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# Contribution of Statistical and Hydro- Chemical Methods of the Waters of the Dallol Bosso Area in the Fillingue and Ballayara Departments

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**Abstract**

The present study is concerned with the Dallol Bosso area table water quality particularly in the departments of Filingué and Balayara (Region of Tillabéri Republic of Niger). A series of physicochemical and microbiological analyzes were carried out on the water resources of the area. The results of these analyzes were processed from a hydro-chemical method using the Piper Triangular Diagram and Multi-Varied Statistical Methods including Principal Component Analysis (PCA) and Ascending Hierarchical Classification (AMP). Piper's Triangular Diagram showed that the waters of the study area could be divided into three main chemical facies: chlorinated and sulphated calcium and magnesium nitrate (61.1%), sodium bicarbonate and potassium (22.2%), and sodium and potassium chloride (16.7. The Normal Principal Component Analysis (PCA) and the Hierarchical Ascending Classification indicated that the mineralization of the waters of the zone was controlled by three major phenomena: the mineralization-residence time which results in the hydrolysis of the silicate minerals for the groundwater, the Soil pluviolessivage and the influence of human activities in the production of polluting waste.

This study also shows that the studied water resources in the area were strongly influenced by human activities, with the presence of Escherichia coli-like faecal coliforms resulting from recent human pollution.

As a whole, these groundwater’s require in some cases, a specific treatment before supply.

**Keywords:** Principal Component Analysis, Ascending Hierarchical Classification, Piper Diagram, Hydrochemistry and Groundwater.

## INTRODUCTION

Intensive use of natural resources and increased human activities have negative impact on groundwater quality [1]. Indeed, groundwater is increasingly used by people in general and particularly by the rural world for their domestic needs.

The chemical composition of water coming from the natural environment is very variable. It depends, among other things, on the geological nature of the soil from which it originates and the reactive substances it may encounter during the flow [2,3]. However, water quality may be altered when external substances come into contact with the aquifer. The understanding of the hydraulic properties of the aquifers and the hydro-chemical characterization of the water they contain are necessary for the planning and management of groundwater resources. The present study is concerned with the groundwater quality of the study area, with emphasis on the departments of Fillingué and Ballayara.

The applied methodology is based on the determination of the Groundwater Hydrogeochemical Classification from the Piper diagram and the use of multivariate statistical methods (Principal Component Analysis (PCA) and Ascending Hierarchical Classification (AHC).

### Presentation of Dallol Bosso

The Dallol Bosso is a drained valley of a former tributary of the Niger, 10 to 20 km wide, extending 330 km from north to south in the regions of Tillabéry and Dosso, between Mali and Benin. It covers about 40,000 square kilometers. The average altitude goes from 249 m to 175 m from the north to the south of the Dallol.

The climate is sub-desert in the North (rainfall 330 mm), Sudan in the extreme South (780 mm) and Sahelian in the central part (Paquier et al., 1985) [4]. Flow is currently limited to the rainy season (Boukari et al., 1993). The shallow groundwater and permanent pools in the southern part make it suitable for agriculture, livestock and fisheries [4].

In the Dallol, the water table is confused with the alluvial layers. The lower and middle layers are essentially recharged through the water table. The latter is itself fueled by the direct infiltration of rainwater and especially runoff into endorheic areas favorable to the accumulation of water in the ponds, where it undergoes seasonal and interannual fluctuations.

Our study concerned three (03) Municipalities of Fillingué and Ballayara departments. These are Tondikandia and Imanan (Fillingué Department) and Tagazar (Ballayara Department). The area of this study extends over an area of approximately 4215.38 Km2, between 13.528 ° and 14.298 ° Latitude North, and between 2.562 ° and 3.548 ° East Longitude (Figure 1).

The socio-economic activities of the area are mainly focused on agriculture and livestock. All three towns are crossed by the Dallol Bosso, making the study area one of the most favorable areas for the development of market gardening in Niger. Indeed, the water table (CT3 and alluvium) is easily accessible by well and drilling, especially in the shallows where it is almost flush. This has favored the proliferation of a multitude of waterworks with market gardening vocations and mixed in the lowlands and surroundings, next to homes and in the fields.

The relief of the study area consists of seven (07) systems which are: the alluvial system, the plateaus, the slopes, the glacis, the wind system, the closed depressions and others (residual buttes, snags, collinettes, small ponds). The most dominant are the plateaus, the alluvial system, the glacis and the slopes and the order of dominance varies from one commune to another.

The soils of the study area differ depending on the relief, but the most encountered are the soft soils of the valleys and dunes, the clay soils of the shallows, the encrusted soils with sandy-clay plating of the plateaux, glacis and slopes.

Most of the dallol soils come from reworked wind formations and belong to the subclass of tropical ferruginous soils. Their texture is sandy on the surface; the clay content does not exceed 5% while the sand content is always between 90 and 97%. Their texture is bad, which favors the erosive action of the wind [5].

**Hydrography:**

The most important component of the current hydrography of the study area is represented by Dallol Bosso and its ponds, although the flow is no longer permanent. This valley has no permanent flow and its hydrographic system is highly degraded: upstream of Ballayara, the valley is increasingly invaded by recent sand dunes, and downstream, there is no longer a well-defined watercourse in the rainy season; but a string of ponds episodically connected by diverting flows.

**Hydrogeological framework of the area of the Dallol Bosso:**

The region's groundwater resources are located on the one hand in alluvial formations in the valley and on the other in the underlying sedimentary formations of Continental Terminal and Continental Hamadien [6].

Hydrogeological framework of the Dallol Bosso zone:

