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Research Article

Study of the physico-chemical and bacteriological quality of water intended for consumption in the town of Gagal, southwestern Chad

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Abstract
The city of Gagal suffers from insufficient drinking water, and the population turns to surface water, wells and drillings without guarantee of quality. In order to characterize the hydrogeochemical and bacteriological properties of the waters of the aquifer system in the city of Gagal, to contribute to improving its knowledge, field campaigns were undertaken to sample the groundwater.The present study focuses on the hydrogeochemical and bacteriological characterization of drinking water in Gagal, southwestern Chad. The methodology consisted of acquiring existing data, a field campaign, and a chemical and bacteriological analysis of the water in the laboratory. The results of the physicochemical analyses revealed that the values of the parameters such as conductivity, pH (5.23), Ca^{2+} (26.11 mg/L), Mg^{2+}(5.14 mg/L), Na^{+}(3.54 mg/L), K^{+}(1.34 mg/L), HCO_3^-(81.74 mg/L), Cl^- (11.77 mg/L), SO_4^-(1.94 mg/L), and NO_3^- (8.70 mg/L) conformed to the WHO potability standards. Piper's diagram showed calcic and magnesian bicarbonate facies represented by 75%; and calcic and magnesian sulfate chloride facies in 25% of the analyzed waters. The bacteriological (Total coliforms (0 to more than 135,200 CFU/100 ml), *Escherichia coli* (0 and 14,400 CFU/100 ml), faecal enterococci (0 and 4600 CFU/100 ml)) study confirmed that the water from the wells and boreholes showed pollution of bacterial origin. Using these waters may endanger the populations with the risks of hydric diseases.

Keywords: Groundwater, Physico-chemical characterization, Hydrogeochemistry, bacteriology, Mayo-Kebbi, Chad

INTRODUCTION

In the cities of French-speaking sub-Saharan Africa, access to drinking water is at the forefront (Baron, 2006) and many lack this resource (Quaye et al., 2022). The freshwater contained in the groundwater represents 0.3% of the quantity of water on Earth (Gleick, 1996) but human access to this water resource is very resource intensive (Mallongi et al., 2019). Despite its small quantity, this freshwater is not extensible, yet the population's growth and need for water is growing significantly (Haig et al., 2020). Indeed, some authors state that in the face of the rapid urbanization of African countries, particularly developing countries, cities and precarious or peri-urban neighborhoods are penalized by the lack and/or absence of urban services (Dos Santos et al., 2017). 2.1 billion people lack access to safe drinking water in their homes and more than double that number lack safe sanitation (Unicef, 2017; Angelakis et al., 2023). Having noted, many efforts made to supply drinking water to the populations of certain secondary cities in developing countries are still subject to a lack of water, in quantity and especially in quality (Magande 2023). This disturbing report affects African countries, including Chad, much more. In Chad, groundwater constitutes an important part of the country's hydraulic heritage due to its relatively easy exploitation. The access rate to drinking water is 61% nationally (MEEP, 2018) and 25% in the Mayo-Kebbi West province (SUEZ, 2016), which ranks the province 14th nationally. The town of Gagal, the subject of this study, is part of the Mayo-Kebbi West province. This secondary town faces rapid urbanization, spontaneous housing construction, open defecation, household waste dumping, agropastoral activities, and water shortage.

The water table of the Southern aquifer covering an area of 160,000 Km^2 has been the subject of some previous studies (Torrent, 1965; Schneider, 1968; Schneider and Wolff, 1992 and Mahamat Nour et al., 2019). However, these studies were based on the entire Southern Continental Terminal water table, whose data do not provide adequate detail at the scale of the town of Gagal. In the absence of the Société Tchadienne des Eaux (STE), the population in the locality relies exclusively on groundwater from surface water, wells and boreholes, the quality of which is of concern. According to the United Nations, in 2009, 22 of the 24 countries listed as "low human development" on the United Nations Human Development Index were in sub-Saharan Africa (Adeyeye et al., 2023).

