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Hydrochemical And Statistical Characterization Of Basement Aquifer Groundwater in The Extreme Northern Togo

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ABSTRACT: About two third of the population in the North of Togo lives in rural and semi-rural areas, depends on groundwater for drinking, for domestic and agricultural uses. Hydrochemical and statistical methods investigation are carried out on the groundwater of the basement aquifer system in the North of Togo in order to determine the mineralization water process. Chemical analysis were made at Laboratory of Water Chemistry (LCE) at University of Lomé according to AFNOR methods. The quality of groundwater has been conducted by using multivariate statistical and spatial analyses. Major chemical elements show that this aquifer system is composed by fresh water dominated by the Ca-Mg-HCO_3 and Ca-HCO_3 water types (about 93%). According to hydrochemical and multivariate statistical analysis, groundwater mineralization is caused by the silicates weathering related to the residence time of water in the aquifer, anthropogenic activities in urban environment and agricultural area, soil CO_2 diffusion and cation exchange process.

Keywords:- Birrimian aquifer, Hydrochemical, multivariate statistical analysis, mineralization water process.

I. INTRODUCTION

On a global scale, about two third of the population in the Savannas region in Togo, lives in rural and semi-rural areas, depends on groundwater for drinking and for domestic uses [1]. Surface water is easily accessible, but they are subject to increasing pollution and a significant temporal and seasonal variation in their quantity. Unlike surface water, groundwater has the advantage of being less exposed to pollution, being available near demand points and having a quantity that varies little with the seasons [2]. This supplying point once of good quality, is currently threatened by various points and diffuse sources of contamination [3]. It is the main source of water supply for people in the Savannah region of Togo, given the occasional drying up of traditional water points (backwaters, springs and traditional wells) following the effects of climate change.

Indeed, Togo is a small country in West Africa covering an area of 56,600 km^2. It is divided into five major economic regions, the fifth region being the Savannah region located in the extreme north of the country. The study area is located in the Savannah region, which is bordered in the North by Burkina Faso, in the South by the Kara region, in the West by Ghana and in the East by Republic of Benin. The rate of drinking water supply in the region in 2007 was estimated at 16.6% in rural and semi-rural areas, 44.2% in urban areas with an average of 24.7% [1]. In front of this shortage, the Togolese State, with the help of a few donors, initiated a national program of village hydraulics throughout the Savannah region, the objective of which was to supply drinking water in all areas of the country, sub-prefectures and more generally in all urban, peri-urban and rural areas of the region [4]. This program has made it possible to build several water points in villages only from groundwater. Nowadays, no study has been done in order to characterize these waters qualitatively and quantitatively.

At the national level, the works carried out concerned the coastal sedimentary basin and the few works done in the basement are those of [5] (in plateau region) and [6] (in Kara region). The study done on the Birrimian basement of the Savannah region by [7] focused on a mathematical model of the structure and functioning of the exploited basement aquifer. This study shows that the overall rainfall shortage since 1970, and which increased from 1983 to 1985, resulted in a decrease in annual recharge for these three years. The present study aimed to determine the hydrogeochemical characteristics of groundwater of the basement aquifer in northwestern Togo for domestic use. Specifically, the study focused on determining the quality of groundwater, the processes influencing this quality, the chemical facies and the influence of geological formations on the water resources, to monitor the spatial evolution of physicochemical parameters.

II. MATERIAL AND METHODS

II.1- Study area, geological and hydrogeological context

The study area, which is the Birrimian basement of northwestern Togo, is situated between latitude 10°43 ' and 11°08' N, and longitude 0°09 ' and 0°33 E. It is limited to the West by Ghana, North by Burkina Faso, East and to the South by non-metamorphic primary sedimentary formations of the Togolese part of the Volta Basin (Oti Basin). **Figure 1** shows the location of the study area and the sampling points.

In geological context, the formations of the study area belong to the eastern edge of the West African Big Craton Man Ridge. This ridge which develops largely in the North-West of the Togolese part, is a vast geological set well represented in West Africa. It covers an area of about 1345 km^2, belonging to the so-called stable area, and is located about 600 km north of the capital Lomé. For the reasons of the study, we had taken part of the sandstones of Dapaong which collect the fractured basement. It is the oldest formation represented in Togo, where it is attributed to Birrimian in comparison with the Birrimian formations observed in Ghana, Burkina Faso and Côte d'Ivoire. It consists of granito-gneissic basement and includes diverse crystalline formations. In comparison with similar formations of the same type in Burkina Faso, they are considered Archean (or pre-Birrimian) to early Proterozoic (Precambrian C or Birrimian) [7]. There are gneisses, migmatites, amphibolites, granites, granodiorites and diorites. The geological map is shown in **Figure 2**.

The main hydrogeological formations of the granito-gneissic basement are those of the great units of the eastern edge of the West African craton. The fissured medium that constitutes this region is the granito-gneissic domain whose hydrogeological conditions are relatively homogeneous and correspond to the lithological families [7]. In crystalline and crystallophyllian environments, the aquifer zones correspond to the altered surface levels (alterites and alluvium) and deep basement levels (cracks and / or fractures), which are in many cases superimposed and form the same aquifer system [8]. There are two types of aquifers: the aquifer of alterites exploited by modern or village wells, the aquifers of fissures and fractures captured by the boreholes within in case of the programs of drinking water supply in these localities. The alteration of these formations produces a thick layer of alterites which varies between 2 and 40 m or more.

The climate the Sudanese type characterized by a regime uni modal with one rainy season from May to October; and the dry season from October to April. The mean annual rainfall recorded at meteorological station of Dapaong is 1050 mm with a mean temperature of 33.6°C. The total annual evapotranspiration oscillates between 1600 to 1800 mm [9].

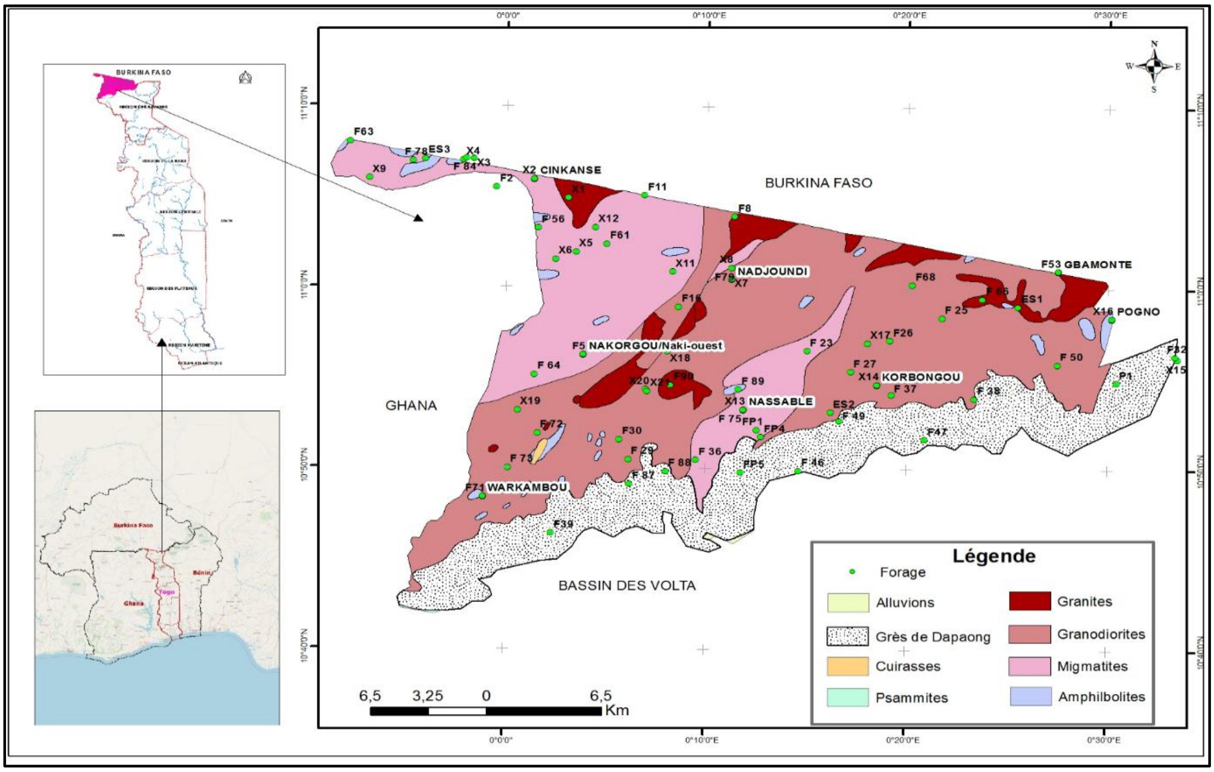


Figure 1: Map of the study area showing the sampling points.

