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Assessment of the physico-chemical and bacteriological quality of the waters of the quaternary aquifer of the city of Mao in Chad

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The objective of this work is to characterize the quality of drinking water in the city of Mao and its surroundings. This study is based on 20 water samples collected in the city of Mao and its surroundings between 2018 and 2020. The parameters considered are the physicochemical parameters (pH, T°, Electrical conductivity), major chemistry and bacteriological. The chemical analysis made it possible to highlight three types of chemical water facies: chlorinated and sulphated calcium and magnesium facies; a calcium and magnesian bicarbonate facies; and finally a sodium and potassium chloride or sodium sulphate facies. The results of the physico-chemical analysis are for the most part below the drinking water standard defined by the WHO/Chad except the boreholes of "*Fezan, the Eglise Cath, and Djougou N*" which have concentrations of nitrates above the standard set by WHO/Chad. Indicators of bacteriological pollution were identified in seven boreholes ("*Bozonga1, Hydraulique, Lycée A. Zezerty, Hopital, Governorat, Ecole N Inst, STE (Société Tchadienne des Eaux)*").

Key words: Assessment, Chad, Mao, Quaternaire aquifer, physico-chemical and bacteriology.

INTRODUCTION

Water is the major constituent of living matter (Harvey, 1950; Galiani et al., 2005; Molden, 2013). As a result, not only its availability but also its quality is becoming a major concern of populations around the world. It is a precious and very indispensable resource for living beings. However, it can also be a source of disease when pollution 'gets involved' (Shands et al., 1985; Fawell and Nieuwenhuijsen, 2003; Saha et al., 2013; Rajgire, 2013; Chaudhry and Malik, 2017; Mallongi et al., 2019).

Developing countries are the most affected not only by the problem of the quantity of water supplies but also by the quality of the water itself (Jiménez, 2006). In these countries the adequate structures for the prevention of water quality are insufficient, limited only to large cities(Tantawiwat et al., 2005; Gonzales, 2008).

Currently, in Chad, most of the population uses potable

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groundwater or even surface water without any prior treatment for consumption.

In the Kanem sector, the populations' need for drinking water is covered only by groundwater, either by the operation of open wells, or by human-powered boreholes.

The Quaternary aquifer of the Lake Chad basin covers an area of more than 500,000 km^2 (Bouchez et al., 2016; Goni et al., 2021) and occupies the center of the Chadian basin and separates from the underlying artesian aquifer of the Pliocene by a thick layer clay (Zaïri, 2008; Abderamane et al., 2013). This quaternary aquifer provides permanent water access to the local population (Schneider and Wolf, 1992; Moussa et al., 2020; Schneider and Wolf, 1992).

Mao, the main city of Kanem and the capital of the province, is supplied with water mainly by the Société Tchadienne des Eaux (STE) and some boreholes but there is a lack of qualitative information on the exploited waters. Cannot the galloping demography of the region and the development features which will be naturally affected to their socio-economic life influence the physico-chemical and bacteriological quality of the resource? To this question and were it not for the vagaries of the climate of these decades, must be added the lack of monitoring tools in the Mao sector, which constitutes a major problem for precisely characterizing the hydrochemical and bacteriological quality of this water table.

To date, few studies have been carried out to clearly diagnose the quality of drinking water in the city of Mao and its surroundings. The objective of this study is to provide knowledge on the state of play of the hydrochemical and bacteriological parameters of drinking water in the city of Mao and its surroundings to help decision-makers in their approach.

MATERIALS AND METHODS

Presentation of the site

Study zone

The Kanem is one of the 23 provinces of Chad whose capital is Mao. The province lies between 14 and 15th degrees East longitude and 13 and 14th degrees North latitude (Figure 1). The study site is restricted to the city of Mao and its surroundings and extends between 14.09° and 14.15° North and between 15.29° and 15.33° East.

Kanem province has 333,387 settlements (INSEED, 2009), that is, a density of 3 habitat/km^2, unevenly distributed in its three departments (Kanem, North Kanem and South Kanem). Economic activities are mainly based on agriculture, animal husbandry, trade, crafts and other less important occupations.

Climate framework

The climate is of the Sahelo-Saharan type throughout the area with a sub-desert tendency in the northern part. In the southern part, it transitions with the Sahelian climate.

The histogram of monthly average precipitation calculated over a period from 1988 to 2018 shows that the precipitation is marked by a strong irregularity. August is considered the rainiest month. Three quarters of rain fall in July and August. The monthly rainfall is between 0 and 73 mm (Figure 2). The annual rainfall at Mao station for the period from 1988 to 2018 shows that the annual heights vary from year to year around an average of 186 mm. The maximum recorded reached 368 mm in 2012 and the minimum 85 mm in 1989.

The average temperatures recorded in previous years vary from 30 to 42°C with an average of 37°C. The months of December to February are marked by a cold season and the months of March to June are marked by the dry season.

The value of evaporation is approximately of the order of 2500 mm/year in cumulative annual average. This value, which is several times greater than the annual precipitation, therefore plays a major role in the water balance.

