Research Article

International Review of Aquatic Ressources Research, Management and Engineering 2024 **Vol 6, Serie 1 Pages**

Submission (3 May 2024) Accepted and Published (6 August 2024) www.ijarme.org

An evaluation of the health risks linked to the contamination of metallic trace elements in Quaternary groundwater on the West African coast: case of the west coast of Lomé, Togo.

Evaluation des risques sanitaire lié à la contamination des éléments traces métalliques des eaux souterraines du Quaternaire des côtes Ouest-Africaine: cas de la côte l'Ouest de Lomé, Togo.

Koudjo ADJE[1,2], Housseni AHOUDI[1], Kamilou OURO-SAMA[1], Hodabalo DheoulabaSOLITOKE[1], Kissao GNANDI[1].*
1 Université de Lomé, Faculté Des Sciences, Laboratoire de Gestion, Traitement et Valorisation des Déchets, Département de Géologie et Environnement, BP : 1515, Lomé-Togo.
2 Ecole Normale Supérieure d'Atakpamé, Département Sciences de la Vie et de la Terre, 200 BP 80, Atakpamé-Togo
**Email : adjekoudjo@gmail.com, +228 90 74 23 46*

Abstract

The problem of water contamination is preoccupying in the cities of Africa. The objective of this study is to assess the health risks linked to the consumption of water from wells in the Kodjoviakopé district (Lomé). To achieve this objective, the analysis of physicochemical parameters such as turbidity, pH and conductivity, as well as certain metallic trace elements (cadmium, lead, iron, arsenic, and chromium) were analyzed in 24 water samples from the wells in this area collected in March 2023. It appears from the analysis of the results that the water is highly mineralized, contaminated with cadmium, lead and arsenic and present a strong contamination factors. In descending order of contamination factor, we note 220 times higher than the WHO standard for arsenic; 33.92 times for lead and 1.76 times for cadmium. The calculated risk quotient is greater than 1 for As, Cd and Pb in both adults and children as well as Cr in children. The overall, collected well water is contaminated. This therefore poses a public health problem. Raising public awareness of the effects of water contaminants and the policy of drinking water supply and sanitation in the area must be a priority for the country's authorities.

Keywords: groundwater, contaminants, wells, water, west coast, Kodjoviakopé

Résumé

Le problème de la contamination de l'eau est préoccupant dans les villes d'Afrique. L'objectif de cette étude est d'évaluer les risques sanitaires liés à la consommation de l'eau des puits du quartier de Kodjoviakopé (Lomé). Pour atteindre cet objectif, l'analyse des paramètres physico-chimiques tels que la turbidité, le pH et la conductivité ainsi que certains oligo-éléments métalliques (cadmium, plomb, fer, arsenic et chrome) ont été analysés dans 24 échantillons d'eau des puits de ce secteur collectés, en mars 2023. Il ressort de l'analyse des résultats que l'eau est fortement minéralisée, contaminée en cadmium, plomb et arsenic et présente de forts facteurs de contamination. Par ordre décroissant de facteur de contamination, on note 220 fois supérieur à la norme OMS pour l'arsenic ; 33,92 fois pour le plomb et 1,76 fois pour le cadmium. Le quotient de risque calculé est supérieur à 1 pour l'As, le Cd et le Pb chez l'adulte et l'enfant ainsi que pour le Cr chez l'enfant. L'ensemble de l'eau du puits collectée est contaminée. Cela pose donc un problème de santé publique. La sensibilisation du public aux effets des contaminants de l'eau et à la politique d'approvisionnement en eau potable et d'assainissement dans la zone doit être une priorité pour les autorités du pays.

