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Nitrate Pollution and Health Risks Analysis in Water Resources in Locality of Mbankomo (Center-Cameroon)

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Abstract
Elevated nitrate levels in water resources, resulting from human activities and inadequate wastewater management, can have detrimental effects on consumer health. This article aims to analyze nitrate levels in the water resources of Mbankomo and assess the associated health risks to the local population using a determinist approach. Nitrate concentration is determined in 20 samples including 10 in the dry season (2022, March) and 10 in the rainy season (2022, October). Nitrate concentrations were determinate by High Performance Liquid Chromatography (HPLC) ion chromatography method on Dionex ICS-1100 with a diameter of 0.45 µm. The Nitrate pollution Index (NPI) was used to quantify water nitrate pollution and Potential health risk assessment for nitrate pollution in water of Mbankomo was determined by commonly using health indices such as daily water intake (CDI), hazard quotient (HQ), and non-carcinogenic hazard index (HI). Nitrate concentrations varied from 0.03 to 0.08 mg/L, with an average of 0.05 mg/L, in the dry season and from 23.66 to 116.74 mg/L, with an average of 59.83 mg/L in the rainy season. 50% (5 samples) of points investigated have NO_3- concentration higher than the WHO limit of 50 mg/L probably due to Anthropogenic inputs. Concerning the NPI, about 60% of the samples have negligible to moderate pollution and 40% have significant and very significant pollution. The average hazard index (HI) values for adults and children were 1.13, 1.88, respectively. 80% of the samples (8 samples) from children had an HI greater than 1, while 50% (5 samples) of the samples from adults exceeded an HI of 1. Accordingly, water samples from Mbankomo may expose children and adults to non-cancer health concerns. Children are more vulnerable to non-carcinogenic health risks than adults, possibly due to their lower body weight. Immediate attention and remedial measures must be implemented to protect residents from the adverse effects NO_3^- in the study area.

Keywords
Nitrate pollution, health risk, water resource, Mbankomo, Center-Cameroon

1. Introduction

The Earth is known as the blue planet because more than 72% of its surface is covered by water. However, freshwater accounts for only 2.8% of the Earth's surface and groundwater resources, most of which are difficult to access (BRGM, 2011). Water is essential for human well-being, security, social development and economic growth. In many developing countries today, the availability of safe and hygienic water has become a pressing human concern. This challenge is further complicated by population growth, which makes access to safe drinking water increasingly difficult (Addo et al., 2013). To achieve this, it is essential to protect the quality of these resources in the medium and long term. We are currently witnessing a significant mobilisation of various stakeholders - including scientists, heads of state, local authorities, NGOs and others - to address the issue of water resources. This collective effort is supported by laws, decrees, summits, conferences, international symposia, and social and research initiatives. Human activities have led to the contamination of water resources, rendering it temporarily or permanently unfit for human consumption. Various substances can enter water sources through natural processes or human activities and affect the health of communities exposed to this contaminated water (Fakhri et al., 2021).

Among the pollutants, nitrate has increased the risk of water pollution due to its high solubility (Lev, 2020; Aea, 2021). Nitrate contamination of water resources has emerged henceforth as a major public health concern worldwide, particularly in regions where agricultural practices and urbanisation contribute to elevated levels of this compound.

Nitrate is widely used in agriculture as a mineral fertilizer and as a preservative in food products (Fan and Steinberg, 1996; WHO, 2011) Surface waters typically have low concentrations of nitrate, ranging from 0 to 18 mg/L, although these levels can fluctuate with seasonal changes. Available evidence suggests that nitrate concentrations in surface water and groundwater are increasing due to surface runoff, particularly from agricultural land. Under aerobic conditions, nitrate concentrations in groundwater are influenced by soil properties.

Elevated nitrate levels in drinking water can lead to methemoglobinemia (commonly known as blue baby syndrome), as well as miscarriage, infertility, and the formation of nitrosamines, which are associated with various types of cancer (Jamaludin et al., 2013; Ward et al., 2005). The World Health Organization (WHO) has established a reference limit for nitrate in drinking water at 50 mg/L (Fabro et al., 2015). The main factors affecting the presence and distribution of nitrate (NO_3^-) in aquifer systems include natural processes such as water-rock interactions, evaporation, and hydrodynamics, along with human activities (Abba et al., 2023; Chen et al., 2024).