Geological context

The geology of the study area corresponds to an old erg, oriented NNW-SSE, whose interdune hollows were invaded by water from a lacustrine transgression during which fine, clayey sediments were deposited (Schuster et al., 2005; Moussa et al., 2016). As you move away from the edge of Lake Chad, you gradually move north-east to a vast tabular area, the Bir Louri plateau, with less marked interdune depressions; these are once again getting very deep in Mao's region. Oriented NNW-SSE, these lakes are modest in size (1,000 to 1,500 m by 500 to 800 m) (Maglione, 1968; Servant, 1973; Ghienne et al., 2002; Abderamane et al., 2013; Bouchez et al., 2019). The Kanem presents an ancient erg (Upper Pleistocene) powerful and very extensive in the interdunes in which clays and diatomites were deposited (Holocene). They can be distinguished, according to their texture, several classes of soils, each with their particular constraints (Lannoy, 1991):

(1) Halomorphic soils which have no constraints, except when the water table is shallow. They then evolve towards more or less salty soils;
(2) Subdesert sands on sands;
(3) Vertisols with a clay texture, locally present a flooding constraint.

Hydrogeology

The hydrology of the province is characterized by the presence of units called “ouadis”. The latter are interdune depressions in the shape of a closed basin and of dimensions which vary between one and several tens of hectares.

The hydrogeological study of the study area shows the existence of three major aquifer systems in this basin, according to the work of Servant (1973), Roche (1980) and Olivry et al. (1996).

(1)The Quaternary water table is contained in: cracked clays (10 m at most), which line interdune depressions and aeolian sands which are likely to contain fossilized evaporite deposits;
(2) The intermediate Pliocene aquifer, the so-called "base" aquifer 75 m thick is in fluvial sands. In the center of the basin this water table is artesian.
(3) The lower aquifer or the deep aquifer of the Continental terminal is contained in fluvial sands, poorly classified, with ferruginous sandstone debris. The thickness of this formation is very variable, 200 to 300 m.

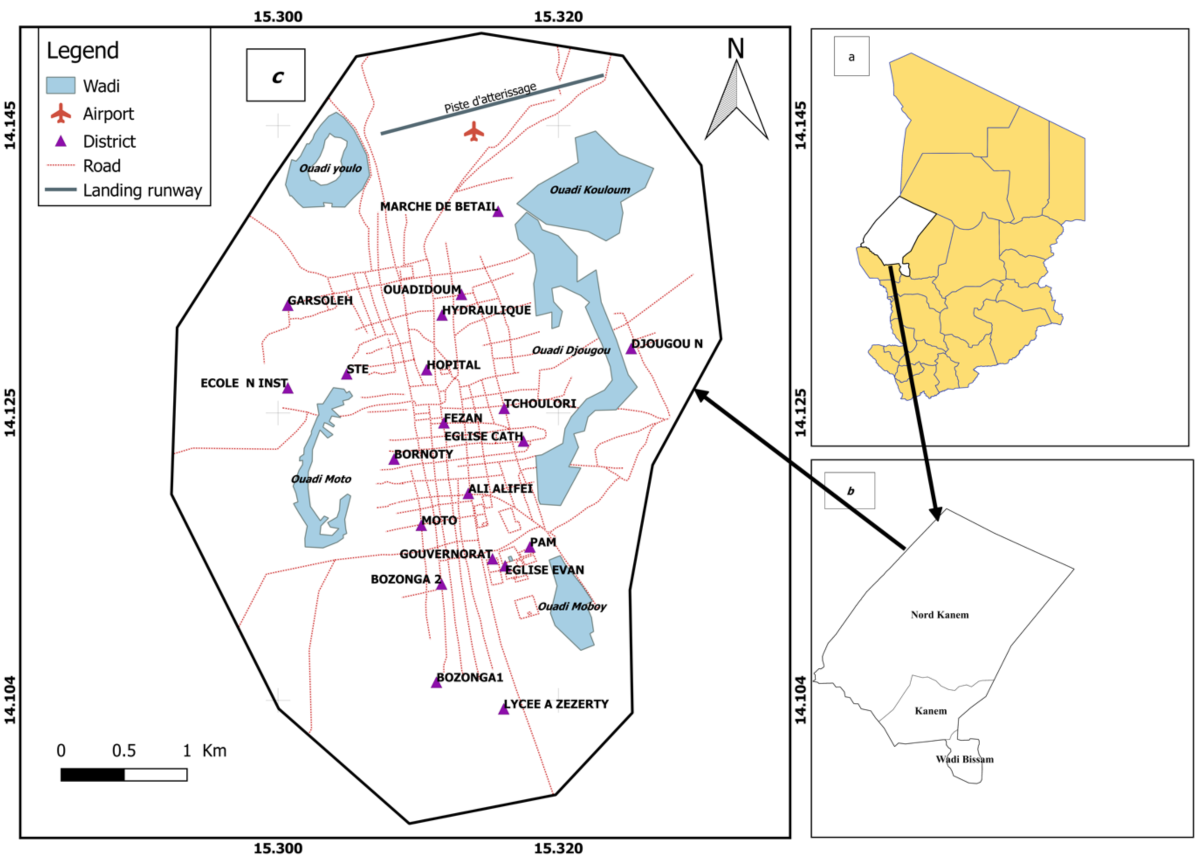

Figure 1. Location map of the study area: a) map of Chad, b) map of Kanem province, c) map of the study area. Source: IGN (1976).

