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Assessment of Health Risks Associated with Nitrate in Drinking Well Water: Case Study, M'Bahiakro (Central-Eastern Côte d'Ivoire)

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Abstract

Nitrate contamination of groundwater is a worldwide problem, particularly in agricultural countries. Exposure to high levels of nitrates in groundwater can have adverse effects on the health of residents who use groundwater for drinking. This study aims to assess the health risk associated with the ingestion of nitrates in well water in the town of M'bahiakro. Health risk maps were created on the basis of hazard quotients (HQ) using the US Environmental Protection Agency (USEPA) health risk assessment model. The results indicate that residents of the Koko, Dougouba and Baoulekro neighbourhoods, whatever their age, are potentially exposed to the toxic effects of NO_3^- during their daily intake of nitrate-contaminated well water, with reference to hazard quotients (HQ) greater than 1. Nitrate concentrations in the groundwater should therefore be controlled in order to prevent their harmful effects on the health of the population and guarantee its use in rice-growing activities in M'Bahiakro.

Keywords

Nitrate, Well, Health Risks, M'Bahiakro

1. Introduction

Water has always been one of the most important natural resources for human life. However, the ever-increasing degradation of water resources, particularly groundwater in most agricultural countries, is one of the most worrying environmental issues of the 21st century [1]. This degradation is generally of anthropogenic origin, and is strongly linked not only to pathogens, but also to chemical substances, particularly nitrates, which can have toxic effects on human health [2].

In Côte d'Ivoire, various rice-growing activities have been set up in a number of regions close to major cities, where the demographic pace has accelerated considerably with the popularisation of city centres. This has led to excessive water consumption and large-scale wastewater discharges that are degrading the quality of groundwater, particularly the main water tables in the country's major cities [3]. Numerous studies have been carried out on the quality of water from wells tapping the water tables in most of the country's cities [4]-[7]. They show that this water, which is very useful for domestic water needs, is often subject to nitrogen contamination, which can have a direct and negative impact on the well-being of consumers. The locality of M'Bahiakro, the subject of this study, is no exception to this observation. This locality is devoted to intensive farming practices and is renowned for its irrigated rice production of over 2000 tonnes/year, with an increasing population in the town centre. As a result, the city is consuming more and more water [8]. According to these authors [8], more than 90% of the city's families rely on well water to make up for the potential shortage of drinking water, or use it as their main source of drinking water throughout the year. However, work carried out on the M'Bahiakro water table by [9] has shown that more than 70% of the well water consumed has nitrate concentrations above the drinking water potability threshold. This could increase the risk of methaemoglobinaemia [10] or non-Hodgkin's lymphoma in the long term [11] [12]. The aim of this study is to assess the potential health risk associated with the ingestion of nitrates in well water in the town of M'Bahiakro. The importance of this assessment is to identify the areas of the town most exposed to the potential effects of nitrate in order to contribute to consumer health prevention.

In the remainder of this work, the general knowledge of the study area and the main theoretical aspects required to assess the health risks of well water are described. The results of the parameters measured and the health risk associated with nitrate are then presented and discussed. A conclusion followed by an outlook will mark the end of the work.

2. Materials and Methods

The aim of the study was to assess the health risks associated with nitrate in 19 well waters consumed in M'Bahiakro on the basis of the hazard quotient (HQ) using the US Environmental Protection Agency (USEPA) health risk assessment model.

2.1. Presentation of the Study Area

2.1.1. Geographical Location

The study area is part of the Iffou region and the District des Lacs, located in central-eastern Côte d'Ivoire. The department of M'Bahiakro in Côte d'Ivoire was created by law no. 85-1086 of 17 October 1985 as an administrative post in 1947, a sub-prefecture in 1961 and a commune in 1985, by splitting the department of Bouaké. This split resulted in the current boundaries of the M'Bahiakro district, which include the Dabakala department to the north, the Prikro and Daoukro departments to the east, the Bouaké department to the west and the Bocanda department to the south. The town of M'Bahiakro covers an area of 5.538 km^2 and is divided into 4 districts : Koko (North), Baoulekro (East), Dougouba (West) and N'Gattakro (South).

2.1.2. Socio-Economic Context

According to the 2021 general population and housing census (RGPH), the department has a population of 78,369, 49,758 of whom live in the M'Bahiakro sub-prefecture, with an estimated density of 7000 inhabitants per km^2 [13]. This department, which is mainly populated by indigenous people, is an administrative district with potential (soil, rivers, rainfall, etc.) that is favourable to agricultural activities. Agriculture is the main activity, dominated by cash crops such as cocoa, coffee and rubber. In addition to these crops, rice-growing plays an important role, thanks to the construction of a hydro-agricultural dam and the development of nearly 450 ha of land by the Ivorian government in order to anticipate food crises and support the city's population.

