion for children and adults is above 10^{-4} for all drilling stations. These results indicate that there is a high risk of developing stomach cancer linked to lead for the population [29]. Through dermal, the ILCR of all sampling sites varies between 10^{-7} and 10^{-6} regardless of the metal, whether cadmium or lead. This result indicates that the risks of cancer through the body are negligible. So, Ingestion ILCR > dermal ILCR in our study, means that the main route of exposure to metal-related cancer is water ingestion. However, ILCRs for children obtained remain higher than those for adults. These results are in agreement with those of Tanouayi et al. [30] who showed that children are the most exposed to the toxic effects of heavy metals present in the groundwater of Hahoe-Kpogame (southern Togo).

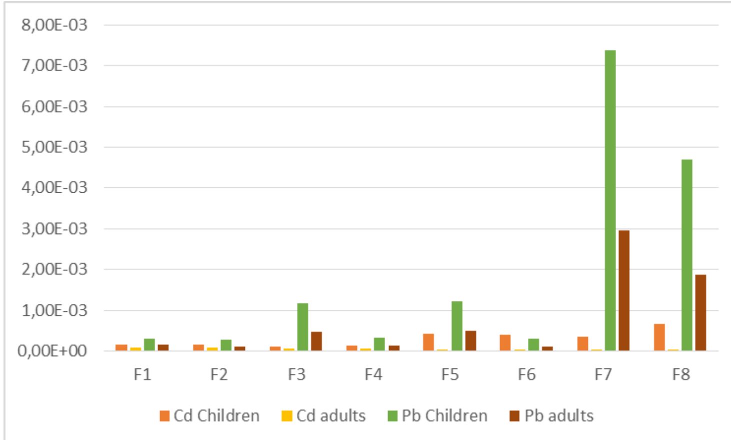

Figure 3: Cancer risk from heavy metals in children and adults through ingestion

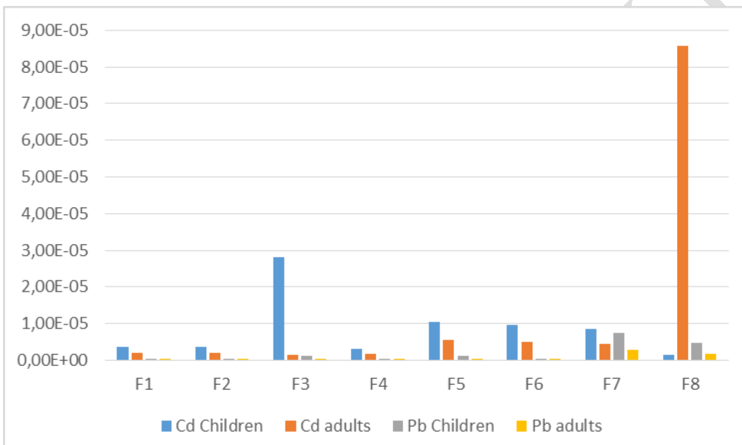

Figure 4: Cancer risk from heavy metals in children and adults through the skin

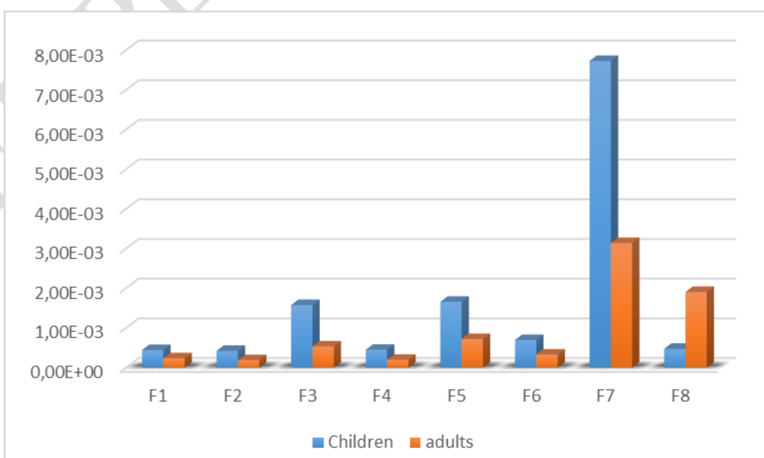

Figure 5: Cumulative cancer risk by sampling point

4. Conclusion

The aim of this study was to assess the carcinogenic and non-carcinogenic risks linked to heavy metals (Cd, Pb, Cu, Fe and Al) present in drilling water consumed by the populations of Bouaké. Heavy metals health risks (non-carcinogenic and carcinogenic) was determined by the hazard quotient (HQ) method and the incremental lifetime cancer risk (ILCR) method. Generally, the concentration of heavy metals analyzed (Cd, Pb, Cu, Fe, AL) remain minimal in all the studied samples and they are below the threshold set by the WHO for drinking water. However, hazard index (HI) values greater than 1, as well as ILCR greater than 10^{-4} through ingestion for cadmium (Cd) and lead (Pb) at almost all sampling points indicate that there is a real risk of developing cancers or other diseases linked to Cd and Pb for the population of Bouaké.

Acknowledgement, the authors would like to express their infinite gratitude to the staff of the Laboratoire Géosciences et Environnement, UFR des Sciences et Gestion de l'Environnement (SGE) at Nangui Abrogoua University (Abidjan – Cote d'Ivoire) for their help and assistance.

Conflict of Interest: The authors declare that there are no conflicts of interest.

References