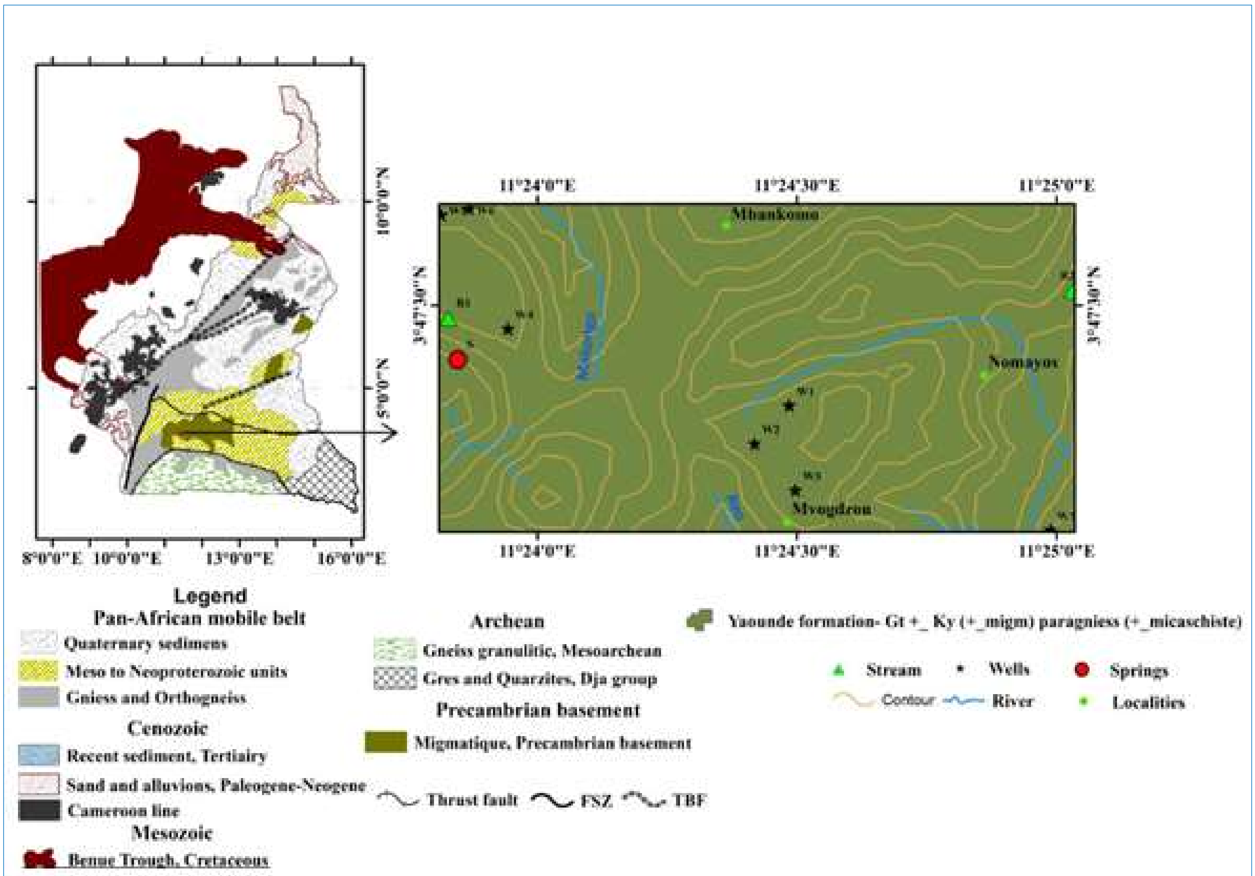

Fig. 1. Geologic map of the study area with water sample

In Mbankomo, a town in Central Cameroon, the increasing use of fertilizers and the discharge of untreated wastewater has raised alarms about the potential health risks associated with nitrate exposure. While nitrate is essential for plant growth, it can pose serious health risks when present in high concentrations in drinking water. Health risk assessment is the most important approach for evaluating the nature and likelihood of adverse health effects in individuals who consume water with elevated levels of contaminants (Jin et al., 2024).

This article aims to analyze nitrate levels in the water resources of Mbankomo and assess the associated health risks to the local population. By examining the sources of nitrate pollution, the extent of contamination and the potential health impacts, this study aims to provide a comprehensive understanding of the challenges faced by the community. It will also highlight the need for effective management strategies to reduce nitrate pollution and protect public health. Through this analysis, we hope to provide valuable insights that can inform local policy makers and stakeholders in their efforts to ensure safe drinking water for the residents of Mbankomo.