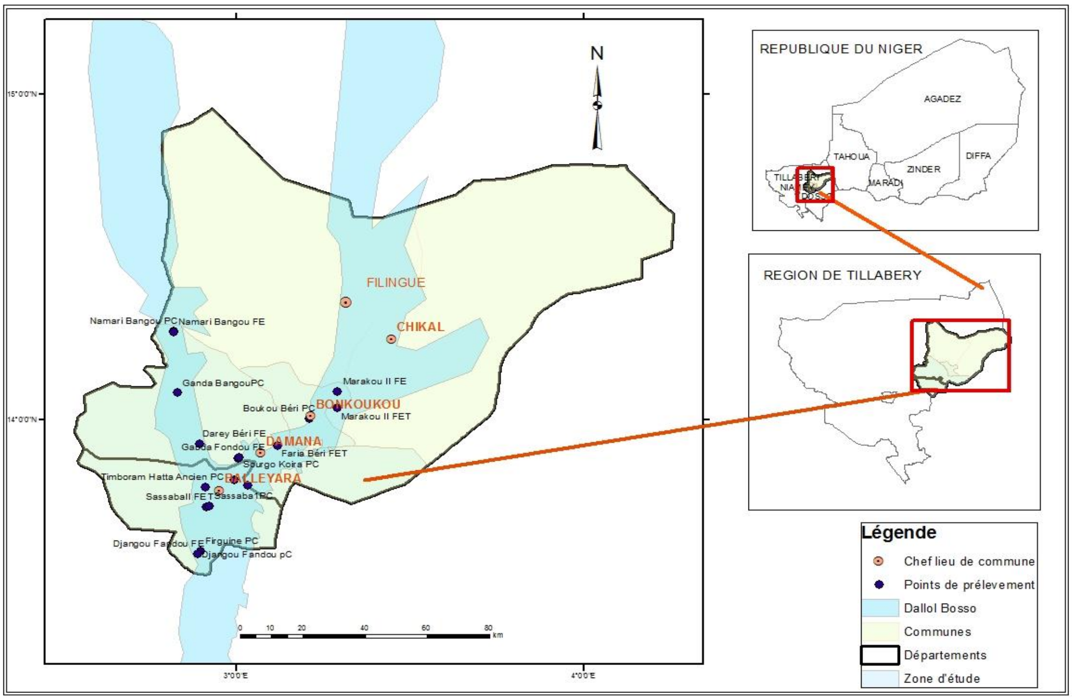


**Figure 1:** Presentation of the study area

## METHODOLOGY

Samples were made and packaged in vials specially prepared for this purpose. Samples for boreholes with taps are made after running water in a vacuum for about three minutes. The sample vials were then filled in for analysis. For wells, samples are taken using a specially designed sampler. The sampling device was thoroughly washed with distilled water before each sampling. Almost all the water points of the aquifers are intended for the supply of drinking water.

The collected samples were then labeled and placed in a cooler thermostated at approximately 4 ° C and transported for analysis. The water samples were collected from eighteen (18) water points including nine (09) cemented wells, four (04) auger drillings and five (05) village mechanical drillings in three (03) communes. of which two (02) for the Department of Fillingué (Imanan and Tondikandja) and one (01) for the Department of Ballayara (Tagazar).

The physical parameters namely pH, temperature, conductivity, turbidity were measured in situ respectively using a pH meter, a portable colorimeter that covers wavelengths of 400 to 800 nanometers equipped with tungsten filament lamp, WTW 330 brand conductivity meter and Hach 2100 portable turbidimeter.

The chemical parameters were analyzed in the water quality control laboratory of the Regional Directorate of Hydraulics and Sanitation of Tillabéry. These analyzes were carried out using the classical methods recommended by the French AFNOR standards.

The hydrotimetric titre, calcium, magnesium, total alkalimetric titre and bicarbonates were determined by the volumetric method.

Sulphates, nitrates, nitrites, fluorides, chlorides and total iron were determined by the colorimetric method.

Potassium and sodium were determined by flame emission spectrometry (or flame photometry).

The membrane filtration technique followed by incubation and counting was used to determine the bacteriological parameters (total coliforms and fecal coliforms)

**Data processing:**

The values of the measured parameters were compared with the WHO guideline values to determine the physicochemical and bacteriological quality of the waters studied and their suitability for human consumption.

The results of the physico-chemical analyzes were then processed by the hydro-chemical method and the multivariate statistical analysis methods. The hydro-chemical method required the use of Piperet Riverside diagrams, made under the Diagrams software, thus making it possible to determine the chemical facies of the waters of the zone studied.

The multi-variate statistical approach was carried out from a Normal Principal Component Analysis (PCA) and an Ascending Hierarchical Classification (AMP). Statistical analysis was performed on 18 samples and 10 variables (pH, CE, $HCO_3^-$,$Cl^-$, $SO_4^{2-}$, $NO_3^-$, $Na^+$,$K^+$, $Ca^{2+}$ and $Mg^{2+}$) using the XLSTAT 2017 software. This analysis makes it possible to synthesize and classify a large number of data in order to extract the main factors which at the origin of the simultaneous evolution of the variables and of their reciprocal relationship [7, 8, 9, 10, 11, 12, 13, 14]. It makes it possible to highlight the similarities between two or more chemical variables during their evolution.

## RESULTS AND DISCUSSION

### Assessment of the potability of waters

In our study area, recorded temperatures vary from 28.5 ° C (SassabaI PC) to 32.7 ° C (Djongou Fandou FE), passing through an average of 31.36 ° C and a median of 31, 45 ° C. The pH values measured in our study area vary from 5 (Djongou Fandou, FE) to a maximum of 7.6 (Timboran, Hatta PC) with an average of 6.28 and a median value of 6.45. Of the 18 samples analyzed, 14 have an acidic character of between 5 and 6.7, ie 77.8%, 3 are slightly neutral or neutral and only 1 basic. It can therefore be considered that these waters have a pH-acid with a neutral tendency in places.

The electrical conductivity of our study area ranged from 48.2µS / cm at Djongou

Fandou to 735µS / cm at Timboran Hatta for an average of 249.64 µS / cm and a median of 214.50 µS / cm, proving that the waters of the study area are weakly mineralized, except the Timboran Hatta well which records the maximum value, followed by Marakou II FET with 418µS / cm.

For surface water and groundwater, turbidity can indicate the presence of disease-causing organisms such as bacteria, viruses, and parasites that can cause nausea, cramps, diarrhea, and other illnesses resulting head. For healthy groundwater, turbidity can be for healthy groundwater, turbidity can be caused by the presence of clay, silt and suspended inorganic material from natural sources. It is important to know where the turbidity of water comes from. [15]

The turbidity of the waters in the study area ranged from 0.30 NTU (Djangou Fandou FE) to 12.48 NTU at Firgoune PC and the mean and median are respectively 2.82 and 1.39 NTU. All the water points sampled had turbidity values below 5 NTU (maximum value set by WHO), except for M'boria Banifandou and Firgune (12.4 and 12.5 NTU respectively).

The hardness of the water is an indicator of the level of limestone in the water: it corresponds to its calcium and magnesium content. The more it contains, the more it is "hard". Its content varies essentially according to the nature of the crossed lands (calcareous or gypseous ground) [16]. For groundwater, the most common source of calcium and magnesium is rock erosion, such as limestone and dolomite, and minerals such as calcite and magnesite [17]. The total hardness or Hydrometric Title (TH) of the analyzed water varies from 10 to 149 mg / l of CaC passing through an average of 46.1 mg / l of CaC. Knowing that 10 mg / L of CaC corresponds to 1 ° F (French degree), this total hardness ranged from 1 to 14.9 ° F passing through an average of 4.61 ° F. Thirteen (13) waters analyzed, 72.2%, are very soft (TH <5 ° F); (5) analyzed waters (27.8%) are soft (5 ° F <TH <20 ° F). Calcium and magnesium have beneficial effects for the human body. Indeed, calcium is essential in the constitution of our bones and our teeth. Magnesium fights fatigue, fights digestive spasms and constipation [17].