. Aware of the fact that no specific study has been conducted on the groundwater of the city of Gagal likely to be affected by geological and/or anthropogenic processes and that sustainable development can not be possible without the control of water-related problems. To better understand groundwater resources, a study on water quality is essential in the study area. This work could help improve future investments and provide information to decision-makers. This study's general objective was to contribute to the hydrochemical and bacteriological characterization of drinking water in the town of Gagal in southwestern Chad.

MATERIALS AND METHODS

Study area

The town of Gagal is located between 8°57'15'' and 9° 07'14'' north latitude and 15°05'12'' and 15°19'25'' east longitude and is 50 km southeast of the town of Pala, capital of the province of Mayo-Kebbi West, in southwestern Chad (Fig. 1).

The province of Mayo Kebbi West has a Sudanian climate, subject to the Harmattan and Monsoon regimes, with two seasons in the year, a rainy season of six months from April to October and a dry season for the rest of the year. The average inter-annual rainfall at the Pala station from 1997 to 2020 was 977 mm, the average annual maximum temperature was approximately 36°C and the annual minimum temperature was 14°C. The geology of the study area consisted mainly of the Continental Terminal and Continental Intercalary formations. This formation corresponded to the deposition of the first large lacustrine transgressions at the time of the individualization of the Oligocene-Miocene. It was found at different depths that varied from 400 to 600 m (Schneider, 1968), with a thickness of 200 m. This formation of the terminal continental begins with sandy clay and continues with lateritic clays and sandstones, suggesting several sedimentary cycles exist (Pias, 1970). Hydrogeologically, the Gagal study area is characterized by a Koro water table that is drained in the valley bottoms by the rivers. It was less than 10 m from the ground surface in the alluvial plains and deeper when one moved away from the valleys towards the summits of the Koros. The structures can then exceed 60 m and 80 m in depth. Ngounou Ngatcha (1993), who had carried out boreholes for hydrogeological knowledge in the Maroua region of Cameroon in 1978, communicated indicative information on the characteristics of the Terminal Continental that could be found in the West Mayo Kebbi Province. From this, it is stated that the basin had a general water table, but due to the heterogeneity of the sedimentation, the boreholes showed varied characteristics.

Methodology

Data acquisition

A field study was conducted during base waters from April 09 to 15, 2022. This campaign focussed on identifying existing structures in the study area, the survey of the geographical coordinates of the structures, collecting water samples for hydrochemical and bacteriological analysis and physical parameters *in situ* (conductivity, temperature and pH). During the study, 20 structures were selected (11 wells and 9 boreholes) for a global representation of the water table in the study area (Fig. 1). The samples for the physicochemical and bacteriological analyses were taken and packaged in plastic bottles. Samples for the boreholes were taken after running the water in a vacuum for a few minutes and using a specially designed sampler for the wells. At each water point, 2 samples were taken according to the type of analysis to be done. After measuring the physical parameters of the water (temperature, pH and conductivity) *in situ*, the water samples were immediately stored in a cooler containing ice chips to keep them at a temperature between 2° and 5°C. The water samples were packaged and transported quickly to the National Water Laboratory (LNE) of the Ministry of Urban and Rural Hydraulics of Chad (N'Djamena).

The volumetric dosage for the contents of chemical ions bicarbonate, chloride, calcium, and total hardness were determined with the help of Digital burettes, the ions (nitrate and sulfate) with the use of Spectrophotometry DR3900 and the ions (sodium and potassium) by Flame-photometry. The total coliforms, faecal enterococci and *Escherichia coli* were determined by Membrane filtration. This last one allowed to trap the bacteria and deposit them in Petri dishes in different culture media during the incubation period (24h to 48h) and they took a brown coloration for the total coliforms, yel-