Existing data collections

This study is based on existing data and new field data. The existing data concern the climatic, geological, hydrodynamic and hydrochemical data of the area which were provided by the Center for Documentation and Geographic Information (CDIG), the National Water Laboratory (LNE) and the National Research Center for the Development (CNRD) of Chad. Physico-chemical data from ten structures in and around Mao City in the National Water Laboratory's database were collected. These data were measured and sampled between February and July, 2018.

Water sampling and analysis

In addition to existing data, a field campaign was carried out from September 24 to 29, 2020 to sample 10 new structures (wells and boreholes).

***In situ* measurement of physicochemical parameters**

The physicochemical parameters such as: electrical conductivity, temperature and hydrogen potential were measured *in situ* immediately after taking water samples, using the various devices. The pH meter and conductivity meter. The uncertainties on the pH measurements are 0.1 units, on the electrical conductivity 10 µS/cm and on the temperature 0.5°C.

Sampling and analysis of water for chemistry and bacteriology

For the sampling, ten water points were chosen. Figure 1 shows their exact location in relation to the study area.

For the major elements, the samples were taken in polyethylene bottles, a material that only releases very few soluble elements and therefore does not alter the chemical composition of the stored samples. Two 60 ml bottles of water filtered through a 0.45 µm membrane were taken. The sample intended for cation analysis is immediately acidified to avoid precipitation of carbonates. These samples were analyzed at the National Water Laboratory (LNE). The major ions were determined, the cations (Ca^{2+}, Mg^{2+}; K^+ and Na^+) and the anions (Cl^-, NO_3^-, SO_4^{2-}, HCO_3^-). The various analyses are carried out essentially by volumetric assay and by a DR 3900 spectrophotometer.

Additional water samples were taken in 1-L bottles for bacteriological analyses. The following bacteriological parameters: total coliforms, faecal enterococci and total aerobic flora, *Escherichia coli* were considered during the analyses. According to the LNE protocol, the general principle for the analysis is as follows: take the sample and pour it into the funnel of the ramp, aspirate it with a pump allowing the sample to be filtered through a filter paper

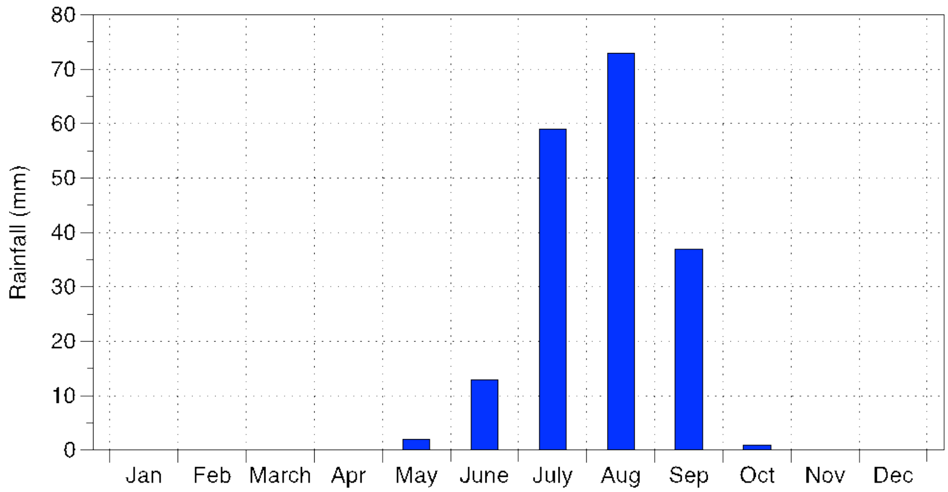

Figure 2. Interannual monthly mean rainfall in Mao station meteorological (1988-2018).

or membrane. Carefully place the filter paper with sterile forceps in a Petri dish to finally keep it in an incubator set at 37°C or 44°C for a specific time for each type of bacteria sought. Finally, read the result.

The operating mode is as follows:

(1) Sterilize all equipment located under the laminar flow hood with a bunsen burner;
(2) Install the ramp under the laminar flow hood;
(3) Take 100 ml of the sample and pour it into the funnel of the ramp;
(4) Start the pump to aspirate the sample from the vial located above the ramp;
(5) Carefully remove (without touching it with your hand) the filter paper with sterile forceps, and place it in the Petri dish (culture medium): chromocult and close the dish immediately;
(6) Number the Petri dish (date and number) for identification;
(7) Put the box in the incubator (set at 37°C for 24 h and at 44°C for 48 h);
(8) After the analysis, the medium must be sterilized with the materials for 10 min under a laminar flow hood with ultraviolet light.

The incubation time of the culture media are: chromocult and PCA: 24 h; Slanetz: 48 h. The culture media are specific to the bacteria sought: PCA for the total aerobic flora; Chromocult for *E. coli*; Slanetz for faecal enterococci (Faecal coliforms are detectable at 44°C and total coliforms at 37°C).