However, calcium and magnesium can also have adverse effects on humans. Exceptionally hard water can affect operation and life, plumbing systems and appliances. At very high concentrations, calcium can have negative effects on the absorption of other essential minerals for the body. The calcium levels in the waters of our study area are low, ranging from 1.60 mg / L (Namari Bangou, FE) to 36.40 mg / L (Timboram Hatta, PC), for an average value of 11.68 mg / L and a median of 8.40 mg / L. The low concentration of calcium indicates that these waters did not cross limestone or gypsum soils. The magnesium values obtained are also low and range from 0.61 mg / l (to Firguine, PC) and 14.09 mg / l (to Timboram Hatta PC), with average values of 4.11 mg / l and median of 3.22 mg / l. These low values of calcium and magnesium concentration are close to the results obtained by Ousseyni (2016) [18]. in the alluvial layer of Dallol Bosso, Birni N'Gaouré Falmey zone. They could be explained by the sandy nature of the soil in the study area. Sodium is an essential ion of body fluids. This substance is not harmful to the concentrations normally present in foods and sources of drinking water. However, high sodium levels can cause problems for people who have a salt-depleted diet because of hypertension, heart or kidney problems. [17].

In our study area, sodium has very variable values, ranging from very low, 2.80 mg / L (Djangou Fandou, FE) to a maximum value of 50 mg / L (Faria Béri, FET) through mean and median values of 16.03 mg / l and 14.40 mg / l, respectively. All these values were below the maximum allowable concentration set by WHO. 83.3% of the water points (n = 18) have a sodium content of 20mg / L and 16.7% have a sodium concentration of between 20 and 50 mg / L. The origin of sodium in these waters would therefore be essentially natural with an anthropogenic contribution in places.

Potassium concentrations in the study area vary widely, from 1.6 mg / l (Namari Bangou, PC) to a maximum of 50 mg / l (Timboran Hatta, PC, with mean and median respectively of 7.99 mg / l and 4.50 mg / l). Three water points (16.7%) contain levels greater than or equal to the maximum limit of 12 mg / L set by WHO, six water points (33.3%) have values between 5 and 11 mg / L and nine (50%) have levels below the median, ranging from 1.6 to 4 mg / L. This latter range appear to represent the potassium content of groundwater in our study area where anthropogenic input is negligible. Sulphate promotes the elimination of toxins. It is also an essential element of cartilage, hair, blood vessels and connective tissue. Sulphate (S) ions at concentrations above the guideline value in drinking water can cause diarrhea in humans [19].

The sulphate levels recorded in our study area were very low and range from 0 to 10 mg / l, passing through an average and a median of 4.94 mg / l and 5 mg / l respectively. They therefore remain well below the maximum limit of WHO (500 mg / L). This low content assumes that the sulphate ions of these waters do not therefore come from gypsum formations. According to Banton et al (1997) [20]., their probable origin could be the oxidation of pyrite. The chloride ion concentration in our study area remains in compliance with WHO guidelines for drinking water and range from very low (0.3 mg / l at Djangou Fandou FE) to low (28.3 mg / l at Timboram Hatta PC) with an average of 7.71mg / l and a median of 6.85mg / l. Low values were also found by Amadou et al. (2014) [21]. in the wells of the study area (12 mg / L at Sandiré and 22 mg / L at Bonkoukou). Thus, 77.8% of the water points sampled have a content of less than 10 mg / L and 22.2% have a content of between 10 and 30 mg / L. The origin of chlorides would probably be natural in these waters.

Bicarbonate or hydrogen carbonate is vital in maintaining the acid-base balance and pH of our cells and natural waters [22]. The bicarbonate content of our study area range from very low (4.88 mg / l at Sourgo Koira PC) to low (152.5 mg / l at Timboram Hatta PC) with an average of 42.16 mg / l and a median of 27.76 mg / l. This bicarbonate closes of natural origin and would come mainly from the dissolution, in the water, of the C of the area and the ground.

The presence of nitrate in drinking water is mainly attributed to human activities. The use of synthetic fertilizers and manures, associated with crops and intensive farming, promotes the appearance of nitrates in water. The deficient septic systems, as well as the decomposition of plant and animal matter, can also be a source of nitrates in water (Levallois et al., 1994) [23]. The nitrate content of the study area is highly variable, ranging from 3.08 mg / l to Marakou II FE to 108.68 mg / l in Namari Bangou PC, passing through an average of 45.662 mg / l and a median of 39.6 mg / L. These values are close to the results found by Ousseyni (2014) [24]. in the study area (mean 51.85 mg / L and maximum 99.8 mg / L). The mean and median values agree with the levels found by Amadou et al. (2014) [21]. In the wells of dallol Bosso (42.65 mg / l at Sandiré and 43.8 mg / L at Bonkoukou). The variation in the nitrate content of the water in the study area is a function of the type of structure that captures the water table, the depth of the aqueduct, and the activities taking place in the area. 38.9% of the waters have nitrate pollution with potential human health effects and 33.3% of the samples analyzed contain a nitrate concentration above the WHO maximum limit of 50 mg / L; this means that the consumption of these waters is dangerous, especially for newborns (those younger than three months) because they may be exposed to methemoglobinemia

Nitrates and nitrites are naturally occurring ions in the environment. They are the result of a nitrification of the ammonium ion ($NH_4^+$), present in water and soil, which is oxidized to nitrite by the bacteria of the genus Nitrosomonas, then nitrate by the bacteria of the genus Nitrobacter. The conversion of nitrates to nitrites is proportional to the dose of nitrates ingested but also to microbial activity.

All samples analyzed in the study area contain nitrite. Their nitrite content ranged from 0.016 mg / L to 0.406 mg / L through mean and median values of 0.151 mg / L and 0.109 mg / L, respectively. One of the most important elements in health-related drinking water is fluoride. It occurs in water as fluoride (F-) ions. The presence of fluoride in groundwater can be attributed to septic effluents from areas where the water is fluoridated [18]. At very high concentrations (above 1.5 - 2 mg / L), fluoride in the drinking water can cause dental or bone fluorosis. All samples analyzed in our study area have a low fluoride level, ranging from 0.00 to 0.54 mg / l with an average of 0.18 mg / l. This low fluoride content in the study area would expose consumers to a risk of tooth decay, especially if the food they eat is also fluoride-free. In fact, 88.88% of the samples analyzed have a fluoride content of less than 0.5 mg / L. Iron and manganese are often present in a natural state together. The most common sources of iron and manganese in groundwater are natural. The total iron content of our study area range from 0 (Ganda Bangou PC) to 0.97 mg / l (M'Boria Banifandou) with an average of 0.15 mg / l and a median of 0.05 mg / l. Only three (03) water points (M'Boria Banifandou, Firguine PC and Marakou II FET), ie 16.7%, have values higher than the maximum concentration of 0.3 mg / L set by WHO. The presence of iron in the waters of our study area would therefore be essentially natural.

