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Hydrogeochemical and Microbiological Characterization of Groundwater in the Maïné-Soroa Commune

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ABSTRACT

The Quaternary aquifer, mainly known as the Manga aquifer, is one of the groundwater reserves used to supply drinking water in the commune of Maïné-Soroa. This study assessed the physio-chemical and bacteriological quality of the groundwater and determined the origin of its mineralization. Twenty-two (22) samples were taken from 22 different water points (8 wells and 14 boreholes), of which twelve (7 wells and 5 boreholes) of the 22 samples were subjected to bacteriological and physicochemical analyses. The data collected were then subject to multi-variate statistical analyses, including Normalised Principal Component Analysis (NPCA) and Hierarchical Ascending Classification (HAC). The results of this study showed that the water table temperature varies between 30°C at Issari Bagara and 36.6°C at Konkondo, with an average value of 32.64°C. Electrical conductivity ranged from 125.1 µS/cm at Konkondo to 2080 µS/cm at Aridi, with an average value of 724.89 µS/cm. Water pH values range from 5.69 at Barmadi to 8.47 at Kil peulh, with an average of 6.83. Overall, the water is moderately mineralized and rather hard (TH), with an average of 243.17 mg/l. Most of the water in this aquifer has physicochemical parameters that do not exceed WHO standards. The cation-anion combination shows that groundwater is predominantly sodium-potassium chloride or sodium-sulfate (59.09%), sodium-potassium bicarbonate (36.26%) and, to a lesser extent, calcium-magnesium chloride and sulfate (5.54%). Principal Component Analysis and Hierarchical Ascending Classification show that mineralization of the waters studied is controlled by two major phenomena: anthropogenic surface inputs (pollution) and water-rock interaction, including hydrolysis of silicate minerals. Bacteriological analysis revealed that 33.33% of the water studied was of poor quality. These results show that most of the structures are poorly protected and could be polluted by human or animal waste.

INTRODUCTION

Preserving the quality of the environment is one of the concerns of our societies at the eve of the 21st century. The combination of the consequences of climate change and the deterioration of the natural environment, particularly water resources, has gradually become a global concern.

In Africa, groundwater in urban and rural areas is subject to multiple constraints due to strong demographic growth and the inadequacy, or even the absence, of sanitation (GROEN.C et al, 1988, BOUBAKAR.H, 2010). Sewerage systems, septic tanks, urban and industrial wastewater and solid waste are the main sources of groundwater pollution in urban areas, while in peri-urban and rural areas, the use of agricultural inputs contributes significantly to the degradation of groundwater and surface water quality. In Niger, demographic growth has resulted in an increase of the population primary needs, including access to drinking water in urban and rural areas, and the increase in the production of wastes of all kinds. Studies carried out on water resources in Africa (KOUASSI ERNEST.A et al 2008, 2010 and 2012; BOUBAKAR.H, 2010) have identified numerous sources of pollution, both surface and groundwater, in several localities including the commune of Maïné-Soroa in south-east Niger, where irrigated agriculture is practiced along Komadougou River. This exposes water resources (both surface and groundwater) to various types of pollution, notably through the excessive use of fertilizers and pesticides, but also through the dumping of waste at the refugee sites, in this commune, with the advent of the Boko Haram crisis. Two major aquifers are tapped in the commune of Maïné-Soroa to supply the local population with water. These are the deep Pliocene aquifer or middle groundwater and the Quaternary groundwater, also known as the Manga aquifer. The Pliocene aquifer, which is fossilized, is a major water reserve in the area. However, it is tapped in areas where the groundwater is of poorer quality (LEDUC.C et al, 1998).

However, data analysis results from studies recently carried out in Niger by BOUBAKAR.H (2010), VASSOLO.S (2015), ZABEIROU.H et al, (2020) have revealed risks of pollution of groundwater resources, particularly by nitrogen compounds and bacteria.

This study focuses on characterizing the water physio-chemical and microbiological parameters in the Manga aquifer in the commune of Maïné-Soroa.

The methodology used is based on the determination of the hydrogeochemical classification of groundwater using the Piper diagram and the use of multivariate statistical methods, in particular, the Principal Component Analysis (NPCA) and the Hierarchical Ascending Classification (HAC).

STUDY AREA PRESENTATION

Location of the urban commune of Maïné-Soroa

The urban commune of Maïné-Soroa is located in the department of the same name, in the Diffa region of southwest Niger. It is bounded to the east by the commune of Chétimari, and to the west by that of Goudoumaria. To the north, it borders the communes of N'guel Belly and Foulatari, and to the south on the state of Yobé (Federal Republic of Nigeria) for more than 30 km, whose natural border is the Komadougou Yobé river. The study area belongs to the Sahelian zone, whose rainfall is characterized by great spatio-temporal variability, and whose vegetation consists of steppes (arborescent, shrubby, and grassy) with a strong presence of typical Sahelian species (PDC, 2014).