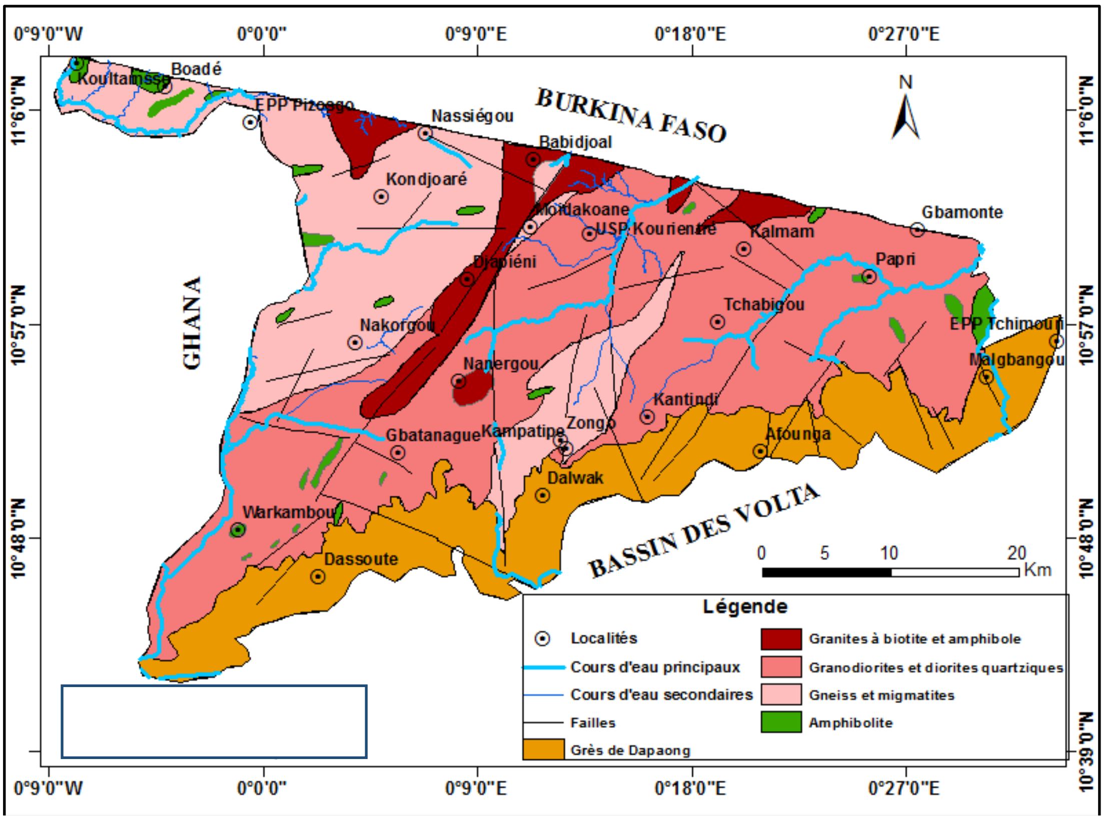


Fig 2: Geological Map of the study area

II.2- Sampling and analysis methods

A total of 74 water samples were collected in September 2017 out of several of the study area. (**Figure 1**), from different aquifers (3 wells and 68 boreholes) and 3 surface water. These water samples were taken in polyethylene bottles of 1.5 liters, and preserved for analysis.

Measurements such as water temperature, pH, Electrical Conductivity (EC), and total alkalinity as HCO_3 were carried out on site. The boreholes and wells were purged with pumps until stabilization of pH, Electrical conductivity and temperature before the field measurements were performed. Then, water samples were collected and stored in 1.5 L clean high-density polyethylene bottles with poly-seal caps. Conductivity and temperature were given using a multimeter Inolab "WTW". For surface water sampling, samples were collected from flowing part of the rivers. A static water levels were measured in wells and boreholes using a light Sounder. The chemical analysis were made at the Chemistry Laboratory of Water (LCE) of the University of Lomé according to AFNOR methods. The major elements Ca^{2+}, Mg^{2+} were determined by complexometry with EDTA 0,01M after titration; Na^+ and K^+ by direct reading using a photometer of JENWAY flame mark PFP7. Ions Cl^- were determined by the argentimetric method, NO_3^- and SO_4^{2-} by molecular spectrophotometry of absorption after calibration. Total alkalinity (HCO_3^- and CO_3^{2-} was determined by titration with a hydrochloric acid solution (0.1 M) by using phenolphthalein and helianthin as indicators.

II.3- Data processing

The results of the physicochemical analysis were treated by methods of multivariate statistical analysis coupled with the hydro chemical methods. The hydro chemical method required the use of Piper Diagram and the index of saturation carried out under the Diagram software, for the identification of the facies of water and the study of saturation with respect to certain minerals. The statistical approach is based on the use of the Analysis in Normalized Principal Components (ACPN) and Hierarchical Ascending Classification (CHA) to study the phenomena at the origin of the mineralization of water and those of the pollution/contamination. These statistical methods are usually used in the field of Sciences of water, with excellent results [10]. Indeed the ACP STATE makes it possible to synthesize and classify a significant number of data in order to extract from them the principal factors which are at the origin of the simultaneous evolution of the variables and their reciprocal relation [11]. It makes it possible to highlight the resemblances and the graphic position which would present two or several chemical variables during their evolution. The Ascending hierarchical clustering (CAH) is a tool to analyze data of water chemistry and for the formulation of geochemical models [12]. The statistical analysis were carried out with software XL-STAT 2007. The values of the parameters were compared with the World Health Organization [13] value guides for drinking water. The values of the ionic balance characterizing the samples taken within the framework of this study are all lower than 5% reflecting the good quality of the analysis carried out.

III. RESULTS AND DISCUSSION

III.1- Results

III.1.1- Physical Parameters

"*In situ"* measurements related to three parameters such as: temperature (T°C), potential of hydrogen (pH) and electric conductivity (EC) (Table 1). Temperature of groundwater in the study area ranges from 27.4 to 30.1°C with mean temperature about 28.4°C. They presented a range of narrow temperature: the amplitude of variation is small as the coefficient of variation CV shows it (Table 1). The values of pH recorded during the sampling campaign ranges from 5.68 to 8.88 with a mean pH about 7.34 thus close to neutrality. Water is characterized by a great space variability of electrical conductivity. Electrical conductivity ranges from 24 µs/cm (well P3) to 1747 µs/cm (borehole FP1). Waters with high conductivity are located in urban environment. This indicates that the basin is characterized by important heterogeneities and the conductivity values are affected by different geochemical processes. **Figure 3** shows the space conductivity distribution of groundwater in the study area. It shows that the lowest mineralization water are located in the Mid-west of the study area (which would correspond to a recharge zone). That is put forward by the piezometric map (**Figure 4**) which indicates a dividing line). The alkalinity of water is connected to the pH system, and ranges from 12.2 mg/L to 414.8 mg/L with a mean alkalinity about 181.8 mg/L. These two parameters make it possible to calculate the partial pressure of balancing CO_2. It is influenced by the addition or the consumption of the protons. The values of the log (pCO_2), characterizing groundwater and surface water study, ranges largely from -2.78 to -0.18 with an average of about -1.41. Tables 1 and 2 indicate the variations of the physical parameters.

Table 1: Physicochemical parameters of groundwater

	Min	Max	Mean	Std dv	CV en %
Cond	**24**	**1747**	**355**	**242,8**	**68,4**
pH	**5,68**	**8,8**	**7,34**	**0,459**	**6,25**
T°C	**27,4**	**30,1**	**28,3**	**0,76**	**2,68**
O_2 diss	**2**	**10,6**	**6,75**	**2,27**	**33,63**
HCO_3^-	**12,2**	**414,8**	**181,76**	**89,08**	**49**
log(pCO_2)	**-2,78**	**-0,18**	**-1,41**	**0,47**	**-33,94**

Table 2: Physicochemical parameters of surface water

	Min	Max	Mean	Std dev	CV en %
Cond	46,00	111,00	77,67	32,53	41,88
pH	7,24	8,27	7,70	0,52	6,79
T°C	28,50	29,30	28,87	0,40	1,40
O_2 diss	7,80	9,40	8,43	0,85	10,08
HCO_3^-	30,50	73,20	52,87	21,42	40,52

III.1.2- Variation of the Chemical Parameters

The physicochemical parameters of the groundwater quality data were statistically analyzed and the results are presented in form of minimum, maximum, mean and standard deviation (**Table 3**).

- Major Cations

The calcium contents range from 4 mg/L to 156 mg/L with an average of 31.2 mg/L. While the values of magnesium obtained vary between 0.72 mg/L and 79.2 mg/L with an average of 13.3 mg/L. The water hardness is an indicator of the limestone level in water: it corresponds to its calcium content and magnesium. The more it contains some, the more it is "hard". As a whole, these results thus reveal that water is in extreme cases soft and fairly hard. Hard water of tendency is water of boreholes: FP1 (72 °F), FP6 (33 °F) and FP8 (32°F). Sodium presents contents ranges from 0.8 mg/L to 114 mg/L for an average value of 22.1 mg/L. The values of potassium, just like sodium are very low. Potassium vary between 0.5 mg/L and 36 mg/L, for an average of 3.18 mg/L.