The results of the bacteriological analyzes showed that all the analyzed waters were contaminated and the total coliform (TC) colony concentration varies from 150 to TNC (too many to be counted) per 100 ml of sample whereas the value allowed by the WHO guidelines are 0 Colony Units / 100 ml. Indeed, more than half (10) of the samples show TNC results for total coliforms. As for faecal coliforms (CF), their concentration range from 0 (one sample) to 2200 FCU / 100 ml of water for 15 samples and NTC for the other 3.

It appears that from a bacteriological point of view, the waters were unfit for human consumption without treatment prior to the date of the analyzes from a physico-chemical point of view, the water quality of our study area is acceptable. However, some water points must be monitored more or less regularly for potassium ions, nitrates and nitrites which seem to be limiting factors in the quality of these waters. Moreover, the results of the bacteriological analyzes show that all the samples analyzed contain germs indicating fecal contamination.

The physico-chemical quality of the waters analyzed is acceptable, they are bacteriologically unfit for human consumption without prior treatment. The postponement of aquifer water test results on the Piper Triangular Diagram (Figure 2) highlights the influence of lithological facies on water quality and also allows for the estimation of percentages of chemical elements and their classification.

The results of the chemical analyzes of the water were plotted on the Piper Diagram to identify the different chemical facies of the water table of Dallol Bosso.

Thus, the different chemical facies are as follows:

- A chlorinated and sulphated calcium and magnesium nitrate group, consisting of ten (10) samples, ie 55.6%, essentially derived from the water points constituting neutrality in the cation triangle and those belonging to the nitrate or nitrate subgroup and chlorinated;
- A bicarbonate sodium and potassium group, consisting of four (04) or 22.2%, resulting exactly from the samples forming the bicarbonated predominance in the triangle of anions and also of those of the sodium-potassium subgroup in the cation triangle;
- A sodium chloride and potassium group consisting of three (03) water points, or 16.7%, from the sodium-potassium subgroup;
- A calcium and magnesium bicarbonate group consisting of a (01) single sample, ie 5.5% with a calcium chloride and magnesium nitrate tendency.

The waters studied overall have three main chemical facies (Figure 3): chlorinated and sulphated calcium and magnesium nitrate (61.1%), sodium and potassium bicarbonate (22.2%), and sodium chloride and potassium (16, 7%).

