Mariko A., Lam A.A., Dridri A., Benaabidate L., Hamadoun B., DAO A., Kamagaté B., Seguis L. / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 2, Issue 5, September- October 2012, pp.1211-1220

Hydrogeochemical Characterization of Groundwater in Sandstone Fractured Media by Multivariate Statistical Analysis: a case study of Bani Basin, Mali

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Abstract

Hydrogeochemical parameters of 258 water samples from wells in broken sandstone basin of Bani in Mali are studied using statistical analyses. This study aims to determine the characteristics of groundwater quality, water classes and pollution indicators of anthropogenic origin. The study shows a strong link (R^2 = 0,88) between electrical conductivity and cations (Ca^{2+}, Mg^{2+}) and anions (SO_4^{2-}, CO_3H^-) which may suggest the possibility of predicting the calcium magnesium waters from measurements of conductivity in situ. Bicarbonate calcium magnesium faces are dominant. The PCA allows identifying three classes of water. The PCA1 corresponds to normal water carbonate calcium magnesium (A) opposite to contaminated water (B) containing iron and nitrate (> 50mg / l) of probably anthropogenic origin. The PCA2 shows on the other hand salts water (C) charged with sodium, chlorinates and potassium.

I- Introduction

The surface and underground water resources play an important role in the socio-economic development (Tidjani. And al; on 2006).Their availability on both quantitative and qualitative levels establishes a decisive criterion of choice of the strategies presence of communities, type of land use, the conservation of the ecosystems and the biodiversity … To satisfy the problem of the availability in drinking water of the rural population in environment(middle), works (wells, drillings, restraints) were set up through programs of rustic hydraulics by various participants(speakers) (Government, NGO (NON-GOVERNMENTAL ORGANIZATION), rustic associations) (GHENIS; on 2002). Since the introduction of the industrial crop of the cotton, in the 1960s in particular on the pond of Bani, the custom (usage) of the agricultural fertilizers (pesticides) knows a more and more strong progress (Tidjani. And al; on 2006). This "agricultural revolution" as well as the recent development of the gold-bearing activity (mine manufacturer, gold washing) in the pond can have a negative impact on the quality of the water resources the study of which is the object of this work.

This study has for objective to make the inventory of fixtures being able to serve as reference to the later studies and to bring to light a possible onset of the process of pollution at least punctual of the subterranean waters probably associated with the human activity in aid of the agricultural fertilizer.

II- Presentation of the survey area:

The area of study is located between the longitudes 3 ° and 7 ° West and between the latitudes 11 ° and 14°Nord (Figure 1). It gathers together a part of Koulikoro, Sikasso and Segou regions with a surface of 336457 km^2 representing is 40 % of the whole versant pond of Bani.

Characterized by a Sudanese climate; the precipitation vary between 740 and the 1000mm / year. The relief is influenced by the heights which decrease gradually from South to North. What results in the fact that the southern parts train form the main zones of food supply area of water systems.

The basement is established (constituted) by two geological formations: the tabular infra Cambrian and the terminal / quaternary continent. Due to the lack of data litho stratigraphy; we refer to the report on hydro geologic study of the South of Mali; in October, 1970 (SAAD, K.F; in 1970).

The infra cambrien: it is the biggest emergence met in the zone of study. It is essentially made gritty and salty faces. Its lithologic succession and its thickness are however very variable according to the areas of deposits and their structural evolution (PALAUSI, G; on 1962). Example the Stoneware of Koutiala; very vast, homogeneous formation which thickness varies between 20 - 200 m.

The terminal / quaternary continent: essentially sandy and gritty clayey. We find recent covers consisted of the terminal and quaternary continent (PALAUSI, G; on 1959) there; former alluviums Waterways and Dolerites.

