Revue-IRS

Revue Internationale de la Recherche Scientifique
(Revue-IRS)
ISSN: 2958-8413
Vol. 3, No. 1, February 2025

NATURAL GEOCHEMICAL BACKGROUND LEVEL OF GROUNDWATER IN THE MAMBANG, MORGORDOM AND KODJELEO FAR NORTH REGION OF CAMEROON

Marceline DJAMILA[1], Théodore Arnaud EBANDA OBOUGOU[2], Françoise Yannick ATEBA[3], Diane NDONGO MINDONGO[4], André Firmin BON[5]

1, 2 and 4: National Advanced School of Engineering of Maroua

3 and 5: Higher Institute of Agriculture, Forestry, Water and Environment of Ebolowa

Abstract: Water is an essential natural resource for sustainable development due to its importance. Access to this resource and adequate sanitation is a daily struggle in developing countries it is therefore necessary to know its state and ameliorate its quality. This study is a contribution to a better qualitative understanding of groundwater in the Far North, particularly in the localities of Mambang, Kodjeleo and Mogordom. The methodological approach consisted of field investigations, measurements of physico-chemical parameters in situ and laboratory work. The processed data was analyzed using statistical methods, classical and numerical methods based on the determination of the water quality index and the natural background level.The results obtained showed that the waters of the study area tended towards neutrality ($6.98 \leq pH \leq 7.34$), with average to excellent mineralization ($571 \leq EC \leq 1038$). Three main facies types were identified with the water type dominating the study area Calcium, Magnesium, Sulphate (66.67%). This multiplicity of facies suggests that there are several factors that control water quality in these localities. The water quality index shows that the waters are of poor quality (66.67%) and the values of the geochemical natural background level are: Ammonium ions 0.16mg/l; Chlorine 46.67mg/l; Cadmium 0.00038 mg/l; Lead 0.00065mg./l and Fluoride 0.27mg/l respectively. Although the number of samples is limited, this study provides the elements for better local water management and regulation based on the values of the natural background level and threshold in this part of the Far North of Cameroon.

Keywords: Natural background level, water quality index, groundwater, hydrochemical facies, metallic pollution index.

Digital Object Identifier (DOI): https://doi.org/10.5281/zenodo.**14878402**

1 Introduction

Water is an essential natural resource for sustainable development due to its importance. Access to this resource and adequate sanitation is a daily struggle in developing countries. According to the report of the World Health Organization (WHO 2006), 17% of the world's population do not have access to a good and safe drinking water, and about 42% do not have access to adequate sanitation. To this effect, it is essential to safeguard the quality of these resources in the medium and long term

In Cameroon, less than 40% of inhabitants in rural areas and 65% in urban areas have access to drinking water (Fonteh 2003; Nanfack et *al*. 2014). With the increase in the current population, particularly in rural areas (BUCREP 2010), the shortage of drinking water supply (DWS) is filled by water courses, springs, wells and boreholes of which the qualities are generally unknown. (Djeuda et *al*. 2001) which is the case of Mogordom, Kodjeleo and Mambang where this study is being carried out. Our area of study is situated in the sub-sahelian zones, characterized by less dense population with an intense socioeconomic activities (agriculture, livestock) leading to poor management of water resources. The riparian populations therefore resort to water from wells, boreholes and rain, the qualities and quantities of which are little known for their daily needs.

In the last decades, studies have been conducted on water quality in the far north region Cameroon. For instance, Moussa *et al.* (2016) worked on the assessment of bacteriological quality of groundwater from boreholes in Maroua (Far North Region), this work showed that the physico-chemical parameters showed that boreholes water have low to high mineralization. The water pH varied from acidic to basic. The contamination of borehole waters by bacterial indicators of feacal pollution would be due to soil properties that encourage the infiltration of waste water coming from the septic tanks, of solid waste dumpsites located close to the boreholes and by lack of maintenance of boreholes and the position of the potential sources of pollution in relation with the sense of outflow of the groundwater Bon et *al*. (2020a and 2020b) carried out a study on the contribution of a geostatistical model of Electrical Conductivity in the assessment of the Quaternary aquifer of the Lake Chad basin Kousseri, and the Parameterization of groundwater quality of the Quaternary aquifer in N'Djamena (Chad), Lake Chad Basin: application of numerical and multivariate analyses this work showed that the Lake Chad basin aquifer water is from basic to acidic nature. However, little or no work have been done on the proposition of the Natural background level of groundwater in the locality of Mambang, Mogordom and Kodjeleo. The works that have been concerning natural background level of groundwater in far north region Cameroon is that of Ngo Ngos (2022) in the Ouazzang basement. which indicated that the geochemical natural background level.of groundwater indicates a serious problem in terms of qualitative potentials.

The present study has objective to contribute to the best qualitative knowledge of water resources in the Far North Region, particularly in the locality of Mambang; Mogordom and Kodjeleo, in order to determine the Natural geochemical Background level of groundwater in these localities.

2 MATERIALS AND METHODS

2.1 Location of study area

Mambang, Mogordom and Kodjeleo are localities situated in the Far North Region of Cameroon in the Diamare division, Meri subdivision. They are located between the meridians 14° 17'14'' East; 14° 17' East and 14°18'East and between the parallel 10° 39'59''North; 10° 40'north and 10°41'North (figure.1). It occupies the Eastern part of meri and are limited in the North by Mazagai, in the south by Maroua, in the west by godola and in the East by Doubel.