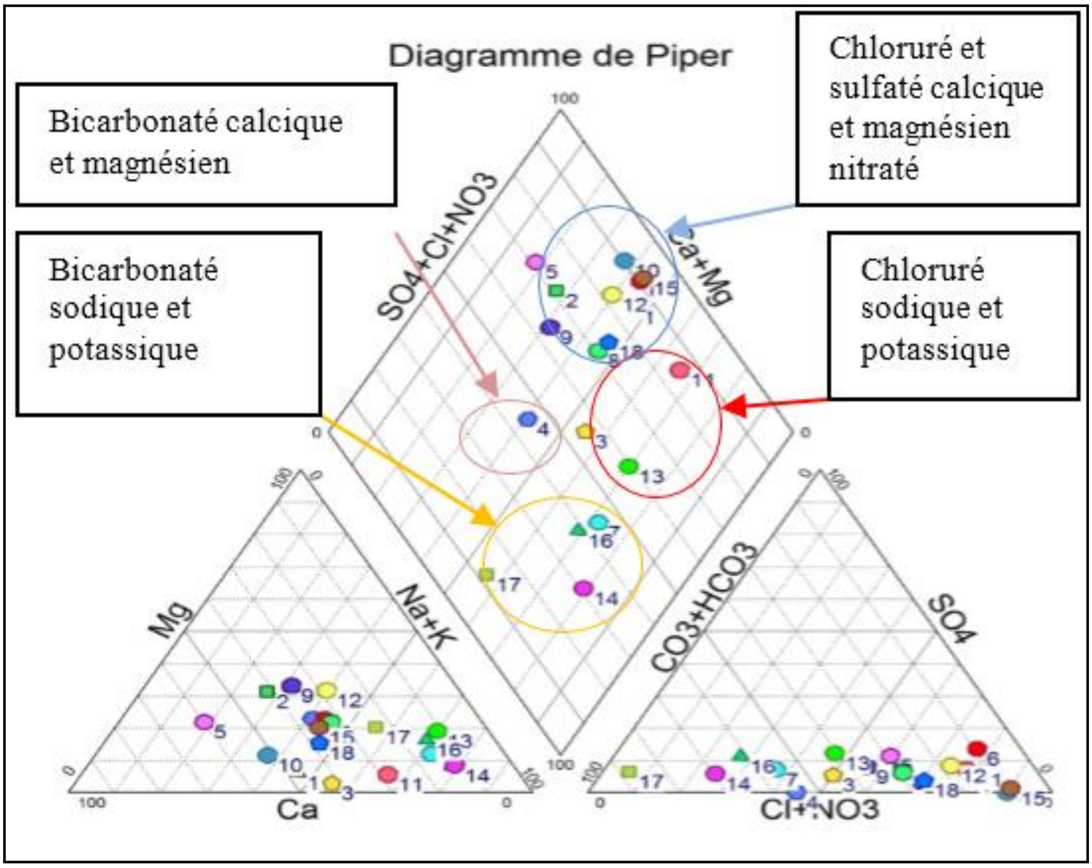


**Figure 2:** Chemical facies of groundwater

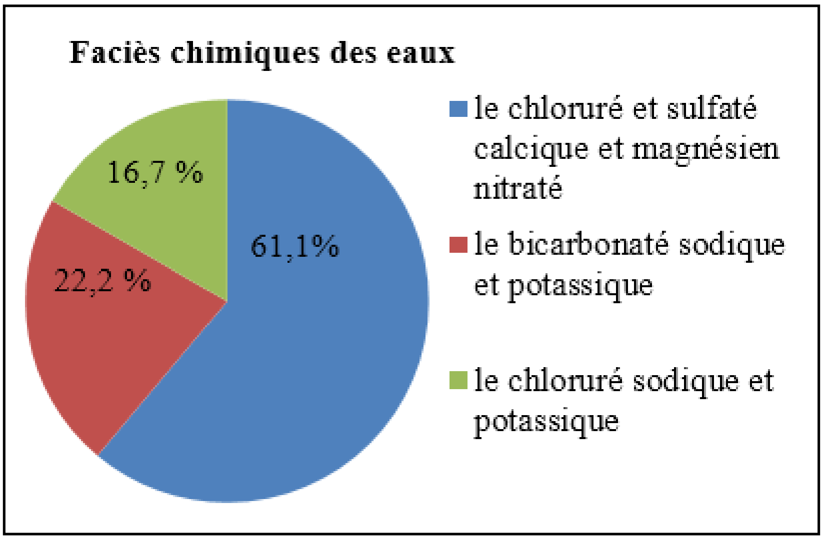


**Figure 3:** Distribution of chemical facies

**Results of the Analysis of Principal Normal Components (PCA)**

The results of the Principal Principle Analysis are presented in Tables 2, 3 and Figure 3. The link between all the two-by-two variables and the correlation coefficients between these variables are given by the correlation matrix (Table 1).

**Table1:** Correlation matrix between water variables.

| Variables | pH | CE | $HCO_3^-$ | $Cl^-$ | $SO_4^{2-}$ | $NO_3^-$ | $Na^+$ | $K^+$ | $Ca^{2+}$ | $Mg^{2+}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| pH | 1 | | | | | | | | | |
| CE | 0.67 | 1 | | | | | | | | |
| $HCO_3^-$ | 0.75 | 0.77 | 1 | | | | | | | |
| $Cl^-$ | 0.68 | 0.89 | 0.74 | 1 | | | | | | |
| $SO_4^{2-}$ | 0.22 | 0.04 | 0.10 | -0.03 | 1 | | | | | |
| $NO_3^-$ | 0.01 | 0.52 | -0.04 | 0.27 | 0.04 | 1 | | | | |
| $Na^+$ | 0.40 | 0.49 | 0.64 | 0.43 | 0.39 | 0.10 | 1 | | | |
| $K^+$ | 0.51 | 0.71 | 0.65 | 0.81 | -0.31 | 0.18 | 0.06 | 1 | | |
| $Ca^{2+}$ | 0.58 | 0.86 | 0.49 | 0.73 | -0.09 | 0.66 | 0.07 | 0.67 | 1 | |
| $Mg^{2+}$ | 0.37 | 0.77 | 0.54 | 0.53 | 0.17 | 0.60 | 0.20 | 0.53 | 0.77 | 1 |

Table 1 shows that the conductivity is strongly correlated with the elements $Ca^{2+}$ (0.86), $HCO_3^-$ (0.77), $K^+$ (0.71), $Mg^{2+}$ (0.77) and $Cl^-$ (0.89). The correlation coefficient between pH and $HCO_3^-$ is 0.75, it is quite strongly correlated with EC (0.67) and Cl- (0.68) and moderately with $Ca^{2+}$ (0.58). $HCO_3^-$ ions are strongly correlated with $Cl^-$ (0.74), and are correlated to a lesser degree with $Na^+$ (0.64) and $K^+$ (0.65). Cl- ions correlate with $K^+$ (0.81) and $Ca^{2+}$ (0.73).

Thus, the pH is strongly correlated with $HCO_3^-$. There is also a strong correlation between the conductivity and each of the ions and between these ions taken two by two. The pH therefore plays a very important role in the solution of these elements. The strong correlation of conductivity with F1 components assumes that the mineralization of the water is mainly due to these elements. The causes of this mineralization are essentially of a natural nature (pluvio lessivage, nature of the lands crossed, and evaporation due to the outcropping of the water table). It can therefore be said that this factor represents the axis of the overall (essentially natural) mineralization of groundwater in the study area. However, there is a great variability of this mineralization from one point to another. This great variability is mainly due to the sedimentary nature of the horizons containing the aquifer and to the topography of the terrain (presence of several cases of endorheism).

Apart from the rather weak link between sulphate and nitrate (0.39), there is no significant correlation between the three components of factor 1. However, $Na^+$ and $NO_3^-$ are correlated with the neighboring ions of the second factor (respectively $HCO_3^-$ and the ions $Ca^{2+}$ and $Mg^{2+.)}$ This supposes that, although these two ions ($Na^+$ and $NO_3^-$) belong to the anthropic pole of the mineralization, they also exist at the natural state and are present in the water respectively in the form of bicarbonate and calcium and magnesium salts.

It is therefore retained that the mineralization of groundwater in the dallol Bosso zone has an essentially natural origin because most of the ions contributing to this mineralization are well correlated with the F1 axis representing the natural pole of the mineralization.

This multidimensional analysis of the data is a factorial and linear method dealing with numerical characters (in our case, the results of the physicochemical analyzes of the waters), in fact, in order to find the relations between the different variables, to group those which have a similar type of variation and possibly determine the origin of the mineralization of the waters that we have resorted to this method Ten (10) variables are taken into account in the case of our study: pH , CE, $HCO_3^-$, $Cl^-$, $SO_4^{2-}$ , $NO_3^-$, $Na^+$, $K^+$, $Ca^{2+}$ and $Mg^{2+,}$ which shows that the percentage of the variance expressed is 53.807% for the factor 1, 17.097% for the factor 2 and 13.877% for factor 3 (Table 2) Factors 1 and 2 alone account for 71.1% of the total variance, and representation using these first two factors satisfactorily accounts for the point clouds structure We can therefore retain these two axes.

Correlation of the variables with the first two axes of the plane (F1xF2):

The analysis in Figure 4 shows that pH, CE, $HCO_3^-$, $Cl^-$, $K^{+,}$ $Ca^{2+}$ and $Mg^{2+}$ correlate well with factor1. They then constitute the elements of the factor F1. This axis, representing 53.81% of the total variance, represents the overall natural mineralization of the water. The others, $SO_4^{2-}$, $NO_3^-$, $Na^+$, form the axis 2 and constitute the factor F2 (17.3% of the total variance) which reflects the anthropic pole of the water mineralization. The correlation levels of these elements with the two axes have been presented in Table 3.