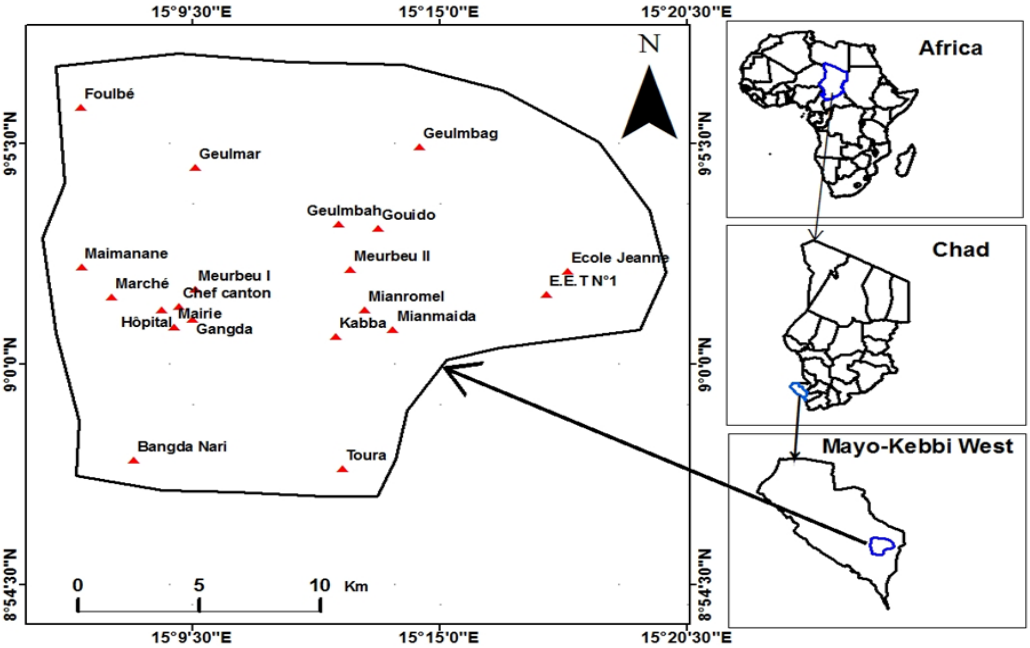

Fig. 1. *Location of the study area (Red dots are the sampled water points)*

low for the faecal enterococci and blue for the *E. coli*.

Drinking water quality index

The groundwater quality for consumption was assessed using the Drinking Water Quality Index (DWQI). DWQI with 10 different water quality parameters (pH, Na, K, Cl, TDS, Mg, SO_4, Ca, HCO_3 and NO_3) using WHO standards (2007). The index was calculated by assigning weights (w) to water quality parameters (i) based on their perceived threat to water quality. This was achieved by translating the concentrations of the constituents into a single value that reflects the composite influence of water quality parameters. The relative weight (Wi) was calculated using-

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \qquad \text{Eq. 1}$$

where W_i is the relative weight, w_i is the weight of each property of water, and *n* is the number of properties. The quality parameters were given weights (W_i) on a scale of 1 to 5 according to their importance and their role in determining drinking water quality, as presented in Table 1 (Ramakrishnaiah et al., 2009; Vasanthavigar et al., 2010).

The q_i quality score was determined using the value of each parameter according to the WHO (2007) standards (Table 1) as follows:

$$q_i = \frac{C_i}{S_i} \times 100 \qquad \text{Eq. 2}$$

where q_i is the quality rating, C_i is the concentration of the water quality parameter (i) and *Si* is the desirable limit of each parameter in the WHO (2007) standard.

The sub-index (SI_i) was determined for each parameter, which is then used to determine the DWQI as follows:

$$SI_i = W_i \times q_i \qquad \text{Eq. 3}$$

and

$$DWQI = \sum_{i=1}^{n} SI_i \qquad \text{Eq. 4}$$

DWQI was classified into five categories (Table 2) (Şener et al., 2017; Verma et al., 2020).

RESULTS AND DISCUSSION

Physico-chemical parameters of the water

The conductivity values of the water in the study area (Fig. 2 Table 3) varied from 26 µs/cm in the Toura district (OP8) to 618 µS/cm in Gangda (OF18), with an arithmetic mean of 152 µS/cm and it appeared that 85% of all the structures measured in-situ had electrical conductivity values below the WHO (2007) guide value of 300 µS/cm. These were very weakly mineralized waters. It was strongly dependent on the geological nature of the environment, the time of transit and the rocks in contact with the water, and the possible anthropic impacts.