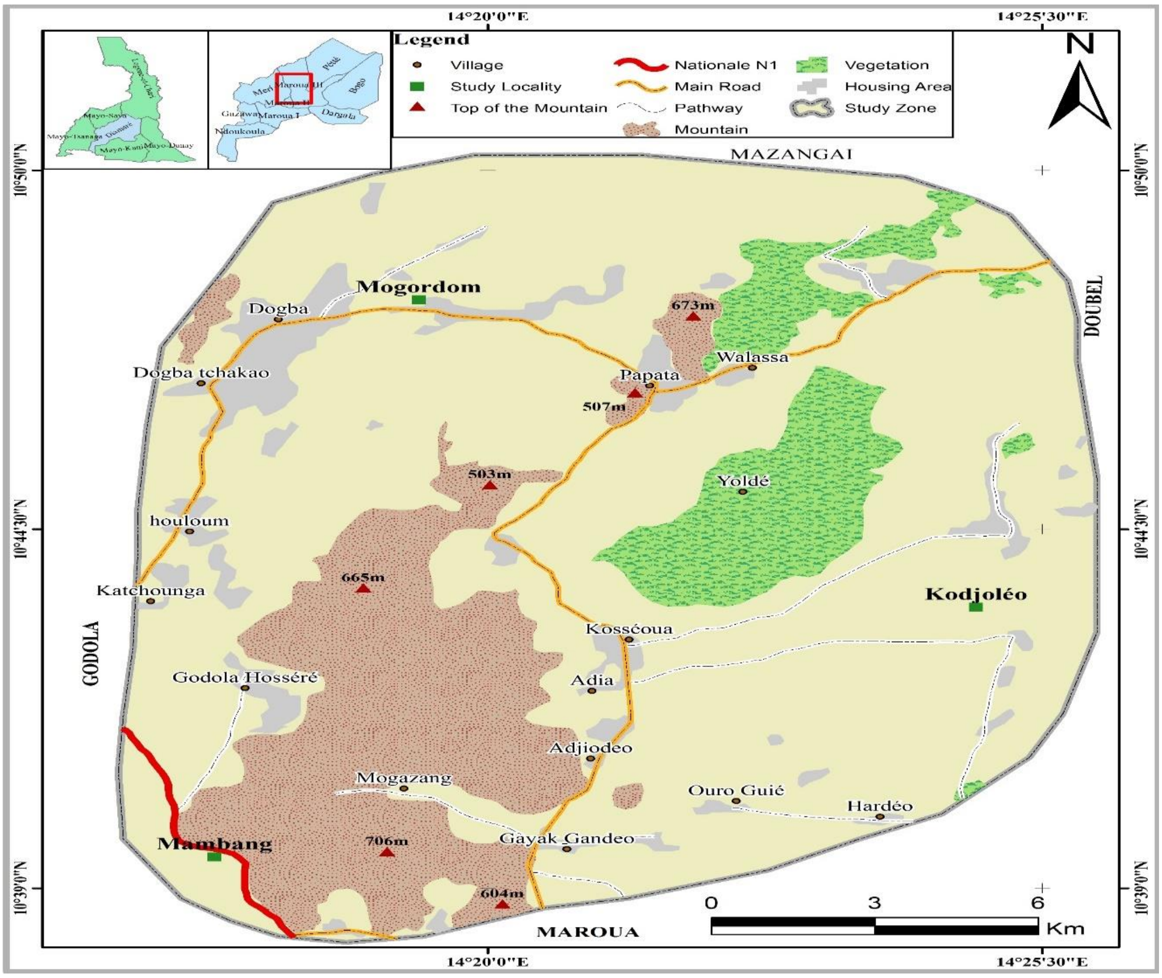

Figure 1. Map of study area

2.2 Geology and hydrogeology

Far north is constituted of more of gneiss and biotite to Amphiboles (Brambant and Gavaud 1985). The Mambang, Mogordom and Kodjeleo locality is constituted of alluvial, ancient dune sand, biotite granite and amphiboles which are meanly metamorphic and igneous rocks. Detay (1987) shows that the Cameroonian Quaternary Plain extends from the foot of the Mandara Mountains to Lake Chad; it belongs to a vast geographical unit found in Chad, Nigeria and Niger. Two domains characterize the quaternary filling, and they in turn are also subdivided into several layers:

- The Logone-Tchad domain includes the Chari-Tchad, lower Logone and Bec-de-Canard aquifers;
- The transition zone is subdivided into aquifers of the plain of Mora, Nord-Diamaré, and Kar-Hay.

The filling is fairly uniform overall, even if the thickness and grain size of certain levels vary significantly. The recent Quaternary includes:

- The clayey-sandy and sandy-clayey alluvium of the Logone and its tributaries and those of the temporary rivers that flow into Mayo Kebbi and Lake Chad;
- The coarse alluvium, with blocks, of the eastern rivers issuing from the Mandara mountains;
- Lacustrine clays and silts that form the upper part of the Chadian plain;

- Aeolian sands which constitute constantly reworked dunes and the Limani-Yagoua dune cord.

The early Quaternary is represented by several tens of meters of alternating clays and sands in discontinuous layers and lenses.

The North-Diamaré aquifer belongs to this Piedmont domain which was thus designated by Dassibat (1967) because of its generalized aquifer characteristic, induces a solution of continuity between the underflow aquifers of the Tsanaga, Motorsolo and Boula mayos. . This unit "presents different hydrogeological characteristics without however any modification being observed in the landscape itself" (Tillement 1970).

2.3Sampling and Chemical analysis

Six (6) groundwater samples including 2 dug wells and 4 borehole (fissured aquifer) were used to determine the groundwater hydrogeochemical characteristics. The sampling points were selected based on criteria such as accessibility, owner's agreement and water table conditions for the dug wells. The water samples were taken in September 2022, corresponding to the short rainy season. Samples from the dug wells were taken during hours when water extraction for domestic purposes is most intense (between 7 a.m. and 10 a.m.) in order to obtain a representative sample of water from the aquifer. Water samples were collected in sterilized 0.5l polyethylene bottles, according to standard methods prescribed by APHA (2012) and stored at 4 ◦C in a cooler for laboratory analysis. Temperature, electrical conductivity (EC)/Total Dissolved Solids (TDS) and pH were measured in situ using a Hanna HI98129 brand multiparameter. The pH and EC/TDS electrodes were previously calibrated using standard buffer solutions pH 4.01, pH 7.01 and 1413 µS/cm respectively. The accuracy of temperature, pH and EC measurements are 0.5, 0.05 and 0.02 units respectively. The analysis of anions and cations, Pb and Cd were analyzed in the laboratory of geochemistry and water analyses (LAGE) at Nkolbisson (Cameroon).

2.4 Data compilation and statistical analysis methods

After analysis in the laboratory, the data obtained for the various physico-chemical parameters in this study were compared with that of WHO (2012) standard of drinking water. Major ions were plotted in the Piper diagram (1944) in order to determine the different hydrochemical facies and water type in the study area. In order to further characterize the physical behavior of the sampling sites and the processes that control groundwater chemistry, multivariate statistical analyzes including correlation matrix and principal component analysis (PCA)) were applied to the water samples taking into account of 15 hydrochemical variables (pH, Temp, EC, Ca, Mg, Na, K, Cl, NO3, SO4, HCO3, PO4, NH4, Pb, Cd and F. These analyzes were performed using SPSS and Diagram software

2.5 Estimated WQI

WQI is a parameter that permit us to evaluate water quality in order to have a better interpretation of the water to know if it's good for Domestic or for agricultural purposes. the following steps were used for determining the WQI. In the first step, the unit weight (Wi) for each water quality parameter was determined using the following formula (I.1)

$$W_i = \frac{k}{S_i} \qquad \textbf{(I.1)}$$

Where

S_i is standard value of i^{th} parameter recommended by WHO;

K is the proportionality constant which is calculated by using the following equation (I.2)

$$k = \frac{1}{\left(\Sigma\frac{1}{S_i}\right)} \qquad \textbf{(I.2)}$$

In the second step, quality rating or sub-index (q_i) was computed for each of the parameters using the expression (I.3)

$$q_i = \frac{v_i - v_o}{s_i - v_o} \times 100 \qquad \textbf{(I.3)}$$

Where

v_i is estimated value of i^{th} parameter in the analysed water sample;

v_o is ideal value of this parameter in pure water (it is zero for all parameters except pH = 7.0 and DO = 14.6mg/L);

S_i is recommended standard value of i^{th} parameter given by WHO.

In the final step, the overall WQI was calculated by using following formula (I.4 and I.5)

$$WQI = \frac{\sum q_i W_i}{\sum W_i} \qquad \textbf{(I.4)}$$

$$k = \frac{1}{\left(\sum \frac{1}{S_i}\right)} \qquad \textbf{(I.5)}$$

Computed WQI values were classified into five categories, excellent, good, moderate, poor, and very poor (Li et *a*l. 2010; Zotou et *al*. 2019).