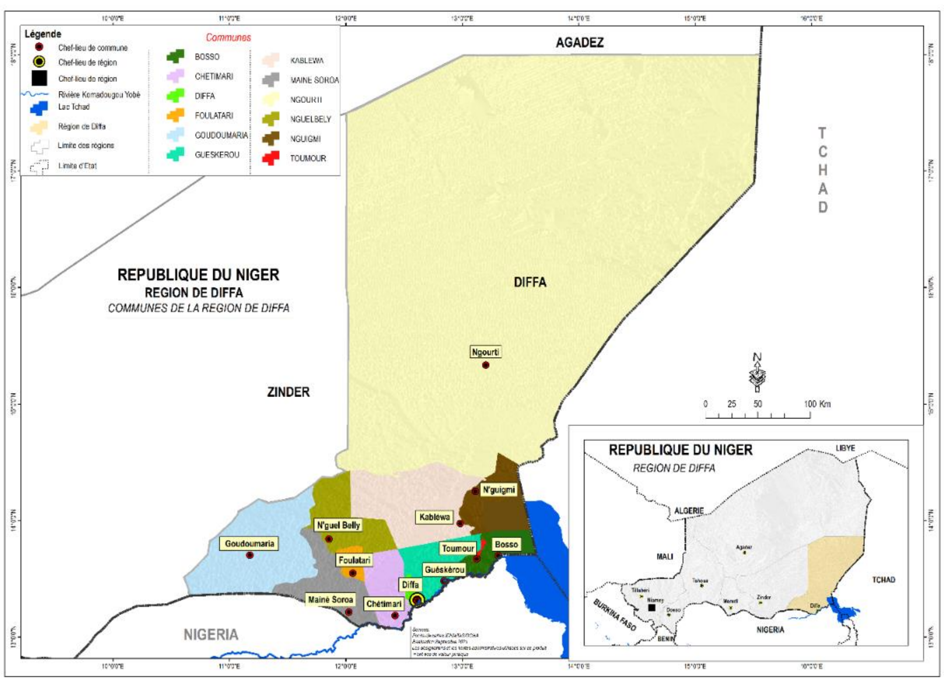

Figure No. 1: Location map of the urban commune of Maïné-Soroa

The Geological and hydrogeological context

Quaternary deposits dominate the outcropping geological formations. There are alluvial deposits from the Kadzel, as well as current deposits from the Komadougou Yobé (clay and silt) and a sandy plateau made up of a few rare red dunes in the northern part of the municipality. The Komadougou Yobé (PLEA, 2017) crosses the southern part of the study area. The main reservoirs are the Manga water table or Quaternary water table, the Pliocene water table or middle water table, and the deep water table under pressure. The free Quaternary aquifer uninterruptedly covers the Manga and Kadzel. Of continental origin, the Quaternary deposits are characterized by great spatial and vertical heterogeneity. The few silty or clayey levels encountered in the Quaternary do not have sufficient lateral extension to give the water table a captive character. It is considered free throughout the basin (UNDP-FAO-CBLT, 1973, in ZAIRI. R, 2008). It is the main source of drinking water for the commune of Maïné-Soroa. According to recent isotopic studies carried out in the region, the free Manga water table is very little replenished (3mm/year) (LEDUC.C & al, 1998, GAËLLE., 2004, in ZAIRI. R, 2008).

MATERIAL AND METHODS

Material

Several tools were used to collect and analyze the data for this study.

These included:

✓ Equipment for in situ measurements of physical water parameters (conductivity meter, pH meter, thermometer);

✓ Polyethylene bottles for taking samples for chemical parameter assays in the laboratory;

✓ Laboratory equipment including the DR/2000 spectrophotometer and the WAGTECH/7100 flame photometer, for the determination of chemical parameters;

✓ Laboratory materials (beaker, Erlenmeyer flask, burette) and specific reagents for each chemical element.

Tools for bacteriological analysis, including:

✓ A vacuum filtration system comprising: a vacuum pump, filtration funnel, funnel clamp, filter support, receiving flask with tubing;

✓ A sterile white cellulose nitrate filter membrane with black grid (porosity 0.45µm);

✓ Sterile petri dishes with absorbent pad used as microbe culture media;

✓ An autoclave to sterilize the pipettes, 70% ethanol to sterilize the handling area, as well as sterilized gloves to avoid contamination during sampling;

✓ distilled water to inhibit the culture medium and finally an incubator for the bacteria.

Software for data processing, including mapping (ArcGIS), statistical analysis (Minitab14), and hydrochemistry (Diagrams).

Methodological approach

Sampling

A sampling campaign was carried out at twenty-two (22) water points, twelve (12) of which were subjected to bacteriological analysis. The water points sampled were distributed in such a way as to spatially represent the entire study area. Samples were taken from eight cemented wells (08) and fourteen (14) boreholes, all tapping the Manga water table. Samples were taken from wells in operation (at least 30 minutes of pumping or drawing), and at standpipes, in order to obtain a fairly representative sample of the water table. The walls of the standpipe are pre-sterilized with 90° alcohol. Samples are taken in polyethylene bottles, rinsed with the water to be analyzed, then resealed hermetically without allowing air bubbles to pass through. They are then stored for 24 hours at 25°C, before being transported to the Water Quality Monitoring and Control Laboratory of the Regional Directorate of Hydraulics and Sanitation (DRH/A) in Diffa. For bacteriological analysis, sampling was carried out in such a way as to avoid any accidental contamination. Sampling is carried out by placing the sterilized bottle under the stream of water to be sampled. Once filled, the bottle is carefully recapped and placed in a cooler containing ice trays, before being transported to the laboratory. To avoid contamination and ensure that the water is fairly representative, it is advisable to hold the bottle by the bottom and allow the water to drain for one minute before sampling. Bacteriological analysis was carried out 48 hours after sampling, while certain chemical parameters (TAC, TH, Ca^{2+}, Mg^{2+},K^{+}, Na^{+}, HCO_3^-, NO_2^-, NO_3^-, F^-, Cl^-, SO_4^{2-}et FeT) are determined in the laboratory within the same week.

Methods of analysis

Several analytical methods were used in the present study, including spectrophotometry for the determination of Nitrates (NO_3-), Nitrites (NO_2−), Sulphates (SO_4^2-), Fluorine (F-), and total iron, and volumetric for calcium ions ($Ca2^+$), magnesium ions (*Mg2+*), chlorides (Cl-), TH and Total Alkalimetric Title (TAC). Finally, flame photometry was used for potassium (K^+) and sodium (Na^+) ions. Bicarbonate ions ($HC03^-$), are calculated from the TAC and pH.

The physical parameters (pH, EC and T) were measured in situ, during the sampling campaigns, using a pH meter and a conductivity meter equipped with a temperature probe (temperature and conductivity).

Microbiological analyses

The germs sought in this study are faecal coliforms (Escherichia coli) and total coliforms.

The bacteriological analysis concerned twelve (12) water points, including eight (8) cemented wells and five (5) boreholes tapping the Manga aquifer. The samples taken were subjected to bacteriological testing in the laboratory using the AquaSafe MSL50. The method consists filtering 100ml*2 of water through two porous membranes (filters), one of which is used to determine faecal coliforms and the other total coliforms. The bacteria present in the sample are retained on the surface of the filter. The filter is then transferred using forceps to a rehydrated culture medium placed in a petri dish. The seeded petri dishes were then placed in a bacteriological oven and incubated at 37°C for 18 hours for total coliforms and 44°C for 24 hours for faecal coliforms. The nutrients in the medium penetrate through the filter pores to feed the bacteria. During incubation, each bacterium develops and gives rise to a colony. The colonies found on the surface of the filter are then counted using a colony counter. Their number corresponds to the quantity of bacteria present in the sample.