Mots clés : eaux souterraines, contaminants, puits, eau, côte ouest, Kodjoviakopé

Introduction

The problem of access to drinking water is a permanent concern of humanity. The poor often suffer from low water quality and face health problems linked to this product on a daily basis. In 2022, 2.2 billion people still lacked safely managed drinking water, including 115 million people drinking surface water, and 2 billion people still lacked basic hygiene services, including 653 million without any equipment (WHO/UNICEF, 2023). In Togo, the national non-service rate at the end of 2022 is 33% (Togo First). The population of the Kodjoviakopé district in Lomé living on the Togolese coast is mainly occupied by indigenous people with a modest standard of living. This population uses groundwater from unprotected large diameter wells, notably that of the Quaternary water table of the coastal sands. This exposed water, therefore of dubious quality, is used not only for domestic needs, but also as drinking water. Among water pollutants, trace metal elements (TMEs) constitute one of the major risks in today's world. These metallic trace elements prove dangerous to human health when their concentrations in the environment become high. ETMs, like all pollutants, are concentrated in ecosystems due to human activities, including agriculture, livestock, industry, transport and the discharge of domestic wastewater (Nanfack *et al*., 2014; Smatti -Hamza *et al*., 2019). Through contamination of the soil, the atmosphere or through the consumption of food or water by ETMs, humans are exposed (Tankari *et al*., 2013; Yé *et al*., 2020) several studies undertaken in Africa in aquatic environments to assess contamination levels by ETMs revealed significant pollution (Zegaoula and Khellaf, 2014; Nakweti *et al*., 2021). Thus, the evaluation of metal contamination in water makes it possible to predict contamination in humans. This study is focused on water analysis and aims to provide data necessary for planning and decision-making. Indeed, several studies have noted the state of pollution of ETMs on the east coast of Togo, which is a mining and industrial extraction zone of the country. The study area is neither industrial, nor mining, nor agricultural; however, it is located in an old neighborhood; and like other neighborhoods do not have a sanitation plan; it is close to the very polluted lagoon system, its water table is superficial, located in a depression and receives runoff from surrounding localities with all their contaminants. The objective of this study is to contribute to the evaluation of the physicochemical quality of Togolese coastal waters and to assess the health risk linked to this contamination of water by metallic elements.

Material and methods

Study area

Kodjoviakopé, the study area is bordered to the west by the border of Ghana, to the south by the Atlantic Ocean and to the east by the former Palace of the Governors. It is a district of downtown Lomé (Togo), close to the business center, the administrative center and the Lomé Grand Market. It is located between latitudes 6°06' and 6°07'N; then between 1° 12’0 and 1°12’3E. It is part of the coastal zone which is composed of a sandy shore, an arid terrestrial plateau and a coastal depression whose level is below sea level (RNEMC, 2007). The coastal depression is occupied by a coastal lagoon system. The coastal zone of Togo is the center of significant concentrations of economic activities, notably agriculture (market gardening), livestock breeding, fishing, industry, trade, transport and tourism. The Littoral represents 11% of the national territory with the particularity of hosting approximately 42% of the Togolese population and 63% of the urban population. The concentration of central services and economic, industrial and commercial activities in Lomé makes the coastal zone a pole of attraction for migratory movements. The sources of groundwater pollution are industrial wastewater, domestic wastewater, sewage and cesspool wastewater, chemicals (fertilizers, etc.) pesticides, (RNEMC, 2007) as presented in figure 1.