Table 1: Computed water quality index value

WQI values	Water quality
<50	Excellent
50-100	Good
100-150	Medium
150-200	Poor
>200	Extremely poor

2.6 Estimation of heavy metal pollution index

The metallic pollution index is a parameter that permits to evaluate the level heavy metals pollution in water. This method consist in attributing a weight or indices of each metal according to its contribution to weathering process of water quality (Prasad et Sangita. 2008; Singh et Rakesh. 2016). Metallic pollution index is calculated on three stapes (Mohan et *al*. 1996).

- Determination of relative weight or index (Wi) attributed to each mineral and it is obtained by the following formula (II.7)

  $$Wi = {}^{k}/_{S_i} \qquad \textbf{(II.7)}$$

  Where K is the proportionality constant,

  Si is the authorized standard value of I parameter according to WHO norms (2011)

- Calculation of sub-index values of each parameter and it is gotten as thus:

  $$Qi = 100 * {}^{V_i}/_{S_i} \qquad \textbf{(II.8)}$$

  Where Vi is the value gotten from the field for the ith parameter and Si is the permissible standard value of the ith parameter

- Estimation of heavy metal pollution index

  $$HPI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \qquad \textbf{(II.9)}$$

2.7 Determination of natural geochemical background levels and geochemical threshold values

The natural geochemical background (NBL) and geochemical threshold value (TV) levels were determined in order to assess contamination of groundwater. Edmunds et *al*. (2003) define the background level of a substance in groundwater as the concentration of a given element, species or chemical present in solution which is derived from natural geological, biological or atmospheric sources. In terms of process, these sources have significant differences. Local variation in environmental conditions is best reflected when its assessment considers the characteristics of a particular region (e.g. geology and hydrogeology) (Gao et *al*. 2020). Various methods and approaches exist in the literature to identify NBLs and generally involve geochemical and statistical methods (Muller et *al*. 2006; Nakic et *al*. 2007; Rotiroti et *al*. 2015; De Caro et *al*. 2017).

The pre-selection method which is consist in sampling water samples with an unknown depth and eliminate those parameters having values higher or equal to the WHO standard (2011) in order to eliminate the polluted samples was used in this study. The NBL obtained will be helpful to determine the threshold values for groundwater. According to Last et *al*. (2014) TV represent a groundwater quality standard that is based on interactions with aquatic and terrestrial ecosystems, interference with legitimate uses or functions of groundwater, and hydro-geological characteristics including background levels. In this study it was proposed to define the TV following two different cases based on the ratio between the Natural Background Level and a relevant reference value (Muller et *al*. 2006):

Case 1: NBL < REF: TV = (NBL + REF) / 2

Case 2: NBL > REF: TV = NBL

REF is an appropriate reference value, defined by the World Health Organization (WHO) and the threshold values is calculated using the NBL (Min and Max).

3 Results and Discussion

3.1 Chemical characteristics

3.1.1 Physico-chemical characteristics

The groundwater of Mambang, Mogordom and Kodjeleo had pH value which varied from 6.98(P1) to 7.34(P5) with a median of 7.19 and an average of 7.18 (table 2). Although the pH was slightly basic in most cases, it was generally going towards neutral with a maximum of 7.34 for site P5. Thus pH was within the WHO 2004 limit (6.5 to 8.5). The pH values of the study area are similar to those of Cornelius et *al*. 2019 in the groundwater of Maroua-Cameroon ($6.27 \leq pH \leq 7.88$). The variations of pH values are likely associated with the nature of the lands crossed because pH of groundwater is not different from the pH of crossed soil and human activities around sampling points (Close et al. 1989; Mkandawire 2008; Nouayti et *al*. 2015). According to Djuikom (2006), the pH of water can also be influenced by the action of microorganisms and the proximity of latrines with water point.

The temperature of the groundwater in the study area ranged from 27.1°C to 28.3°C with an average of 27.59°C and a median of 27.50°C. The temperature of water does not have a direct impact on the man's health. However temperature values above 20°C enhance the development of micro-organisms of the environment. Although the temperatures of the water samples are higher than recommended by the WHO 2017 (25°C), they can be considered to be normal in the respective environment (Alhou *et al*. 2009) Indeed, our study site is situated in an area with an average annual temperature estimated at 28.3 °C. Rise of the temperature of water samples can be explained by the impact of ambient temperature, sampling hour and season.

The electrical conductivity of the area had valued which ranged from 571 µS/cm (P3) to 1038 µS/cm (P5) with a median of 708.50 µS/cm and an average of 742.83µS/cm. the mineralization of groundwater of these three localities is average to excellent (Detay 1993) (Appendix I). The values obtained falls within WHO (2011) standard (1500mg/l) but are greater to those obtained by Bon *et al.*, 2020 ($73 \leq CE \leq 1562$). And greater than the values obtained by Ngo Ngos 2022 in the Ouzzang basement (203.1 to 840 µS/cm). The variations of electrical conductivity would result from the washing of the rock reservoir within which water stay (Mkandawire 2008). The values of electrical conductivity in groundwater could be as result of prolonged contact of groundwater with the basement. The relative difference of EC observed in groundwater samples could be related to the heterogeneity of aquifers which should be considered to be compartmental hydrosystem and does not favor the continuous circulation of groundwater (pedretti *et al.* 2016) or the combined effect of geogenic processes and anthropogenic factors (Abderamane et *al.* 2013; Ouedraogo et *al.* 2016; Bon et *al.* 2020).

The TDS values of groundwater ranged from 282 mg/l (P3) to 498mg/l (P5) with a median of 346.00ppm an average of 363.08mg/l. This values indicates that the water in the study area is fresh (TDS < 1000 mg/L).

3.2 Chemical composition of groundwater in the study area

3.2.1 Major Cations and the total cationic charge TZ+

The alkaline-earth concentration (Ca^{2+} and Mg^{+}) content varied from 17.67 mg/L (P2) to 149.36 mg/L (P5) and 32.96 mg/L (P2) to 97.22 mg/L (P4) respectively with an average of 83.43 mg/L and 73.87 mg/L respectively. The alkaline concentrations (Na^{+} and K^{+}) oscillated between 27.57 mg/L (P6) to 80.33 mg/L(P5) with a median of 57.63 mg/L, an average of 52.25 mg/L and 4.48 mg/L (P1) to 25.22 mg/L(P3) with a median of 11.62 mg/L and an average of 13.54 mg/L respectively. The ammonium ion (NH_4^{+}) varies between 0.15mg/L to 1.71mg/L with a median of 1.04mg/L an average of 0.91mg/L (Table 2).

The concentrations of Ca^{2+} are relatively higher in the boreholes (P1, P2 and P4) the availability of Ca^{2+} ion in groundwater can be as a result of the rocks that are being found in the substratum which are igneous rocks which contained minerals like biotites and amphiboles (Ramesh and Jagadeeswari 2013) and are lower in wells (P3 and P6) and the concentrations of Mg^{+} is higher in boreholes (P1, P2, P4 and P5). The concentrations of K^{+} are very low as compared to the concentrations of Na^{+} in all the groundwater of the study area. The lower concentration of potassium ion might be due to the fact that the potassium ions are more absorbed by clay than the sodium ions because of their atomic radius which are greater than that of the sodium ion and it might also be because of the high solubility of sodium which affirms or confirms its high concentration in water.