2. Materials and Methods

2.1. Study Area

Covering an area of 1.300 km^2, the commune of Mbankomo is situated in the Centre Region of Cameroon within the Mefou-et-Akono department, approximatively 22 km from Yaounde. It lies between 11°13' and 11°39'east longitude and 3°37' and 3°57' north latitude, comprising 66 villages. The average altitude is 787 meters, with a population density of 46 inhabitants per km^2 (Fig. 1). From geological point of view, according to the work of Nzenti et al. (1988 and 1998), Toteu et al. (2004) and Metang et al. (2022), the Yaoundé region is located in the mobile zone of Africa, more precisely in the Pan-African chain aged 540 to 600 million years. This base extends over an area of more than 7000 km² (Mvondo, 2003). On a regional level, two lithological groups are identified there: one with weak metamorphism (Ayos, Bengbis, and Yokadouma series) and another with medium to high metamorphism (Yaoundé and Nanga-Eboko series), which is made up of gneiss, migmatites, micaschists, amphibolites, and calcic silicate rocks. From a hydrogeological perspective, the studied region is part of crystalline bedrock, which is basically composed of two aquifers: a deeper discontinuous aquifer connected to major cracks and an upper aquifer situated in the granular worn bedrock (Tchapnga et al., 2001). The top aquifer is nearly isotropic and ranges in depth from 8 to 20 meters. Water discovered beyond 20 meters in the lower aquifer is anisotropic (Tchapnga, 1987; Bosso 2000, unpublished work). The saprolite voids that contain the water of the upper aquifer have a poor permeability yet a considerable capacity to store groundwater. The water in the lower aquifer is located within the basement bills and fissures that were created by weathering processes and the passage of altered deep veins across the bedrock (Wyns, 1998; Taylor and Howard, 2000; Maréchal et al., 2003; Lachassagne and Wyns, 2005).

2.2. Water Sampling and Treatment

20 samples including 10 in the dry season (2022, March) and 10 in the rainy season (2022, October) are collected. Among these samples, 14 are taken in excavated wells that captured the shallow aquifer (2–12 m) after ten minutes of pumping to remove standing groundwater; 4 in the stream and 2 in the springs. The sampling points were localized using Garmin e-Trex GPS unit.

Fig. 1 displays the sampling locations. The procedure for gathering and examining these water samples was founded on American Public Health Association principles in order to preserve a consistent technique (APHA, 2012). The 500 mL pre-cleaned sample bottles were used to collect the freshwater samples. To prevent leaks and contamination during handling and transit, each sample of bottles was securely sealed (Kumar et al, 2024). To identify the precise sampling location, the containers were appropriately labeled with the date, time, GPS coordinates, etc. Before being used for the final chemical analysis, all of the collected samples were first kept cold and brought to the lab, where they were kept in a freezer at 4 °C. Water quality parameters analyzed in accordance with standard methods of (the American Public Health Association (Li and Qian 2011). HPLC ion chromatography method on Dionex ICS-1100 with a diameter of 0.45 µm was used for obtaining nitrate concentration.

2.3. Nitrate Pollution Assessment

The nitrate pollution in the water points under investigation was measured using a single-parameter water quality index called the nitrate pollution index (NPI). (Bahrami et al., 2020; Kharroubi et al., 2024; Lakhdari and Bouselsal, 2024). The Nitrate pollution Index (NPI) can be used to quantify water nitrate pollution and can be indicated that anthropogenic activity has contaminated the water with nitrates. This index is produced using *Equation 1* (Obeidat et al. 2012).

$$NPI = C_s - HAV / HAV \tag{1}$$

where; Cs is the nitrate concentration in the sample, and HAV is the threshold value of the anthropogenic source (human-affected value), taken as 20 mg.L^{-1} (Obeidat et al. 2012). Table 1 shows the five categories into which water quality was divided based on the NPI's obtained results.

Table 1. Values and categories of NPI and WHO limits on NO_3 (WHO 2011; Obeidat et al., 2012; Almasi et al., 2016)

NPI value	NPI interpretation	NPI class	NO_3 (mg.L^{-1})	WHO standard	NO_3 class
< 0	Clean (unpolluted)	1	< 50	Desirable limit (DL)	1
0 – 1	Light pollution	2	= 50	Maximum permissible limit (MPL)	2
1 – 2	Moderate pollution	3	> 50	Not permissible limit (NPL)	3
2 – 3	Significant pollution	4			
> 3	Very significant pollution	5			

2.4. Health Risk Assessment

It is essential to evaluate the health concerns associated with the contaminants in drinking water. In this study, we estimated the non-cancer impacts of nitrate using an empirical model that was proposed by USEPA (1989). Taking into account that there are multiple methods for nitrate to reach the human body, the chronic daily intake (or CDI) of these substances by drinking or dermal contact water can be stated as mg/kg/day. The population in the study area was split into two groups, children and adults, in order to evaluate the health risks. The health risk assessment makes use of the reference values and standard methodologies recommended by the US Environmental Protection Agency (USEPA, 2001). Exposure hazards by ingestion and cutaneous pathways were computed using *Equation 2* and *Equation 3*.