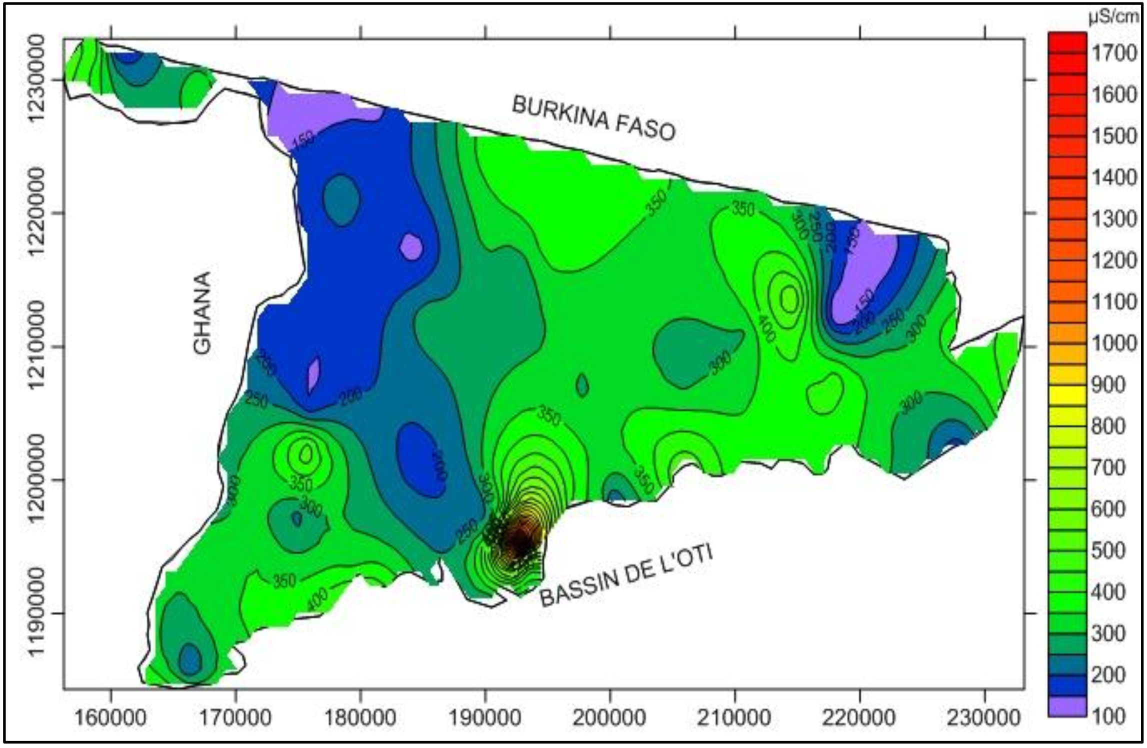


Figure 3: Map of spatial distribution of water electric conductivity (September 2017)

- Major Anions

Just like the cations, the anions exist with low dose in the majority of sampled water of this study. Except the bicarbonates (HCO_3^-) which post the highest contents in the water samples. These contents vary from 12.2 mg/L to 414.8mg/L with an average about 181.8 mg/L. More than 50% of the water points have a content bicarbonates higher than the average value. The recorded chloride rates are very low and vary between 0 mg/L and 215.2 mg/L, with an average of 11.86 mg/L. This standard deviation shows a great variability of the contents point chlorides from one point to another. The sulphates contents range from 0.3 mg/L (in 32 observations is 43.2 % of the total staff complement) to 80.9 mg/L in FP1, with an average of 4.98mg/L.

Table 3: Summary of groundwater quality data in the study area

Variables	Units	Standards WHO, 2011	Minimum	Maximum	Mean	Std dev
Cond	µs/cm	180-1000	24.0	1747.0	343.3	244.1
pH	-	6.5-8.5	5.7	8.9	7.4	0.5
HCO_3^-	mg/L	-	12.2	414.8	182.3	89.3
Ca^{2+}	mg/L	-	4.0	156.0	31.2	20.9
Mg^{2+}	mg/L	-	0.7	79.2	13.3	11.1
Na^+	mg/L	≤ 200	0.8	114.0	22.1	17.7
K^+	mg/L	≤ 12	0.5	36.0	3.2	4.3
NO_3^-	mg/L	≤ 50	0.0	328.2	22.8	47.2
Cl^-	mg/L	≤ 250	0.0	215.2	11.9	32.4
SO_4^{2-}	mg/L	≤ 250	0.3	80.9	5.1	11.9
SiO_2	mg/L	≤ 10	11.4	106.6	58.1	23.6

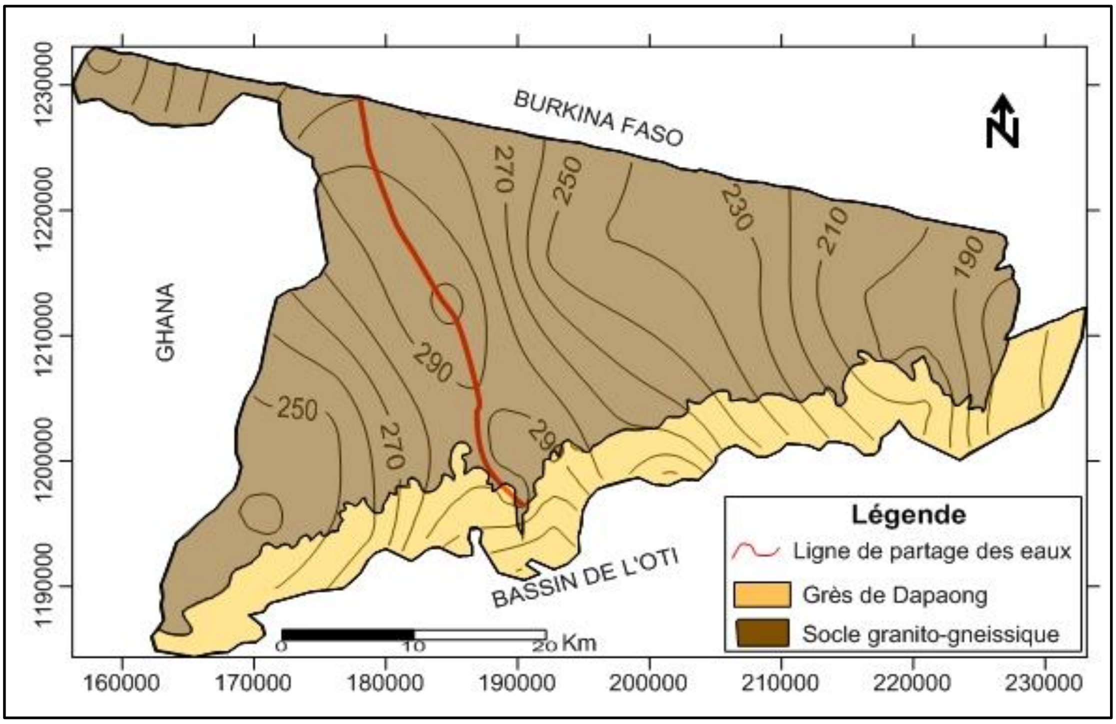


Figure 4: Piezometric map of the study area (September 2017)

III.1.3- Hydrochemical facies

In an attempt to determine water types, chemical compositions of the analyzed water samples were plotted on the Piper Diagrams (*Piper, 1944*). The hydrochemical facies of groundwater and surface water is given by Piper Diagram (Fig 5). Groundwater in the Birrimian basin in the north of Togo exhibit heterogeneity in water type. Four groundwater type are clearly identifiable: HCO_3-Na-K (1 sample or 1.4%) for borehole; Cl-SO_4-Ca-Mg (4 samples or 5.4%) for borehole; HCO_3-Ca-Mg (29 samples or 39.2%) for boreholes, wells and surface waters; and the facies HCO_3-Ca (40 samples or 54.1%) for boreholes and surface waters. The facies bicarbonates calcic dominates at a rate of 93.2%.

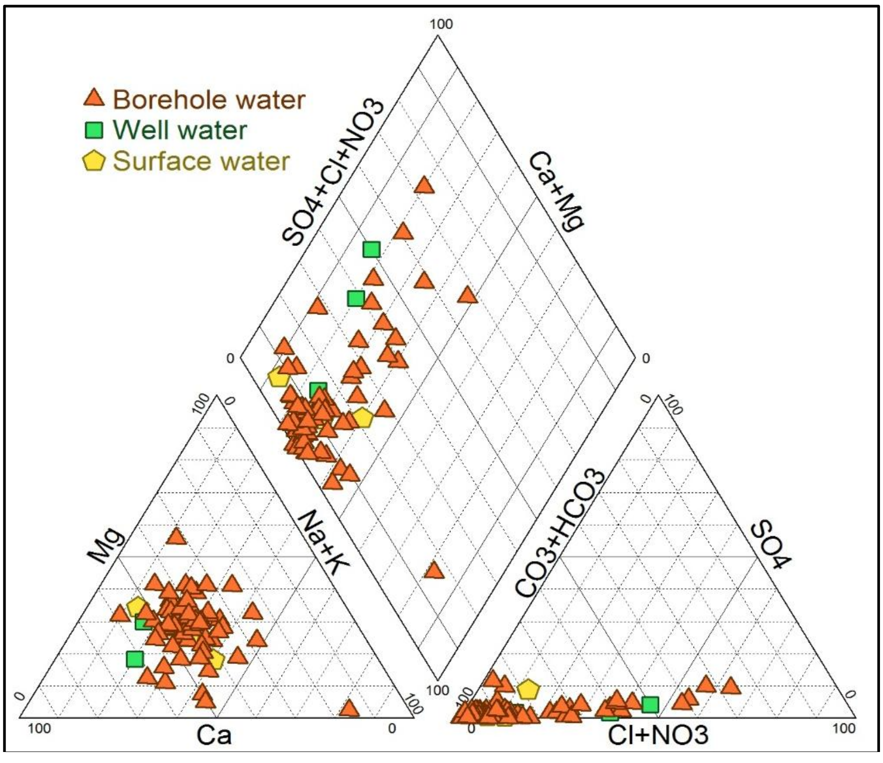


Figure 5: Piper Diagram showing the hydrochemical compositions of groundwater and surface water

III.1.4- Statistical analysis of the chemical parameters

- Factorial Matrix

It was carried out starting from a table of contingency of (74) observations and (11) variables. This analysis made it possible to identify three principal factors of which the two first factors contribute to 70.2% of the original variance. The eigenvalues of the first three factors are presented in **Table 4.**

Table 4: Eigenvalues and percentage of expressed variance

Facteurs	F1	F2	F3
Eigenvalue	6.335	1.387	1.103
% expressed Variance	57.791	12.609	10.026
Plurality of expressed variance	57.791	70.200	80.226

The factor F1, with an expressed variance of 57.59%, is the most significant follow-up of the factors F2 and F3, with respectively 12.61% and 10.03% of the original variance. The first two factors translate the main part of required information and make it possible significantly to represent the essential part of the observations and the variables expressed about 70.2%.