2.1.3. Temperatures and Rainfall

The M'Bahiakro region receives an average of 1154.71 mm of rainfall per year and the interannual potential evapotranspiration (PET) is 1691.44 mm, with an actual evapotranspiration (AET) value of 869.67 mm. Surface runoff is 179.38 mm, of which the quantity of water likely to infiltrate to feed aquifers is 105.65 mm, or 9.15% of precipitation. Average monthly temperatures vary between 25.2˚C and 28.5˚C [14].

2.2. Data Collection

2.2.1. Study Seasons

Measurements of physico-chemical parameters were carried out in 19 wells during the rainy season (October) and the dry season (February) of 2018, seasons during which an increase in nitrate concentration in M'Bahiakro well water was noted by the work of [8].

2.2.2. Physico-Chemical Parameter Data

The water depths in the wells and the physico-chemical parameters of the water, in particular pH, temperature (T˚C), electrical conductivity (EC), oxidation-reduction potential (Eh) and dissolved oxygen (O_2), were measured in situ. The depths of the water were determined using the SEBA 300M electric light and sound probe between 5 and 6 a.m., the times when no water is supposed to be drawn from the wells selected, in order to consider the water table in its stable state. At the same time, parameters such as pH, T˚C, EC, Eh and O_2 were measured directly in the wells using a portable HANNA HI 9828 multiparameter calibrated for the two seasons of the study.

2.2.3. Nitrate Data

The water samples for the nitrate analyses were taken the day after the in situ parameter measurements, also between five and six o'clock in the morning. The water samples were taken using 500 mL polyethylene bottles that were dipped directly into the wells by means of a rope. Each bottle was rinsed three times with the water to be collected, then filled to the brim and hermetically sealed before being stored in a cooler. The bottles containing the water samples are stored at a temperature of 4˚C, as indicated by a thermometer in the cooler. This temperature of 4˚C maintained in the cooler with the aid of ice accumulators is useful for keeping the nitrates stable in the water. The preserved water samples are taken to the laboratory on the day of sampling. At the laboratory, nitrate analysis was carried out within twelve hours of sampling, using a flame molecular absorption spectrophotometer in accordance with AFNOR standard NFT 90-045.

2.3. Assessment of Nitrate-Related Health Risk

The nitrate concentrations determined will be used to assess the health risk associated with nitrates for consumers (children and adults) based on the quantification of the hazard quotient. According to [15], due to insufficient evidence of the carcinogenicity of nitrate in drinking water in humans, only non-carcinogenic health effects resulting from long-term exposure to nitrate in drinking water are quantified in terms of hazard quotient (HQ). The hazard quotient obtained on the basis of the US EPA health risk assessment model is described by Equation (1),

$$HQ = \frac{ADE}{RfD}, \tag{1}$$

where RfD is the reference dose and, according to [16], is 1.6 mg/kg/day. On the basis of the work of [17], which considers the first clinical manifestations of methaemoglobinaemia in children under 3 months of age to be the effect, a No Observed Adverse Effect Level (NOAEL) was set at 1.6 mg/kg bw/day (expressed as N), or 7 mg/kg bw/day (expressed as NO_3^-). This corresponds to a nitrate concentration of 44 mg/L with a daily water intake of 0.64 L, or 0.16 L/kg b.w./day. This limit is also the Reference Dose (RfD) without application of an additional uncertainty factor, since the USEPA considers this to be the 'critical' toxic effect for the most sensitive population.

The ADE is the Average Daily Dose for Oral Exposure to nitrate, estimated according to the USEPA model using Equation (2),

$$ADE = \frac{C \times R \times EF \times ED \times CF}{Bw \times AT}, \tag{2}$$

where the various parameters used to estimate oral DJM exposure using the USEPA model are given in **Table 1**.

Table 1. Parameters for estimating nitrate exposure by the oral route.