The equivalent cations TZ^{+} (µeq/L) = Ca^{+} + Mg^{2+}+Na^{+}+K^{+}) ranged from 1.70 to 5.45 with a median of 3.86 and an average of 3.66 (table 2). The TZ^{+} content in groundwater can be due to the mineralogical composition of rocks in the study area. This values are lower than the mean calculated value for streams and rivers in the world which is 1470µeq/L (Meybeck et Ragu. 1996; Gaillardet et *al*. 1999).

The potassium ion of Three water samples (P3,P4 and P6) exceeded the WHO permissible limit for drinking water (K=12), the Mg^{2+} values were higher in all the groundwater samples and NH_4^{+} values were higher in all samples except P2 and P3. The high concentration of K^{+}, Mg^{2+} and NH_4^{+} in groundwater samples might be due to the over use of fertilizers for good crop production and also the use of insecticides and pesticides.

3.2.2. Major Anions and the total Anionic charge TZ^{-}

The value of Chlorine and Nitrate ion oscillated from 25.46mg/L to 82.93mg/L with an average of 53.72 mg/L, a median of 49.70mg/L and from 1.75mg/L to 13.40 mg/L with an average of 5.12mg/L and a median of 3.92 mg/L respectively (table 2). The values of Cl^{-} ion of all groundwater samples were lower than the WHO (2011) permissible limit but showed a high concentration at P3 and P5. The concentrations of Nitrates were lower than the WHO 2011 permissible value. The values of fluorine and phosphate ions oscillated from 0.13mg/l to 0.84mg/l with a median of 0.24mg/l and an average of 0.32mg/l and from 0.00mg/l to 0.04mg/l with a median of 0.00mg/l and an average of 0.01mg/l respectively (table 2). All the values of fluorine in the groundwater samples were below the WHO 2011 permissive value. The presence of fluorine in groundwater could be due to weathering and leaching of fluoride-bearing minerals from rocks and sediments. Fluoride when ingested in small quantities (<0.5mg/L) is beneficial in promoting dental health by reducing dental caries (Rao et *al*. 2015) and a higher concentration of fluorine (> 1.5 mg/L) when ingested may cause fluorosis (Wu et Sun. 2016 ; Rao et *al*. 2017.). The concentration of phosphorous were all 0 except for P6 that recorded a concentration of 0.04mg/l this could be explained by the process of soil leaching by precipitation and runoff mobilizing phosphate ions during rainy periods. The concentrations of sulphates and bicarbonates ions varied from 16.27 mg/L to 79.11 mg/L with an average of 36.91 mg/L, a median of 27.60 mg/L and from 70.0 mg/L to 150 mg/L with an average of 105 mg/L and a median of 97.50 mg/L respectively. The sulphate ions had concentrations less than the WHO 2011 permissive value and the presences of Sulphate ions in groundwater can be due to the use of fertilizers All the water samples had HCO_3^- concentration less than that of WHO 2011 limit except for P2 (150 mg/L) which had a concentration of HCO_3^- greater than the WHO permissive value. The high concentration of HCO_3^- in the sample indicates the intense chemical weathering processes taking place in this aquifer.

The value of the major anionic equivalent (TZ^-) varied between 2.37 (P4) to 5.10 mg/L (P5) with a median of 3.23 mg/L and an average of 3.51 mg/L. the highest concentration were observed at P2 and P5.

In general, the abundance of nitrate, chlorine, ammonium and potassium will much more be from anthropogenic origin that is either by the proximity of latrines to water point, either by soil and plants treatment by chemical fertilizers (mineral fertilizers oraganic fertilisers,and organo-minerals) to ameliorate and increase crop productivity and chemical insecticides to wipe out insect; to wipe out bad herbs; to treat the system and makes it clean by the help fungicides and bactericides.

The concentration of Pb observed oscillated between $0.15.10^{-3}$mg/L to $1.39.10^{-3}$ mg/L with an average of $0.70 .10^{-3}$ mg/L. The concentration of Cd varied from $0.17.10^{-3}$ mg/L to $1.03.10^{-3}$ mg/L with an average of $0.49.10^{-3}$ mg/L. The increasing order of these two elements is as follows Pb>Cd and present a low concentration as per the norms proposed by WHO (2011) for human consumption. The concentrations of heavy metals are significantly in the different points. The origin of these heavy metals in groundwater could either be from natural origin (present in the crust), either from anthropogenic origin (agriculture with the use of pesticides and fungicides).

The results of HPI are shown in table 4. The HPI value gotten from the study is less than the value indicated to be a critical value for metallic pollution 100 (Bhardwaj et *al.* 2017). Rakotondrabe et *al*. 2017 obtained a value greater than the value obtained in the study area (1195.36) in the Betare Oya. This value obtained similar to the value obtained by Ngo Ngos (2022) in the basement of Ouazzang (54.912). We should note that HPI does not depend on the abundant of an element in water but on the effects that these elements have on human health when they consume it. The results shows that the two heavy metals showed a high unit index (Wi) just as in the calculations made by Bhardwaj et *al.* 2017. Hence even their low concentrations in water samples can make the water quality poor and lead to high values of HPI (Reza and Singh 2010). These results should be taken into account as there is a serious threat to ecological and human health

Generally the major ion concentrations in the study area were in the following order:

For the cations we have $Ca^{2+} > Mg^{2+} > Na^+ > K^+ > NH_4^+$

For the Anions we have $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- >$

The values of the WQI calculated showed the water in the area of study is made up 66.67% poor quality and 33.33% excellent quality as shown in table 3.

Parameters	Unit	Min	Max	Avg	Med	SD	WHO 2011
PH		6.98	7.34	7.18	7.19	0.1257	7.5
Cond	µS/cm	571.00	1038	742.833	708.5	159.84	1500
Sal	Ppm	0.02	0.5	0.27	0.3	0.16	
Temp	°C	27.1	28.3	27.59	27.5	0.4248	25
Alc	µmol/l	1725.24	1824.56	1764.25	1753.47	45.06	
MES	mg/L	1.77	5.6	3.2	2.96	1.27	25-40
Sodium	mg/L	27.57	80.33	52.25	57.63	20.77	200
Ammonium	mg/L	0.15	1,71	0.91	1.04	0.65	0.5
Potassium	mg/L	4.48	25.22	13.54	11.62	8.99	100
Magnesium	mg/L	32.96	97.22	73.87	76.46	22.03	30
Calcium	mg/L	17.67	149.36	83.43	77.6	50.86	75
Cd	µg/L	0.17	1.03	0.485	0.42	0.322	0.01
Pb	µg/L	0.15	1.39	0.698	0.61	0.488	0.003
Fluorine	mg/L	0.13	0.84	0.321	0.24	0.262	1.5
Chlorine	mg/L	25.46	82.93	53.72	49.7	20.5	250
Nitrate	mg/L	1.75	13.4	5.12	33.92	4.4	10
phosphate	mg/L	0	0.04	0.0067	0	0.1633	5
Sulfate	mg/L	16.27	79.11	36.91	27.6	24.84	250
TDS	Ppm	292	513	373	357	75.42	500
Carbonates	mg/L	150	70	97.5	105	29.665	200
TZ+	meq/L	1.70	5.50	3.66	3.85	1.40	
TZ-	meq/L	2.37	5.10	3.51	3.22	0.95	

Table 2. Statistical summary of physical and chemical parameters of groundwater in the study area

Table 3. Calculated WQI values

	WQI	Range	% of samples
Max	238.31	Poor quality	66.67%
Min	31.17	Excellent quality	33.33%
Average	115.56		
Median	123.26		
SD	77.65		