Data processing

Statistical analysis of the hydro-chemical data, based on the quantitative description, in particular the minimum, maximum, mean, standard deviation and coefficient of variation, was carried out using Minutab14 software.

The minimum (Min) and maximum (Max) represent the largest and smallest values in the sample, respectively. *The arithmetic mean (Avg)* is a quantitative series defined by the sum of the observed values, divided by the total number of people, while the *standard deviation* corresponds to the square root of the observed variance. The *coefficient of variation (CV)* indicates the dispersion of the numerical variable used in the analysis. It is equal to the ratio of the standard deviation to the mean. The higher the value of the coefficient, the greater the dispersion around the mean. Once the analytical results had been verified and validated by calculating the ionic balance, they were processed mainly using statistical techniques and diagrams.

Multi-variable statistical analysis

A statistical approach, based on the use of the bi-variable correlation matrix, Principal Component Analysis (PCA) and Hierarchical Ascending Classification (HAC) was used to better assess the influence of ions on water mineralization and thus determine the various phenomena at the origin of this mineralization.

The bi-variable correlation matrix

Bivariate analysis is used to highlight the relationships between ions taken in pairs, on the one hand, and their contribution to the hydrogeochemical evolution of the water, on the other. These relationships are illustrated by a so-called linear correlation coefficient, ranging from -1 to 1. The closer the coefficient is to the extreme values -1 and 1, the stronger the linear correlation between the variables. The sign of the coefficient indicates the direction of the relationship. If the two variables tend to increase or decrease together, the coefficient is positive, and if one variable tends to increase while the other decreases, the coefficient is negative (Grasland. C, 1998; Ricco. R, 2017).

Principal Component Analysis (PCA)

This technique makes it possible to summarize the maximum amount of information contained in a mass of data onto a few factorial axes. The projection of individuals onto a factorial plane offers the advantage of apprehending the similarity or opposition between the characteristics of individuals and the sources of their variability (ABDOU BABAYE. M.S et al, 2016). In this study, Principal Component Analysis was performed on 15 variables: C.E, le pH, T°, Mg^{2+}, TH, Ca^{2+}, K^{+}, Na^{+}, HCO_3^{-}, NO_3^-, NO_2^-, Cl-, SO_4^{2-}, F^{-} et le FeT. It was carried out using Minitab 14 software.

Analysis by Ascending Hierarchical Classification (AHC)

Hierarchical Ascending Classification highlights the phenomenon behind the mineralization of groundwater, but also the similarities and graphical positions between two or more chemical variables as they evolve.

Method for determining the main hydro-chemical facies

The different chemical facies of groundwater were determined using the Piper diagram (1944). This is used to characterize the geochemical facies of water based on the various major elements. The diagram is composed of two triangles representing anionic and cationic facies, followed by a rhombus synthesizing the overall facies. The point clouds concentrated in one pole represent, for the different samples, the combination of cationic and anionic elements (BEN YAZZA A, 2014). This diagram is frequently used in hydrochemistry to determine water facies with very good results (AHOUSSI K. et al, 2010; 2013).

RESULTS

The geolocation of the sampling sites provides an overview of the spatial distribution of the samples used for the various tests and analyses in the laboratory. The sampling sites are shown in figure No.2.

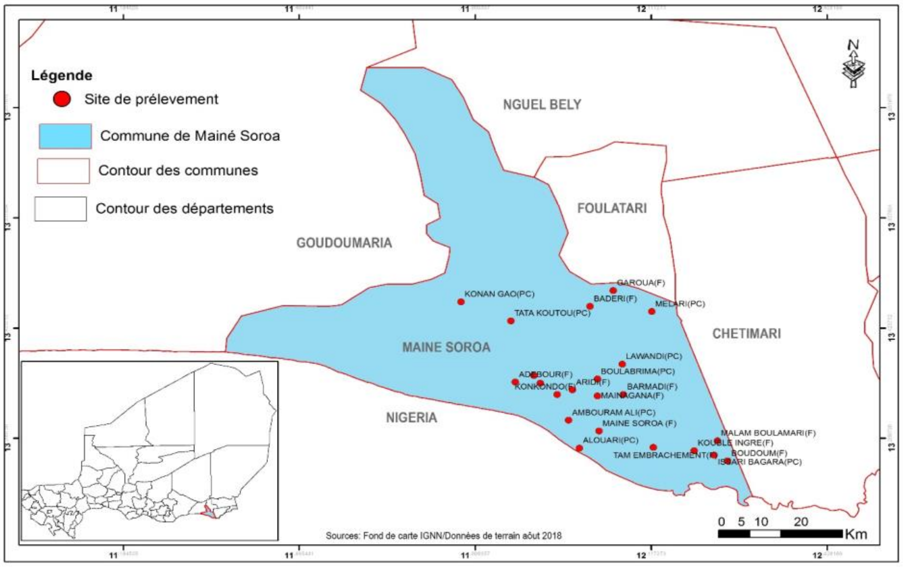

Figure No. 2: **Distribution of sampling sites**

Descriptive statistics results

The statistical results for the physio-chemical parameters are given in Table No. 1. The choice of these two parameters gives us an idea of the quality of the water as well as the chemical elements present in solution.