RESULTS AND DISCUSSION

Physicochemical parameters

The electrical conductivity of water illustrates variations in the mineralization of groundwater. The conductivity oscillates between 78 and 501 µS/cm with an average of 246 µS/cm (Figure 3a). This conductivity is moderate according to PIR (2016).

The temperature measured in the field varies between a minimum of 25°C to a maximum of 29°C with an average of 27°C. It approximates the average temperature of the ambient air, which could be explained by a thermal equilibrium with the aquifer system of the quaternary with the atmosphere. In most of the Sahelian regions at about less than 30 m depth, the groundwater temperature is roughly equal to the average air temperature (Ngounou, 1993).

The average pH content of the water sampled in the study area is around neutrality. It ranges between 6.25 and 8.93 with an average of 7.08. The minimum is observed at PAM with a value of 6.25 (Figure 3b). The water from this borehole has an acidic character and this water acidity could be linked to the dissociation of carbonic acid from atmospheric CO_2 dissolved in water and the renewal of this gas present in the water. In an open environment, the abundance of CO_2 in the soil maintains acidic pH while as soon as the environment closes (deep aquifer) the hydrolysis of the silicates consumes the acidity and the pH increases (Bourrié, 1978).

Chemical parameters

Statistic data

The statistical description of the chemical data of the groundwater of the city of Mao shows values strongly influenced by the extreme values (Figure 4). The minimum, average and maximum values are summarized in Figure 4. Analysis of this graph shows that Na and Cl are very variable for the sampled waters. These high values are observed in places and can be attributed to the process of water-rock interaction or by local

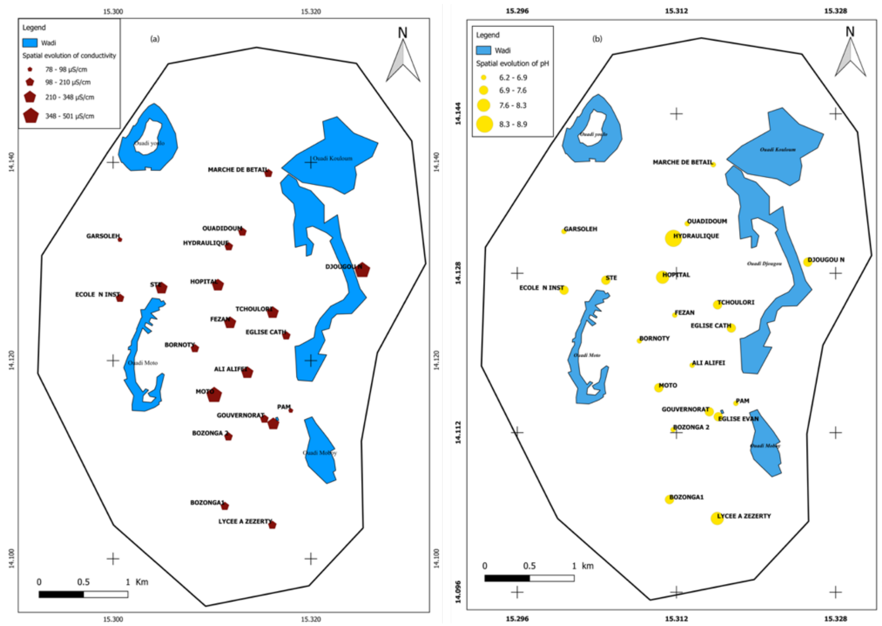

Figure 3. Spatial distribution of groundwater electrical conductivity and pH.

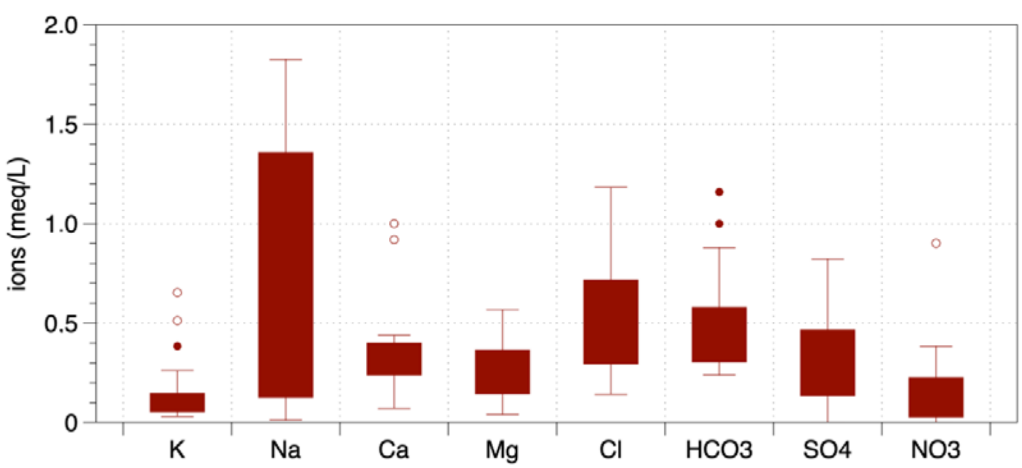

Figure 4. Statistical description of chemical data.

contaminations. K, Ca, Mg and NO_3 show less variability. The distribution of the main ions depends both on the intensity of evaporation processes and on the intensity of water-rock interaction processes, which is related to the residence time of groundwater.