Table 5 presents the contribution of the various variables in the definition of the principal factors. This table shows that the factor F1, is defined by electrical conductivity EC (r=0.986), calcium (r=0.903), magnesium (0.891), sodium (0.932), sulphates SO_4^{2-} (R = 0.928), nitrates NO_3^- (r=0.84), and chlorides Cl^- (r=0.891). Thus the axis F1 (57.59%) represented the phenomenon of mineralization by hydrolysis but also expresses an anthropic effect (correlation between F1 and NO_3^-, Cl^- and SO_4^{2-}) due to pollution.

Table 5: Correlations between the variables and the factors

	F1	F2	F3
Cond	**0.986**	0.149	-0.010
pH	0.098	0.294	0.781
HCO_3	0.507	**0.796**	-0.185
Ca	**0.903**	0.280	-0.131
Mg	**0.891**	0.253	-0.037
Na	**0.822**	0.033	0.121
K	0.549	-0.484	0.006
NO_3	**0.840**	-0.280	0.120
Cl	**0.932**	-0.312	0.086
SO_4	**0.928**	-0.294	0.071
SiO_2	-0.271	0.072	**0.632**

The connection existing between all the variables taken two by two and the coefficients of correlation between these various variables are given by the matrix of correlation (**Table 6**). While being based on the coefficient of correlation r=0.64 [14] criticizes, a test of correlation of the various studied parameters highlighted a close connection between Ca^{2+}, Mg^{2+}, Na^+ SO_4^{2-}, Cl^-, NO_3^- and electrical conductivity. This relation results in the coefficients of correlation approaching "1". Taking into consideration this table, one can make several noticed:

- A good correlation between conductivity and Ca^{2+} (0.94), Mg^{2+} (0.924), Na^+ (0.808), SO_4^{2-} (0.864), Cl^- (0.874) and NO_3^- (0.804).
- A discrete correlation between the bicarbonates, Ca^{2+} and Mg^{2+}; like between calcium and the anions (NO_3^-, SO_4^{2-} and Cl^-) then between Mg^{2+} and these some anions.

Principal Component Analyses (PCA)

PCA in the factorial design F1xF2 is presented by **Figure 6.** The space of the factorial variables designated by F1xF2 shows that this plan expresses 70.2% of the original variance. This graph highlights the regrouping around the factorial axis F1 (57.59%) which is determined by the EC, hardness, the SO_4^{2-}, Cl^-, Na^+ and NO_3^-. This factorial axis expresses total mineralization by the dissolution of the rock then process of anthropization due to the high contents of sulphates, nitrates and chlorides.

The Factor F2 which explains 12.61% of the total inertia of the points representative of the observations and determined by the HCO_3^- (r=0,796). This plan highlights the surface exchange which proceeds between water and CO_2 biogenic.

Table 6: Pearson correlation among physicochemical properties in Birrimian basement aquifer $p < 0.05$ starting from a table of contingency

Variables	**Cond**	**pH**	**HCO_3^-**	**Ca^{2+}**	**Mg^{2+}**	**Na^+**	**K^+**	**NO_3^-**	**Cl^-**	**SO_4**	**SiO_2**
Cond	**1**										
pH	0.099	**1**									
HCO_3^-	**0.617**	0.126	**1**								
Ca	**0.940**	0.023	**0.671**	**1**							
Mg	**0.924**	0.039	**0.626**	**0.899**	**1**						
Na	**0.808**	**0.251**	**0.497**	**0.619**	**0.585**	**1**					
K	**0.452**	-0.026	0.064	**0.296**	**0.299**	**0.562**	**1**				
NO_3^-	**0.804**	0.029	0.078	**0.727**	**0.738**	**0.569**	**0.334**	**1**			
Cl^-	**0.874**	0.041	0.187	**0.762**	**0.782**	**0.716**	**0.613**	**0.905**	**1**		
SO_4^{2-}	**0.864**	0.085	0.207	**0.746**	**0.737**	**0.763**	**0.601**	**0.868**	**0.962**	**1**	
SiO_2	-0.222	0.104	-0.159	**-0.234**	-0.114	**-0.266**	-0.184	-0.119	-0.187	**-0.269**	**1**

The projection of observations in the factorial design F1xF2 shows that we can subdivide the points of measurement into three groups (**Figure 7**):

➢ **First group** (Boreholes: FP1, FP6, FP8) which accounts for 4.22% of the sampled points. They are the boreholes with high mineralization controlled by a pollution more specifically as these boreholes are located in full urban environment.

➢ **Second Group:** constituted by the boreholes and wells fairly to slightly mineralization and characterized by a mineralization due to the residence time.

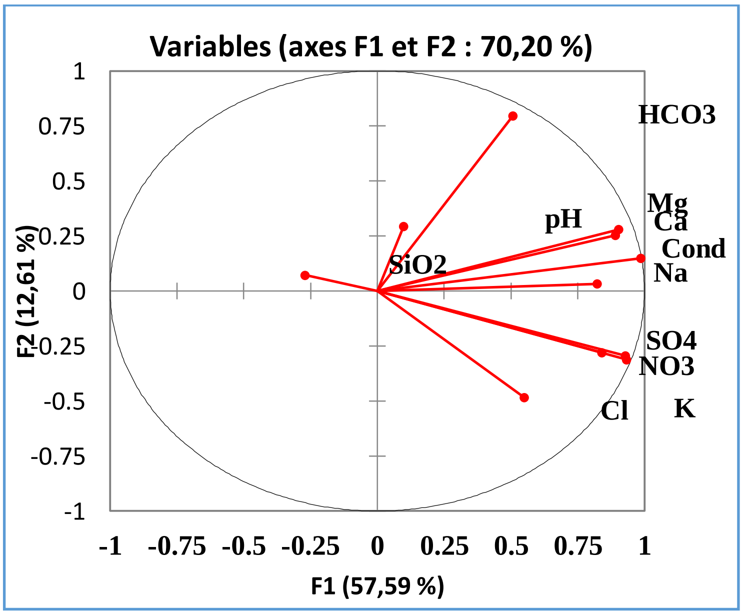


Figure 6: Factorial variables in space F1 –F2

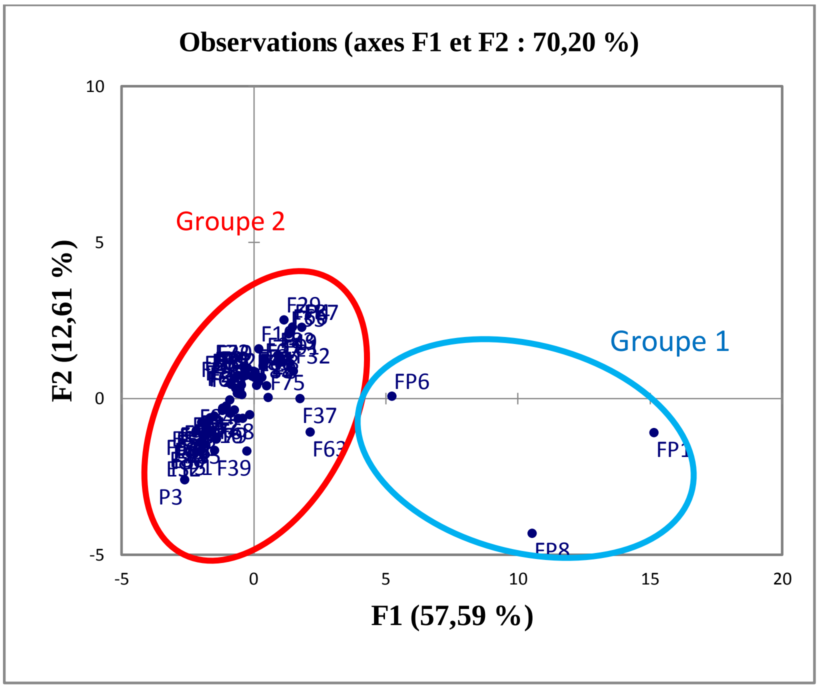


Figure 7: Projection of the points of measurement of groundwater on the factorial design F1xF2

Hierarchical Cluster Analysis (HCA)

Dendrogram (**Figure 8)** resulting from the Hierarchical Cluster Analysis (HCA) highlights three principal groups of variables:

The first group is made of the major EC and all ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, NO_3^-, SO_4^{2-}, Cl^-, and HCO_3^-). This group accounts for the mineralization time of stay or the phenomenon of minerals hydrolysis. It also indicates the presence of chlorides and the compounds nitrogenized like NO_3^- therefore showing the contribution of the anthropic activities in the mineralization of groundwater.

The second group made up of pH which highlights the phenomenon of mineralization starting from the contact between water and CO_2 atmosphere and especially the CO_2 biogenic which by dissolution enriches water by bicarbonates.

The third group translates the silicates weathering phenomenon.

In comparison with the results of hydrochemical characterization, statistical analysis and taking into account the geological, hydrogeologic context and aim of the study, it is interesting to study the processes of mineralization, by establishing the various correlations between the major ions, the index of saturations and cations exchanges.