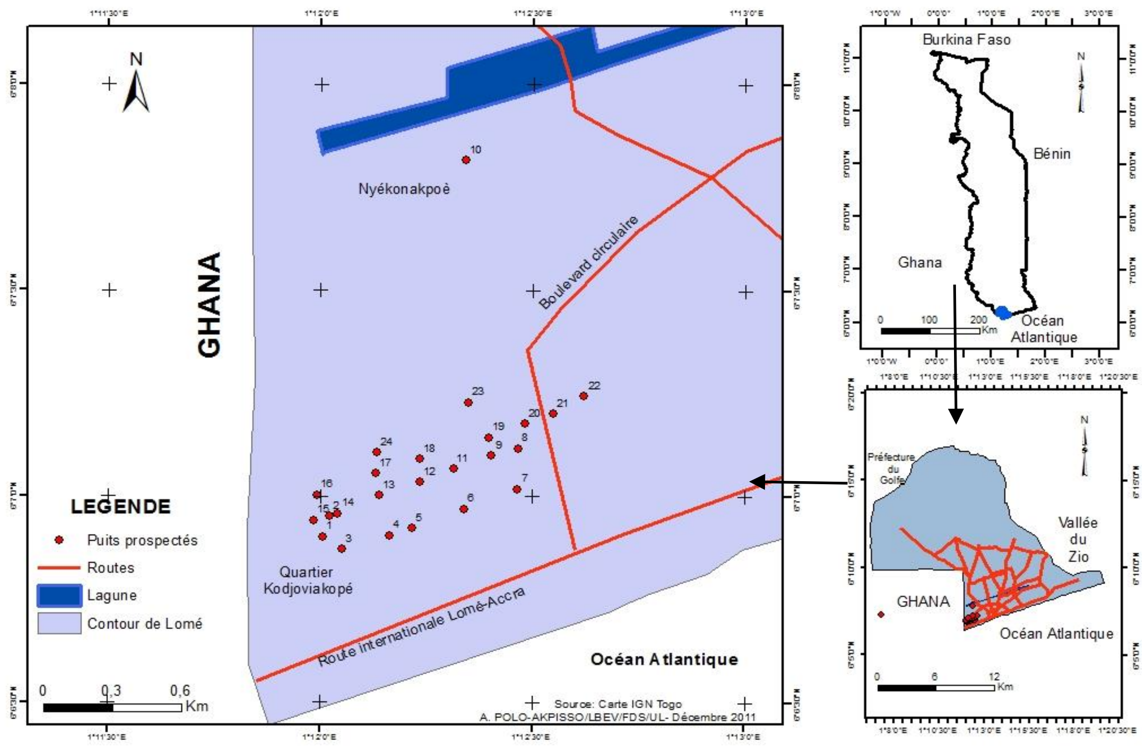

Figure 1: Map showing the location of sampled points in the study area

Technical sampling

Twenty-four (24) well water samples were collected in March 2023 for ETM analysis in polyethylene bottles with a capacity of 500 ml. These bottles are previously washed with 10% nitric acid, rinsed with distilled water and dried in the laboratory. A rope bucket was used for water intake. It is carefully dipped and removed into the well without rubbing against its walls. The first quantity of water drawn from the bucket is poured into the bottle and used for rinsing. The second filled quantity serves as a sample for analysis. These samples are labeled and packaged in a cooler containing ice cubes. The samples are then sent to the laboratory. Once in the laboratory, the water intended for the determination of trace metal elements is acidified to 1% with nitric acid (for the solubility of trace metal elements and to avoid their adsorption) and placed in the refrigerator at 4°C until analyzes (Diop *et al*, 2019).

Physico-chemical analysis

The physicochemical parameters of water such as temperature, electrical conductivity, total dissolved salts and turbidity are measured in situ in the field using the multiparameter and pH using a pH- Crison BASIC20+ meter. The determination of ETM in water was done using the Thermo Electron Corporation atomic absorption spectrometer. AA S series spectrometer. ***Expression of results and statistical analysis***

The contamination factor (CF) makes it possible to express the level of trace element contamination in water samples compared to WHO standards:

FC= (concentration of the element in water)/ (WHO standard of the element)

If FC $\geq$ 1, there is pollution; if FC $\leq$ 1, there is no pollution.

Risk characterization

To estimate the health risk linked to water ingestion, the daily exposure dose (DJE), the hazard quotient (QD) and the excess individual risk (ERI) are calculated. The DJE is estimated based on average TME concentrations and body weight. Its analytical expression (mg/kg/d) is as follows: DJE = Ci x Q x /Pc

DJE: Daily exposure dose by ingestion of groundwater expressed in mg/kg/d; Ci: Exposure concentration relative to groundwater expressed in mg/l; Q: Quantity of water administered by ingestion expressed in L/d (The average consumption of drinking water is estimated at 2 l/d (i.e. 2 kg/d) for adults and at 1.5 l/d (i.e. 1 .5 kg/d) for children) (Volatier, 2000); Bw: Body weight (The average body weight of children aged 0 to 15 is 28 kg and that of an adult is classically equal to 70 kg) according to. The QD corresponds to the ratio between exposure to a contaminant and the exposure considered to be without risk. Its simplified formula is as follows: QD = DJE/VTR

Where TRV corresponds to the Toxicological Reference Value (Bisson *et al*., 2009). For any QD > 1, the exposed population is in danger and for any QD < 1, the population is theoretically out of danger (US EPA, 1991) as presented in table I.