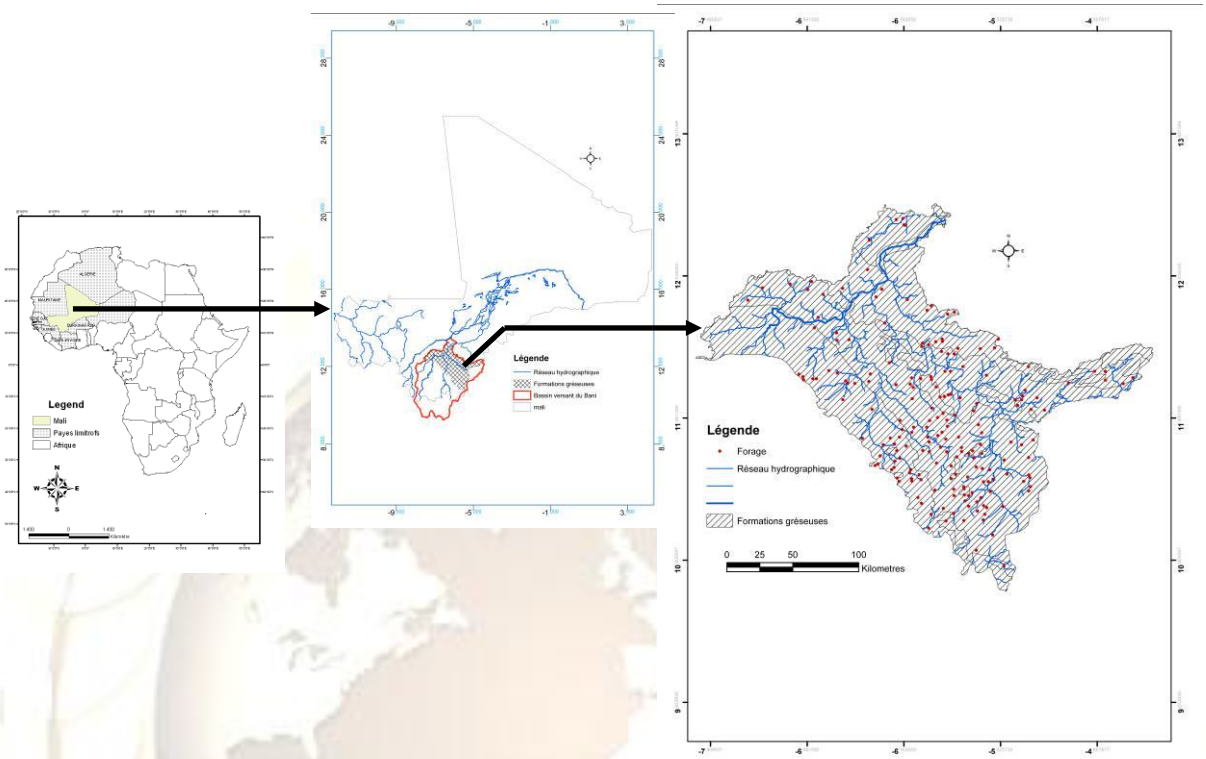


Figure1: Geographic location of the survey area

III- Material and Methods:

III-1. Material:

The data of water samples analysis used result from the database SIGMA (Management IT system of the water resources of Mali) of the National Hydraulic Management (NHM) (GHENIS; on 2002).

On 647 drillings realized within the framework of the project of rustic hydraulics in the whole of the pond overturning of Bani and having been the object of physico-chemical analysis; only 258 drillings are listed on stone wares that is 40 % which continent of the hydro chemical information of the zone of study.

These drillings are characterized by data of chemical analysis (Ca_2^+, Mg_2^+, K^+ , HCO_3^-, CO_3^{2-}, SO_3^{2-}, Cl^-, NO_3^-, pH, Conductivity) and geographical address (longitude and latitude). Those who allow their integration in a tool SIG (ArcGis 9.1).

They left between 2 geological formations (quaternary terminal tabular and continent Infracambrien); subdivided into 7 homogeneous hydro geological units (tab.1) and (fig.2).