The temperature values measured *in situ* varied from a minimum of 28°C to a maximum of 32°C with an arithmetic mean of 30°C (Fig. 2). The average was close to the average ambient air temperature (29°C) of the study area, which a thermal equilibrium of the Continental Terminal aquifer system with the atmosphere could explain. In most Sahelian regions at depths of

Table 1. Drinking water standards WHO (2007), weight, and relative weight

Parametres	WHO standards	Weight wi	Relative weight (WI)
TDS (mg/L)	1000	5	0.179
pH	8.5	4	0.143
Na (mg/L)	200	2	0.071
K (mg/L)	20	2	0.071
HCO_3 (mg/L)	125	3	0.107
Cl (mg/L)	250	3	0.107
Ca (mg/L)	100	2	0,071
Mg (mg/L)	50	1	0.036
SO_4 (mg/L)	250	4	0.143
NO_3 (mg/L)	45	2	0.071
Total		**28**	**1,000**

less than 30 m, the groundwater temperature was approximately equal to the average air temperature (Ngounou Ngatcha, 1993). The pH values measured on the 20 samples ranged from 4.31 to 6.18 pH units, with an average of 5.23 pH units (Fig. 2). Overall, the waters were weakly acidic. According to WHO (2007), drinking water should have a pH between 6.5 and 8.5, although pH does not influence consumer health (WHO, 2008). The groundwater in the study area had an average of 5.23 pH units and presented a slight difference from the (pH = 6) obtained by Schneider and Wolff (1992) and Bouchez et al. (2019) in boreholes in the Koros region.

Chemical parameters of the water

The chemical analyses of the groundwater samples showed that for all the results, the calculated ionic balances (IB) were within the range -5% < IB < 5%, except for the wells in the Bangda Nari and Mianmaida districts. This error in the ionic balance of these two samples may come from an analytical error or particular mineralization (significant presence in the water of ions that were not analyzed) (Mahamat Nour, 2013, Verma et al., 2020). The results revealed that the groundwater in the city of Gagal consisted of the proportions of ions, namely, bicarbonate (35%), calcium (35%), magnesium (11%), chloride (9%), nitrate (4%), sodium (4%), potassium (1%) and sulfate (1%). These waters were mainly dominated by the HCO_3^- ions, representing 35% of the total ions. However, 72% of the total anions were followed by the Ca^{2+} ions, representing 35% of the total ions and 68% of the total cations. The distribution of actions and anions in the Piper diagram showed calcic and magnesian bicarbonate facies represented by 75% of the water samples and calcic and magnesian sulfate chloride facies by 25% of the water samples (Fig. 3).

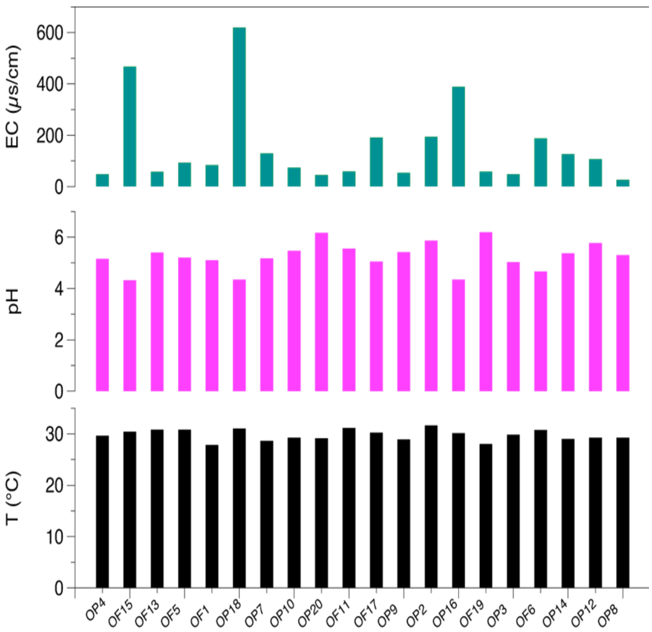

Fig. 2. *Physico-chemical parameters of water of study area*

Correlation matrix and water mineralization

The correlation matrix (Table 4) presents the relationships between the chemical elements analyzed based on the critical correlation coefficient (Suzanne, 2008). The correlations of the 20 groundwater samples analyzed from the study area showed significant correlations between some chemical elements and others did not (Table 4). The correlations observed between these elements could be explained by the fact that these elements evolved in the same way or had the same origin. The electrical conductivity showed a mineralization that ranged from the highest 618 µS/cm to the lowest 25.6 µS/cm. This can be explained by the short residence time of the water in the surrounding rock. Na□ and K□