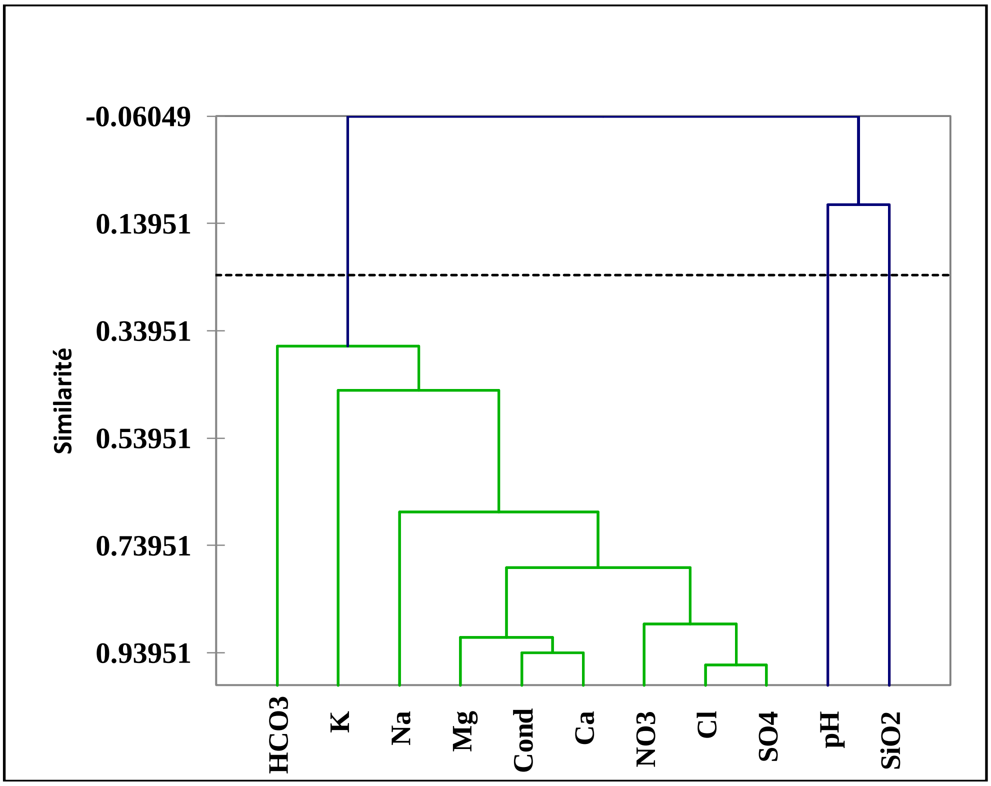


Fig 8: Dendrogram of the physicochemical parameters of groundwater

III.1.5- Process of water Mineralization

The mineralization of groundwater is characterized by the presence of more abundant ions than others. The abundance of these elements results from an origin which can be either natural or anthropic. It is then controlled by physical or chemical processes. Among these processes we can enumerate those related to the interaction with boxing, depend on lithology, the time of transit of water within the aquifer formation and the chemical processes controlling the setting in solution. Anthropic influences as the lack of system of adequate cleansing and the high agricultural activity can also contribute significantly to mineralization of groundwater.

III.1.5.1- Relations expected following the hydrolysis of silicates

The Geology of the study area consists of granodiorites, diorites quarzites and granites made up primarily of plagioclase, amphiboles and biotite. These silicated minerals are attacked by water in the ground rich in CO_2 to release in solution the components such as Na^+, Ca^{2+} Mg^{2+} and silica (**Figure 9**). The first and the main thing produced to be formed during this deterioration are kaolinite according to the following reaction:

$2NaAlSi_3O_8 + 2CO_2 + 11H_2O \Rightarrow Al_2Si_2O_5(OH)_4 + 2Na^+ + 2HCO_3^- + 4H_4SiO_4$

Albite (sodic plagioclase) Kaolinite Silica

The acidity of the water which is related to its free CO_2 contents decreases by consumption of this CO_2. Water consequently becomes increasingly alkaline as the reaction advances, i.e. the concentration in HCO_3^- increases. **Figure 9** presents the variations of the contents of cations and bicarbonates according to silica. According to **Figure 9** there is a correlation significantly positive between the contents of cations (Ca^{2+}, Na^+, Mg^{2+}) and silica. Even if the correlation is not very clear, nevertheless a discrete positive variation is noticed. The relation between the content of silicates and that of bicarbonates shows that silicates evolve/move linearly with bicarbonates. More the weathering of silicates advanced, more the chemical composition of water shows an increase in silica and the bicarbonate concentrations. It is noticed that some points are probably distinguished and are due to an external pollution.

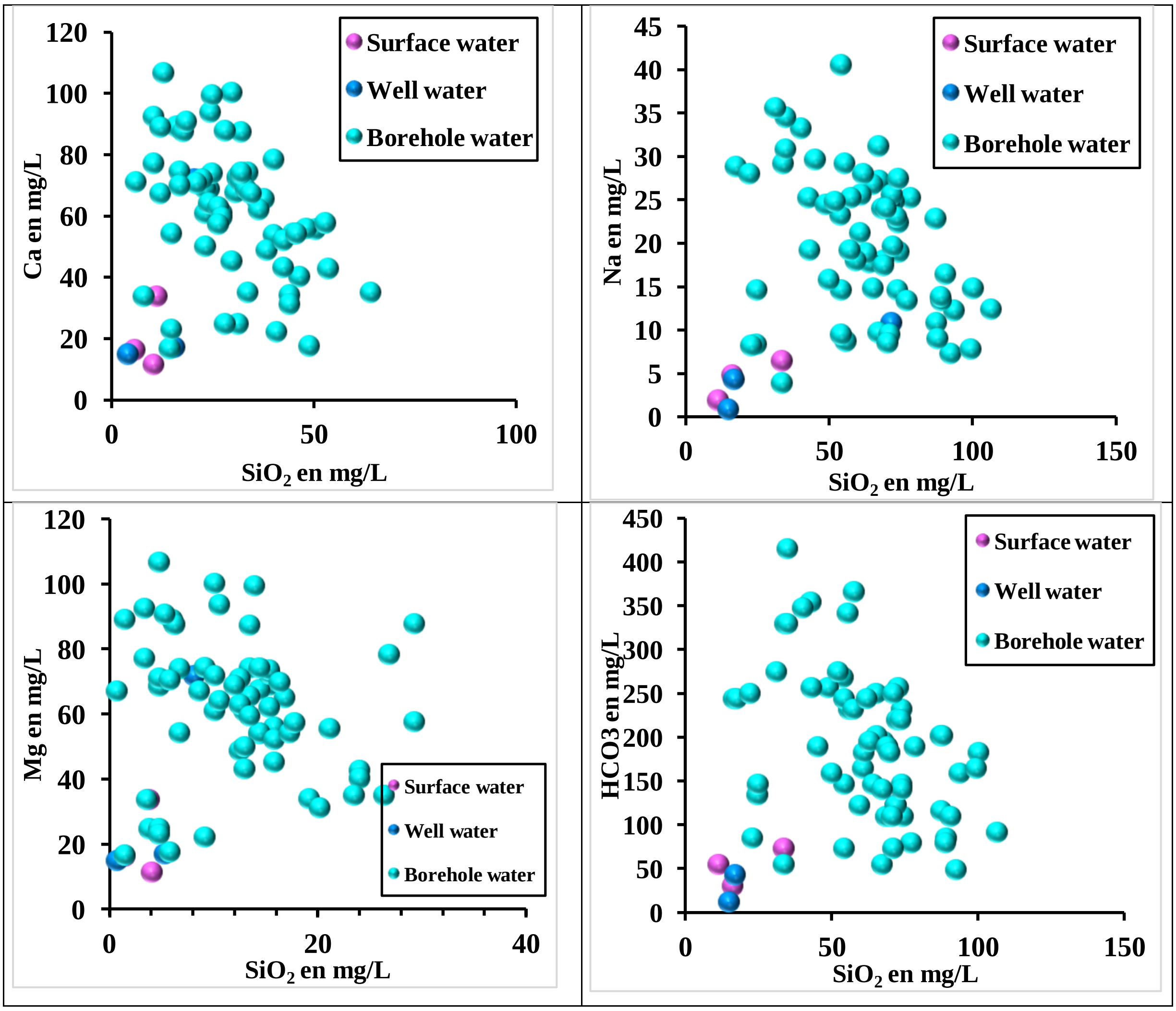


Figure 9: Relationship between the contents Ca^{2+}, Mg^{2+}, Na^{+} and HCO_3^{-} with silica.

Figure 10 shows the relationship between [Ca^{2+}+Mg^{2+}] and [SO_4^{2-}+HCO_3^{-}]. This Figure shows that most of the groundwater samples and surface water samples are plot below and along the y= x line due to excess of bicarbonates as only eight samples representing 11% were found to be above the aquiline. This Figure indicates that silicate weathering is the main source of sodium and bicarbonate and it exerts major control on groundwater and surface water in the study area.