$$CDI_{ing.} = (C_{water} x IR x EF x ED)/(BW x AT) \quad (2)$$

$$CDI_{der} = (C_{water} x SA x KP x EF x ED x ET x CF)/(BW x AT) x 10^{-6} \quad (3)$$

where; CDI_{ing} and CD_{der} represent the chronic daily dose by ingestion and dermal effects, respectively (µg/kg day). Cwater is the concentration of NO3 in groundwater (mg/L). IR is the ingestion rate of water in L/day (adults = 2.5 L/ day; children = 0.78 L/day). SA is the exposed skin area in cm^2 (adults = 16,600 cm^2; children = 12,000 cm^2). KP is the dermal permeability coefficient for water (0.001, no unit). EF is the water exposure frequency (365 days). ED is the exposure duration in years (adults = 64, and children = 12,). ET is the water exposure time in hours/day (0.4 h/day for adults and children). BW is the body weight in kg (adults = 65 and children = 15). AT is the average residence time measured in days/year. CF is the conversion factor (0.001 for adults and children).

The hazard quotient (HQ) of NO_3 exposure via ingestion and dermal pathways can be calculated using *Equation 4* and *Equation 5*.

$$HQ_{ing} = CDI_{ing}/RfD \quad (4)$$

$$HQ_{der} = CDI_{ing}/RfD \quad (5)$$

where; HQ_{ing} is the ingestion-based hazard quotient. HQ_{der} is the dermal-based hazard quotient. RfD is the reference dose of NO_3, i.e., 1.6 mg/kg/day (USEPA, 2014). Hazard index (HI) is the overall risk of exposure via both digestion and dermal pathways and can be calculated by *Equation 6*.

$$HI = HQ_{ingestion} + HQ_{dermal} \quad (6)$$

If the HI values are higher than one, it may cause non-carcinogenic health hazards.

3. Results and discussion

3.1. Nitrate Concentrations

Table 2 lists the detected levels of nitrate in the water samples from both dry and rainy season. The concentrations varied from 0.03 to 0.08 mg/L, with an average of 0.05 mg/L, in the dry season and from 23.66 to 116.74 mg/L, with an average of 59.83 mg/L in the rainy season.

Table 2. Concentration of Nitrate in study area and in different seasons

Season	Concentration (mg/l)	W1	W2	W3	W4	W5	W6	W7	S	R1	R2	Min	Max	Mean	SD
Dry	Nitrate	0.05	0.05	0.04	0.08	0.05	0.08	0.05	0.03	0.03	0.04	0.03	0.08	0.05	0.01
Rainy	Nitrate	23.66	33.51	116.74	89.73	44.77	44.81	61.15	55.29	26.52	102.07	23.66	116.74	59.83	32.49

From these data we notice that the nitrate concentrations which are in trace during the dry season increase exponentially in the rainy season. This phenomenon can be explained by the fact that, during rainy season, heavy rainfall can lead to increased runoff from agricultural fields where fertilizers containing nitrates are used. This run of carries nitrates into water bodies, raising their concentration, especially after dry periods when the soil has accumulated these nutrients. Otherwise, increasing rainfall can overwhelm sewage systems, leading to higher concentrations of nitrates from domestic wastewater entering rivers and streams (Raij-Hoffman et al., 2024; Wang et al., 2024). 50% (5 samples) of points investigated have NO_3^- concentration higher than the WHO limit of 50 mg/L (Fig. 2). Seldom is geological formation cited as the source of nitrate. Nonetheless, the sole natural mechanism that can be suggested as the source of nitrate is microbial nitrification. As demonstrated by *Equation 7* and *Equation 8*, ammonia undergoes this process first as nitrite and then as nitrate with bacterial activity.

$$2NH_4 + 4O_2 = 2NO_2 + 4H_2O \quad (7)$$

$$2NO_2 + O_2 = 2NO_3 \quad (8)$$

Anthropogenic inputs must be the cause of an abnormal nitrate concentration level (> 50 mg/L) (Panno et al. 2006). Nitrate concentrations in surface- or shallow-level groundwater are often regulated by localized factors like sewage leaks and non-point sources like agricultural practices (Wang et al. 2017, Jayarajan and Kuriachan, 2021). Higher contamination levels have been found to be mostly linked to shallow groundwater, river and spring and are caused by manures, agriculture patterns, river-aquifer interactions, denitrification, precipitation surpluses, wastewater irrigation, redox conditions, waste disposal networks, animal wastes, industry, and associated biogeochemical processes in groundwater (Jia et al. 2020; Taufiq et al. 2019; Zendehbad et al. 2019; Jayarajan and Kuriachan, 2021).