**Table 2:** Intrinsic values and percentages of variance expressed for the main axes.

| | F1 | F2 | F3 |
|---|---|---|---|
| Intrinsic value | 5.381 | 1.729 | 1.388 |
| Variability(%) | 53.807 | 17.290 | 13.877 |
| % cumulated | 53.807 | 71.097 | 84.974 |

**Table 3:** Correlations between Variables and Factors

| | F1 | F2 |
|---|---|---|
| pH | 0.747 | 0.365 |
| CE | 0.977 | -0.038 |
| $HCO_3^-$ | 0.823 | 0.421 |
| $Cl^-$ | 0.905 | 0.038 |
| $SO_4^{2-}$ | 0.064 | 0.599 |
| $NO_3^-$ | 0.444 | -0.541 |
| $Na^+$ | 0.462 | 0.691 |
| $K^+$ | 0.781 | -0.245 |
| $Ca^{2+}$ | 0.864 | -0.407 |
| $Mg^{2+}$ | 0.776 | -0.246 |

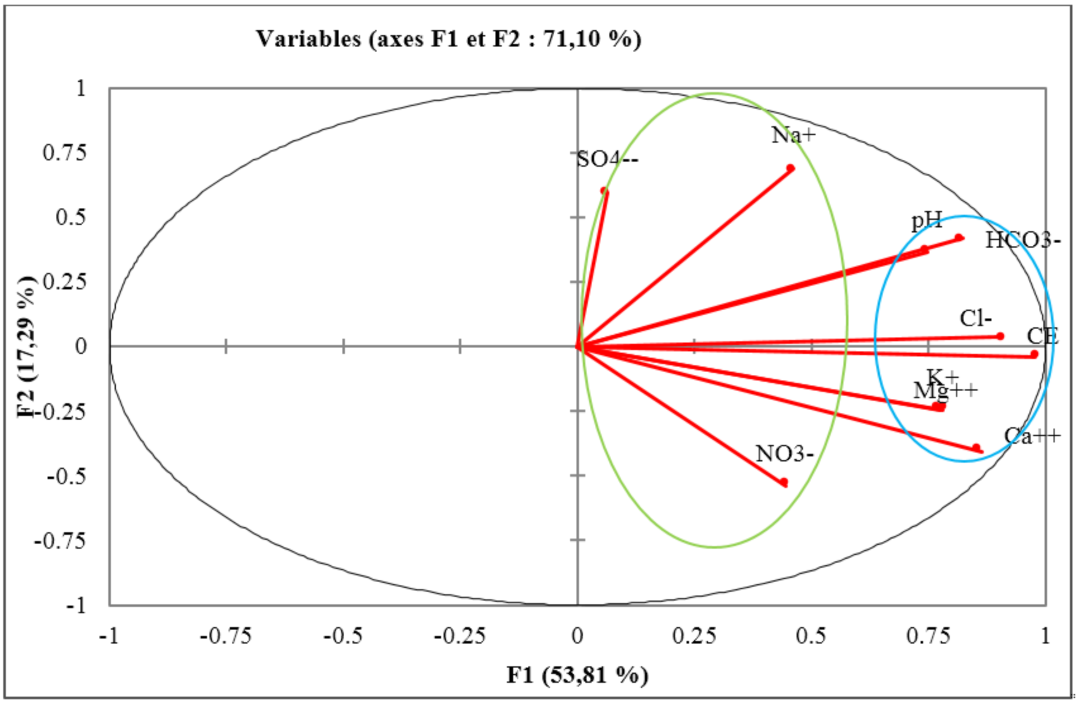


**Figure 1:** Projection of variables on the factorial plan (F1xF2).

**Representation of water points in the factor space (F1xF2):**

The graphical representation in the factorial space of the observations (Figure 5) shows the distribution of the 18 water points taken in two main groups, according to factors F1 and F2.

Thus, group I consists of the water points N °: 1; 2; 4; 5; 6; 8; 9; 10; 11; 12; 13 and 18. These waters follow the factor F1 within a horizontal ellipse. The water point N ° 4 is individualized by deviating from far away from the others. Three subgroups were identified within this group, depending on their mineralization and pH. This is subgroup I.1 consisting of water points 8 and 13, on the extreme left of the ellipse, characterized by very low mineralization (48.2 to 57 µs / cm) and an acidic pH (5 to 5.6). Its characteristics are similar to those of rainwater; it is the phenomenon of pluviolessivage that prevails in this subgroup.

Subgroup I.2 consists of water points No. 1; 2; 6; 10 and 11 with an average conductivity of 164.17 µs / cm and an average pH of 5.96. These waters are therefore weakly mineralized and fairly acidic. Subgroup I.3 consists of samples # 5; 9; 12 and 18 with slightly mineralized waters (248 to 418 passing through an average of 331 µs / cm) and pH ranging from acid to neutral ( 5.8 to 7.04) passing through an average of 6.34. The mineralization of these waters is due to all the ions of the axis, in particular the $Ca^{2+}$ and $Mg^{2+}$ ions with a non negligible contribution of the $NO_3^-$ ions. The water characteristics of this subgroup are similar to those of the waters of the CT3 water table.

Finally, the most recalcitrant water of this axis is No. 4 with a basic pH (7.6) and a relatively high conductivity (735 µs / cm). Indeed, the maximum values in pH, CE, $HCO_3^-$, $Cl^-$, $K^+$, $Ca^{2+}$ and $Mg^{2+}$ were recorded in this water. It is an old, shallow cemented well, without superstructures of protection, so subject to inflow by runoff and wind. It can therefore be assumed that this situation is due to recent pollution of this water point (probably through runoff).

Group II consists of waters N ° 3; 7; 14; 15; 16 and 17. These waters are grouped around the axis 2 according to a vertical ellipse. Sample No. 15 retracts toward the end of the negative pole of the axis. These waters are characterized by a pH of very low acid to neutral (6.4 to 7.1) passing through an average of 6.76. Sample 15 is individualized with a pH of 5.4. As for their conductivities, they vary from 193.1 to 347 µs / cm passing through an average of 282.5µs / cm. These waters are therefore slightly mineralized and this mineralization is mainly due to $HCO_3^-$, $NO_3^-$ and $Na^+$ ions, the others contributing to limited proportions. The presence of nitrates in these waters, although not very important, would be anthropogenic.