Table1: the drillings by hydrogeologic unity (unit)

Geological Formations	*Hydrogeological units*	*Number of*
Tabular infracambrian	72a	9
	72b	10
	73a	10
	73b	75
	74c	36
	75a	106
Continent terminal/quaternaire	15a	12

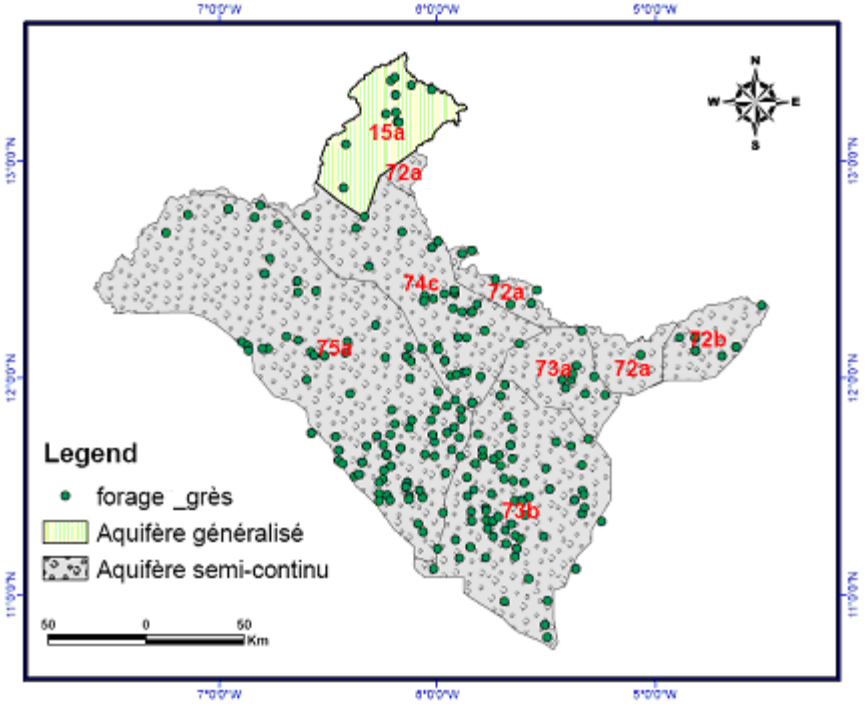


Figure 2: Map of hydro geologic unit of Bani Grit / drillings

III - 2. Methods:

Having to collar the data; they were tested by reliability (calculation of the Ionic balance). It is the report (relationship) of the relative distance between the normed positive and negative charges by the sum of all the loads (responsibilities) expressed in percentage:

$$\varepsilon = \frac{\sum^{+} - \sum^{-}}{\sum^{+} + \sum^{-}} * 100$$

The aim of the test is to estimate the quality of the results of samples analysis.

Followed a descriptive statistical processing is made before passing in the multiple statistical processing with the ACP. The Analysis in Main Constituents (A C P) is a statistical multiuse method of data analysis. It tries to sum up the information contained in a growing picture of individuals and quantitative variables (Ali Kouani, and al, on 2007). It was made by the XLSTAT software in 2009; downloadable (Google). The method was subject to several studies of hydrogeology, pollution, remote detection and other (Vincent Cloutier and al, on 2008); (Mahler and al, on 2008); (Yebdri and al, in 2006).

It has been used in the present study for the following purposes:

- ✓ Differentiation of water groups;
- ✓ Identification of water origins;
- ✓ Identification of the processes that control the dynamic of water on the water-bearing scale.

After the multiuse statistics; to determine the chemical faces, we had recourse to the diagram load mostly used in hydro geochemical studies.

The diagram of Piper permits to establish the various chemical facies of a set of water samples. It consists of two triangles permitting to represent the cationic facies and the anionic facies and of a rhombus synthetizing the global facies.