1. Afforo G. M. E., Sangaré N., Koffi B. (2022) Les agences immobilières dans l'accès aux Logements locatifs à bouaké (côte D'ivoire) : opportunité ou contrainte ? Collection Recherches & Regards d'Afrique, Vol 1(1), 25p
2. Oura R.K. (2020) Urbanisation, enjeux fonciers et fragilisation de la cohésion sociale dans le périurbain de Bouaké. Revue Espace Géographique et Société Marocaine, 41(42), 12p.Akesson A., Julin B., Wolk A. (2008) Consommation alimentaire de cadmium à long terme et incidence du cancer de l'endomètre postménopausique : une étude de cohorte prospective basée sur la population. Cancer Res., 68, 6435-6441.
3. Silué B., Cissé G., Koné B., Zurbrügg C., Savané I. (2012) Equité D'accès à L'eau Potable Dans un Contexte de Diversité de Modes D'approvisionnement: Cas de la Ville de Bouaké (Côte D'ivoire). European Journal of Scientific Research, 72(2), 298-310. http://www.europeanjournalofscientificresearch.com.
4. Mel Eact, Yeo B. (2018) Problématique de l'approvisionnement en eau potable dans la ville de Bouaké (Côte d'Ivoire). Revue Ivoirienne des Sciences Historiques, n°004(Décembre 2018), 40-51.
5. Thomas T. Maillard. (2019) La ressource en eau dans la région de Gbêkê (Côte d'Ivoire). [Rapport de recherche] Région Normandie, 13p.
6. Vodela J. K., Renden J. A., Lenz S. D., McElhenney W. H., Kemppainen B. (1997) Drinking water contaminants (arsenic, cadmium, lead, benzene, and trichloroethylene). Interaction of contaminants with nutritional status on general performance and immune function in broiler chickens. Poult Sci, 76, 1474–1492.
7. AOAC, Association of Official Analytical Chemists (2003) Official methods of analysis of AOAC International. 17th Edition. 2nd revision. Association of Analytical Communities Gaithersburg, Maryland, USA
8. ATSDR, Agency for Toxic Substances and Disease Registry (2007) Toxicological Profile for Arsenic, U.S. Department of Health and Human Services, Public Health Service, accessed online at https://www.atsdr.cdc.gov/toxprofiles/tp2.pdf.
9. Kouadio E. F. (2021) Facteurs associés à la qualité et évaluation des risques sanitaires liés à l'eau de consommation de sept localités de la Côte d'Ivoire. Thèse de Doctorat, Institut National Polytechnique Félix Houphouët Boigny- Yamoussoukro, 66p.
10. WHO (World Health Organization) (2016) Lead in drinking-water: background document for development of WHO guidelines for drinking-water quality. Genève : OMS, 564p.