Table 1: Oral toxicological reference values and duration of exposure according to the types of effects (PVTR, 2009).

Substances	**Route and duration of exposure (Critical effect)**	**VTR**	**US EPA (year)**
As	**Chronic ingestion (black foot disease)**	3.10^{-4} mg/kg/j	2015
Cd	**Chronic ingestion (cancer)**	1.10^{-3} mg/kg/j	2009
Fe	**Chronic ingestion (Iron overload)**	$0.8.10^{-3}$ mg/kg/j	2015
Cr	**Chronic ingestion (cancer)**	3.10^{-3} mg/kg/j	2015
Pb	**Chronic ingestion (increased plumbing)**	$4.\ 10^{-3}$ mg/kg/j	2009

For repeated toxic effects without threshold (carcinogenic and mutagenic effects), the health risk assessment is quantitative. The probability of developing cancer for the entire life of exposed subjects is called excess individual risk (ERI), the expression of which is as follows: ERI = DJE× ERU0 ×T /Tm with ERUo: the excess risk unit by oral route (mg/ kg/d)-1 (As: 1.5; Cr: 0.42; Pb: 0.0085; T: duration of exposure (year); Tm: is the average duration of entire life (years). Only the trace metal elements As, Cr and Pb are considered in the ERI calculation due to the availability of ERUO for these elements.

For ERI <10-6, the risk is negligible; 10-4<ERI<10-6 the risk is tolerable; and for an ERI >10-4, the risk is unacceptable (USEPA, 1989).

Results

Distribution of physico-chemical parameters

Values of physicochemical parameters (pH, Conductivity, total dissolved salts/TDS and turbidity of the water from each well).The values of pH, conductivity, TDS and turbidity of water from each well are recorded in Table II.

Table II: pH, conductivity, TDS and turbidity of well water.

Samples	pH	Conductivity (µS/cm)	TDS	Turbidity (NTU)
p1	6.88	581.00	1 199.26	1.70
P2	7,04	1 064.00	807.09	0.70
P3	6.92	1 139.00	863.98	1.60
P4	6.56	1 634.00	1 239.46	0.40
P5	6.82	1 321.00	1 002.04	3.40
P6	6.91	1 133.00	859.43	1.10
P7	6.98	1 291.00	735.79	0.90
P8	6.95	1 273.00	979.28	0.20
P9	6.98	761.00	544.82	0.40
P10	6.76	970.00	735.79	0.50
P11	6.84	6.66	9.09	4.70
P12	6.94	676.00	483.96	0.40
P13	6.77	840.00	637.18	0.6
P14	7.00	1 389.00	1 053.62	1.50
P15	6.71	1 213.00	920.11	0.50

P16	6.64	108.00	822.26	0.60
P17	6.76	1 036.00	785.85	0.40
P18	6.89	1 367.00	1 036.93	0.30
P19	7.03	684.00	489.69	0.50
P20	6.53	859.00	651.59	0.90
P21	6.53	1 423.00	1 079.41	0.20
P22	6.67	987.00	748.68	0.70
P23	6.43	1 438.00	1 090.79	0.40
P24	6.57	742	531.21	21.0
Averages	6.80	1 037.98	804.475	1.82
Standards	6.5<ph<9.5	250	189.64	1
Pollution factors	-	4.15	4.24	1.82
Averages	6.80	1 037.98	804.475	1.82

µS/cm: micro siemens per centimeter; NTU: nephelometric turbidity unit; pH: Hydrogen potential; EU: European Union

The results in Table 2 show that the pH values range from 6.49 to 7.04. The values all comply with the standard set by WHO for drinking water (6.5_9.5). The conductivity ranges from 6.66 to 1634; and all these samples have a conductivity value higher than the WHO standard for drinking water (250) except the water from well P11. Total dissolved solids (TDS) values fluctuate between 1,239.46 and 9.09. Turbidity values range from 0.2 to 21.0; seven samples present turbidity values higher than the standard set by the EU for drinking water (1 NFU): P1; P3; P5; P6; P11; P14; P24. The turbidity values of the other samples comply with the European standard for drinking water. The values of trace metal elements in the water from each well are recorded in Table III.