Order of abundance of chemical elements

The cations present an order of abundance of the type: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ (Figure 5a). The sodium contents fall between 0.01 and 1.83 meq/L with an average value of 0.71 meq/L. The calcium contents vary from 0.07 to 1 meq/L and its average content is 0.36 meq/L. The magnesium concentrations are also little variable and between 0.04 and 0.57 meq/L with an average of 0.26 meq/L. The average potassium content is 0.16 meq/L. It shows a small variability with a minimum value of 0.04 meq/L and a maximum value of 0.51 meq/L. The anions present an order of abundance of the type: $Cl^- > HCO_3^- > SO_4^{2-} > NO_3^-$ (Figure 5b). Chlorides dominate all other ions with a variation between 0.14 and 1.18 meq/L with

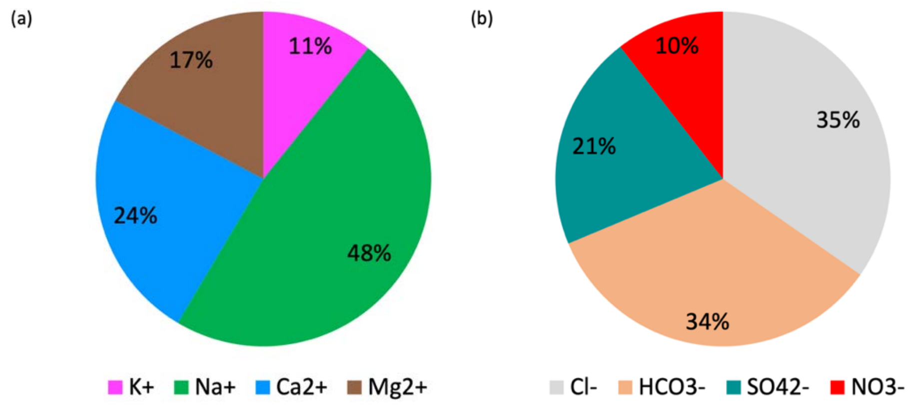

Figure 5. Order of abundance of chemical elements.

an average content of 0.51 meq/L. The bicarbonate concentrations vary from 0.24 to 1.16 meq/L with an average of 0.50 meq/L. Note that the sulphate concentrations are on average of 0.31 meq/L and nitrates on average of 0.16 meq/L. These values are relatively low with respect to chlorides and bicarbonates. Likewise, they are important in certain points, and we find that this phenomenon is linked to pollution from the surface of certain boreholes.

Spatial distribution chlorides

Figure 6a shows spatial evolution of chlorides. The chloride contents in the analyzed water are not very variable, they oscillate between 5 and 42 mg/L. The samples analyzed are all eligible for the WHO/Chad drinking water standard which limits chloride concentrations to 250 mg/L.

The chloride ion is an ideal tracer for demonstrating the dissolution of chloride salts and evaporation (Cook and Herczeg, 2000). The origins of such a geochemical organization are diverse. It could result from a variability over time in the chloride concentrations of the recharging poles of the free water table, or even precipitation; mineralization process within the reservoir: by dissolving sodium chloride minerals (halite: NaCl or sylvite: KCl). The chloride ion can also have an origin by the use of the amendment rich in chloride used in the polders of Lake Chad (Carmouze, 1976). According to sedimentary descriptions, no mention has ever been made of the presence of chloride salts within the Quaternary reservoir (Gear and Schroeter, 1973). However, salts have been described on the surface near Lake Chad (Carmouze, 1976). Therefore,it can be assumed that they were deposited by wind in the region and that they could represent a potential source of chlorides to the free water table.

Sulphate distribution

The sulphate contents in the water studied are not very variable, they oscillated between 0 and 39.5 mg/L (Figure 6b). This increase would probably be due to the leaching of the evaporite layers (gypsum, calcites, aragonites, etc.) of the geological bedrock (Abderamane, 2012) and all of which meet the WHO/Chad standard for drinking water which is less than or equal to 250 mg/L.

Spatial distribution of nitrates

Nitrates are the final stage of organic nitrogen oxidation, are soluble in water, and are found in low concentrations naturally in groundwater and surface water. The nitrate contents of the water samples analyzed vary between 0 and 55.9 mg/L (Figure 6c) with an average of 8.43 mg/L. The standard defined by WHO/Chad is less than or equal to 50 mg/L. A borehole exceeds the standard set by the WHO/Chad; it is that of the Catholic Church. This degradation appears to be due to human activity.