Table 2. Drinking water quality classification range (Şahin Kiy and Arslan, 2021)

DWQI	Range of water type
< 50	Excellent
50 - 100	Good
100 - 200	Poor
200 - 300	Very poor
> 300	Unsuitable

Table 3. Data characteristics and type of analysis of water

Name	ID	T° (°C)	pH	EC (µs/cm)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	K^+ (mg/L)	Na^+ (mg/L)	HCO_3^- (mg/L)	NO_3^- (mg/L)	Cl^- (mg/L)	SO_4^{2-} (mg/L)
Bangda Nari	OP4	29.6	5.2	47.1	16.2	4.6	1.1	2.8	26.8	21.7	11	1.4
Chef canton	OF15	30.4	4.3	466	44.2	9.1	1.6	4.6	141.5	18.6	17	1.9
Ecole Jeanne	OF13	30.8	5.4	56.9	14.4	3.6	2.3	4.1	41.5	0.6	19.9	0
E.E.T N° 1	OF5	30.8	5.2	92.2	29.6	5.8	0.4	2.3	97.6	5.6	7.1	3.8
Foulbé	OF1	27.8	5.1	83.4	26.4	6	0.3	2.3	92.7	1.2	7.1	1.9
Gangda	OF18	31	4.3	618	55.4	11.5	1.3	4.6	153.7	29.8	23.1	1.9
Guelmar	OP7	28.6	5.2	128.4	35.8	7.9	1.4	2.8	126.9	6.2	10.3	2.9
Guelmbag	OP10	29.2	5.5	73.2	23.6	3.1	1.6	2.8	58.6	0.5	18.8	2.4
Geulmbah	OP20	29.1	6.2	43.8	14.2	2.4	1.6	3.2	19.5	16.7	11.7	5.3
Gouido	OF11	31.1	5.5	58.3	10.4	2.2	1.2	3.5	39	3.6	3.9	2.9
Hôpital	OF17	30.2	5	190.6	40.6	9.1	2	4.6	139.1	14.3	11.7	3.4
Kabba	OP9	28.9	5.4	53.2	8.8	2.2	0.8	3.2	36.6	2.5	3.9	1.9
Maimanane	OP2	31.6	5.9	193.2	30.2	5.5	0.8	3	80.5	13	12.8	2.9
Mairie	OP16	30.1	4.3	388	63.8	4.8	2	5.5	178.1	12.3	18.8	0
Marché	OF19	28	6.2	57.6	10.4	3.1	2.1	3.7	43.9	2.5	6.7	0
Mianmaida	OP3	29.8	5	46.9	8.8	2.9	1.6	3.2	41.5	1.9	6	4.8
Mianromel	OF6	30.7	4.7	186.7	36.6	7.2	2	4.4	122	13.4	9.9	0
Meurbeu I	OP14	29	5.4	125.6	23.2	5	1.6	3.5	92.7	3.1	7.8	1
Meurbeu II	OP12	29.2	5.8	106.4	22.4	3.8	1.2	3.5	78.1	6.2	9.9	1
Toura	OP8	29.2	5.3	25.6	7.2	3.1	0.4	3.5	24.4	0.5	17.8	0

Table 4. Correlation matrix of groundwater analysis results

	pH	CE	Ca^{2++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{--}	NO_3^-
pH	1									
CE	-0,7	1								
Ca^{++}	-0,66	0,86	1							
Mg^{++}	-0,58	0,78	0,78	1						
Na^+	-0,62	0,66	0,58	0,35	1					
K+	-0,13	0,12	0,13	0,01	0,62	1				
NH_4^+	0,55	-0,28	-0,33	-0,31	-0,27	-0,11				
HCO_3^-	-0,68	0,8	0,96	0,81	0,56	0,14	1			
Cl-	-0,46	0,58	0,5	0,37	0,5	0,26	0,34	1		
SO_4^{--}	0,19	-0,01	-0,04	-0,01	-0,26	0	-0,08	-0,06	1	
NO_3^-	-0,37	0,71	0,59	0,65	0,41	0,07	0,45	0,4	0,12	1