Table III: Contents of lead (Pb), cadmium (Cd), iron (Fe), chromium (Cr) and arsenic (As) in wells.

Samples	**Concentration in mg/l**				
	Cd	**Pb**	**Fe**	**Cr**	**As**
P1	0.04	0.25	-	0.08	3.43
P2	0.06	0.37	-	-	0.22
P3	0.04	0.19	-	0.08	1.62
P4	0.06	0.26	-	0.03	2.42
P5	0.05	0.33	-	-	4.48
P6	0.05	0.36	-	0.07	2.58
P7	0.04	0.29	-	-	0.54
P8	0.05	0.42	0.04	0.05	1.43
P9	0.06	0.33	-	0.07	2.84
P10	0.06	0.34	-	-	1.72
P11	0.06	0.32	0.04	0.03	0.10
P12	0.06	0.32	-	0.05	4.06
P13	0.06	0.29	-	0.03	2.45
P14	0.06	0.24	-	-	4.17
P15	0.05	0.49	-	0.05	1.51
P16	0.04	0.32	-	0.04	2.50
P17	0.04	0.34	-	0.04	0.58
P18	0.06	0.44	-	0.02	0.52
P19	0.06	0.39	-	0.06	4.40
P20	0.05	0.35	-	0.03	0.29
P21	0.04	0.44	-	0.01	0.04
P22	0.07	0.32	-	-	4.44
P23	0.06	0.32	-	0.05	3.87
P24	0.05	0.42	0.02	-	2.60
Minimum value	**-0.04**	**0.19**	**0.02**	**0.01**	**0.04**
Maximum value	**0.07**	**0.49**	**0.04**	**0.08**	**4.48**
Average Contents	**0.05**	**0.34**	**0.00**	**0.03**	**2.20**
Standard (mg/l)	**0.03**	**0.01**	**0.20**	**0.05**	**0.01**
Pollution factors	**1.76**	**33.92**	**0.02**	**0.65**	**220.04**

-value below detection limit

The results show a variation in cadmium levels ranging from 0.4 to 0.7 mg/l, all of these values are higher than the standard value (0.03 mg/l) recommended by the WHO for cadmium in drinking water.The range of lead levels is 0.19 to 0.49 mg/l, which is higher than the WHO recommended value (0.01 mg/l) for lead in drinking water.

All water samples had iron concentrations below the detection limit of the device; except samples from wells P8; P11; P24, which have respective concentrations of 0.04 mg/l; 0.04 mg/l; 0.02 mg/l; all less than 0.2 mg/l set by the French standard for iron in drinking water. Chromium levels range from 0.01 to 0.08 mg/l; only five (5) wells: P1, P3, P6, P9 and P19 have a chromium concentration higher than the standard (0.05 mg/l) set by the WHO; or 14% of wells. Three wells have chromium concentrations equal to the standard; the rest of the wells have chromium concentrations below the standard or below the detection limit of the device. Arsenic levels vary from 0.04 to 4.48 mg/l, all samples have an arsenic concentration higher than the standard (0.05 mg/l) set by the WHO for drinking water.

Daily exposure dose (DJE)

The results of estimating EDIs by ingestion of well water in adults and children are presented in Table IV.

Table IV: Daily exposure doses

ETM	As	Cd	Fe	Cr	Pb
Adultes	$1.4.10^{-3}$	$9.7.10^{-3}$	0	$8.6.10^{-4}$	$6.3.10^{-2}$
Enfants	$2.7.10^{-3}$	$1.8.10^{-2}$	0	$1.6.10^{-3}$	$1.2.10^{-1}$

Hazard Quotient (HQ)

The calculation of the risk quotient per ingestion of water for is recorded in the table below V

Table V: risk quotient by water ingestion for adults and children.

ETM	As	Cd	Fe	Cr	Pb
Adultes	1.43	2.43	0.0	0.29	209.52
Enfants	2.68	607.14	0.0	95.24	698 412.70

The risk quotient is greater than 1 for As, Cd and Pb in both adults and children and for Cr in children.