IV- Results and Discussion:

IV- 1. Results:

Data analysis by the calculation of the Ionic balance to reveal that 37 % of samples have an Ionic balance upper to 10 %. It means that the dosages are not respected during the analysis hence the great difficulty to work with the data.

Has descriptive Statistics

The central trends (picture 2) show a big dispersal of the values of the series around the averages. Some extreme values beyond the standards of the WHO and the EU are observed on the following ions: Ca_2^+, Mg_2^+, and SO_4^{2-}.

Table 2: descriptive statistics of the major ions.

Variable (mg/l)	*Minimum*	*Maximum*	*Average*	*Gap*
Ca^{2+}	0.4	400.8*	21.1	32.1
Mg^{2+}	0.1	286.5*	18	27.4
Na^{+}	0.1	97.2	5.4	9.8
K^{+}	0.2	32.5	6.5	3.8
HCO_3^{-}	2.0	432	116.4	98
CO_3^{2-}	5.0	155	32.3	8
Cl^{-},	0.1	30	3.5	4.5
SO_4^{2-}	0.2	1125*	32.5	106
NO_3^{-}	0.1	10.5	1.4	0.8

*Maximum widely upper to the standards of the WHO and the EU.

It's limp in mustache; publicized in 1977 by the American statistician John Tukey (figure.3) to licence the synthesis of the descriptive statistics and to compare the relevance of elements between them.

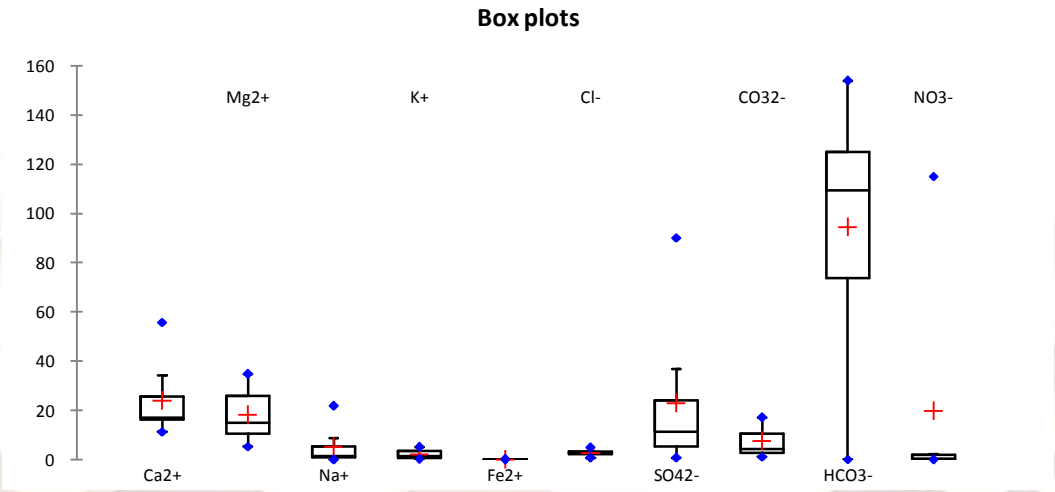


Figure 3: diagrams limp and mustaches

The nitrate presents relatively extreme marked values which can indicate a case of pollution (more than 100 mg / l of NO3-upper to the standard of the WHO). Besides, bicarbonates remain the most represented anions, calcium and magnesium, the most dominant cations. This confers on these waters a facies bicarbonate facies calco-magnésien as the diagram of Piper shows further.

B- Analysis of Main Constituents (A.C.P):

1- Matrix of correlation

The analysis of the coefficients of correlation (picture.3) shows that the couples of parameters (Ca^{2+}, Mg^{2+}), (Ca^{2+}, SO_4^{2-}), (Mg_2^{+}, SO_4^{2-}), (K^{+}, CO_3^{2+}), (Cl^{-}, CO_3^{2+}), (CO_3^{2+}, HCO_3^{-}) present coefficients of correlation R> 0,60. Chlorides and carbonates are strongly bound to R = 0, 90.