The primary sources of nitrate in water in the research area may be agricultural operations and farm animals. During the farming season (rainy season), a significant amount of manures and fertilizer are used, and the excess precipitation leaks into the water. Urbanization and the construction of new structures, which are likely to upset the soil and soil aeration and create an atmospheric contract with the nitrogen-fixing microorganisms, were identified by Wakida and Lerner (2005) as another intriguing source of nitrate.

Overall, this could lead to more nitrate mineralization in the soil, which would raise water levels. Fig. 3 shows the spatial variation in nitrate concentration in the study site during the rainy season. It can be seen from this figure that, apart from the centre and north-west of the study area where nitrate concentrations are below WHO standards, all the rest of the study area has nitrate-contaminated water (above 50 mg/l) and is therefore a major threat to human health.

3.2. Nitrate Pollution Index (NPI)

NPI values in the research area fall between 0.18 (W1) and 4.84 (W3) (Table 3). About 60 percent of the samples have negligible to moderate pollution (W1, W2, W5, W6, S and

R1) and 40 percent have significant and very significant pollution (W3, W4, W7, and R2). The spatial variation in the nitrate pollution index is shown in Fig. 4. From this, it can be seen that most of the localities in the study area have moderate to very high nitrate pollution. Only a small part of the site in the center and north-west (yellow corridor) has nitrate-free water. Nitrate pollution in water is regarded as a global issue with significant consequences for human health.

It is an established fact that water sources which are uncontaminated by nitrate typically exhibit low levels of substance. However, it is hypothesized that aquifers and rivers exhibiting nitrate concentrations in excess of 10 mg/L are likely to be influenced by anthropogenic sources of nitrate contamination.

3.3. Human Health Risk

For adults and children, the corresponding chronic daily intake by ingestion (CDI_{ing}) values of nitrate (mg/kg/d) were 0.71 to 3.50 (average of 1.79), 1.18 to 5.82 (average of 2.98), and the corresponding chronic daily intake by dermal contact (CDIderm) values of nitrate (mg/kg/d) were 0.0056 to 0.027 (average of 0.014), 0.0096 to 0.047 (average of 0.024) for adults and children respectively (Table 4).

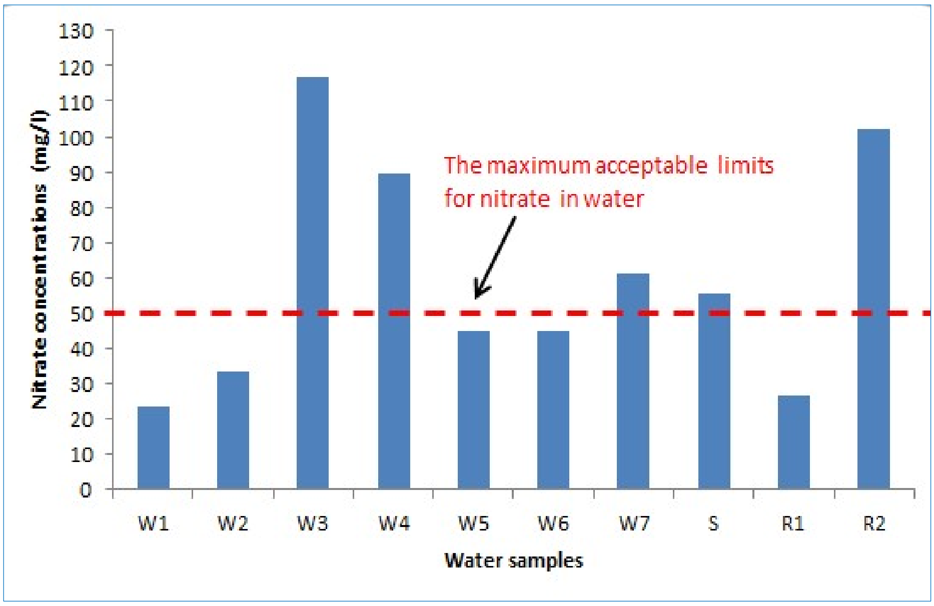

Fig. 2. Distribution of nitrate concentrations (mg/L) in the water of the study area