Risk quotients (QG) for threshold effects for adults and children (RI)

Risk results regarding threshold effects are presented in the following table VI:

Table VI: Health risk indices for threshold effects

ETM	As	Cr	Pb
Adultes	4.10^{-2}	1.10^{-4}	3.10^{-05}
Enfants	7.10^{-2}	2.10^{-4}	6.10^{-05}

On the one hand, the results of the calculation of the excess individual risk show that the ERI is higher than 10-4 for As in adults than in children, very slightly higher than 10-4 for Cr in children; on the other hand, Pb gave ERIs lower than 10-4.

We can deduce that the ingestion of groundwater from wells in the municipality of Kodjoviakopé represents a danger for the health of the inhabitants in terms of these trace elements (As, Cd and Pb), particularly for children due to the risk quotient which is greater than 1.

Discussion

The pH values range from 6.49 to 7.04 and all comply with the standard set by WHO for drinking water (6.5_9.5). The average value of all pH values of water from all wells is 6.80. This shows a slightly acidic pH. This acidic pH is explained by the acidification of organic matter as demonstrated by the blackish nature of the soils (figure 2) and domestic wastewater thrown into the city.

All samples have conductivity values above the WHO standard for drinking water (250) with the exception of water from well P11. Seven out of 24 samples showed turbidity values above the standard set by the European Union (EU) (1 NFU). The conductivity and TDS averages are 1037.98 and 804.475 respectively, which are high compared to their standards set by WHO for drinking water (250 and 189.64). Each of the two parameters has a pollution factor 4 times higher than its standard. This shows strong mineralization of this aquifer. This strong mineralization is due to soil leaching, the saline intrusion of sea water and the nearby lagoon system. Studies of marine waters have shown strong mineralization; Solitoke *et al.,* recorded a conductivity of 62,700 µS/cm for a TDS of 35,900 mg/l (Solitoke et al., 2018). This leaching naturally leads to the dissolution of a certain number of mineral salts. It can also be caused by human activity caused by domestic effluent (sewage). The turbidity of well water is higher than the standard set by the WHO, with a pollution factor of 1.8 times. The turbidity of these waters comes from the sandy nature of the soil and the very superficial level of the water table. Indeed, the soils of this part of the coast are sandy and therefore permeable to suspended matter (clay, silt, colloidal organic particles), which explains the high turbidity of these waters. The presence of these suspended materials could also occur via the wells, these unprotected wells also have a large diameter.

Figure 2: Unprotected large diameter well (A) and black sandy soil (B)

For ETM (Cd, Pb, Fe, Cr and As), the analysis results show variability in content between these different elements. On the one hand, some elements have levels above the WHO standards set for drinking water, and on the other hand, other elements have acceptable levels (WHO, 2011). Cadmium has a pollution factor of 1.7 times. The water from Kodjoviakopé wells is therefore polluted with cadmium and therefore harmful to health. This pollution would be due to the washing of electrolytic coatings, paint accumulators from the anthropogenic activities of the inhabitants of the locality and its surroundings because it is located at a low altitude compared to other neighborhoods. This cadmium pollution can also come from rain and car fumes because the neighborhood is located near national road number 2 (№ 2). The high concentration of cadmium in the lagoon as shown by the work of BUAKA (2009) shows that it also contributes to the pollution of this element (Buaka, 2009). Likewise, the concentration of lead in the water from Kodjoviakopé wells is much higher than the concentration set by the WHO for drinking water. The lead pollution factor is very high (33.92). Lead therefore presents risks to the health of consumers. The infiltration of domestic effluents, household waste water, lead from the combustion of fossil fuels by automobile engines due to the location of the neighborhood near national road number 2 (№ 2) , washes, paints, batteries, household waste of all kinds due to the old age of the district and especially the Nyékonakpoè lagoon located upstream to the north of the district. In fact, there is a slight increase in lead concentration values from the sea to the lagoon. These results are similar to those obtained by Buaka (2009) a little further north and northeast of the study site, notably in the lagoon system of Bè and Nyékonakpoè (Buaka, 2009) and to those obtained by Laboe (2004) relating to the assessment of water pollution from boreholes and wells in the districts of Adidogomé and Kegué (LABOE, 2OO4). The iron concentration in the water from Kodjoviakopé wells is lower than the concentration set by the EU for drinking water with a low pollution factor (0.02) and therefore not polluted in this element due to the high value of the iron. Standard set by the EU for this element which is a trace element and therefore useful for human health.