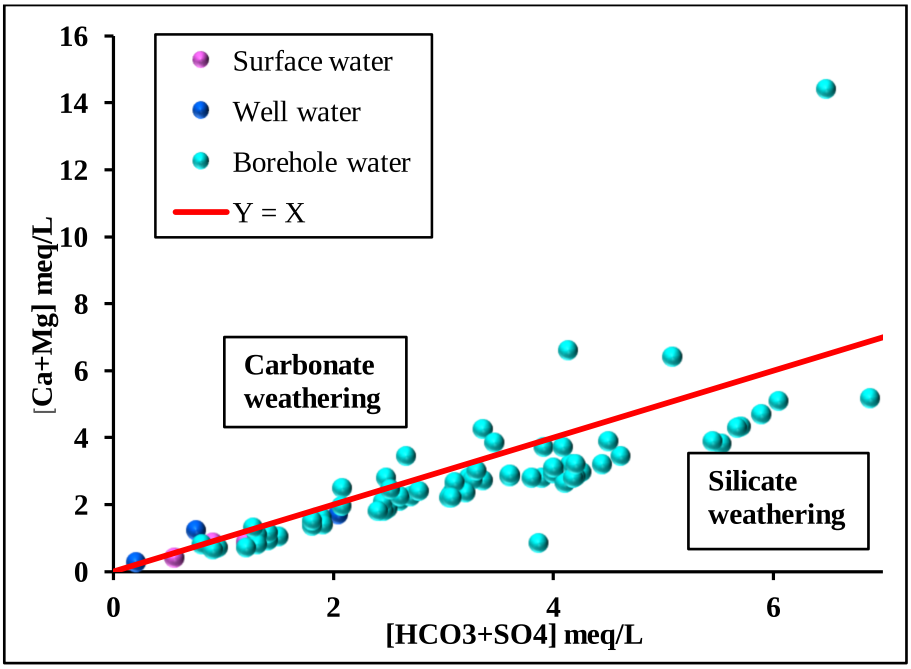


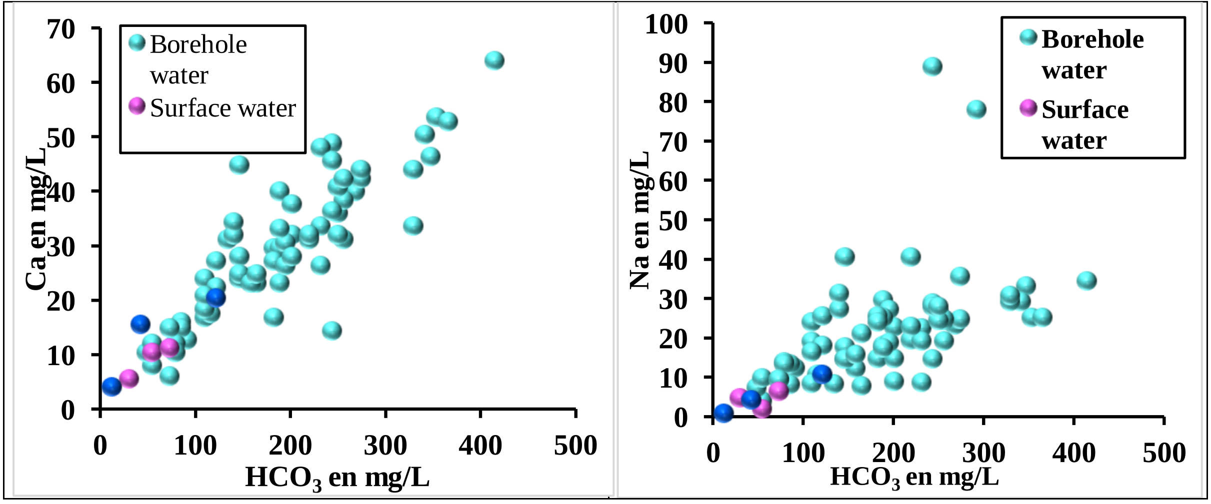
Figure 10: Relationship between [Ca+Mg] and [HCO_3 +SO_4]

III.1.5.2- Relations between cations and bicarbonates

Figure 11 shows the relationship between the contents of cations (Ca^{2+}, Mg^{2+}, Na^{+} K^{+}) and of $HCO3^{-}$. We observes a linear increase of cations concentration (Ca^{2+}, Mg^{2+}) with the HCO_3^{-}content except for some points which are under the influence of a anthropic pollution. It appears clear that the setting in solution of calcium in water is under the action of dissolved CO_2 on the calcic minerals aluminosilicates which is the prevalent process [Ca = f(HCO_3^{-})]. The relation through the two elements gives a coefficient of correlation R = 0.67.

The relation is more or less good for sodium, but looser for potassium. This indicate that potassium and sodium could have an external origin with the system water-rock. This is the consequence of a high anthropic pressure. The positive correlation at the same time of these cations and bicarbonates reflects the setting in solution of these ions during the weathering of silicates.

In general, alteration of basement minerals, in the absence of human activity, water becomes rich in alkalinity and cations. More the process of alteration advances, more the content of HCO_3^{-} increases. The linear correlation between some chemical elements make it possible to study the origin of mineralization by evaluating the degrees of dependence between the various parameters concerned. It is also advisable to study the index of saturations compared to minerals.



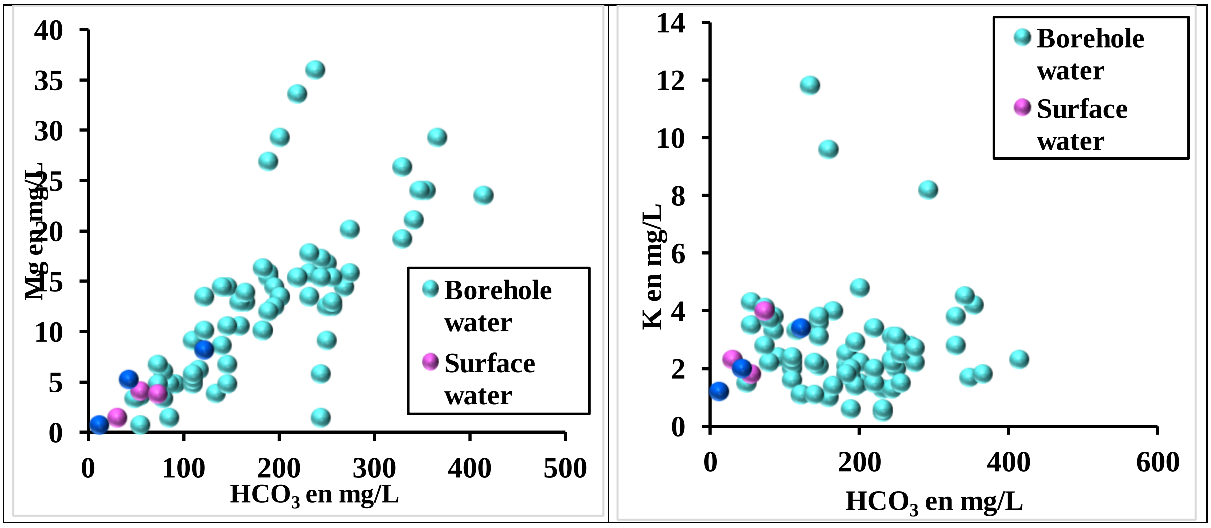
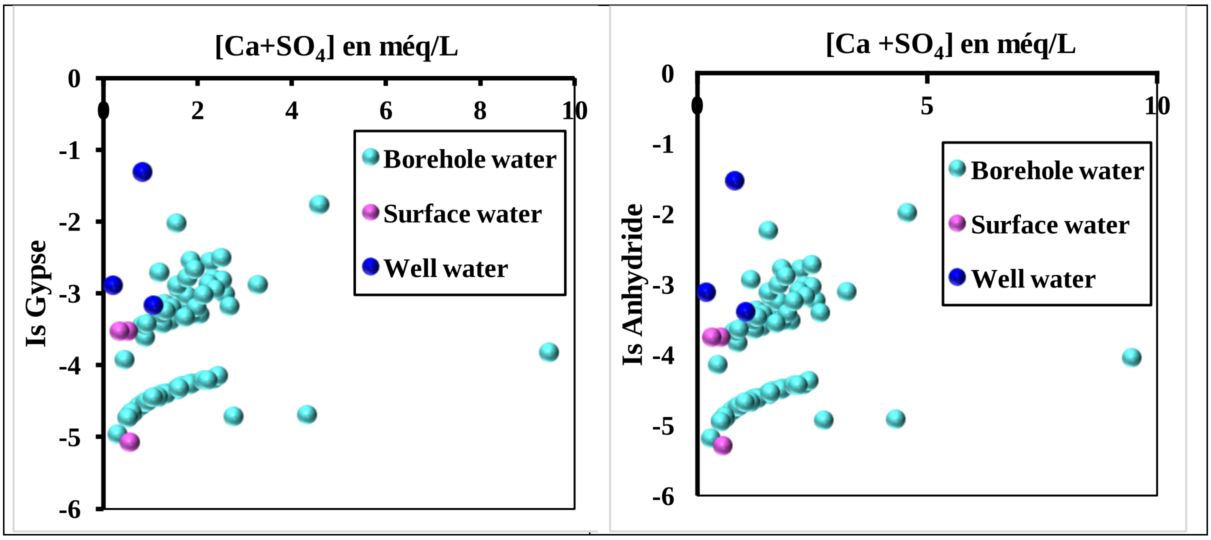


Figure 11: Relationship between Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} and HCO_3^- in groundwater of the study area.

III.1.5.3- Saturation index

The saturation index (SI) is usually used in geochemistry, and defines the saturation state of minerals in the water. It can provide significant information on the various hydrogeochemical processes controlling the groundwater chemistry [15; 16]. ***Deutsch and Siegel (1997)*** stated that it is possible to predict the minerals that are responsible for controlling water quality from groundwater data without collecting the samples of the solid. When the SI<0, the minerals will be dissolved and the water is said to be undersaturated with respect to the mineral. It may describe a short residence time or a lack of the considered mineral in the aquifer from which the water is discharging [17]. On the other hand, when groundwater is supersaturated with respect to a mineral, the SI is >0, which means that the mineral will be precipitated. When SI is just equal to 0, it indicates that the water is saturated with respect to the mineral. However, due to uncertainty related to the minerals concentration, water with SI values comprised between -0.5 to 0.5 could be considered as saturated with respect to the mineral in question. In this study, SI of calcite, dolomite, gypsum, anhydrite and aragonite were calculated with Diagrams software for groundwater samples.