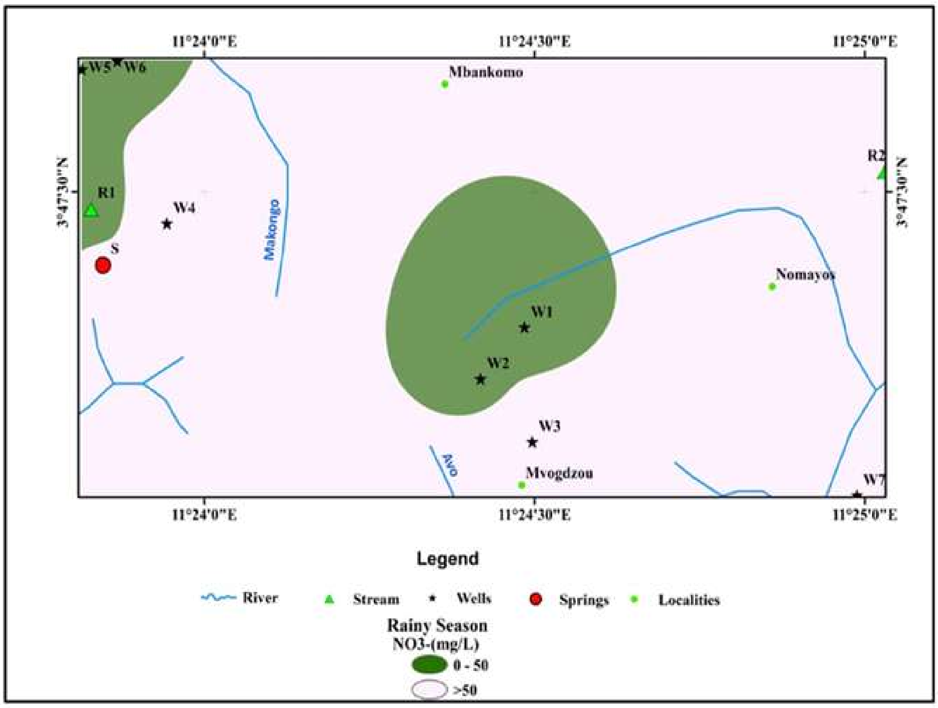

Fig. 3. Spatial distribution of nitrate concentration in rainy season

Table 3. NPI values in the study area

Parameter	W1	W2	W3	W4	W5	W6	W7	S	R1	R2	Min	Max	Mean	SD
NPI	0.18	0.67	4.84	3.49	1.24	1.24	2.06	1.76	0.32	4.10	0.18	4.84	1.99	1.62

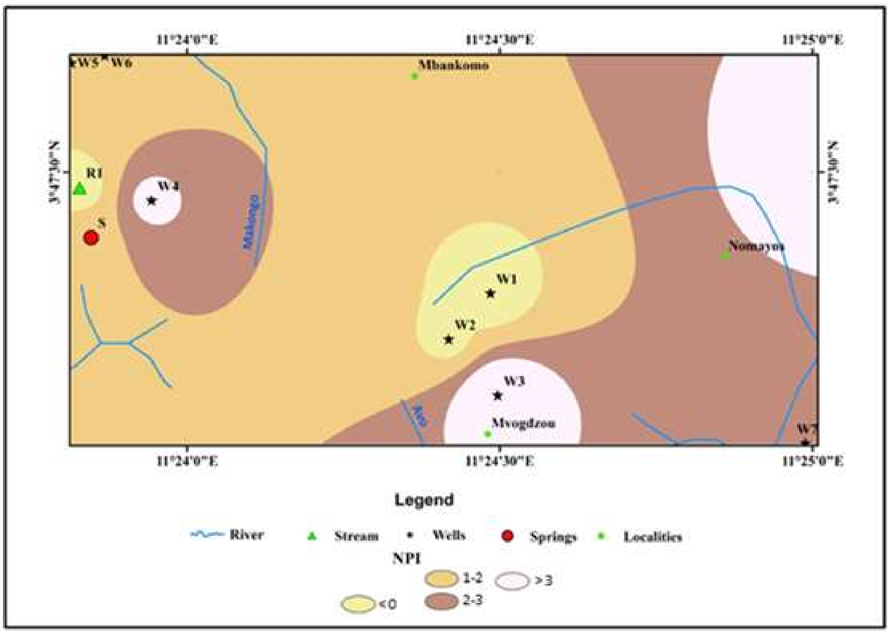

Fig. 4. Spatial distribution of nitrate pollution index (NPI) concentration in study area