The chromium concentration is generally lower than the concentration set by the WHO (0.65). For this element, the waters of certain wells are an exception, notably wells P1, P3, P6, P9, P19 with degrees of pollution 1.6 times the WHO standard for wells P1, P3; 1.4 times for wells P6, P9; 1.2 times for P19 wells. Consequently, this parameter constitutes a risk of pollution of the waters of the aquifer studied. The presence of chromium in these waters is due to discharges of domestic effluents and infiltrations from the leaching of dyes.

The waters have levels of arsenic well above the concentration set by the WHO for drinking water; with a very high pollution factor (220). Well water is therefore polluted by arsenic and is therefore dangerous. Its presence in these waters would be due to the combustion of coal or waste and detergents.

The average contents of metallic trace elements Cd, Pb, Fe and As respectively 0.05; 0.34; 0.00 and 2.20 mg/l in the present study are all higher than the average levels of the same elements found by Djade et al. (2020) in the groundwater of the Zouan-Hounien department (Western Ivory Coast), which are respectively 0.8.10-2; 3.10-3; 2.23 and

1.1810-3 mg/l except Fe (Djade et al., 2020). The high levels observed in this study are due to the influence of marine pollution and the lagoon system.

The assessment of the excess individual risk (ERI) for the carcinogenic effects concerning the metallic trace elements Pb, Cr and As shows that exposure to Pb is unlikely (IRI < 10-4). However, exposure to As and Cr presents a risk of carcinogenic effects (ERI >10-4) in both children and adults.

Conclusion

The present study concerning the analysis of the quality of certain physicochemical parameters of water from 24 water samples from wells of the alluvial aquifer of the district of Kodjoviakopé shows a high mineralization with a slightly acidic pH and a high load of materials in suspension. In addition, these well waters are contaminated with ETMs, notably cadmium, lead and arsenic, with high pollution factors for the latter elements. In descending order of content, we note 220 times the WHO standard for arsenic; 33.92 times for the head; 2.17 times and 1.76 times for cadmium. However, the other elements analyzed, which are iron and chromium, showed values which remain low compared to the different standards set by the WHO for drinking water for these different elements. In view of these results, we can conclude that the well water used in the Kodjoviakopé district is polluted due to environmental conditions. Indeed, the existence of anti-hygienic practices such as the absence of protection of wells, location of the neighborhood near the busy road No. 2, presence of illegal dumping everywhere, the burying of household waste, the absence of evacuation and treatment systems for domestic effluents and the pollution of the Lomé lagoon with which the water table communicates can justify this contamination. The shallow depth of these wells is also a factor likely to cause pollution. Thus the daily use of this water as drinking water poses a public health problem as shown by the calculation of health risks. To avoid such consequences, the population of this locality must avoid unsanitary practices which contribute to contamination and must also avoid using these waters for their food.

References

Buaka KW. 2009. Evaluation de la pollution des eaux de forages et des eaux de puits par les éléments minéraux azotés et métalliques dans les quartiers péri-urbains de Lomé, Master, Ecole Supérieure des Techniques Biologiques et Alimentaires (E.S.T.B.A.), Université de Lomé, Togo, p.49

Diop C, Diatta A, Ndiaye A, Cabral M, Toure A, Fall M. 2019. Teneurs en métaux traces des eaux et poissons de cinq étangs de Dakar et risques pour la santé humaine, Journal of Applied Biosciences 137: 13931 – 13939. DOI : https://dx.doi.org/10.4314/jab.v137i1.1

Djade PJO, Traore A, Koffi KJT, Keumean KN, Soro G, Soro N. 2020. Evaluation du niveau de contamination des eaux souterraines par les éléments traces dans le département de Zouan-Hounien (Ouest de la Côte d'Ivoire). Journal of Applied Biosciences 150: 15457 – 15468. DOI : https://doi.org/10.35759/JABs.150.6

Laboe P. 2OO4. Evaluation de la pollution des eaux de forage et des eaux de puits par les éléments azotés métalliques dans les quartiers péri-urbains de Lomé. Master, Ecole Supérieure des Techniques Biologiques et Alimentaires (E.S.T.B.A.), Université de Lomé, Togo, 41p.