Table 4. Calculated values of HPI

heavy metals (µg/l)	mean concentration in g/l(Mi)	highest permitted value for drinking water	Unit weight (Wi=1/Si)	sub-index (Qi = 100 x Mi/Si)	Wi x Qi
Cd	1.03	10	0.1	10.3	1.03
Pb	1.39	3	0.333333333	46.333333	15.4444
			∑Wi = 0.433333333	**∑Wi x Qi = 16.47444**	
HPI=∑Wi x Qi / ∑Wi = 38.01794872					

The classification of the hydro- chemical facies with the help of piper diagram showed that three main water types are identified in the study area which are:

- Calcium-Chlorine -Sulphate type which represents 66.67% of the groundwater in the study area;
- Sodium-Potassium-Chlorine type which represents 16.67% of the water samples in the study area;
- Sodium-Potassium-Bicarbonate type which represents 16.67% of the groundwater samples in the study area. The multiplicity of this facies indicates that there are many factors that controls the quality of groundwater in the study area notably geogenic and anthropogenic factors.

3.3 Environmental Factors Controlling Chemical Composition Of Water.

3.3.1 Correlation Matrix

In this study area correlation matrix was applied to 14 variables (major ions) and physical parameters (temperature, pH and EC). It is clear that there is a strong correlation between Mg^{2+} and Na^{+}(r=0.866) , ammonium and calcium(r = 0.943), a strong correlation between sodium and Magnesium(r = 0.866), sodium and calcium(r = 0.866), Nitrate showed a strong positive correlation with sulphate(r = 0.829), with sodium(r =0.829) and with magnesium(0.886) and calcium(0.829), between Ec and Fluorine(r = 0.866) (table 7). The correlation between magnesium and calcium, sodium and magnesium and sodium and calcium reflects the dissolution of rocks related to the residence time of water in the aquifer (Prasanna et *al*. 2019). And on the other hand it might mean that there presence in water is from the same origin. The high correlation observed between those parameters might indicate that anthropogenic, activities were responsible for the contamination of the assessed groundwater in the study area (Ahmad et *al*. 2022). The other parameters that showed a negative correlation means there are from different origin

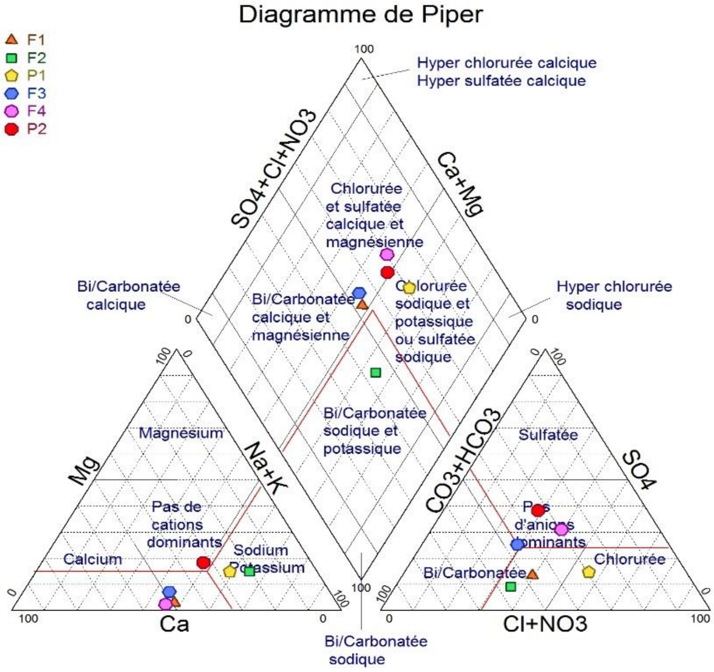

Figure 2. Piper's diagram of study area

3.3.2. Principal Component Analysis

PCA was carried on a subset of 15 selected variables (temperature, pH, EC, F, Cl, NO_3, PO_4, SO_4, HCO_3, Na, NH_4, K, Mg and Ca) representing the overall geochemical parameters. The results are shown in table 5. Four factors were extracted to statistically know the contribution factors influencing chemical composition of groundwater. Based on the significant factors, the results indicates that these factors explain about 93.8% of the variance in the dataset given below.

PCI, accounting for about 48.63% of the total variance was primarily composed of major ions, Temp, pH, and EC. This indicates that their presence in water is due to anthropogenic activities

PCII expressed 19.37 % of the total variance and had high positive loads for the variables pH, Cl, HCO_3^- in the study area. The concentrations of bicarbonates and pH in groundwater are the result of the reaction of soil CO_2 with the dissolution of silicate minerals during water-soil and water-rock interactions (Subba et *al.* 2006).

PCIII expressed 16.4% of the total variance and had a high positive loads for the variables pH, PO_4, K which indicates that the presence of K could be from rock-water interaction and that of orthophosphate could be due to anthropogenic origin.

PCIV expressed 9.40% of the total variables and exhibited a positive load for the variables PO_4, HCO_3, Na, NH_4, Mg and Ca indicating that their presence could be due the use of fertilizers for agricultural purposes and from natural weathering processes. This method was used by Bon et al. (2020b)

3.3.3. Gibbs Diagram

The Gibbs diagram of the groundwater samples in the study area were mainly in the zone of Rock- water dominance, which suggested that chemical rock weathering and the geological formation present are the major mechanisms controlling the physico-chemical composition of groundwater in areas of study. This is mainly controlled by the geology of the rock substratum and the type of soils crossed by the substratum in the study area. Similar results were observed by Gao et *al*. 2020 in the waters Xian in the Northwest of china, Fantong et *al*. 2016 in Coastal zone water in littoral Douala, Ngo Ngos.2022 in the Ouzzang basement.

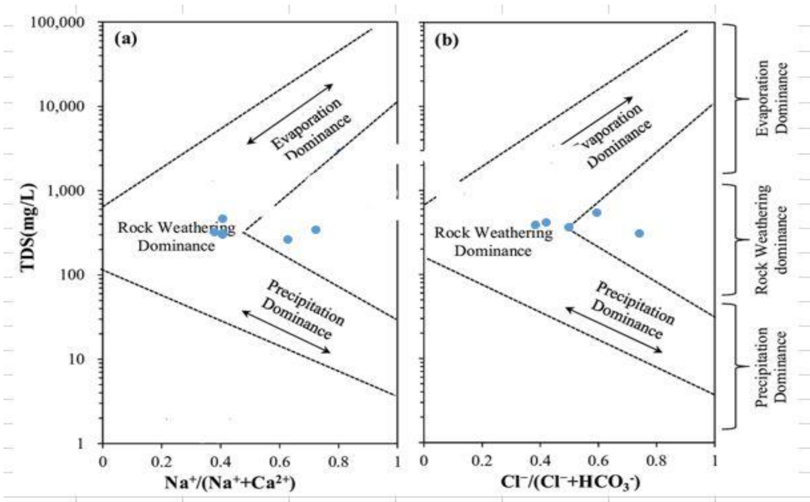

Figure 3. Gibbs diagram

Table 5. Principal component analysis of study area

	principal component parameters			
	I	II	III	IV
Temperature	0.605	-0.480	-0.118	-0.219
pH	0.464	0.545	0.663	-0.112
EC	0.871	0.387	-0.212	0.192
F	0.884	0.400	-0.201	-0.015
Cl	0.466	0.534	0.125	-0.527
NO_3	0.952	0.061	0.190	-0.226
PO_4	-0.342	0.221	0.692	0.593
SO_4	0.764	0.271	0.497	0.302
HCO_3	0.234	0.771	-0.524	0.200
Na	0.824	-0.408	-0.043	-0.327
NH_4	0.758	-0.355	-0.90	0.516
K	-0.524	-0.049	0.793	-0.283
Mg	0.546	-0.724	0.401	0.062
Ca	0.845	-0.477	-0.065	0.201
Eigenvalue	7.294	2.905	2.460	1.410
% of variance	48.628	19.367	16.397	9.403
Cumulative %	48.628	67.995	84.392	93.795