Parameters	Oral exposure parameters			
	Units	Children	Adults	References
C (Nitrate concentration)	mg/L	Field data		Study area
IR (Absorption rate)	L/day	1	2.2	[18]
EF (Exposure frequency)	day/year	365	365	
ED (Exposure time)	year	6	30	
CF (Conversion factor)	kg/mg	10		
AT (Average time)	day	6 × 365	30 × 365	
BW (Body weight)	kg	Field data		Study area

In the present study, the hazard quotient (HQ) for the health of consumers (children and adults) was calculated in each neighbourhood using the maximum NO_3^- concentrations at each water point over all the sampling periods, the average weights of children (15 kg) and adults (60 kg) obtained in the study area, and the various assessment parameters presented in **Table 1** above. According to [2], if the HQ value exceeds 1, the risk of adverse non-carcinogenic health effects is unacceptable, whereas if HQ is less than 1, it is at an acceptable level. The risk zone was described in three classes according to the work conducted by [2], namely:

- class1 ($0 \leq HQ \leq 1$) insignificant risk, corresponding to acceptable non-carcinogenic zones;
- class 2 ($1 < HQ \leq 2$) relatively significant risk, representing unacceptable non-carcinogenic zones;
- class 3 ($HQ > 2$) very significant risk, representing unacceptable non-carcinogenic zones.

3. Results and Discussion

3.1. Water Parameters Measured in Situ

The physico-chemical parameters of the well water measured in the dry and rainy seasons are presented in **Table 2**. Well water from the M'Bahiakro aquifer is acidic, with pH values varying on average between 4 and 6 throughout the seasons. This acidity is in line with that of the characteristic aquifers of Côte d'Ivoire, particularly in the basement zone [19]. Well water temperatures vary between 27 and 30˚C. This variation in well water temperature is in line with seasonal variations in ambient atmospheric temperatures as defined by meteorological data in Côte d'Ivoire. The redox potential (Eh) for these sampling campaigns varied on average between −25.1 mV and 69 mV. Dissolved oxygen (O_2) rose from 0.38 mg/L to 6.64 mg/L in the dry and rainy seasons respectively. The overall Eh and O_2 values obtained could be explained by the fact that well water in the study area is open to the atmosphere and evolves in an oxidising environment. These waters are also highly mineralised, with average EC values ranging between 360 and 990 µS/cm, well above the acceptable value for drinking water recommended by the WHO [20]. These high EC values could be linked to the nature of the groundwater recharge. Water depths in the wells average 4.64 meters during the dry season and 3.45 meters during the rainy season. The water table seems to be fed more during the rainy season. According to the work of [21], the town of M'Bahiakro is characterised by a gently sloping terrain with gradients ranging from 0 to 6% and dominated by coarse sand. These physical characteristics could have an impact on groundwater recharge, especially during rainfall events.

Table 2. Physico-chemical parameters measured in situ.

Years 2018		February				October			
Parameters	Units	Min	Average	Max	SD	Min	Average	Max	SD
pH		4.6	4.1	5.9	±0.7	3.1	5.7	7.7	±0.7
Eh	mV	−25.1	28.6	30.5	±0.3	−18.4	32.2	68.6	±10.1
T	˚C	27.3	28.8	30.5	±0.7	27.2	28. 3	29.7	±0.6
EC	µS/cm	118.5	369.4	841	±256.8	187.5	984.1	2539.1	±736.0
O_2	mg/L	0.0	0.4	1.1	±7.1	1.1	2.6	6.8	±4.7
Depth	m	1.9	4.8	7.2	±1.1	1.6	3.5	6.7	±1.2

3.2. Nitrate Concentrations

The average nitrate concentrations in well water in the four districts of the town of M'Bahiakro are shown in **Table 3**. In the town, all the well waters with nitrate concentrations above the acceptable level were observed in the neighbourhoods of Koko, Baoulékro and Dougouba, where the mean concentrations were 83.7 ± 53.4, 58.5 ± 23.8 and 90.1 ± 29.8 mg/L of NO_3^- respectively. Most of the nitrate enrichment in these well waters is linked to the discharge of domestic wastewater (latrines, septic tanks) into the water table [9]. The Kruskal-Wallis test also showed that the difference in the level of nitrate contamination of well water in the different neighbourhoods was statistically significant (p-value = 0.03974 < 0.05) (**Table 3**). In line with the work carried out by [21], it can be said that the physical properties of the soil in the different districts of M'Bahiakro are determining factors in nitrate pollution of well water. According to these authors, the southern part of the town, characterised by coarse sands and lower slopes (0 to 3%), unlike the northern, western and eastern parts, is more favourable to groundwater recharge. Thus the low nitrate concentrations observed in the N'gattakro district, unlike in Koko, Baoulékro and Dougouba, could be linked to the phenomenon of dilution of nitrate concentrations in well water, as also highlighted in the work of [22].

Table 3. Nitrate concentrations in well water.