Table 5. Distribution of bacteria in the wells and boreholes of the study area

		Wells		Boreholes	
		Negative	**Positive**	**Negative**	**Positive**
Bacteria	*Total coliforms*	0%	100%	11%	89%
	Escherichia coli	27%	73%	78%	22%
	Fecal enterococci	64%	36%	100%	0%

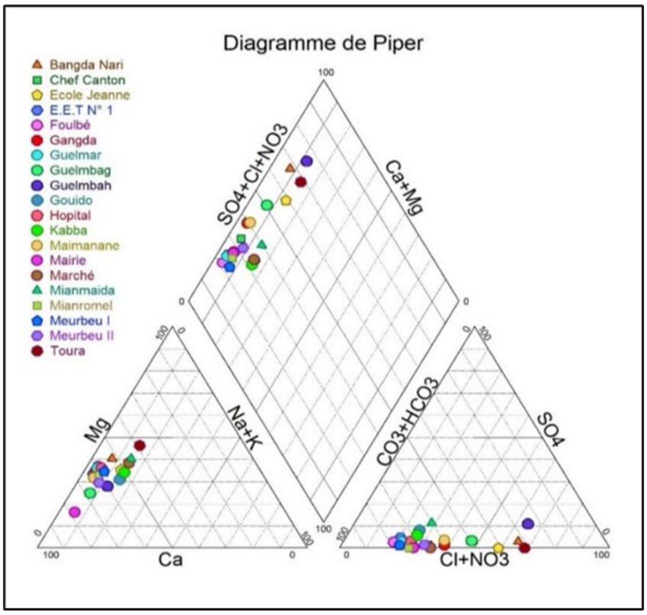

Fig. 3. *Piper diagram of Gagal groundwater*

were, therefore, well correlated and evolved similarly. Cl^- and Na^{+} ions were not correlated, so the hypothesis of halite dissolution was ruled out (Fehdi et al. 2009). The dominance of Ca^{2-} over Mg^{2-} can only be explained by geochemical phenomena such as isomorphic substitutions at the levels of the clay layers, $Ca^{2-} \leftrightarrow Mg^{2-}$ exchanges during precipitation or recrystallization reactions of calcite (Edmunds et al. 1987; Abderamane et al., 2013). This would also be due to the dissolution of calcium carbonate through the calcareous nodules. The ratio of Mg^{2+} to HCO_3^- gave a good correlation. This suggests that the magnesium originated from dolomitization formations or else from aragonite. The bicarbonates could be from the dissolution of atmospheric CO_2.

Bacteriological quality of water

Tables 5 presents the proportions of bacteria in the water from wells and boreholes in Ggal city. The total coliform content in the water varied from 0 to more than 135,200 CFU/100 ml. The density of *E. coli* varied between 0 and 14,400 CFU/100 ml and the density of enterococci varied between 0 and 4600 CFU/100 ml. All 11 wells sampled were 100% positive for total coliforms and 11% of the drilling was positive. Of the 11 wells sampled, 73% were positive for E. coli and 27% were negative. As for faecal Enterococci, the results appeared positive in 36% of the wells are contaminated; however, all the wells analyzed were negative, which is 100%. In the collected water samples, the total coliforms, *E. coli,* and faecal enterococci values were higher than the WHO standards (2011). This standard says that the total coliforms, faecal, and Enterococci density in water must be less than one colony unit formed per 100 ml of water (<1 CFU/100 ml). These values indicated a pollution of faecal origin and attested to pollution of bacteriological origin. This pollution was due to open defecation, poorly designed and poorly used latrines, the lack of a protective perimeter around wells, and the short distance between the well and the toilet (Ousmane, 1988; Yang et al., 2018).