3.3.4. Natural geochemical Background level and Geochemical Threshold values

The Geochemical NBL and geochemical TV are indicated in table 6. The values of geochemical NBL are represented in the form of minimum and maximum. The result shows that the concentrations in chemical elements are mostly above the geochemical NBL in shallower water from hand-dug wells than in deep water from boreholes. This can be explained by the fact that shallow groundwater is more sensible to anthropogenic influences. However, samples presenting HCO_3^- contents above the geochemical NBL are mostly observed in boreholes. These samples correspond to the deepest groundwater. Since, this element is only related to natural processes it is therefore clear that the deeper the groundwater flows, the more the groundwater mineralization increases due to water-rocks interactions (Bon et *al*. 2021; Nlend et *al*. 2020). Groundwater depth should be considered in identifying geochemical processes. Likewise, as expected, the majority of samples which show chemical contents above the TV are from hand-dug wells. However, it is worthwhile noting, as it can be seen from Table 6, that both the borehole and well samples had NBL and TV values 5.54 and 5.52 and 7.77 and 7.72 respectively for NO_3^-.

This observation implies that the aquifer pollution is probably not limited to shallower flow path. Thus water from boreholes is also vulnerable to nitrate pollution (Nlend et *al*. 2020). This latter appears as a serious concern in term of qualitative potential of groundwater.

Finally, the natural geochemical background value of nitrate obtained in boreholes and dug wells in this study (5.54 and 5.52 mg/L respectively) is very close to that obtained by Zhang et *al*. (2017) in North China plain on gravel sediments and by Nlend et *al*.(2020). The geochemical TV and geochemical NBL values for lead and Cadmium in boreholes were $0.33*10^{-3}$ and $0.65*10^{-3}$ for lead and $0.19*10^{-3}$ and $0.38 *10^{-3}$ for cadmium respectively. While in wells the values obtained were $0.19*10^{-3}$ and $0.38*10^{-3}$ for Cadmium and $0.58*10^{-3}$ for TV and $1.16*10^{-3}$ for NBL. It is observed that the values are slightly greater in the wells than the boreholes this can be due to the fact both groundwater and well water are vulnerable to heavy metal pollutions but well water is more vulnerable than groundwater and the sources of heavy metal pollution could be due to anthropogenic activities (agriculture with the use of chemical fertilizers, latrines, poor sanitation of the area where boreholes are located, doing laundry) around or near borehole sites. The values for Pb and Cd obtained are close to those obtained by Bon et *al*, 2021(Pb $0.15*10^{-3}$ and Cd $3.052*10^{-3}$) in Yaoundé.

Table 6. Calculated values of NBL and TV

		NBL for Boreholes			NBL for Wells		
Parameters	**Ref**	**Max**	**Min**	**TV**	**Max**	**Min**	**TV**
EC	750	734	683	742	661	571	705.5
Na	200	62.33	55.18	131.165	60.07	27.57	130.035
NH4	0.2	0.16	0.16	0.18	0.16	0.16	0.18
K	100	12.93	4.48	56.465	25.22	23.48	62.61
Ca	75	52.96	52.96	63.98	52.96	51	63.98
Cd	10	$0.38*10^{-3}$	$0.17*10^{-3}$	$0.19*10^{-3}$	$0.38*10^{-3}$	$0.21*10^{-3}$	$0.19*10^{-3}$
Pb	3	$0.65*10^{-3}$	0.56*10-3	0.33*10-3	0.16*10-3	0.15*10-3	0.58*10-3
F	1.5	0.27	0.2	0.88685	0.16	0.13	0.83
Cl	250	46.47	25.46	148.235	70.72	43.79	160.36
NO3	10	5.54	2.19	7.77	5.52	2.33	7.76
PO4	0.1	0	0	0.05	0.04	0	0.07
HCO3	200	100	85	150	95	70	147.5

Key: Ref: reference ; Max: maximum ;Min: Minimum ; NBL: natural background level ; TV: threshold values

Table 7: Spearman's correlation matrix of physico-chemical parameters in the area of study

Variables	Temp	pH	EC	F-	Cl-	NO3-	PO43-	SO42-	HCO3-	Na+	NH4+	K+	Mg2+	Ca2+
Temp	1	0.029	0.429	0.371	0.143	0.714	-0.655	0.257	-0.200	**0.886***	0.486	0.029	**0.829***	0.657
pH		1	0.143	0.029	0.534	0.486	0.393	0.714	0.086	0.143	0.143	0.314	0.029	0.086
EC			1	**0.866***	0.257	0.200	-0.393	0.143	0.771	0.429	0.429	-0.657	0.143	0.371
F^-				1	0.543	0.086	-0.655	-0.086	0.771	0.486	0.314	-0.771	0.086	0.371
Cl^-					1	.200	-0.393	0.086	0.314	0.371	-0.029	-0.143	-0.029	0.143
NO_3^-						1	-0.131	**0.829***	-0.371	**0.829***	0.771	0.143	**0.886***	**0.829***
PO_4^{3-}							1	0.393	-0.131	-0.655	-0.131	0.393	-0.393	-0.393
SO_4^{2-}								1	-0.200	0.429	0.714	0.143	0.543	0.600
HCO_3^-									1	-0.143	-0.029	-0.714	-0.486	-0.143
Na^+										1	0.714	-0.200	**0.866***	**0.866***
NH_4^+											1	-0.429	**0.771**	**0.943****
K^+												1	0.029	-0.371
Mg^{2+}													1	-0.577
Ca^{2+}														1

4 Conclusion

The waters in the study area indicates the occurrence of average to excellent mineralized water (< 1500 µS /cm) and have a pH getting to neutrality ($6.98 \leq pH \leq 7.93$). The TDS value of all the water samples were within the acceptable WHO limits of drinking water indicating that the water was fresh water. The water quality index (WQI) calculated showed that 66.67% were of poor quality and 33.33% were of excellent quality. The HPI value gotten from the study is less than the value indicated to be a critical value for metallic pollution. We should note that HPI does not depend on the abundant of an element in water but on the effects that these elements have on human health when they consume it. The multivariate analysis suggested the omnipresence of the effect of geogenic and anthropogenic processes in the study area.

It is observed that the values of geochemical NBL and geochemical TV are slightly greater in the wells than the boreholes this can be due to the fact both groundwater and well water are vulnerable to heavy metal pollutions but well water is more vulnerable than groundwater and the sources of heavy metal pollution could be due to anthropogenic activities (agriculture with the use of chemical fertilizers, latrines, poor sanitation of the area where boreholes are located, doing laundry) around or near borehole sites.