Neighbourhoods	Number of samples	Median	Mean±SD	Min	Max	p-value
	(n)	mg/L	mg/L	mg/L	mg/L	
Koko (North)	7	63.1	83.7 ± 53.4	10.91	114.3	0.03974
Baoulékro (East)	4	59.4	58.5 ± 23.8	32.3	83	
Dougouba (West)	3	52.6	90.1 ± 29.8	92.6	110.7	
N'Gattakro (South)	4	16.3	17.9 ± 9.1	10.3	28.8	

3.3. Seasonal Distribution of Nitrate Concentrations in Well Water

The distribution of nitrate concentrations illustrated in Figure 1 shows that these concentrations vary in the M'Bahiakro well water according to the seasons studied. A total of 84% of the well water analysed has a concentration above the potability threshold (>50 mg/L), compared with 16% in the dry and rainy seasons. The maximum nitrate concentrations are 148 mg/L in the rainy season and 137 mg/L in the dry season. Well water less affected by nitrate contamination is wells 6, 7 and 8, with maximum values of 45 mgL and 40 mgL in the dry and rainy seasons respectively. Enrichment of all well water in nitrates (NO_3^-) is thought to be the result of contamination by domestic effluent [8] [9]. In the town of M'Bahiakro, the sanitation system is inefficient, as it is mostly made up of independent sanitation structures (septic tanks, cesspools, etc.), the construction of which is not always controlled. According to [21], most of these facilities are located at distances of less than 10 m from wells, which are no more than 7 m deep. The high nitrate concen-trations observed in well water could therefore be explained by the infiltration of effluent from on-site sewage treatment works into the wells during the dry and rainy seasons. Moreover, in the dry season, when the water table seems to be less supplied by rainwater according to [9], nitrate concentrations are around those observed in the rainy season. Contamination of well water would therefore also have an underground origin, that of waste water (latrines/showers) stored at depth. Nitrates from domestic wastewater stored deep down in latrines would therefore reach well water more easily during the rainy season according to the work of [23] and [24]. These authors have shown that contamination of groundwater by chemical elements is more marked in the rainy season.

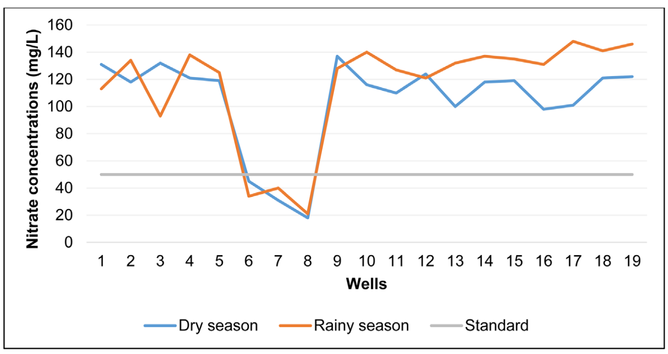

Figure 1. Nitrate concentrations in well water.

And according to the authors [2] and [26], the high nitrate concentrations observed in well water during the seasons could affect the health of the people who consume it.

3.4. Health Risk Associated with the Presence of Nitrate in Well Water

The assessment of the health risk associated with exposure through ingestion of nitrates in well water showed that part of the study area had a HQ > 1, indicating that residents in this area would be subject to the adverse effects of NO_3^- during daily intake of nitrate-contaminated well water. This part of the study area covers the neighbourhoods of Koko, Dougouba and Baoulekro. It was observed that the HQ for adults and children due to NO_3^- was greater than 1 (HQ>1), with values of 1.27 (Koko), 1.09 (Dougouba), 1.22 (Baoulekro) and 2.59 (Koko), 2.44 (Dougouba), 2.17 (Baoulekro) respectively (**Table 4**). According to [16], this means that, whatever their age, residents of this part of the study area are potentially exposed to non-carcinogenic health effects associated with NO_3^-. In contrast to the other neighbourhoods, the N'Gattakro neighbourhood in the southern part of the city, characterised by a HQ < 1, indicates that this area is at an acceptable level of non-carcinogenic risk to health. It was observed in the N'Gattakro district that the HQ for adults and children due to NO_3^- is less than 1 (HQ < 1), with values of 0.37 and 0.75 respectively. According to USEPA [16], the potential toxic effects on human health over a lifetime are low or non-existent in this part of the study area. The exposure to nitrate observed in all districts of the town of M'Bahiakro is relatively greater for children than for adults.

Table 4. HQ of well water in the different districts of M'Bahiakro.