The amount of nitrate absorbed by water consumption is more than that absorbed by skin contact with water, as indicated by the fact that all CDI mean values for oral ingestion for both adults and children are higher than their corresponding CDI mean values for dermal absorption. An estimated HQ value less than 1 implies that there are very little health consequences on humans, however an HQ value greater than 1 suggests that water contaminants may not have any carcinogenic effects (Zhang et al., 2021; Özbay, 2024). The HQ of nitrate for adults in the study area ranged from 0.44 to 2.19 (average 1.12), and 0.0035 to 0.017 (average 0.0088) for the ingestion and dermal pathway respectively; and from 0.74 to 3.64 (average 1.86), 0.006 to 0.030 (average 0.015) for the children ingestion and dermal pathway, respectively. The HQ_{ing} values were significantly higher than the calculated HQ_{der} values, indicating that oral ingestion is the main exposure pathway for nitrate, even though the HQ_{der} values were below 1, which is considered acceptable for human health (Muhammad et al., 2011; Habesoglu & Atici, 2022; Özbay, 2024). The study results indicated that the health risks associated with excessive intake of nitrate-contaminated water were greater for children than for adults, highlighting a higher health risk for children in Mbankomo, consistent with findings from previous studies conducted in groundwater across various regions worldwide (Zhang et al., 2020; Jayarajan and Kuriachan, 2021; Su et al., 2023; Fallahzadeh et al., 2024; Ghasemzadeh et al., 2024; Abdipour et al.; 2025).

In the study area, the mean HI values for children ranged from 0.074 to 3.67, while the HI values for adults varied from 0.45 to 2.20, with the highest values recorded in the well number 3 (W3). Eighty percent of the samples (8) from children had an HI greater than 1, while fifty percent (5) of the samples from adults exceeded an HI of 1 (Fig. 5). Therefore, it is not surprising that children and infants face a higher non-carcinogenic risk from nitrate in drinking water compared to adults, due to their lower body weight and relatively underdeveloped enzyme metabolism (WHO, 2016). Research has shown that elevated nitrate levels can lead to methaemoglobinaemia, commonly known as blue baby syndrome (Ward et al., 2005; Fan et al., 2007; Ward et al., 2018). The conversion of nitrate to nitrite occurs primarily in the gastrointestinal tract through the action of enteric bacteria. Therefore, both the dose and the type and amount of bacteria present may influence the risk of nitrate-induced methaemoglobinaemia (Ward et al., 2005).

According to the WHO (WHO, 2016), about 5% of nitrate is converted to nitrite in healthy adults. Nitrate can also be metabolised to nitrite in the stomach when the pH of the gastric fluid is elevated (above pH 5) (Ward et al., 2005; WHO, 2016). This is a concern for adults with gastrointestinal disorders and achlorhydria, and for infants whose gastrointestinal pH is high enough to promote bacterial growth. Therefore, infants, particularly those aged 0-3 months, are generally considered to be the most vulnerable group to nitrate-induced methaemoglobinaemia (USEPA, 1991).

In addition, adults who consume water with high nitrate levels may be at increased risk of high blood pressure, stomach cancer, thyroid problems and respiratory problems (Adimalla and Li, 2018; Mortada and Shokeir, 2018; Giri et al., 2021; Sailaukhanuly et al., 2023). Pregnant women and infants are particularly vulnerable due to their high turnover of thyroid hormones and limited intrathyroidal reserves during fetal and early life. Excessive nitrate intake can pose significant risks to pregnant women and may increase the likelihood of congenital disabilities (WHO, 2016).

Mbankomo city and the area around it is significantly polluted by terrestrial discharges from human activities, especially agricultural and domestic wastewater due to the absence of an urban planning plan leads to an insufficient sanitation system and the proliferation of uncontrolled household waste dumps. The results showed that these areas consistently had the highest nitrate concentrations in water, which can be attributed to anthropogenic pressures. Human activities, including population growth leading to increased domestic wastewater and excessive use of chemical fertilizers in agriculture, contribute significantly to nitrate contamination of water. This pollution poses health risks to people who rely water for drinking (Adimalla, 2020; Erşahin and Bilgili, 2023; Özbay, 2024). This nitrate contamination poses potential health risks to people who rely on water from these affected regions. Nitrate and nitrite are classified as category D substances in the EPA carcinogenicity classification, meaning that their carcinogenic potential has not been established. However, the reduction of nitrate in the body can lead to the formation of nitrosamines and other carcinogenic compounds through reactions with secondary amines (Huang et al, 2017; Moeini and Azhdarpoor, 2021).

Therefore, monitoring nitrate levels in the body is essential for health protection. In addition to drinking water, nitrate can also be ingested through food. As a result, the total risk from different exposure routes may exceed the standard levels. The most effective approach to reduce nitrate risk is to identify and eliminate sources of contamination, especially in high-risk groups and regions (Fallahzadeh et al., 2018; Moeini and Azhdarpoor, 2021).