Table No. 1: Statistical treatment of physicochemical results for municipal waters

Physicochemical parameters	Units	WHO standards 2017	Min(m)	Max(M)	Deviation-T(α)	Avg (µ)	C V (α/µ)
CE	µS/cm	≤400	125,1	2080	593,77	724,89	0,82
PH	-	6,5-8,5	5,69	8,47	0,52	6,83	0,07
T	°C	-	30	36,6	1,42	32,64	0,04
FeT	mg/l	0,3	0	1,47	0,38	0,18	2,07
Cl-	mg/l	250	4	544	144,19	95,81	1,5
SO_4^{2-}	mg/l	400	3	520	145,99	119,13	1,22
NO2-	mg/l	3	0	3,3	0,94	0,57	1,59
Ca^{2+}	mg/l	100	1,6	352	71,06	70,32	1,01
TH	mg/l	500	4	1200	247,55	243,27	1,1
Mg++	mg/l	50	0	77,76	17,39	11,86	1,46
HCO_3^-	mg/l	250	48,8	409,92	90,60	147,28	0,61
K^+	mg/l	12	3,4	22	4,09	7,71	0,53
$NO3^-$	mg/l	50	3,96	151,8	36,44	28,16	1,29
F-	mg/l	1,5	0	0,77	0,23	0,4	0,57
Na+	mg/l	200	86,01	1033,24	249,42	300,49	0,83

Analysis of table No. 1 shows that the maximum electrical conductivity value is 2080 µS/cm, and is recorded at the Aridi borehole, while the minimum value is 125.1 µS/cm. The mean value is 724.89µS/cm and a standard deviation of 593.77µS/cm. The coefficient of variation of around 0.82 reflects the wide variability in the distribution of the mineral load of the water, linked to the lithology and point source pollution. PH values range from 5.69 to 8.47, with an average of 6.83. The coefficient of variation is 0.07. Water temperatures range from 30°C to 36.6°C, with an average of 32.64°C. The coefficient of variation is low at around 0.04.

Chemical parameters

Anions

Nitrate (NO3-) concentrations in the Manga water table vary from 3.96 mg/l to 151.8 mg/l with an average value of 28.16 mg/l and a coefficient of variation of around 1.29. For nitrite (NO_2^-), the highest value was 3.3 mg/l. The results obtained show that most of the samples taken met the standard recommended by the WHO (3mg/l for nitrite and 50mg/l for nitrate). Values above the standard indicate the existence of an anthropogenic source for these ions. The sulphate (SO_4^{2-}) content varies between 520 mg/l and 3 mg/l, with an average value of around 119.13mg/l and a coefficient of variation of 1.22. All the boreholes and wells meet the standards recommended by the WHO, with the exception of Garoua, where the value is over 400 mg/l.

Fluoride concentrations (F^-) ranged from 0.77mg/l to 0mg/l, with an average value of 0.40mg/l. As for chlorides (Cl^-), the highest value is 544mg/l and the lowest is 4mg/l. The maximum value for bicarbonate (HCO_3^-) is 409.92mg/l, and the minimum is 48.8mg/l.

The average obtained is 147.28mg/l and the coefficient of variation is around 0.61.

Cations

Potassium *(K^+)* is the least abundant element, with a maximum value of 22mg/l and a minimum of 3.4mg/l. The mean value obtained is 7.71mg/l, and the coefficient of variation is approximately 0.53. With regard to sodium (Na^+), the highest value recorded was 1033.24mg/l, while the lowest was 84.28mg/l, for an average of 300.49mg/l and a coefficient of variation of around 0.83. Calcium (Ca^{2+}), concentrations range from 1.6 mg/l to 352mg/l, with an average value of 70.32mg/l and a coefficient of variation of 1.01. For magnesium (Mg^{2+}), the highest value observed was 77.76mg/l. The mean value was 11.86 mg/l, with a coefficient of variation of 1.46.

Trace metals

The trace metal element considered in this study is total iron (FeT). The water in the Manga aquifer has low concentrations of iron. Levels vary from 0 mg/l to 1.47 mg/l, with an average of 0.18 mg/l and a coefficient of variation of 2.07. Overall, most of the water analysed had a total iron content below the WHO standard (0.3 mg/l).

Other parameters studied

The total hardness or hydrometric titer (TH) of the water sampled at the various sites varied between 4 and 1200mg/l, with an average of 243.27mg/l. The coefficient of variation is approximately 1.1. For all the water points studied, the TH is lower than the guide value recommended by the WHO (2017), which is 500mg/l, with the exception of the Alouari well and the Aridi borehole, with 1200mg/l and 772mg/l respectively.

Microbiological parameters of the water

Bacteriological analysis was carried out on twelve (12) water points, including seven (7) cemented wells and five (5) boreholes. The elements analysed were total coliforms and streptococci, for which the WHO limits are 3/100 ml and 0/100 ml respectively. The results of the analysis are shown in table No.2.

The classification made according to the different classes identified by the WHO shows that the waters of the Manga aquifer fall into the following three classes:

✓ Class I, which corresponds to water of good quality. This category represents approximately 25% of the water analysed and concerns two (2) boreholes (BADERI and MAINAGANA) and one cemented well (KONAN GOA).

✓ Class II is that of water of poorer quality, and represents approximately 42% of the analyses. This category concerns Five (5) sampled works including two (2) boreholes and three (3) cemented wells.

✓ Class III, which corresponds to poor quality water, concerns only cemented wells. It represents approximately 33% of the water sampled.

The results of this study show that the structures showing signs of contamination are mostly cemented wells, and are used for human consumption and pastoralism. Animal faeces carried by the wells and/or the return of surface wastewater to these structures could be the source of this contamination. Table 2: Results of bacteriological analyses.

Table No. 2: Results of Bacteriological analysis results

VILLAGES	FECAL COLIFORMS	TOTAL COLIFORMS
BOUDOUM(F)	26	12
ISSARI BAGARA(C)	300	250
KONAN GOA(PC)	0	0
AMBOURMA ALI(PC)	400	300
BADERI(F)	2	0
TATA KOUTOU(PC)	0	26
MELARI(PC)	0	200
ALOUARI(PC)	100	50
MALAM BOULAMARI(F)	26	30
MAINAGANA(F)	0	0
BOULABRIMA(PC)	200	150
LAWANDI(PC)	100	0

Hydro-chemical classification of groundwater

The chemical classification of Manga aquifer waters (Figures 3 and 4) shows a wide range of chemical facies, with sodium sulfate facies predominating (59.09%), followed by sodium and potassium bicarbonate facies (36.26%). Chloride, calcium and magnesium sulfate facies are poorly represented at 4.54%.

The order of abundance of anions in the waters of the Manga aquifer is as follows:

$$SO_4^{2-} > HCO_3^- > Cl^- > NO_3^- \text{ or } HCO_3^- > SO_4^{2-} > Cl^- > NO_3^-.$$

This has enabled us to identify the two main groups of waters in which sulfate is dominant in the waters of the northern part and bicarbonate in those of the southern part. For cations, the order of importance is $Na^{+} > K^{+} > Ca^{2+} > Mg^{2+}$. Sodium is the dominant cation in almost all the waters analyzed.