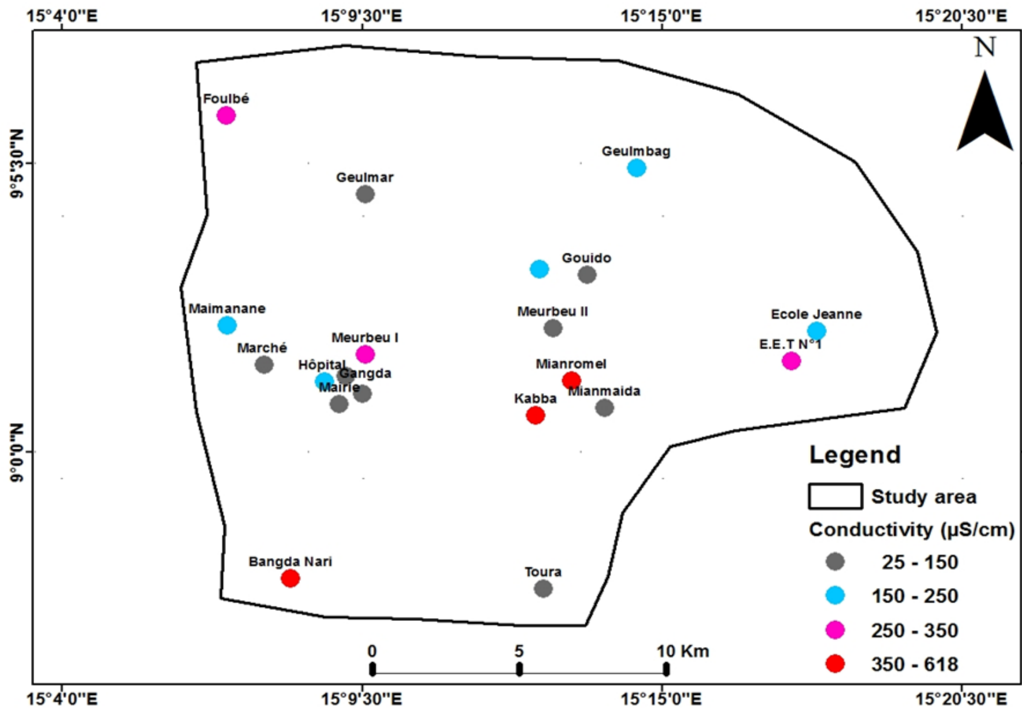

Fig. 4. *Spatial distribution of electrical conductivity for the city of Gagal and its surroundings*