Table 4. Summary of the non-carcinogenic risk (CDI, HQ) of nitrate in water through the oral and dermal routes for adults and children

Health risk indices	Elements	Ingestion			Dermal		
		Min	Max	Mean	Min	Max	Mean
Adults	CDI	0.71	3.50	1.79	5.57E-03	2.74E-02	1.41E-02
	HQ	0.44	2.19	1.12	3.48E-03	1.72E-02	8.81E-03
Children	CDI	1.18	5.82	2.98	9.63E-03	4.75E-02	2.43E-02
	HQ	0.74	3.64	1.86	6.02E-03	2.97E-02	1.52E-02

Table 5. HI values in the study area

	Min	Max	Mean	SD
HI adults	0.45	2.20	1.13	0.61
HI children	0.74	3.67	1.88	1.02

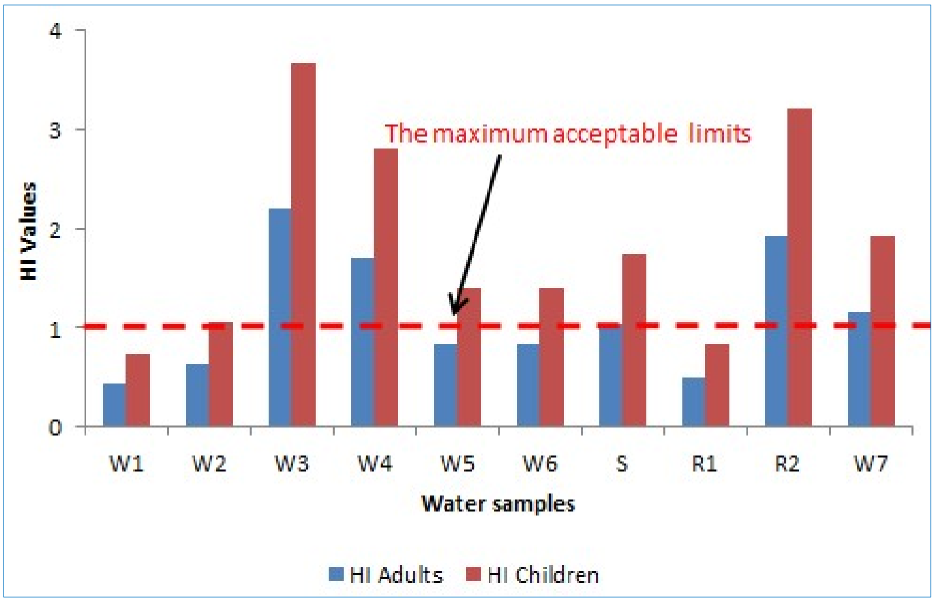

Fig. 5. Health risk assessment of water for nitrate in study area based on HI values calculated for children and adults

4. Conclusion

The commune of Mbankomo is situated in the Centre Region of Cameroon between 11°13' and 11°39'east longitude and 3°37' and 3°57' north latitude. Due to population growth, uncontrolled urbanization and the lack of an adequate water supply system, the area's water resources are under significant stress. This article aims to analyze nitrate levels in the water resources of Mbankomo and assess the associated pollution and health risks to the local population using determinist approach. To achieve this goal, 20 samples including 10 in the dry season (2022, March) and 10 in the rainy season (2022, October) are collected. From these samples, nitrate concentrations were determinate by HPLC ion chromatography method on Dionex ICS-1100 with a diameter of 0.45 µm. From the results obtained, nitrate concentrations varied from 0.03 to 0.08 mg/L, with an average of 0.05 mg/L, in the dry season and from 23.66 to 116.74 mg/L, with an average of 59.83 mg/L in the rainy season. These values which are in trace during the dry season increase exponentially in the rainy season. This phenomenon can be explained by the fact that, during rainy season, heavy rainfall can lead to increase runoff from agricultural fields where fertilizers containing nitrates are used. 50% (5 samples) of points investigated have NO_3^- concentration higher than the WHO limit of 50 mg/L probably due to Anthropogenic inputs. Concerning the NPI, about 60% of the samples have negligible to moderate pollution and 40% have significant and very significant pollution. The average hazard index (HI) values for adults and children were 1.13, 1.88, respectively. 80% of the samples (8 samples) from children had an HI greater than 1, while 50% (5 samples) of the samples from adults exceeded an HI of 1. Accordingly, water samples from Mbankomo may expose children and adults to non-cancer health concerns. Children are more vulnerable to non-carcinogenic health risks than adults, possibly due to their lower body weight. As a perspective, it will be intended to increase the sample size to cover the entire study area and reinforce the results obtained here. It would be beneficial to explore various methods for removing nitrates from water, select the most suitable approach for a specific location, and improve the drinking water quality for the local community.

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Conflict of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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