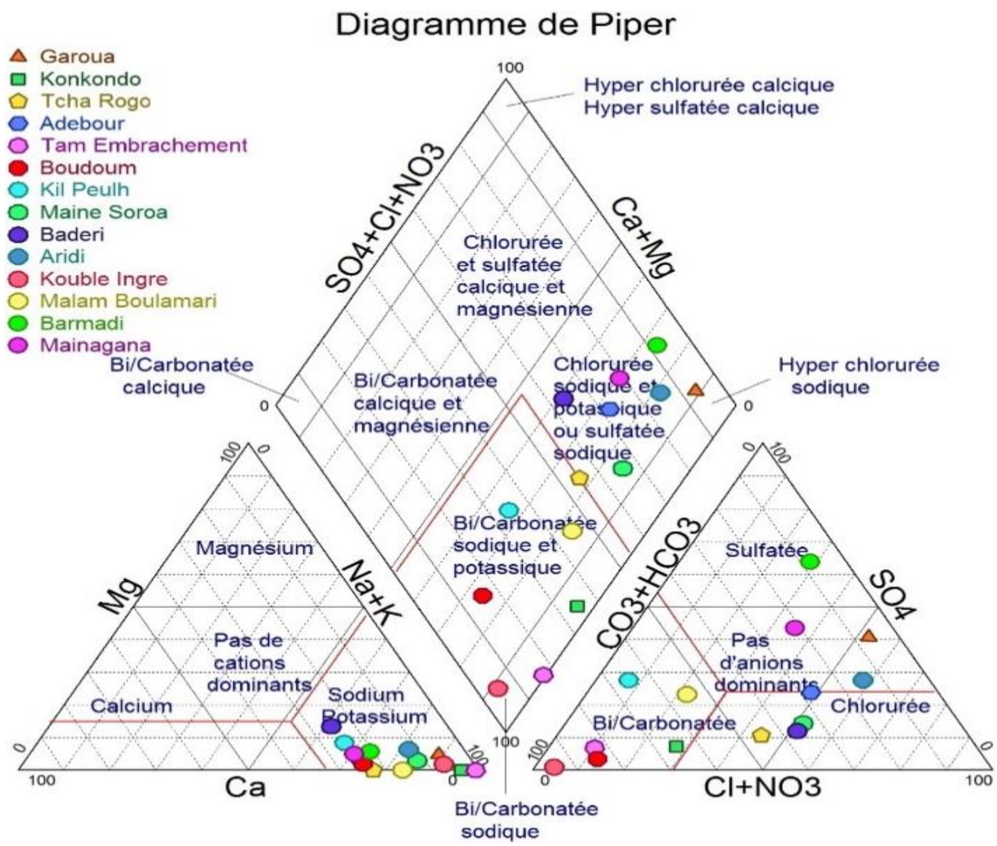

Figure No. 3: Hydro-chemical facies of the waters of the boreholes in the commune of Maïné-Soroa

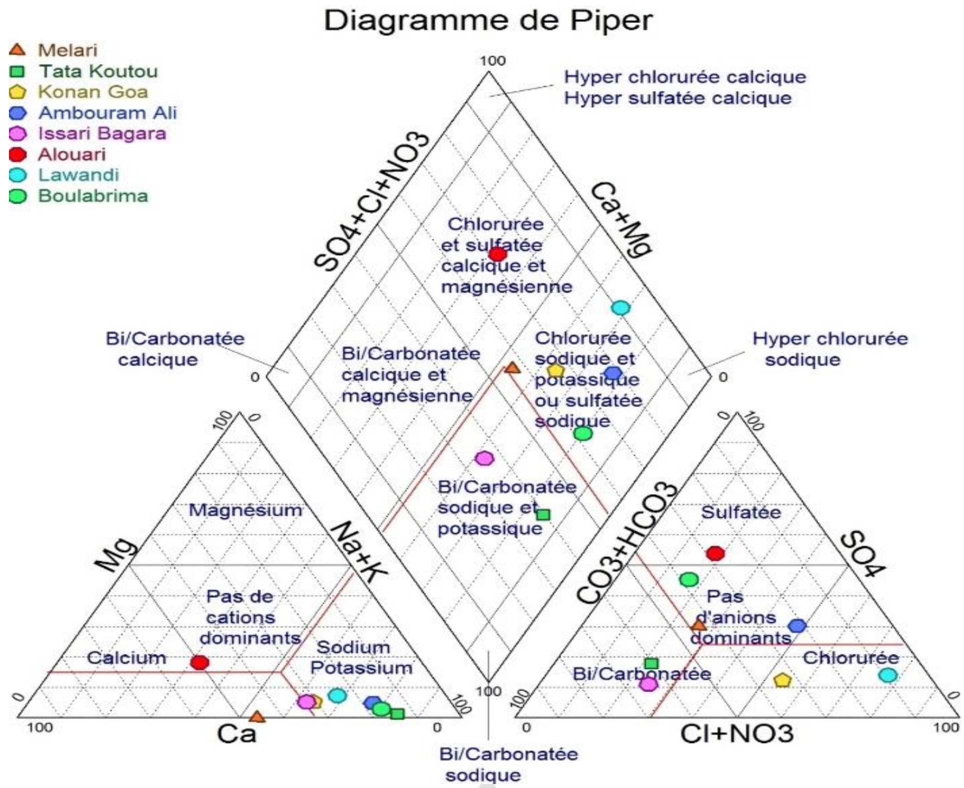

Figure No. 4: Hydro-chemical facies of well water in the commune of Maïné-Soroa

Results of the Multivariate Statistical Analysis

To study the origin of mineral elements and the geochemical processes responsible for groundwater mineralization, two approaches were used, namely the bi-variate correlation matrix and Principal Component Analysis (PCA).

Analysis of the correlation matrix

Thirteen (13) variables were analysed: pH, conductivity, chlorides, sulphates, nitrates, fluorides, sodiums, potassiums, total iron, calcium, magnesiums, nitrites and temperature. Tableau N°3 shows the relationships between all the variables taken in pairs.