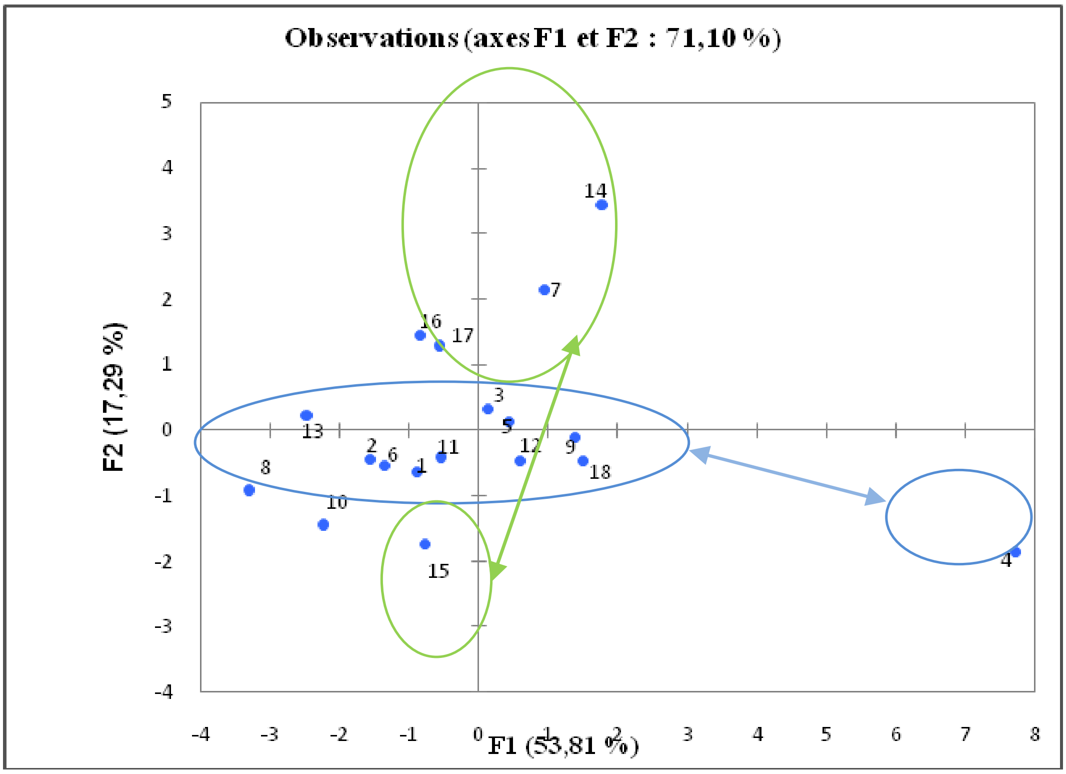


**Figure 5:** Projection of observations in thefactorial plane (F1xF2).

**Ascending Hierarchical Classification Analysis:**

The Ascending Hierarchical Classification (AMP) has classified the water points in our study area into three (03) main classes (Figure 6 and 7). All three classes have the same type of profile (Figure 8); which supposes that these waters come from the same origin. Due to the physicochemical characteristics of these waters, it can be said that they come from the direct infiltration of the rains or the recharge by the endoreic pools formed following the runoff. Indeed, the sampled structures capture the quaternary alluvium (especially wells) and the CT3 (mainly for FE drilling). The quaternary alluvium CT3 forms the water table of the Dallol Bosso in our study area.

Thus, class I consisting of water points 1; 2; 5; 6; 8; 9; 10; 11; 12; 15 and 18 is the most homogeneous. This class contains the highest number of water points at acidic pH (45.45% have a pH between 5 and 5.8 and 45.45% have a pH between 6.2 and 6, 5) with an average of 6. The electrical conductivity of this group range fr 110.7 to 418.00 µs / cm with an average of 237.58 for 91% of water points. It is especially the most nitrated class (the nitrate content varies from 13.2 to 108.68 with an average of 57.84 mg / l, exceeding the WHO standards). We can therefore say that this class is the most homogeneous, the most nitrated (mineralization is also influenced by $NO_3^-$ ions). In the Piper diagram, the waters of this class are chlorinated and sulphated calcium and magnesian nitrate.

Class 2 consisting of waters No.3; 4; 7 and 13. This class is characterized by an average pH of 6.75 (ranging from 5.6 to 7.6). With the exception of water point No. 13, this class is moderately to fairly mineralized (212 to 735 µs / cm). The water points of this class show a great disparity in concentration of major cations and chloride and sulphate. It is also bicarbonated (70 mg / L on average) and slightly nitrated (36.20 mg / L on average). It is therefore the class of slightly to slightly mineralized and slightly nitrated bicarbonate waters with a pH varying from acid to slightly basic, with a great disparity in major cations and in chloride and sulphate. This class consists of a mixture of calcium and magnesium bicarbonate waters, sodium bicarbonates and potassium and chlorides sodium and potassium, slightly nitrated.

And finally class 3 consists of waters 14; 16; and 17. This class is characterized by a low acid pH (6.4 to 6.9) with a neutral tendency with an average of 6.67; average mineralization (295.7 µs / cm on average). It is also the most bicarbonated class (55.51 to 120.78 mg / L with an average of 87.23 mg / L), the most sodium (15 to 50 mg / L with an average of 28.09 mg / L). It also has a moderate average potassium content (7.33 mg / L). It is thus the class of sodium and potassium bicarbonate waters moderately mineralized with a low acid pH with a neutral tendency.

This classification essentially confirms the results obtained by the PCA method and the piper diagram. However, it groups singular or transitioning water points in another class. These are water points No. 3; 4; 7 and 13.