Consumers	Exposures parameters	Koko	Baoulekro	Dougouba	N'gattakro
	RfD = 1.6				
Childrens	ADE	4.05	3.9	3.47	1.2
	HQ ± SD	2.53 ± 2.23	2.44 ± 0.99	2.17 ± 1.24	0.75 ± 0.38
Adults	ADE	2.02	1.95	1.74	0.6
	HQ ± SD	1.27 ± 1.11	1.22 ± 0.50	1.09 ± 0.62	0.37 ± 0.19

Figure 2 and **Figure 3** show the most vulnerable neighbourhoods in terms of exposure to nitrates from drinking well water for children and adults respectively in the town of M'Bahiakro. According to **Figure 3**, 16% of the wells studied in the Koko and N'gattakro neighbourhoods presented an acceptable risk of non-carcinogenic exposure for children, compared with 68% of wells with an unacceptable risk of non-carcinogenic exposure for the neighbourhoods as a whole. However, among adults, 16% of wells in Koko, 11% in Baoulekro, 5% in Dougouba and 21% in N'gattakro had a non-significant non-carcinogenic risk, as shown in **Figure 3**,

which defines 47% of wells with significant non-carcinogenic exposure with HQ > 1 for all neighbourhoods. These results are similar to those of [25] [26], since for these authors, children are more vulnerable to the non-carcinogenic effects of pollutants than adults.

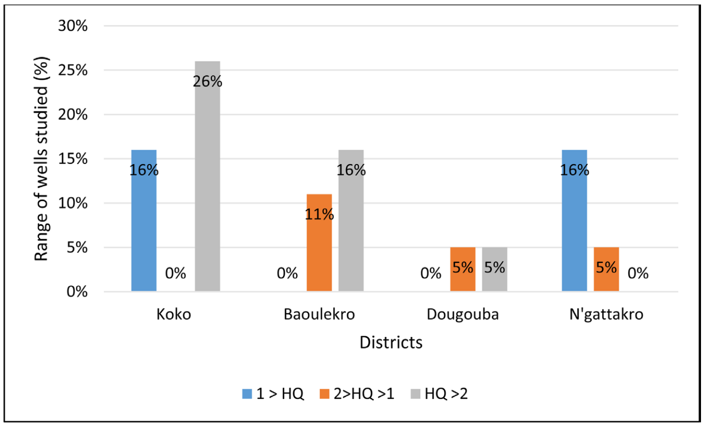

Figure 2. Health risks associated with nitrate ingestion for children.

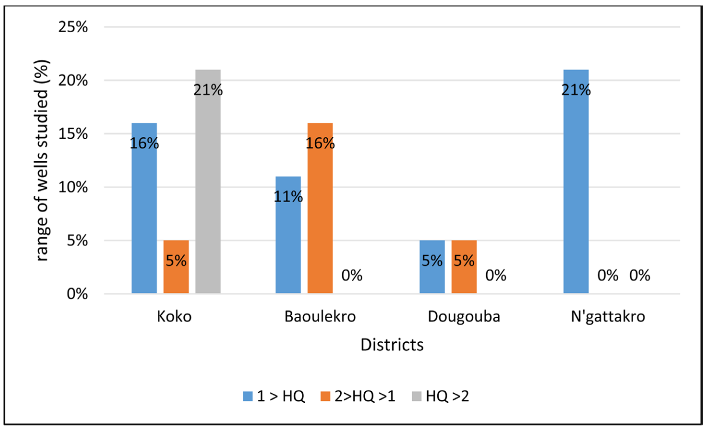

Figure 3. Health risks associated with nitrate ingestion for adults.

4. Conclusion

The water table in the town of M'Bahiakro is an important reserve for disadvantaged populations, whose numbers could increase during the implementation of the irrigated rice-growing project. However, the assessment of the health risk associated with oral exposure to nitrates in well water indicates that residents of the Koko, Dougouba and Baoulekro neighbourhoods, whatever their age, are potentially exposed to the toxic effects of NO_3^- during their daily intake of nitrate-contaminated well water, with reference to hazard quotients (HQ) greater than 1. It is therefore necessary to treat and control nitrate concentrations in the water table in order to prevent their harmful effects on the health of the population in the context of the use of this water table during the implementation of the M'Bahiakro irrigated rice-growing project. This work should provide a starting point for monitoring the impact of human activities on the water in the M'Bahiakro aquifer. Further research is essential to obtain a wider range of qualitative information on changes in the physical and chemical characteristics of the water table. This is why, in future work, we propose to deepen our knowledge of groundwater quality by taking heavy metals into account. These are the main aspects taken into account when setting health objectives designed to prevent carcinogenic risks.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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