Table No. 3: correlation matrix

	T	Ph	CE	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	FeT	Cl^{-}	SO_4^{2-}	NO_3^{-}	NO_2^{-}	F^{-}	
T	1													
pH	0,3	1												
CE	-0,08	-0,5	1											
Ca^{2+}	-0,15	-0,33	0,46	1										
Mg^{2+}	-0,08	-0,29	**0,64**	**0,91**	1									
Na^{+}	-0,08	-0,45	**0,96**	0,22	0,44	1								
K^{+}	-0,03	-0,39	0,58	**0,9**	**0,87**	0,39	1							
FeT	0,03	-0,12	-0,01	-0,03	0,04	-0,04	-0,07	1						
Cl^{-}	0,04	-0,38	**0,91**	0,21	0,42	**0,91**	0,33	0,08	1					
SO_4^{2-}	0,09	-0,52	**0,89**	0,57	**0,71**	**0,81**	**0,71**	0,01	**0,72**	1				
NO_3^{-}	-0,08	-0,21	0,13	0,54	0,52	-0,03	0,34	-0,08	0,02	0,14	1			
NO_2^{-}	0,38	0,1	-0,2	-0,06	-0,11	-0,23	-0,15	0,08	-0,11	-0,18	0,26	1		
F^{-}	-0,04	0,1	-0,04	0,13	0,09	-0,06	0,17	-0,51	-0,1	0,07	-0,08	-0,19	1	

Based on the critical correlation coefficient r=0.64 (Mangin,1974), analysis of the results shows that conductivity is strongly correlated with Na^{+} (0.96), Cl^{-} (0.91), SO_4^{2-} (0.89) ions and to a lesser degree with Mg^{2+} (0.64), K^{+} (0,58) et Ca^{2+} (0,46). ions. This shows that these elements significantly control the mineralization of groundwater. Ca^{2+}ions are strongly correlated with Mg^{2+} (0,91) and K^{+} (0,9), and significantly with SO_4^{2-} (0,57) (0.57) and NO_3^{-} (0,54). SO_4^{2-} correlates strongly with Na^{2+} (0,81), Mg^{2+} (0,71), K^{+} (0,71), Ca^{2+} (0,57) and Cl^{-} (0,72). Sodium in turn correlates strongly with Cl- ions (0.91), but weakly with Mg^{2+} (0,44) and K^{+} (R = 0,39).

pH is moderately negatively correlated with Na^{2+}, SO_4^{2-} and electrical conductivity (EC NO_2^{-} and NO_3^{-} ions show no significant correlation with the other elements. They are, however, weakly correlated with Ca^{2+}, Mg^{2+} and temperature.

Results of the Normalised Principal Component Analysis (NPCA)

Normalised Principal Component Analysis (NPCA) results are presented in tables Nº4 and Nº 5.

The first (Table No. 4) records the eigenvalues, the variances expressed for each factor and their totals. The F1 factor, with an expressed variance of 42.4%, is the most important of all, followed by the F2 factors with 13.7% of the expressed variance. These factors group together the maximum amount of information of the variance sought and make it possible to represent the cloud of points in a significant way because the sum of the variance expressed by these factors is significant enough (56.1%).

Table No.4: Eigenvalues and percentages expressed for the main axes

Factors	Eigenvalue	Total percentage of variance expressed	Cumulative variance expressed (%)
F1	6,35	42,4	42,4
F2	2,05	13,7	56,1

Analysis of the space of variables in the F1xF2 factorial design

The contribution of the different variables in defining the main factors is given in Table No. 5. Each factor is defined by a certain number of essential variables in the identification of the water mineralization mechanism.

Table No. 5: Correlations between variables and factors

Variables	F1	F2
CE	**0,385**	0,027
T	-0,048	-0,297
Ph	-0,208	-0,136
TH	**0,373**	-0,149
Ca++	**0,333**	-0,255
Mg++	**0,362**	-0,179
HCO3-	0,078	**0,403**
Cl-	0,259	0,251
FeT	-0,01	-0,079
SO4--	**0,347**	0,099
NO2-	-0,075	-0,424
NO3-	0,157	-0,442
K+	**0,350**	-0,131
F-	0,031	0,038
Na+	0,277	**0,371**

Thus, the results of the analysis show a clustering of EC and Ca2+, Mg2+, K+, SO42- ions around the F1 axis. The association of these variables around the F1 axis shows that the latter reflects the main source of water mineralization in the aquifer. The Ca^{2+}, Mg^{2+}, K^{+}, SO_4^{2-} correlation expresses; In fact, the natural mineralisation of the water and reflects, on the one hand, the alteration of silicate minerals and, on the other hand, the dissolution of evaporitic minerals.

The F2 factor, expressing almost 13.7% of the total variance, contrasts the $HCO_3^-$and Na^+ ions with the NO_2^- and NO_3^- groups. The Na+, HCO_3^- correlation highlights the water-caisson relationship, in particular the dissolution of silicates and evaporates and Base Exchange phenomena with clay minerals. On the other hand, the presence of nitrates and nitrites in this group indicates rapid mineralisation due to external inputs. The presence of NO_2^- and NO_3^- in high quantities in the study area is essentially linked to human activities. The mineralization of water in the Manga aquifer is therefore characterised by water-rock interaction and surface mineralisation.