It is interesting to notice that all waters are undersaturated with respect to the gypsum, of anhydride and halite (**Figure 12**). It is also noticed that some water shows positive values of the indices of saturation (IS>0) with respect to calcite, aragonite and dolomite. These indices, in the whole, vary between 0 and 1 for calcite and the aragonite, then between 0 and 2 for dolomite; thus reflecting a state of supersaturation with respect to these minerals.



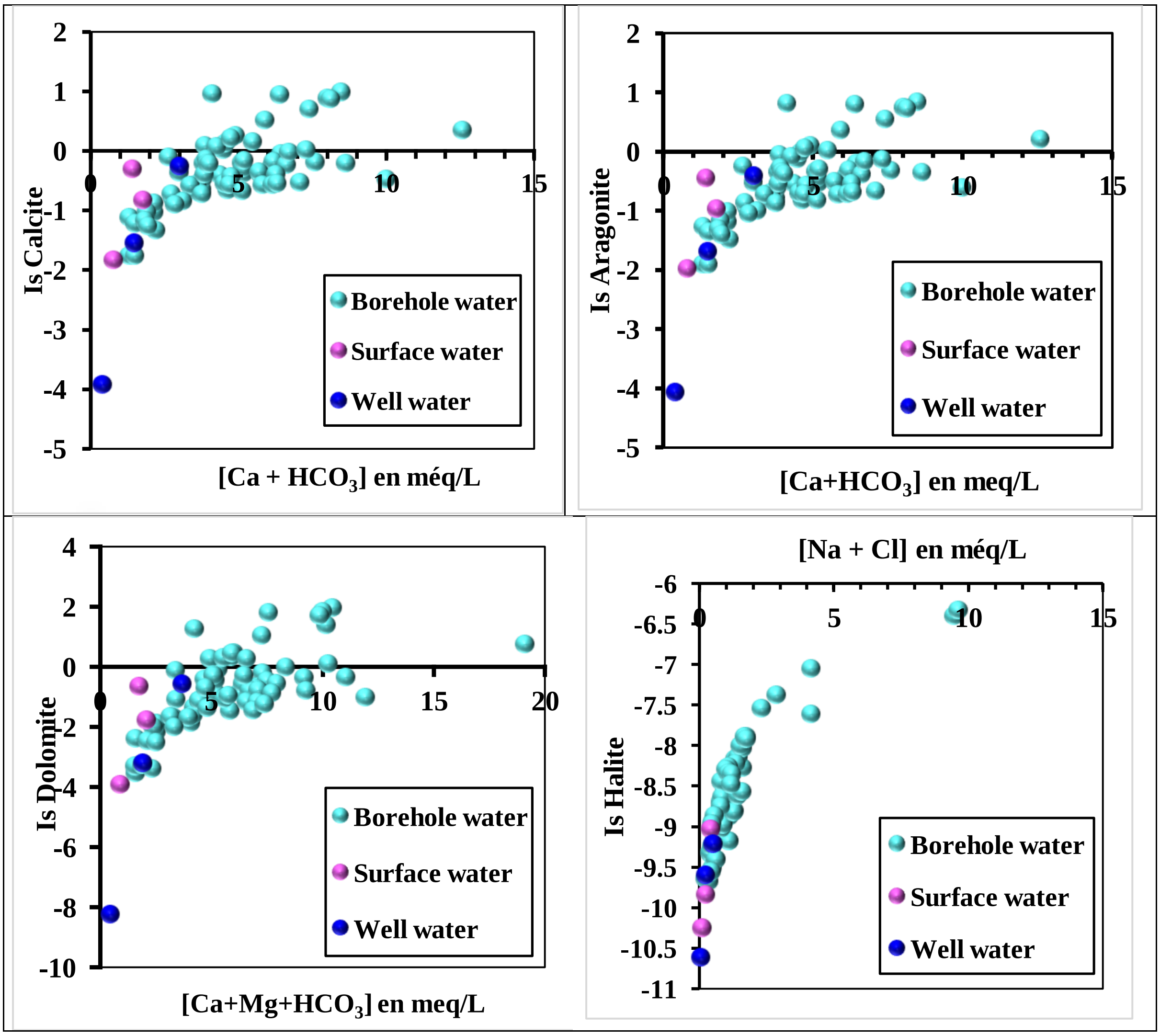


Figure 12: Index of saturation of water with respect to carbonated and evaporitic minerals

III.1.5.4- Basics Exchanges

We often speak about the basic exchanges with the clayey minerals which exist in the aquifer formation and groundwater. These exchanges characterize clayey minerals having the possibility of fixing ions by adhesion and of releasing from others according to the existing electric charge between the layers of clayey minerals and the state of saturation of the solution. **Figure 13** highlights the basic exchanges with the clayey minerals which affect water of the basin during the infiltration of rainwater and their stay within the aquifer. It shows that almost that all the representative points are placed at the turn of the point of origin. What would mean that the clayey minerals undergo a dissolution except that the borehole FPI placed above the origin, releases calcium and fixes sodium. This says the calcium concentration is very high compared to sodium ([Ca^{2+}] =7.78 méq/L; [Na^{+}] = 3.39 méq/L). It is the same for the borehole F32 which fixes calcium and releases sodium ([Na^{+}] = 3.87 méq/L and [Ca^{2+}] = 0.72 méq/L).

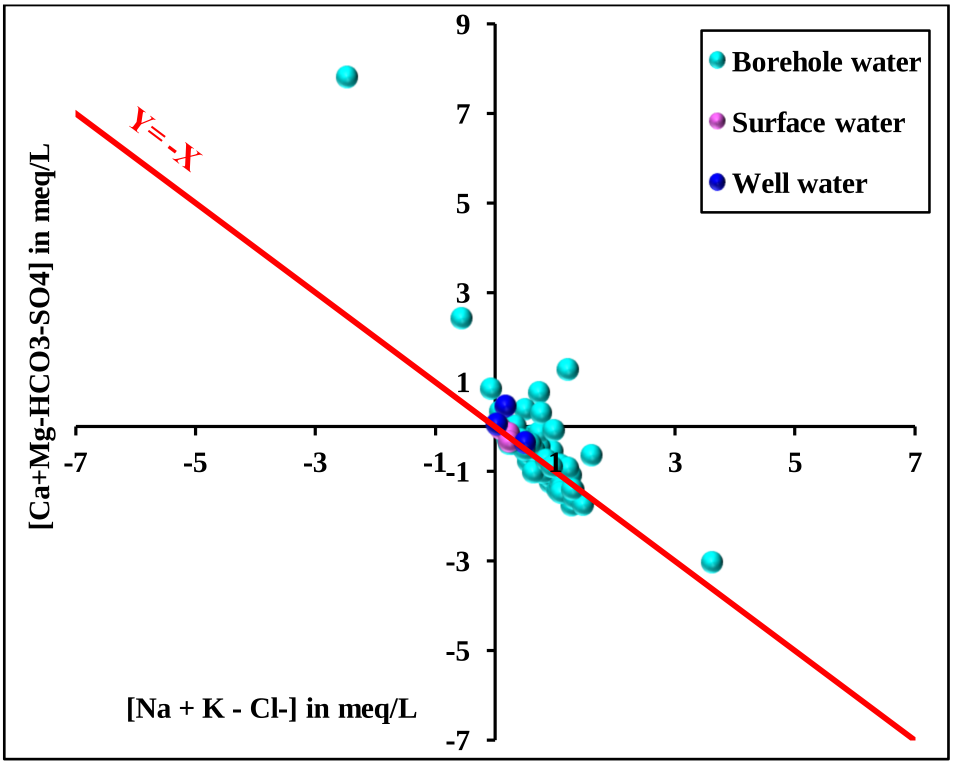


Figure 13: Description of the basic exchanges with clayey minerals in the aquifers

III.2- Discussion

The analysis of basement aquifer groundwater in the north Togo (Dapaong) shows that the temperature ranges from 27.4 to 30.1°C with a mean temperature about 28.4°C. These results are close to those of [18] in Burkina Faso in the basement aquifer, where the temperature is in general very close to the average atmospheric values (28 with 32° C) for well water and (28 with 34° C) for boreholes water [18]. The values of the temperature reflect as well the ambient temperature at the time of the collection of the samples as the climate of the season. That confirms the influence of the climate on the groundwater resources with low depth in the area. At this level, groundwater is more influenced by the seasonal variations of the temperature of the atmospheric air [19].

The values of pH recorded during the sampling campaign vary from 5.68 to 8.88 with an average of 7.34 thus close to neutrality. This trend to neutrality in the aquifers is due to the consumption of CO_2 following the weathering of silicates involving the increase in the alkalinity (HCO_3^- of water [20]. These values are rather homogeneous (low CV) and vary independently of the aquifers collected. They probably do not showing clearly the variation because of the interference of several geochemical processes (dissolution, reduction, oxidation...) with the mixture between water of the alterites and that of the fractured basement.

The alkalinity of water is connected to the pH system, and these two parameters make it possible to calculate the pressure partial of balancing CO_2. The values of log(pCO_2) vary little and evolve/move around 0,03 atm (logpCO $_2$ = - 1.5 atm). According to Mbonu (1991) , this value is frequently associated the atmosphere of the ground; what let think that it is about a contribution of CO_2 in opened conditions system on an unlimited gas tank which is the atmosphere of the ground. The values of the log(pCO_2) characterizing groundwater and surface water of the study area, vary largely between -2,78 and -0,18 with an average of about -1.41. The values which exceed those of the atmosphere indicate that the groundwater gained CO_2 of the breathing of the plants and the degradation of the organic matter of the ground [21]. Moreover, the values of pH follow the same evolution that the pCO_2 and remain lower than 8.3. Therefore alkalinity is essentially made up of bicarbonates (HCO_3^-) [22] which represent in the majority of the cases the anion dominating with more than 50 % of the total mass of the dissolved charge.