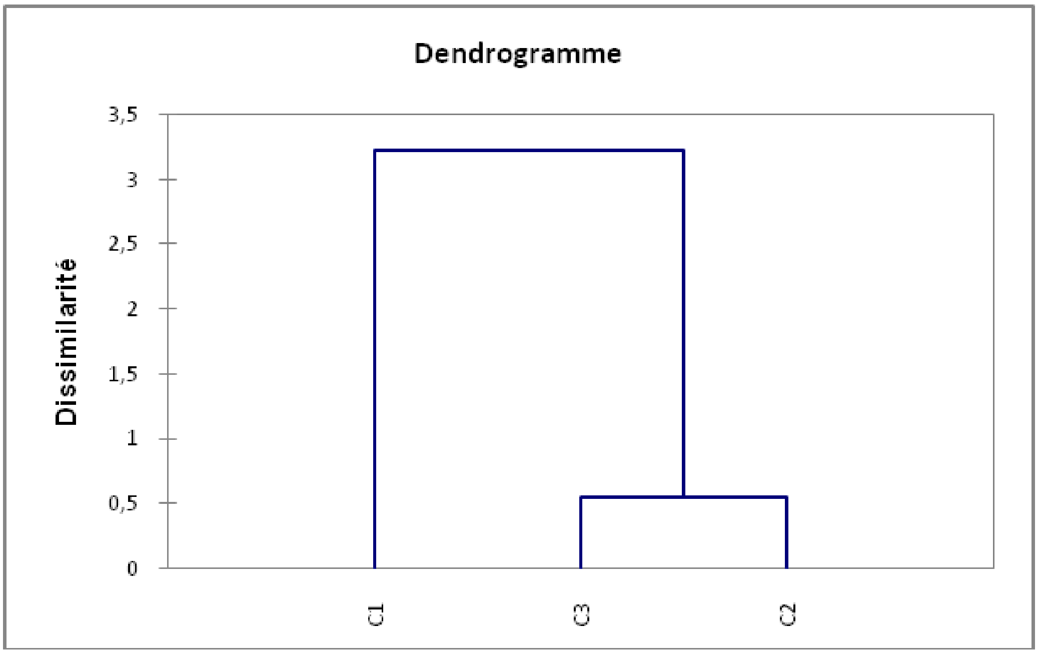


**Figure 6:** Dendrogram of observation classes

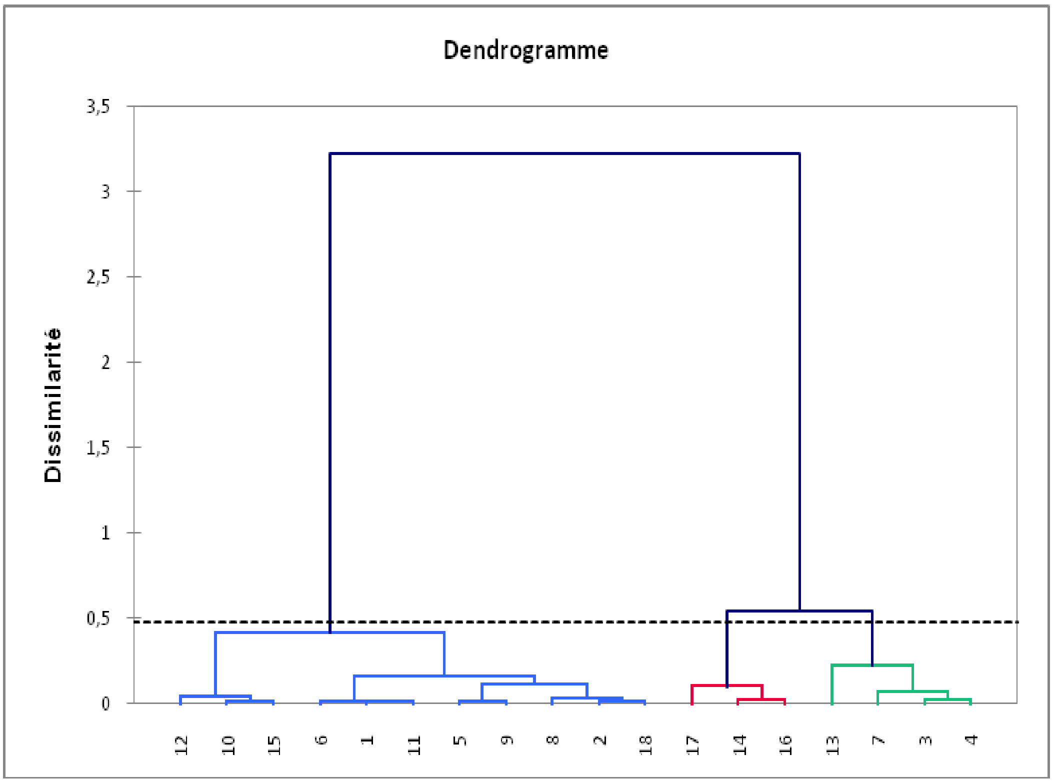


**Figure 7:** Distribution of observations under the different classes.

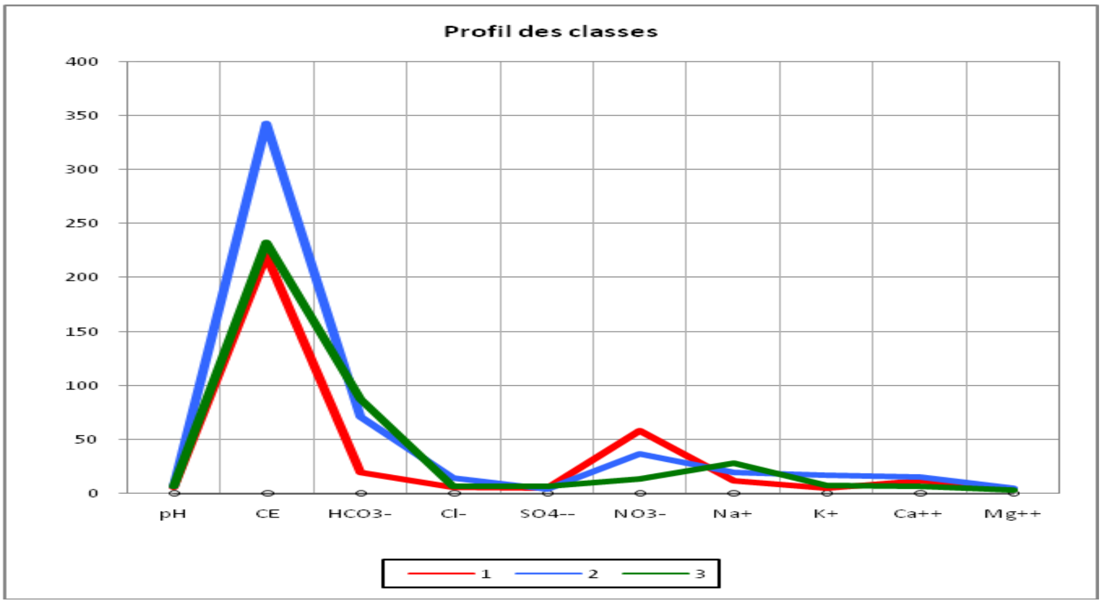


**Figure 8.** Graphical representation of class profiles.

## CONCLUSION

The results of physicochemical analyzes showed that the studied waters have an acid pH and are, from very soft to soft, weakly mineralized overall with high nitrate concentration values far exceeding the WHO guidelines (33.3% ) in certain points and related to a clear influence of human activities. The risk of nitrate pollution therefore threatens the water resource in the study area. Also, potassium levels exceeding the limit values of the WHO guidelines have been recorded in two water points. However, the other physicochemical parameters analyzed remain in compliance with the WHO guidelines for drinking water quality in most cases and the physicochemical quality is therefore acceptable in the absence of other recourse.

As for the results of the bacteriological analyzes, they evolved a large proliferation of bacteria indicating contamination of fecal origin (total and fecal coliforms) and the bacteriological quality is therefore mediocre.

They have three main chemical facies: chlorinated and sulphated calcium and magnesium nitrate (61.1%), sodium and potassium bicarbonate (22.2%), and sodium chloride and potassium (16.7%). The PCA confirmed the essentially natural origin of the mineralization of the waters of the study area with an anthropogenic contribution in places for nitrates and potassium.

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