Nakweti K.J., Lusasi S.W. & Tembeni M.J. (2021). Evaluation Des Teneurs En Eléments Traces Métalliques (Cadmium Et Plomb) Dans L'eau, Les Sédiments Et Deux Espèces De Poissons Clarias Gariepinus (Burchell, 1822) Et Oreochromis Niloticus (Linné, 1758) Dans Le Pool Malebo (Fleuve Congo), RD Congo. European Scientific Journal, ESJ, 17(25), 174. https://doi.org/10.19044/esj.2021.v17n25p174

Nanfack NAC, Fonteh FA, Payne VK, Katte B, Fogoh JM. 2014. Eaux non conventionnelles: un risque ou une solution aux problèmes d'eau pour les classes pauvres. Larhyss Journal, 17: 47-64.

PVTR (Point sur les valeurs toxicologiques de référence) en ligne http://www.ineris.fr/Rapport d'étude/ 17/03/2009.

RNEMC (Rapport National sur l'Environnement Marin et Côtier), 2007. http://hdl.handle.net/20.500.11822/10426

Smatti-Hamza et al., 2019. Niveau de contamination par les éléments traces métalliques cadmium, cobalt, cuivre et zinc de deux cyprinidés et des sédiments du barrage Koudiet Medouar (Batna, Algérie) J. Appl. Biosci. 143: 14606 – 14621 ISSN 1997-5902. DOI : https://dx.doi.org/10.4314/jab.v143i1.1

Solitoke HD, Ouro-Sama K, Tanouayi G, Badassan TE, Ahoudi H, Nyametso AY, Avumadi AMD, Gnandi K. 2018. Etude de la contamination métallique des sédiments d'un hydro système tropicale : Cas du système Lac Zowla - Lagune d'Aného (Sud - Togo). Environmental and Water Sciences, Public Health & Territorial Intelligence. 12(2) : 41-51.

Tankari Dan-Badjo A, Guero Y, Dan Lamso N, Tidjani AD, Ambouta KJM, Feidt C, Sterckeman T, Echevarria G. 2013. Evaluation de la contamination des sols par les éléments traces métalliques dans les zones urbaines et périurbaines de la ville de Niamey (Niger). Revue des Bio Ressources, 2: 82–95.

https://www.togofirst.com/fr/social/2202-13520-togo-de-nouvelles-infrastructures-d'adduction-d-eau-en-gestation-dans-les-régions-maritime Consulté le 26 juillet 2024 11 :10

USEPA, 1989. Risk assessment guigance for superfund. In: Human health evaluation manual Part A, Interim final, Volume 1. EPA/540/1-89/002.

US EPA, 1991, Risk Assessment Guidance for Superfund (RAGS), volume I: Human Health Evaluation Manual (HHEM) supplemental guidance. Washington DC: Office of emergency and remedial response; [EPA/540/R-92/003].

WHO 2011. Guidelines for drinking-water quality, fourth edition. World Health Organization (WHO), chronicle, 451p.

Ye L, Lompo DJP, Sako A, Nacro HB. 2021. Evaluation des teneurs en éléments traces métalliques des sols soumis à l'apport des déchets urbains solides. Int. J. Biol. Chem. Sci. 14(9): 3361-3371. DOI : https://dx.doi.org/10.4314/ijbcs.v14i9.31)

is.fr/hml +

Zegaoula W, Khellaf N. 2014. Evaluation du degré de pollution des rejets liquides et atmosphériques du complexe fertial Annaba (Algérie). Larhyss Journal, 18: 77-91.

WHO/UNICEF, 2023. Joint Monitoring Program for Water Supply, Sanitation and Hygiene (JMP) – Progress on household drinking water, sanitation and hygiene 2000-2022: Special focus on genderBisson, M., S. Vivier, B. La Rocca et C. Gourland, 2009, Point sur les Valeurs Toxicologiques de Référence (VTR), RAPPORT D'ÉTUDE 17/03/2009, N° DRC-08-94380-11776C, INERIS, [En ligne] URL : http://www.iner