Chemical facies of the water in the study area

The chemical facies of the water are closely linked to the nature of the land crossed during the transit of the water as well as to the nature of the leached soils. The chemical elements projected on the Piper Diagram brought out three (03) types of chemical facies of water (Figure 7). The 45% chlorinated and sulphated calcium and magnesium facies: it is located in the following boreholes: "*Lycée A. Zezerty, Hydraulique, Tchoulori, Eglise Cath, Ali Alifei, Fezan, Moto* and *Ouadidoum*". These waters could be affected by evaporation, stagnant or stored in sediments containing gypsum (BGR, 2012). A 30% calcium and magnesium bicarbonate facies: It is present in the following boreholes: *"Bozanga1,*

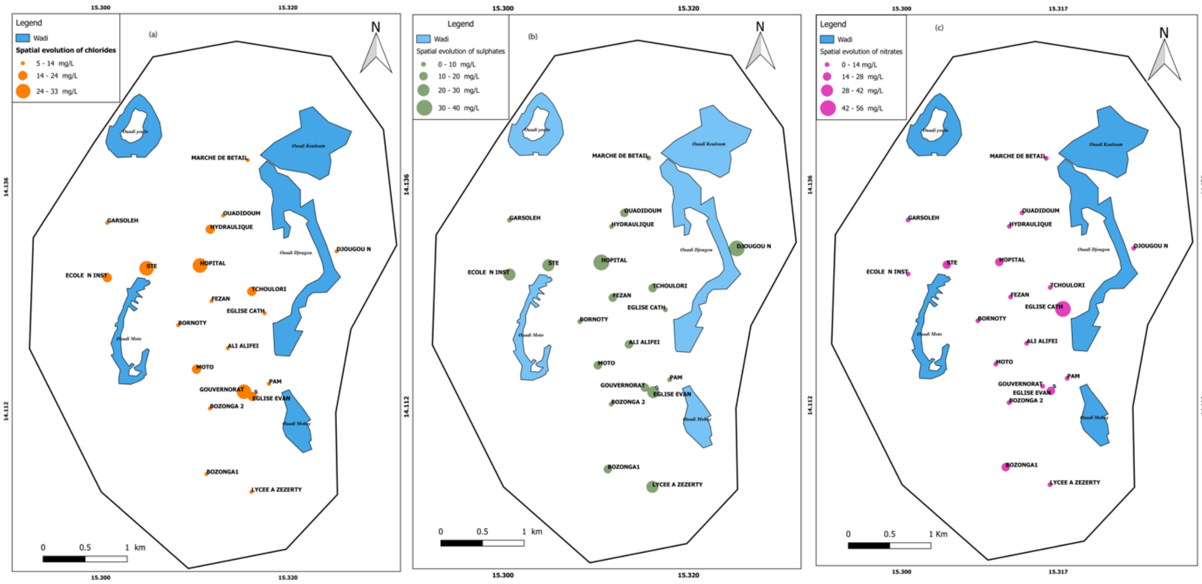

Figure 6. Spatial distribution of chlorides, sulphates, and nitrates in groundwater.

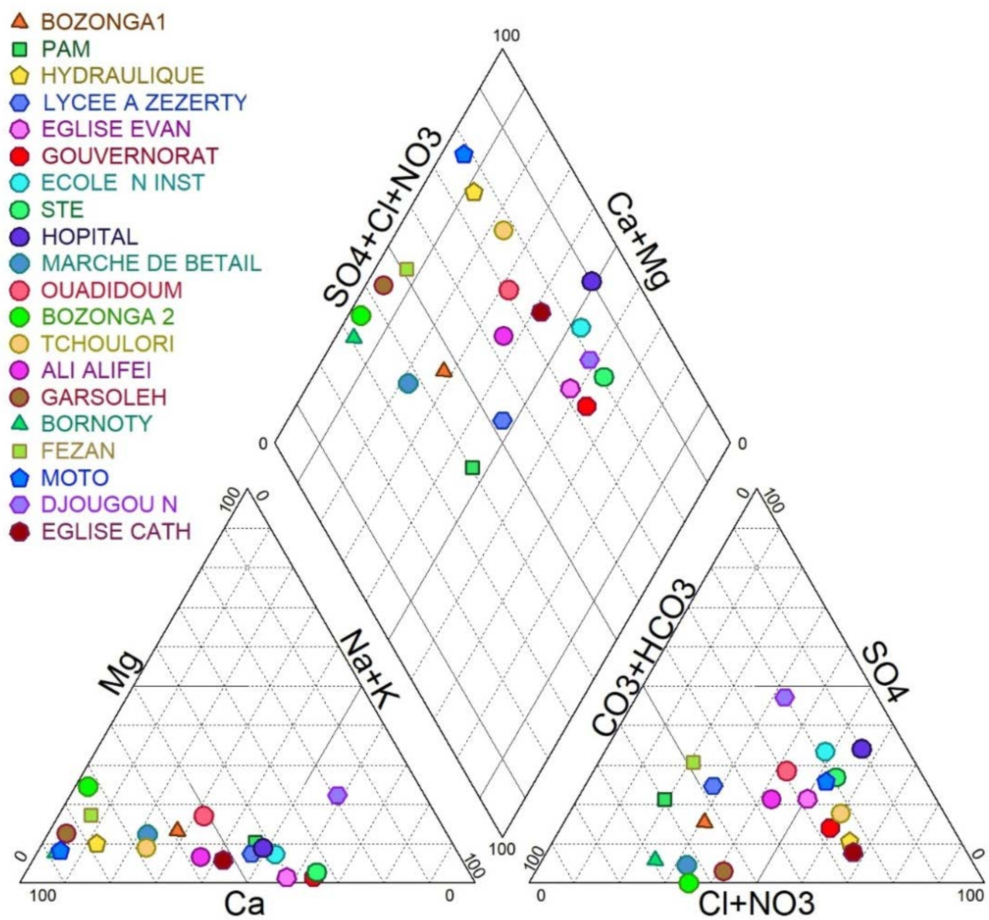

Figure 7. Groundwater piper diagram.