11. USEPA (United States Environmental Protection Agency) (2001) Risk Assessment Guidance for Superfund, Vol I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment), EPA/540/R/99/005. USA Office of Emerage and Remedial Response, Washington DC.
12. OMS (2017) Directives de qualité pour l'eau de boisson : 4e édition, intégrant le premier additif, 564p.
13. USEPA (United States Environmental Protection Agency) (2002) Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites Office of Solid Waste and Emergency Response. Washington, DC (OSWER9355.4-24). Retrieved October 21, 2019 from: https://rais.ornl.gov/documents/SSG_nonrad_supplemental.pdf.
14. USEPA (United States Environmental Protection Agency) (2012) EPA Region III Risk-based Concentration (RBC) Table 2008 Region III, 1650 Arch Street, Philadelphia, Pennsylvania 19103.gov/reg3hwmd/risk/human/index.htm,21p.
15. USEPA (United States Environmental Protection Agency) (2014) Regional Screening Level (RSL) Summary Table–(May 2014), 12p.
16. Giri A., Bharti V. K., Kalia S., Kumar B., Chaurasia O. P. (2021) Health Risk Assessment of Heavy Metals Through Cow Milk Consumption in Trans-Himalayan HighAltitude Region. Biological Trace Element Research. 163-4984.
17. USEPA (United States Environmental Protection Agency) (1989) Risk Assessment Guidance for Superfund: Human Health Evaluation Manual [part A]: Interim Final.Washington, DC, USA.
18. Storelli A., Barone G., Dambrosio A., Garofalo R., Busco., (2020) Occurrence of trace metals in fish from South Italy: Assessment risk to consumer's health. Journal of Food Composition and Analysis, 90, 103-487.
19. Gnonsoro U. P., Yolande A. A., Sangaré N. S., Yao U. K., Trokourey A. (2022) Evaluation du risque sanitaire des métaux lourds (Pb, Cd, Hg) dans les gels hydroalcooliques d'Abidjan, Cote d'Ivoire. Biological Trace Element Research, 200, 2510–2518, 9p. doi: https://doi.org/10.1007/s12011-021-02822-y
20. Lu X., Zhang X., Li L Y., Chen H. (2014) Assessment of metals pollution and health risk in dust from nursery schools in Xi'an, China. Environmental Research. 128, 27– 34.
21. Li Z., Ma Z., van der Kuijp T. J., Yuan Z., Huang L. (2014) A review of soil heavy metal pollution from mines in China: Pollution and health risk assessment. Science of the Total Environment. 468(469) 843–853.
22. Keshavarzi B., Tazarvi Z., Rajabzadeh M. A., Najmeddin A. (2015) Chemical speciation, human health risk assessment and pollution level of selected heavy metals in urban 94 street dust of Shiraz, Iran. Atmospheric Environment, 119, 1–10. doi: 10.1016/j.atmosenv.2015.08.0
23. Liu X., Song Q., Tang Y., Li W., Wu J., Wang F., Brookes P. C. (2013) Human Health risk assessment of heavy metals in soil-vegetable system: a multi-medium analysis. Sci Total Environ. 453, 530-540.
24. Ouattara G., Koffi G. B. Gnanzou A. (2013) Related Structures linked to the emplacement of the Dianfla granodiorite pluton (Central Côte d'Ivoire): Contribution to the understanding of gold mineralization in the birimian area of West Africa. International Journal of Engineering Sciences, 2(8), 404-414.
25. Demir V., Dere T., Ergin S., Caku Y., Celik F. (2015) Détermination et évaluation des risques pour la santé des métaux lourds dans l'eau potable de Tunceli, Turquie. Ressource en eau, 42, 510-518.
26. Health Canada (2017) Aluminum in drinking water. https://www.canada.ca/en/health-canada/programs/consultation-aluminum-drinking-water/document.html, consulté le 01/07/2024
27. Damy P. C. (2011) Synthèse des connaissances sur l'origine et la disponibilité du cadmium dans les eaux continentales, 6p.
28. Roghayeh A. S. A., Aghasi M. (2019) Health risk assessment of heavy metals exposure (lead, cadmium, and copper) through drinking water consumption in Kerman city, Iran. In Environmental Earth sciences, 13p.
29. OMS (2022) Plomb dans l'eau de boisson : risques pour la santé, surveillance et mesures correctives, 26p.

30. Tanouayi G., Gnandi K., Ahoudi H., Ouro-Sama K. (2015) La contamination metalique des eaux de surface et des eaux souterraines de la zone minière d'exploitation des phosphates de Hahotoe-Kpogame (sud-Togo) : cas du cadmium, plomb, cuivre et nickel. Larhyss Journal, 21(Mars 2015), 35-50.