The metal pollution index and the natural geochemical background level indicate serious problems in terms of the quality potential of groundwater in the area of study. This study will therefore help water managers and the community to become aware in terms of the preservation of the resource and also to take the appropriate measures to avoid health problems related to water and to better manage the resources.

REFERENCES

[1] Abderamane, H., Razack, M., Vassolo, S., 2013. Hydrogeochemical and isotopic characterization of the groundwater in the Chari-Baguirmi depression, Republic of Chad. *Environ Earth Sci* 69:2337–2350

[2] Ahmad, S., Rashid, U., Izrar, A., 2022. Assessment of groundwater quality using Entropy-Weighted Quality Index (EWQI) and multivariate statistical techniques in Central Ganga plain, india.

[3] Alhou, B., Micha, J. C., Dodo, A., Awaiss, A., 2009. Etude de la Qualité physico-chimique et biologique des eauxdufleuve Niger à Niamey (Study of the physico-chemical and biological quality of the waters of the Niger River in Niamey).*International Journal of Biological and Chemical Sciences 3*(2), p240–254.

[4] APHA., 2012. Standard Methods for the Examination of Water and Waste Water, 22nd edition. American Public Health Association, American Water Works Association, Water

[5] Bhardwaj, R., Gupta, A., Garg, J.K., 2017. Evaluation of heavy metal contamination using environmetrics and indexing approach for River Yamuna, Delhi stretch, *India. Water Sci*. http://dx.doi.org/10.1016/j.wsj.2017.02.002

[6] Bon, A.F., Doua, S.A., Banakeng, L.A., Narke, C., Chouto, S., Ndam, M.A., 2020a. Contribution of geostatiscal model of electrical conductivity in assessment of the water pollution index of the Quaternary aquifer of the Lake Chad basin (Kousseri- Cameroun). *Arabian Journal of Geosciences*. https:// dio.org/10.1007/s12517-020-5142-1.

[7] Bon, A.F., Abderamane, H., Mboudou, G.E., Doua, S.A., Banakeng, L.A., Boyomo, S.B.B.S., Pilh, S.L., Damo, B.W., 2020b. Parametrization of groundwater quality of the Quaternary aquifer in N'Djamena (Chad), Lake Chad Basin: application of numerical and multivariate analysis. *Environ Sci Pollut Res*. https://doi.org/ 10.1007/s11356-020-10622-5.

[8] Bon, A.F., Aoudou, S.D., Ndam, A.M., Bineli, E.A., 2018. Groundwater pollution index evaluation test using electrical conductivity in a semi-arid quaternary aquifer (kousseri-Cameroon, Lake Chad basin): multivariate statistical analysis approach. Springer nature Switzerland AG 2019 H. I. Chaminé et al. (eds.), Adv. Sust. Environ. Hydrol. Hydrogeol. Hydrochem. *Water res. Adv. Sci. Tech. & Innov*. https://doi.org/ 10.1007/978-3-030-01572-5_70

[9] Bon, A.F., Therese Anny Michelle Ngo Ngoss., Guillaume Ewodo Mboudou., Lucian Asone Banakeng., Jules Remy Ndam Ngoupayou., Georges Emmanuel Ekodeck., 2021. Groundwater flow patterns, hydrogeochemistry and metals background levels of shallow hard rock aquifer in a humid tropical urban area in sub-Saharan Africa- A case study from Ol´ezoa watershed (Yaound´e-Cameroon)

[10] Brambant, P., Gavaud., 1985. Les sols et les ressources en terres du nord – Cameroun. ORSTOM, M.E.R.E.S Paris. 285p .

[11] BUCREP., 2010. *Rapport de présentation des résultats définis du 3ème Recensement Général de la Population et de l'Habitat (RGPH) de 2005. Technical Report*, Yaoundé: MINEPAT. 50p.

[12] Close M.E., Hodgson, L.R., Todgre G., 1989. Field evaluation of fluorescent whitening agents and sodium tripolyphosphate as indicator of septic tank contamination in domestic wells, newZeal.J.marinefresh.res,pp 5663-568.

[13] Cornelius, Tsamo., Guillaume, Patrice Kofa., Lady, Astaharam., 2019. Physico-chemical characterization and zero valent iron treatment of boreholes water of maroua cameroon.

[14] Dassibat, C., 1967. Etude hydrogéologique des monts Mandara.F.E.D. BRGM. YAO. 67 AC.

[15] De Caro, M., Crosta, G.B., Frattini, P., 2017. Hydrogeochemical characterization and Natural 584 Background Levels in urbanized areas: Milan Metropolitan area (Northern Italy). *Journal of 585 Hydrology*, 547: 455-473. DOI:10.1016/j.jhydrol.2017.02.025

[16] Detay., 1987. Caractéristiques synthétiques des forages profonds réalisés dans la plaine du Logone, 76p

[17] Detay., 1993. Forage d'eau (réalisation, entretien et minéralisation). Eds. Masson, Paris, 280 p.

[18] Djeuda Tchapnga, H. B., Tanawa E, Ngnigam E., 2001. L'eau au Cameroun: Approvisionnement en Eau Potable (Tome 1). *Presses Universitaires: Yaoundé.*

[19] Djuikom, E., Njine, T., Nola, M., Sikati, V., Jugnia, LB., 2006. Microbiological water quality of the Mfoundi River watershed at Yaoundé, Cameroon, as inferred from indicator bacteria of fecal contamination. *Environ Monit Assess.*, 122(1-3): 171– 83.

[20] Dumort, J. C., Peronne, Y., 1966. Notice explicative sur la feuille de Maroua ;

[21] Edmunds, W.M., Shand, P., Hart, P., Ward, R.S., 2003. The natural (baseline) quality of groundwater: a UK pilot study. Sci. Total Environ. 310, 25–35.

[22] Fantong, W.Y., Kamtchueng, B.T., Ketchemen-Tandia, B., Kuitcha, D., Ndjama, J., Fouepe, A.T., Takem, G.E., Issa., Wirmvemn M.J., Bopda Djomou, S.I., Ako Ako, A., Nkeng, G.E., Kusakabe, M., Ohba, T., 2016. Variation of hydrogeochemical characteristics of water sin surface flows, shallow wells, and boreholes in the coastal city of Douala (Cameroon) *Hydrological Sciences Journal* 61, 2916-2929 https://doi.org/10.1080/02626667.1173789.

[23] Fonteh M. F., 2003. Water for People and Environment: The United Nations Cameroon water development Report. United Nations Economic Commission for Africa, Addis Abeba, Ethiopia.

[24] Gaillardet, J., Dupre, B., Louvat, P., Allerge, C.J., 1999. Global silicate weathering of silicates estimated from large river geochemistry. Chemical Geology 159 3-30.

[25] Gao, Y., Qian, H., Ren, W., Wang, H., Liu, F., Yang, F., 2020. Hydrogeochemical characterization and quality assessment of groundwater based on integrated-weight water quality index in a concentrated urban area. J. Cleaner Product., 121006 https://doi.org/10.1016/j.jclepro.2020.121006.

[26] Last, G.W., Murraya, C.J., Botta, Y., Browna, C.F., 2014. Threshold values for identification of contamination predicted by reduced-order models. Energy Procedia 63, 3589–3597. https://doi.org/10.1016/j.egypro.2014.11.389.