Table 1. Groundwater correlation matrix of Mao city and its surroundings.

Correlation	T°	pH	EC	NO_3^-	Na^+	Cl^-	Ca^{2+}	K^+	Mg^{2+}	HCO_3^-	SO_4^{2-}
T°	1										
pH	-0.56	1.00									
EC	0.02	0.19	1.00								
NO_3^-	-0.36	0.12	-0.08	1.00							
Na^+	-0.69	0.37	-0.12	**0.58**	1.00						
Cl^-	-0.42	0.59	0.29	0.12	**0.64**	1.00					
Ca^{2+}	0.12	0.06	0.14	0.05	-0.11	0.17	1.00				
K^+	0.19	-0.02	**0.69**	-0.25	-0.26	0.01	-0.19	1.00			
Mg^{2+}	0.14	0.14	-0.01	-0.12	-0.39	-0.39	0.01	0.00	1.00		
HCO_3^-	-0.03	-0.08	-0.33	0.10	0.22	-0.18	0.40	-0.27	0.22	1.00	
SO_4^{2-}	-0.64	0.38	0.46	0.15	**0.59**	**0.58**	-0.11	0.33	-0.13	-0.15	1

Bozanga2, Marché de Bétail, Garsoleh, Bornoty and *PAM*". This type of facies would correspond to the waters which are directly produced by precipitation (BGR, 2012). A facies sodium chloride and potassium or sodium sulphate 25%. This facies characterizes the borehole water from: *"Eglise Evan, Governorat, STE, Djougou N, Ecole N Inst* and *Hopital"*. This type of facies is characteristic of waters resulting either from evaporative phenomena, or from the dissolution of evaporitic formations.

Correlations between chemical elements

The linear correlations between the chemical elements make it possible to see the origin of the mineralization by evaluating the degrees of dependence between the various parameters concerned. The evaluation is done using correlation coefficients determined with statistical calculations. The correlation between two parameters will be significant when the correlation coefficient R will be close to the value 1. Thus, the correlations have been established between the chemical and physicochemical elements (Ouandaogo, 2008).

The correlations relate to the results of 20 analyses of our samples (Table 1). Analysis of this groundwater table shows that there is not a remarkable correlation between the chemical elements except Na vs Cl and Na vs SO_4, Cl vs SO_4, Na vs NO_3 and EC vs K.

This lack of correlation between the chemical elements could by the weak interaction of the geological matrix (sand and or sandy clay), the aquifer exposed to evaporation and to the contamination of certain parameters. These elements evolve very differently.

Bacteriological parameters

A total of ten (10) samples were analyzed, the results of which are shown in Table 2. The analyses focused on the search for the presence of pollution indicators such as: total coliforms, faecal enterococci, *Escherichia* parcels and total aerobic flora.

Total coliforms

Total coliforms are used as indicators of microbiological water quality because they can be indirectly associated with faecal pollution and are very important as indicators of treatment efficiency as well as indicators of decay bacterial after treatment (Bantin et al., 2020; Maheux et al., 2014; Sworobuk et al., 1987).

Total coliforms affected 7 boreholes (*Bozonga1, Hydraulique, Lycée A. Zezerty, Hopital, Governorat, Ecole N Inst* and *STE*), that is, 70% of the water analyzed and 3 unaffected boreholes (*Eglise Evan, Marché de Bétail and the one of PAM*) or 30% analyzed. The results are recorded in Table 2. The number of total coliforms obtained in the water analyzed is 15 to 110 CFU/100 ml. By seeing the positions of the various polluted boreholes in relation to their distances to the garbage dumps, latrines, and household waste in the city, this supposes that the source of this contamination comes from the infiltration water laden with organic matter via the latter (An et al., 2002; Ramteke et al., 1992). Because according to WHO/Chad, drinking water should not contain total coliforms, 0 CFU/100 ml. Boreholes declared negative are very far from latrines, garbage, and public landfills. The "*PAM*" drilling water analyzed is water treated by high-performance devices. The presence of this pollutant in the water can be the cause of water-borne diseases such as the risk of gastroenteritis (Fika, 2019).

The Escherichia parcels

E. coli bacteria are very abundant in the intestinal flora of

Table 2. Summary of bacteriological results (August 2020).