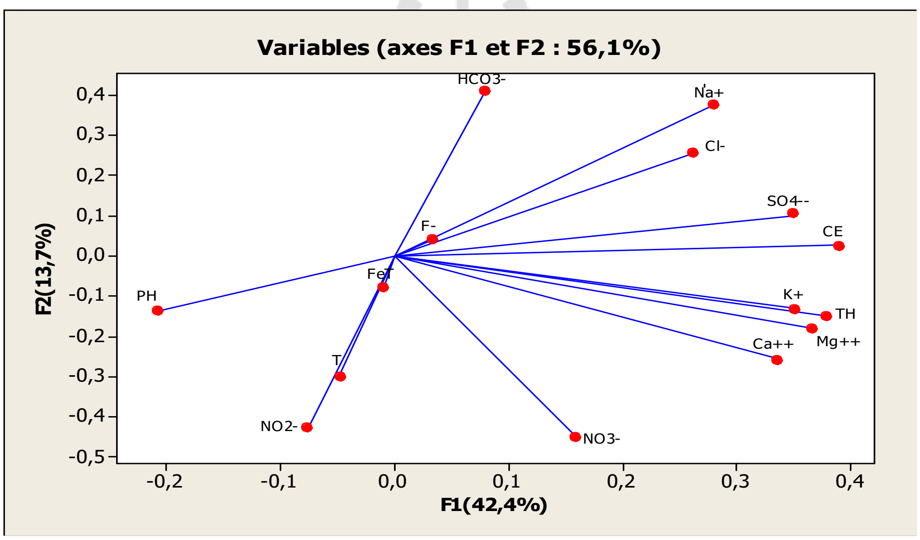

Figure No. 5: **Variable space of the F1×F2 factorial design**

Spatial projection of the F1×F2 factorial plane of individuals

The projection of the individuals on the F1 x F2 factorial plane shows that the waters are grouped according to their degree of mineralization and/or pollution. Highly mineralised waters are placed on the positive pole of the F1 axis and those with low mineralization on the opposite pole. Two groups of waters have therefore been identified. *The first group*, which characterises the water-rock interaction, is made up of highly mineralised samples. These waters have high concentrations of SO_4^{2-} and Na^+ ions and are located in the northern part of the study area. *The second group*, which is weakly mineralised, is strongly associated with HCO_3^- and Na^+ ions. This group includes water taken from the southern part of the study area. Most of these waters have a basic pH. In addition, the presence of NO_3^- and NO_2^- ions in some of the water sampled in this sector indicates pollution linked to anthropogenic activities.

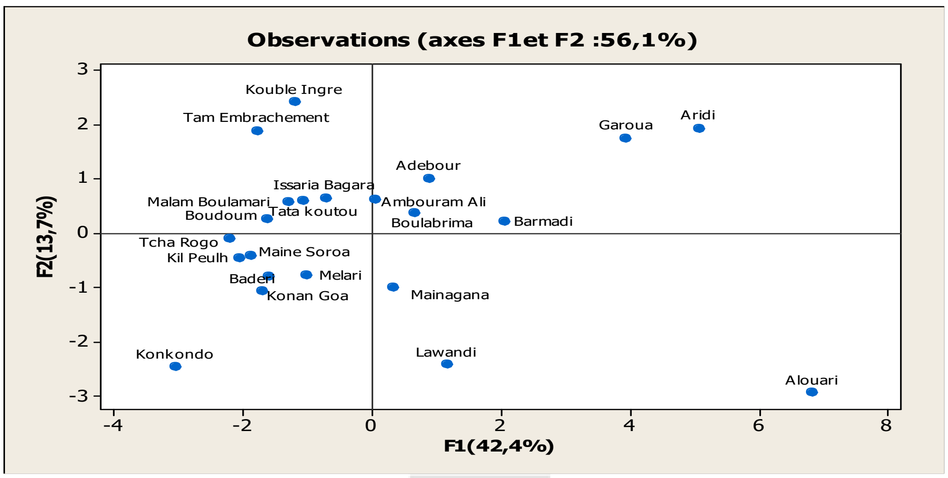

Figure No. 6: Statistical unit space of the F1×F2 factorial design

Ascending Hierarchical Classification (HHC) analysis

The Dendrogram (Figure No. 7) resulting from the Ascending Hierarchical Classification (AHC) highlights two main groupings of variables. *The first grouping*, subdivided into two subgroups, is made up on the one hand of the association of CE, SO_4^{2-}, Cl^- and Na^+, which reflects the interaction between water and rocks, and on the other of the grouping of Mg^{2+}, Ca^{2+}, K^+ and NO_3^- ions, which indicates an input of anthropogenic origin. *The second grouping*, formed by the association of HCO_3^-, F^- ions and the T°, NO_2^- , pH and FeT grouping, also distinguishes the two sources of mineralisation already identified.

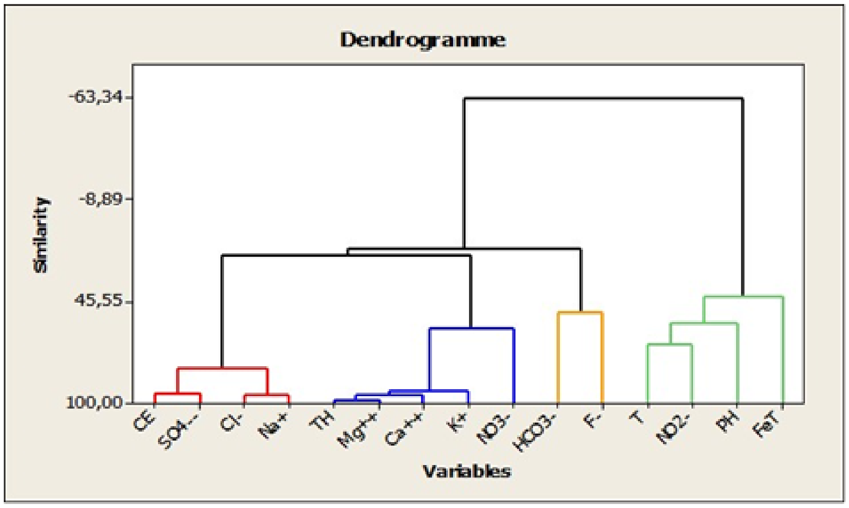

Figure No. 7: Dendrogram of the waters of the urban commune of Maïné-Soroa

DISCUSSION

The results obtained show that the wells and boreholes (sampled) in the commune of Maïné-Soroa are moderately mineralised, with values varying between 125.1 and 2080µS/cm, with an average value of 724.89µS/cm. The results of this study show that the lowest conductivity value is found near the Komadougou Yobé. In the north of the commune, the highest values are found in the centre of the basin. The temperature varies between 30 and 36.6°C, with an average of 32.64°C. The water has an acid PH with an average of 6.83, which means that it complies with the WHO standard of 6,5≤pH≤8,5.

These results are in agreement with the studies of ZAIRI.R, (2008) on the open aquifer of the Lake Chad basin in the Diffa region (Eastern Niger).