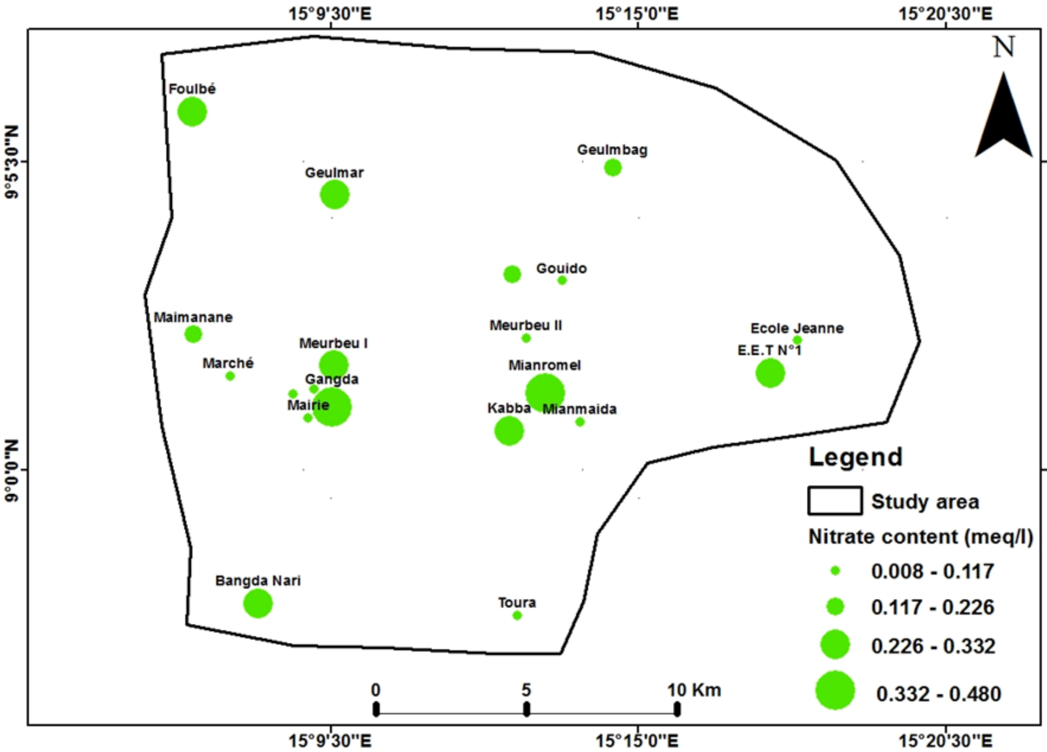

Fig. 5. *Spatial distribution of nitrates for the city of Gagal and its surroundings*

Table 6. Drinking water quality for the city of Gagal and its surroundings

DWQI	Percentage of waters points	Range of water type
< 50	10%	Excellent
50 - 100	60%	Good
100 - 200	30%	Poor

Therefore, water consumption in the town of Gagal could cause waterborne diseases.

However, comparing the measurements of bacteriological treatment efficiency indicators with the usual WHO standards showed that almost all the water studied (95%) was contaminated with faecal matter, requiring treatment before human consumption, except for the Marché well.

Drinking water quality (DWQI)

The DWQI values ranged from 47 to 174, averaging 88. The DWQ results showed that 10% of the region's water was in the excellent category, 60% in the good category, and 30% in the poor category (Table 6).

The strong anthropogenic footprint observed throughout the Lake Chad basin is an important phenomenon affecting Quaternary groundwater. Nitrate concentrations can be high in some wells and boreholes in the Lake Chad basin. The comparison of nitrate and K+ levels (Table 6) was interesting because it allowed to determine whether the sources of these elements were of anthropogenic origin or came from evaporation-dissolution processes. In the case of high nitrate concentrations, high K^+ concentrations were generally not observed, and in the case of high K+ concentrations, the corresponding high nitrate concentrations were not found. This meant that two different processes, namely natural and anthropogenic, could explain the origin of these elements.

Comparing the measurements of the physicochemical elements with the usual Chad and WHO (2011) standard, it can be said that almost all the waters studied had content below the permissible standards. These are EC, pH, calcium, magnesium, sodium, potassium, bicarbonate, chloride, sulfate, and nitrate. So the present study can deduce that the different parameters analyzed do not pose any problem of potability, but the fact that the presence of nitrates exceeded the standard of the WHO in the groundwater could indicate the vulnerability of these groundwaters. The presence of nitrates in groundwater can be attributed to wastewater from toilets that are usually close to boreholes or wells or root trees (Mahamat Nour et al., 2019, Şahin Kiy et al., 2021).

Conclusion

The hydrochemical and bacteriological characterization of the aquifer of the City of Gagal indicated some physicochemical parameters viz. Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^-, Cl^-, SO_4^-, and NO_3^- meet the WHO (2007) potability standards. The Piper diagram distinguished 2 hydrochemical facies, HCO_3^- calcic and Mg^{2+} facies representing 75% and a chloride sulfate calcic and magnesian facies 25% of the analyzed waters. This study showed that well and borehole waters were very vulnerable to bacterial pollution. The total coliform content in the water varied from 0 to more than 135,200 CFU/100 ml, the *E. coli* content varied between 0 and 14,400 CFU/100 ml and the enterococci content varied between 0 and 4600 CFU/100 ml. The water in the Gagal study area was polluted and contained high levels of microorganisms of faecal origin. Unfortunately, the populations of this area use this groundwater as drinking water. This represents a serious public health problem. A large-scale study of the quality of water resources in Nanaie County is also essential for assessing drinking water. These results would help in providing information to decision-makers and provide good quality water to the Gagal area's population in southwestern Chad .

Conflict of interest
The authors declare that they have no conflict of interest.

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