Water is characterized by a great variability of mineralization in space. They are of slightly with fairly mineral-bearing having nevertheless strong mineralization of some boreholes in urban environment. Electric Conductivity varies between 24 µs/cm and 1747 µs/cm. [23] showed that the electric conductivity of groundwater varies from 227 to 1740 µs/cm with an average of 605.3 µs/cm in zone of basement in the basin of

Dargol in Niger. This great variation shows a notable heterogeneity in the mineral charge distribution of groundwater due to lithology and specific pollution. The extreme values of conductivity observed are noticed with boreholes FP1 (1747 µs/cm), FP8 (1184 µs/cm) and FP6 (880 µs/cm). These points are located in urban environment and would be probably of anthropic origin. Borehole FP1 is located near a large dumping ground and probably receives water resulting from the scrubbing of this one. As for borehole FP8, it is beside the gutters by where forwards worn water coming from the big market of the city. ***It is*** showed that the sources of direct pollution are the escapes of the sewerage systems, the septic tanks, surface the water, solid waste, fuel the puddle pools, the infiltration starting from the polluted rivers, the intrusion saltworks, the fertilizers, the pesticides, the scrubbing of the zone unsaturated at the time of the piezometric increase among so much of others. The lowest mineralization at the well P3 (24 µs/cm) is located at an altitude of 333m and is on the rock, it is what explained the lowest mineralization of this well.

However, from the conductivity point of view, we can classify the groundwater of the study area in three groups: that with less mineralization water whose conductivity is lower than 300 µs/cm. This group includes surface water, well and some borehole who are for most of them located in the West and a little extreme East (**Figure 3**). The second group made up of fairly mineralization water whose conductivity lies between 300 and 800 µs/cm. This one occupies Center-East and the South-west of the study area. Finally the third group, with the highest mineralization with conductivities higher than 800 µs/cm. It occupies the Center-South and corresponds to the points sampled in the town of Dapaong.

Water is characterized by a bicarbonate prevalence on nitrates, chlorides and sulphates. As for the cations, calcium prevails followed sodium, magnesium and potassium. The facies HCO_3-Ca and HCO_3-Ca-Mg are the major characteristic of water in basement zone in crystalline medium and cristallophyllian areas. They are largely the dominant ions, and they represent more than 50% of the dissolved anion load. The work carried out in other areas in Côte d'ivoire in medium of basement more precisely in the zone of Soubré in CI [24], the area of Man in CI [25], in Kara region in Togo [6], and in plateau region in Togo [5] also highlight the importance of the calcic and magnesian bicarbonated facies. It is the same for [23] which reveals an abundance of calco-magnesian bicarbonated water (70%) in water of the fissured aquifers of the South-west of Niger. The ions bicarbonates come mainly from the acid hydrolysis of the rocks. For example anorthite (plagioclase of the calcic pole) produced kaolinite and releases from calcium and the ions bicarbonates according to the reaction:

$$CaAl_2Si_2O_8 + 3H_2O + 2CO_2 \longrightarrow Al_2Si_2O_5(OH)_4 + Ca^{2+} + 2HCO_3^-$$

For the cations, calcium and sodium have the most raised contents. That could be due to the fact that the hydrolysis of the rocks, rich in alkaline feldspars and plagioclases acid and low in ferro-magnesiens, gives Ca^{2+} contents and Na^+ dominant for the cations [20]. The rather significant proportion of anorthite in plagioclases, variety most easily liable to deterioration, justifies that Ca^{2+} concentration is higher than Na^+ [26].

The prevalence of the calcic pole would result from the hydrolysis of the basic rocks such as amphiboles. The sodic and potassic bicarbonated facies (F32 in Tchimouri at Pogno in the North-East of the study area) is located at the extreme East; which according to the geological map is established on the chain of the sandstones of Dapaong and would collect claystone rich in sodium. This borehole F32 could have also undergone a cation phenomenon of exchange (Confer Fig 12). Fig 10 also indicates that silicates weathering is the main source of sodium and bicarbonates and it exerts major control on groundwater and surface water in the study area [27]**.** This result is in agreement with the findings of [28] for the entire basement aquifer of Northern Ghana. According to water composition the excess of Na can be attributed to silicates weathering from feldspars. [29] found that if silicate weathering is a probable source of sodium, HCO3- would be the most abundant anion as it is in birrimian basin in Northern Togo. The result is consistent with the salinity values as they are all lower than 500 mg/L except for a few number of samples. It is in the fact [30] stressed that the weathering process taking place in waters with salinity < 500 mg/L is silicate weathering.

Ions SO_4^{2-} , NO_3^- and Cl^- have a significant correlation between them, which shows that they have a common origin. These ions are concentrated in the boreholes of urban environment, it is probably due to urban pollution. However in general, the chlorides are found in the form of traces in the rocks of the crystalline base [31] and it is the same for nitrates and the sulphates which are primarily provided either by oxidation of the pyrites or by the meteoric contribution [32].

The nitrates are present in 50% of the water samples of the boreholes located in urban environment: FP1 (328.2mg/L), FP6 (161.6 mg/L) and FP8 (130.2 mg/L). The nitrates contents of these samples exceed the standard of potability (***Standards WHO***). The ions nitrates are correlated with the chlorides (0.905). These latter are often associated to anthropic activities because are not associated to preexistent rock. The ions nitrates NO_3^- ; are present in nature where they belong to the cycle of nitrogen. They represent the most soluble form of nitrogen. Mainly used as mineral manures for the growth of the plants and the synthesis of organic nitrogenized compounds, the nitrates in excess can be found quickly in groundwater [13]. Waste containing of organic nitrogen represents also a source of nitrates obtained starting from various biochemical processes (ammonification and nitrification) [33]. The concentrations raised out of sulphates which are sometimes associated to high chloride and nitrate concentrations are clearly indicating of an anthropogenic pollution [34]. The impact of the anthropic activities on the quality of groundwater constitutes a major problem of a world nature and is the subject of several studies: [35; 36]. This various works also showed the influence of anthropic contributions in the quality of groundwater. However borehole F63, located in rural medium has a concentration of 123.4 mg/L in nitrates, this justifies an intense practice of agricultural activities accompanied by the use of artificial fertilisers.

The nitrates NO_3^- have a surface origin and thus come from the anthropic activities. However, the nitrate concentrations in boreholes belonging to the chlorinated and sulphated facies calcic and magnesian exceed all the standards of potability of WHO (50 mg/L). This confirms the surface origin of the recharge of these aquifers.

The Factor F1 of the PCA indicates that Cl^-, Na^+, and SO_4^{2-} and NO_3^- are put in solution by the same phenomenon. The regrouping around the axis F1 also indicates the processes of mineralization by surface water infiltration and dissolution of the rock. The elements which define this factor come from infiltration and a long residence time in solution following the contact water-rock. These elements come from the hydrolysis of minerals present in the rocks which constitute the rock substratum of the aquifers which shelter water of the zone of study [37]. Indeed, the factor F1 thus expresses the phenomenon of mineralization residence time by dissolution. The chlorides, sulphates and nitrates are almost always less in water resulting from granites [38; 39], but there place is to notice that the concentrations are not negligible in water of the alterity aquifers.

Sodium Na^+ comes from the deterioration of feldspars contained in the igneous rocks, of the attack of clayey minerals and the dissolution of soluble salt grains contained in the rocks and the beds of evaporites. It should be noticed that the geology of the study area is dominated by the formations of Paleoproterozoïc made up mainly of granites and gneiss. The hydrolysis of such rocks rich in alkaline feldspars and acid plagioclases, explains the fact that the Ca^{2+} contents and Na^+ are dominant for the cations in groundwater. These ions result from the deterioration of the rocks and the weathering of silicated minerals [40].

IV. CONCLUSION

The groundwater quality in the Northern Togo has been evaluated for their chemical composition and suitability for human consumption. In this study, a combined hydrochemical, hydrogeological and varied statistical analysis methods are used to understand the mineralization status and geochemical processes occurring in birrimian basement. This study in hydrochemical results show that groundwater has in majority between fresh water and fairly mineralization water. However, some points have high mineralization because of anthropic origin, signs of an urban pollution. The geochemistry of groundwater beneath the city of Dapaong does suggest that the leaky sewage system, septic wells and other point source of contamination have most likely impacted groundwater quality. The hydrofacies approach shows the existence of four facies largely dominated by the facies HCO_3-Ca and the facies HCO_3-Ca-Mg. The analysis factorial by statistical units highlighted three (3) groups of water: Group 1 made up the highest mineralization water which contents higher nitrates than the standard of potability of WHO. Group 2 is characterized by the high bicarbonates concentrations and an average mineralization, then group 3 concerns the wells and the majority of boreholes of the study area with low electric conductivity. Principal Components Analysis (PCA), Hierarchical Cluster Analysis (HCA) and the different diagrams of correlation indicate that the mineralization of groundwater in the study area is controlled by the silicates weathering related to the residence time of water in the aquifer. These results indicate that future development of urban areas within birrimian basin in North Togo, especially those located on the recharge areas could represent a serious threat to groundwater quality. This study gave results certainly interesting but it deserves to be supplemented by other investigations in particular a study on isotopic hydrology, heavy metals, the pesticides as well as a bacterial study. This work will allow us to have a data base for a follow-up of physicochemical of groundwater in the study area.

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