No.	Sample	*Echerichia coli* (UFC100)	Total Coliforms (CFU 100)	Fecal enterococci (UFC 100)	Total aerobic flora
1	Bozonga1	28	55	> 100	> 100
2	PAM	0	0	0	0
3	Hydraulique	38	> 100	> 100	> 100
4	Lycée A Zezerty	2	66	> 100	> 100
5	Eglise Evan	0	0	0	0
6	Governorat	0	77	> 100	> 100
7	Ecole N Inst	0	> 100	> 100	> 100
8	STE	31	15	> 100	> 100
9	Hospital	10	33	> 100	> 100
10	Marché bétail	0	0	0	0

The reference values for bacteriology are zero.

humans and animals. Their presence in water testifies to its contamination by faeces and may indicate the presence of pathogens (viruses, bacteria and parasites) responsible for water-borne diseases (Scott et al., 2002). The results of the analyses show that *E. coli* are present in 5 boreholes (*Bozonga1, Hydraulique, Lycée Alifa Zezerty, Hopital* and *the STE*), that is, half of the water analyzed is affected. The five (05) other unaffected boreholes are: *Eglise Evan, Marché de Bétail, PAM, Governorat, Ecole N Inst* (Table 2). According to observations made in the field, some boreholes drilled in the city do not respect the minimum distance of 30 m from the latrines. The presence of packages in the samples from the five affected boreholes leads to the conclusion that these boreholes are contaminated with faeces. Consumption of this water polluted with *E. coli* bacteria can cause illnesses such as diarrhea, vomiting and gastrointestinal illness. The results of the bacteriological quality of the analyzed samples showed that some water points are of poor quality, because the presence of these germs can be the cause of several water-borne diseases (Saha et al., 2013; Mallongi et al., 2019).

Faecal enterococci and total aerobic flora

Eglise Evan, Marché de bétail and *PAM* or 30% of the samples analyzed. Faecal enterococci are indicators of old pollution, their presence in water indicates that the contamination is due to enteropathogenic microorganisms which are the *Salmonella* responsible for typhoid disease. Aerobic flora are global germs that grow in the presence of oxygen at a temperature between 25 and 30°C. The presence of its bacteria would be due to the infiltration of water laden with organic matter to reach the water table. Fecal enterococci and total aerobic flora are present in 7 similar boreholes (*Bozonga1, Hydraulique, Lycée A Zezerty, Hôpital de Mao, STE Gouvernorat, Ecole N Inst*), that is, 70% of the water analyzed and absent in 3 boreholes.

Overall water quality

The study of pollution parameters gives an appreciation of the quality of groundwater, the overall quality of which will be interpreted based on a simplified grid by Nouayti et al. (2015). This grid includes three (03) parameters indicating physicochemical and chemical pollution which are (Table 3):

(1) Electrical conductivity which also provides information on the mineralogical quality of the water.
(2) Chloride ions which provide information on the mineralogical quality of water.
(3) Nitrates which are the main indicators of groundwater pollution.

The quality of chlorides in the samples analyzed is generally excellent, as the levels are less than 250 mg/L. The nitrate concentrations vary between 0 and 55.9 mg/L (Table 4), then most samples are of good to excellent quality. The quality of the Bozonga1 sample is average with a grade of 23.8 and that of the Catholic Church is poor.

The results of the samples analyzed showed the excellent quality of the conductivities and that of Djougou Nord which is good.

Conclusion

This work focuses on the hydrochemical and bacteriological characterization of drinking water. It allows

Table 3. Simplified grid for the evaluation of the overall quality of groundwater.

Appreciation	Settings		
	Electrical conductivity (µs/cm)	Chlorides (mg/L)	Nitrates (mg/L)
Excellent	<400	<50	<5
Good	400-1300	100 -150	May-20
Way	1300-2500	150 - 250	20 - 50
Bad	2500-3000	250 - 1000	50 - 100
Very bad	>3000	>1000	>100

Source: Nouayti et al. (2015).

Table 4. Overall quality of groundwater in Mao City.

Sample	Electrical conductivity (µs/cm)	NO_3^- (mg/L)	Cl^- (mg/L)	Overall quality
Bozonga1	175	**24**	10	Way
PAM	78	0	5	Excellent
Hydraulique	169	4	25	Excellent
Lycée A Zezerty	197	9	16	Good
Eglise Evan	244	17	26	Good
Governorat	206	9	42	Good
Ecole N. Inst	144	13	19	Good
STE	249	15	35	Good
Hopital	242	20	37	Good
Marché de bétail	166	0	16	Excellent
Ouadidoum	173	3	15	Excellent
Bozonga 2	147	2	5	Excellent
Tchoulori	348	9	20	Good
Ali Alifei	308	2	15	Excellent
Gardoleh	98	6	7	Good
Bornoty	133	3	11	Excellent
Fezan	264	0	6	Excellent
Moto	427	0.2	27	Excellent
Djougou N	501	1.5	15	Good
Eglise Cath	210	56	12	Bad

to visualize the current situation of the groundwater of the city of Mao and its surroundings.

Analysis of the chemical quality of the water reveals that some samples exceed the values accepted by the WHO/Chad for nitrates. Bacteriological analysis shows that seven out of ten samples are contaminated by germs of faecal origin, so this water should not be consumed. This pollution constitutes a health hazard for the inhabitants who use these waters.

The chemical analysis allowed to identify three types of chemical facies: the chlorinated and sulphated calcium and magnesium facies 45% which is dominant followed of the facies calcium and magnesium bicarbonate 30%, then facies sodium chloride and potassium or sodium sulphate 25% which is of low proportion.

In view of these results, it is judicious to complete this work with an in-depth hydrodynamic study at the scale of the entire water table in the region to know the direction of the overall flow and to carry out a hydrogeochemical and isotopic study would make it possible to determine the origin of the recharge water.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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