[27] Li, P., Qian, H., Wu, J., 2010. Groundwater quality assessment based on improved water quality index in Pengyang County, Ningxia, Northwest China. E-J Chem 7(S1):S209–S216. https ://doi. org/10.1155/2010/45130 4

[28] Meybeck M., Ragu A., 1996. River Discharges to the Oceans. An assessment of suspended solids, major ions, and nutrients. Environment Information and Assessment Rpt. UNEP, Nairobi, 250p.

[29] Mkandawire T., 2008. Quality of groundwater from shallow wells of selected villages in Blantyre District, Malawi.PhyChem Earth, 33: p807–811.

[30] Mohan, S.V., Nathila, P., Reddy, S.J., 1996. Estimation of heavy metal in drinking water and development of heavy metal pollution index. Journal of environment science and health. A-31, 283-289.

[31] Moussa, DJAOUDA., Alain, LECKÉ., Mathieu Kalwé, MAÏNÉ., Zoua, WADOUBÉ., Song, LIANG., Moïse, NOLA., Thomas, NJINÉ., 2016. Assessment of bacteriological quality of groundwater from boreholes in Maroua (Far North Cameroon).

[32] Muller, D., Blum, A., Hookey, J., Kunkel, R., Scheidleder, A., Tomlin, C., Wendland, F., 2006. Final proposal of a methodology to set up groundwater threshold values in Europe. Specific targeted EU research project BRIDGE (contract No SSPI-2004-006538)- report D18. www.wfd-bridge.net

[33] Nakic, Z., Posavec, K., Bacani, A., 2007. A visual basic spreadsheet macro for geochemical background 654 analysis. Ground Water, 45(5): 642-7. DOI:10.1111/j.1745-6584.2007.00325.x

[34] Nanfack, N. A. C., Fonteh, F. A., Payne, V. K., Katte, B., Fogoh, J. M., 2014. Eaux non conventionnelles : un risque ou une solution aux problèmes d'eau pour les classes pauvres. *Larhyss Journal*, 17 : 47-64.

[35] Ngo Ngos, Anny Therese., 2022. Hydrodynamique des aquifers du socle de canton de Ouazzang dans l'arrondisement de Meri, Bassin versant du Mayo tsanaga, Extreme Nord Cameroon

[36] Nlend, B., Celle-Jeanton, H., Huneau, F., Garel, E., Ngo Boum-Nkot, S., Etame, J., 2020. Shallow urban aquifers under hyper-recharge equatorial conditions and strong anthropogenic constrains. Implications in terms of groundwater resources potential and integrated water resources management strategies. Sci. Total Environ. 757, 143887 https://doi.org/10.1016/j.scitotenv.2020.143887.

[37] Nouayti, N., Khattach, D., Hilali, M., 2015. Evaluation de la qualité physicochimique des eaux souterraines des nappes du Jurassique du haut bassin de Ziz (Haut Atlas central, Maroc). J. Mater. Environ. Sci., 6(4) : 1068-1081.

[38] Ouedraogo, I., Defourny, P., Vanclooster, M., 2016. Mapping the groundwater vulnerability for pollution at the pan African scale. Sci Total Environ 544:939–953. https://doi.org/10.1016/j.scitotenv.2015.11. 135

[39] Pedretti, D., Russian, A., Sanchez-Vila, X., and Dentz, M., 2016. Scale dependence of the hydraulic properties of a fractured aquifer estimated using transfer functions. Water Resour. Res. 52, 5008-5024.

[40] Piper, A.M., 1944. A graphic procedure in geochemical interpretation of water analysis. Trans Am Geophys Union 25(6):914–928

[41] Prasad, B., Sangita, K., 2008. Heavy METAL Pollution Index of Ground Water of an Abandoned Open Cast Mine Filled wiyh Fly Ash: a Case Study. Mine Water and the Environment, 27,265. doi: 10.1007/s10230-008-0050-8

[42] Prasanna, M.V., Chidambaram, S., Thilagavathi, R., Thivya, C., Venkatramanan, S., Murali, Krishnan N., 2019. A statistical approach to identify the temporal and spatial variations in the geochemical process of a coastal aquifer, South East Coast of India. GIS Geostat Tech Groundwater Sci:223–235. https://doi.org/10.1016/b978-012-815413-7.00016-x

[43] Rakotondrabe, F., Ndam Ngoupayou, J. R., Mfonka, Z., Rasolomanana Harilala, E., Nyangono Abolo, A.J., Ako Ako, A., 2017. Water quality assessment in Bétaré-Oya gold mining area (East-Cameroon): Multivariate Statistical Analysis approach. *Science of the Total Environment*, 610-611; 831 -844.

[44] Ramesh, K., and Jagadeeswari, P., 2013. International Journal of Research in Chemistry and Environment 31 262-271

[45] Rao, N., Rao, P., Dinakar, A., Marghade, D., 2017. Fluoride occurrence in the groundwater in a coastal region of Andhra Pradesh, India. Appl Water Sci. 7(3) :1467–1478.

[46] Rao, N., Vidyasagar, G., Surya RAO, P., Bhanumurthy, P., 2015. Assessment of hydrogeochemical processes in a coastal region: application of multivariate statistical model. *J Geol Soc India.* 84:494–500.

[47] Reza, R., and Singh, G., 2010. Heavy metal contanimation and its indexing approach for river water. International journal of Environmental Sciences Technology, 7(4) ,785-792. Doi : 10.1007/BF03326187

[48] Rotiroti, M., Di Mauro, B., Fumagalli, L., Bonomi, T., 2015. COMPSEC, a new tool to derive natural background levels by the component separation approach: application in two different hydrogeological contexts in northern Italy. Journal of Geochemical Exploration. 158, 44-54.

[49] Singh, G., Rakesh, K.K., 2016. Heavy metal contamination and its indexing approach for groundwater of Goa mining region, India. Applied Water Sciences. Dio: 10.1007/s13201-016-0430-3.

[50] Subba R, N., Devadas, D.J., Rao, K.V.S., 2006. Interpretation of groundwater quality using principal component analysis from Anantapur district, Andhra Pradesh, India. Environ. Geosci. 13 (4), 239–259. https://doi.org/10.1306/eg.02090504043.

[51] Tillement B. 1970. Hydrogéologie du Nord Cameroun. Bull. Dir. Mines et Géol., Cameroun

[52] WHO., 2011. Guidelines for drinking-water quality World Health Organization

[53] WHO., 2006. Guidelines for Drinking-Water Quality, 4th edn. Incorporating first addendum. World Health Organization,Geneva, Switzerland.

[54] WU, J., SUN, Z., 2016. Evaluation of shallow groundwater contamination and associated human health risk in an alluvial plain impacted by agricultural and industrial activities, mid-west China. Expo Health. 8(3):311–329. XING

[55] Zhang, Y., Chen, Z., Sun, J., Wang, J., 2017. Natural background levels of chemical components in groundwater of Hutuo River catchment area, North China Plain. Environ. Forensic 18 (1), 62–73. https://doi.org/10.1080/15275922.2016.1263904.

[56] Zotou, I., Tsihrintzis, VA., Gikas, GD., 2019. Performance of seven water quality indices (WQIs) in a Mediterranean River. Environ Monit Assess 191(8):505