Normalised Principal Component Analysis highlights two types of mineralisation, the first by *hydrolysis* and the second by *infiltration*. The low mineralization of the water resource in the commune of Maïné-Soroa is due to the drop in recharge of the Komadougou Yobé water table for the villages near this river. The correlation matrix indicates that the chemical parameters influencing the mineralization of water in the Maïné-Soroa commune are sulphate, sodium, calcium, potassium, chloride and water content. Ions such as SO_4^{2-} and Cl^- originate from rainfall or soil leaching in the area, as indicated by multi-variate statistical analysis. Indeed, these results are in agreement with those found by ZAIRI.R, (2008) and LEDUC. C, (1997).

The Ascending Hierarchical Classification (HHC) highlights two (2) groupings of variables. The first group, made up of CE, SO_4^-, Cl^-, Na^+, TH, Mg^{2+}, Ca^{2+},K^+,NO_3^-,F^- and HCO_3^-;accounts for the residence time mineralisation or hydrolysis of carbonate and silicate minerals. It also indicates mineralisation by infiltration of water into the water table, the presence of nitrate being due to certain human activities. However, bicarbonate ions are present due to the dissolution of carbonate in groundwater. The second grouping, made up of T°, PH, NO_2^- and FeT, also highlights the mineralisation phenomenon governed by the infiltration of rainwater into the water table. The presence of iron explains a weak redox mechanism. These results are consistent with those of studies by ZAIRI.R, (2008) and AMADOU H, (2014) carried out in the Tillabéri region of Niger.

The study of physicochemical parameters show a variability of groundwater, including those (parameters) that most influence mineralisation are sulphate levels, which vary between 5 and 520 mg/l with an average of 119.13 mg/l. This is slightly lower than the standard recommended by the WHO (400mg/l). The sodium content varies from 86.01 to 1033.24mg/l, with an average of 300.49mg/l. This is higher than the WHO standard of 200 mg/l.

As for the calcium content of this quaternary water table, it varies from 1.6 to 352mg/l, with an average of 70.32mg/l. This is lower than the WHO standard (100mg/l). Bicarbonate varies between 48.5 and 409.92 mg/l, with an average of 147.28. The average for the Manga water table is below the WHO standard (250mg/l).

In the commune of Maïné-Soroa, the hydro-chemical study revealed three (3) facies for the water in the Manga aquifer, with the predominance of sodium chloride and potassium or sodium sulphate facies (59.09%). The next two facies are sodium potassium bicarbonate (36.26%) and finally calcium magnesium chloride and sulphate (5.54%).

These results are in agreement with other studies that show great variability in chemical facies, including ZAIRI.R, (2008); LEDUC C, (1997). In fact, the work of these authors has shown that the waters of the Diffa department present three (3) hydro-chemical facies: sulphate-sodic to the north of a line 11°36E-13°30N/14° E- 15° E, calcic bicarbonate in the Kadzel and bicarbonate-sodic between the other zones.

Physicochemical analyses show that the characteristics of the Manga water table vary greatly from one point to another. Indeed, the graphical representation in the factorial space of the static units showed two (2) main groupings of water points. The first is made up of water that is generally acidic, moderately hard and mineralised, with conductivity values varying between 696 and 2080µS/cm. These waters therefore do not meet the standard recommended by the WHO. However, they are acceptable for human consumption, except for those with very high sulphate and sodium levels. The second group consists of water that is on the whole moderately hard and poorly mineralised, with conductivity values ranging from, 125.1 à 555 µS/cm, and which meets the standard set by the WHO (≤400µS/cm). The results of the bacteriological analyses show the presence of total and faecal coliforms in the majority of the points sampled, with only three (3) water points meeting the standard recommended by the WHO.

Of the twelve (12) water points sampled for bacteriological analysis, 25% were of good quality, 41.66% of less good quality and 33.33% of poor quality. This means that at these facilities, whose water is of poor quality, there is a significant presence of faecal and total coliforms. The high presence of faecal coliforms in particular can be explained by the fact that many of the facilities are poorly protected and could be polluted by human or animal waste. These results are in agreement with the studies carried out by AMADOU H (2014) in the Tahoua region and by COULIBALY. K. (2005) on wells in certain districts of the Bamako district in Mali.

CONCLUSION

The study of the hydrogeochemical characteristics of the water resources of the Maïné-Soroa commune was carried out using a combination of hydro chemical methods and multivariate statistical analysis. The study highlighted the various physicochemical and bacteriological characteristics of the water sampled. The physicochemical analyses show that the water in the Maïné-Soroa commune is acidic ($pH<7$) and moderately mineralised. The chemical quality parameters are, for the most part, below the WHO drinking water standard, with the exception of a few water points where sulphate, sodium, bicarbonate and nitrite levels are high and sometimes well above the WHO standard. Trace metal levels (FeT) are also low in the water, not exceeding the WHO recommended standard, except in the village of Baderi, where they are higher (1.47mg/l).

The graphical representation in the factorial space of the statistical units revealed two (2) groups of waters. The first group contains waters that are generally acidic and highly mineralised. The sulphate and sodium content and the electrical conductivity of these waters are high.

The second group contains waters that are moderately hard and low in mineral content. Electrical conductivity values do not exceed the WHO standard, with the exception of the Konkondo (TH=8) and Tam embranchement (TH=4) waters, which are very soft.

Normalised Principal Component Analysis (NCPA) and Ascending Hierarchical Classification (HHC) indicate that the mineralisation of the municipality's water is controlled by two major phenomena. These are the *mineralisation-residence time* of water in contact with the bedrock, or hydrolysis in the case of groundwater (boreholes and wells), and the *rainfall-leaching* of soils by the infiltration of substances linked to human activities. Classification of the results of chemical analyses of the water using Piper's triangular diagram revealed three (3) predominantly sodium and potassium chloride or sodium sulphate facies (59.09%), sodium and potassium bicarbonate facies (36.26%), followed by calcium and magnesium chloride and sulphate facies (5.54%). Bacteriological analyses of the water in the study area revealed the presence of faecal coliform and total coliform bacteria. These bacteria could be the result of microbiological pollution from human or animal waste. The very high presence of germs undoubtedly poses a threat to residents who use groundwater to meet their daily needs.

Indeed, this work shows that the results are certainly very interesting, but deserve to be supplemented by other studies using pollution parameters, pesticides and a bacteriological study to complete it.

The results of the present study can serve as a data base for better knowledge and monitoring of the quality of the physicochemical and bacteriological parameters of the water in the Manga aquifer in the commune of Maïné-Soroa.

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