However, some couples such as (Ca^{2+}, Na^{+}), (Fe^{2+}, SO_4^{2-}) have coefficients of negative correlation; what could mean that there are no links between them

Table 3: matrix of correlation by Pearson (n)

Variables (mg/l)	*Ca^{2+}*	*Mg^{2+}*	*Na^{+}*	*K^{+}*	*Fe^{2+}*	*Cl^{-}*	*SO_4^{2-}*	*CO_3^{2-}*	*HCO_3^{-}*	*NO_3^{-}*
Ca^{2+}	1.00									
Mg^{2+}	**0.86**	1.00								
Na^{+}	-0.33	-0.49	1.00							
K^{+}	-0.16	0.01	0.21	1.00						
Fe^{2+}	-0.36	-0.48	0.00	0.45	1.00					
Cl^{-}	0.07	0.37	0.33	0.65	-0.23	1.00				
SO_4^{2-}	**0.61**	**0.74**	-0.22	-0.43	-0.89	0.27	1.00			
CO_3^{2-}	0.05	0.32	0.31	**0.60**	-0.13	**0.90**	0.11	1.00		
HCO_3^{-}	0.58	0.58	0.14	-0.10	-0.46	0.41	0.48	**0.62**	1.00	
NO_3^{-}	-0.04	-0.03	-0.22	0.46	0.54	-0.01	-0.28	-0.29	-0.70	1.00

2- Diagram of the appropriate values and circle of correlation

THE ACP allows to bring to light the most homogeneous groups and their degree of correlation with the factorial axes (picture.4). The correlation is marked all the more (about 1) as the point is closer to the circumference of the circle (Savard; on 2008).

Table 4: the appropriate values

variables	*F1*	*F2*	*F3*	*F4*	*F5*	*F6*
Ca^{2+}	0.359	-0.158	0.320	0.299	0.529	0.237
Mg^{2+}	0.416	-0.047	0.404	0.073	-0.024	-0.017
Na^{+}	-0.058	0.329	-0.460	-0.178	0.727	-0.029
K^{+}	-0.098	0.520	0.321	0.002	-0.016	0.602
Fe^{2+}	-0.389	0.150	0.221	0.500	0.087	-0.538
Cl-	0.232	0.503	0.092	-0.307	-0.083	-0.241
SO_4^{2-}	0.428	-0.188	0.034	-0.438	0.030	-0.300
CO_3^{2-}	0.239	0.516	-0.032	0.110	-0.267	-0.172
HCO^{3-}	0.420	0.129	-0.181	0.470	0.099	-0.181
NO^{3-}	-0.252	0.035	0.573	-0.325	0.308	-0.283
Valeurpropre	4.002	2.699	1.814	0.823	0.541	0.121
Variabilité(%)	40.018	26.986	18.144	8.230	5.409	1.213
% cumulé	40.018	67.004	85.148	93.378	98.787	100.000

So on the factorial plan, elements are classified by correlation with the couple of factorial plan (F1, F2). We distinguish the following groups;

Group A: (Ca^{2+}, Mg^{2+}, SO_4^{2-} and HCO_3^{-}) / F1; positive R coefficient

Group B: (HCO_3^{-}, Cl^{-} and CO_3^{2-}) / F2; positive B coefficient

Group C: (Cl^{-}, CO_3^{2-}, K^{+} and Na^{+}) / F2; negative R coefficient

Group D: (Fe2 + and NO3-) / F1; negative R coefficient

The factorial plan (F1, F2) represents 67 % of the total slowness (figure 4). The projection of the parameters on this factorial plan allowed to bring to light three chemical groups (fig. 5). Waters of the group A are considered normal , those of the group C have high conductivities (salty waters) and the group D is under influence of the pollution of anthropological origin (polluted waters). The group B is not mentioned because these elements are much more representative in the groups A and C (Figure 5).

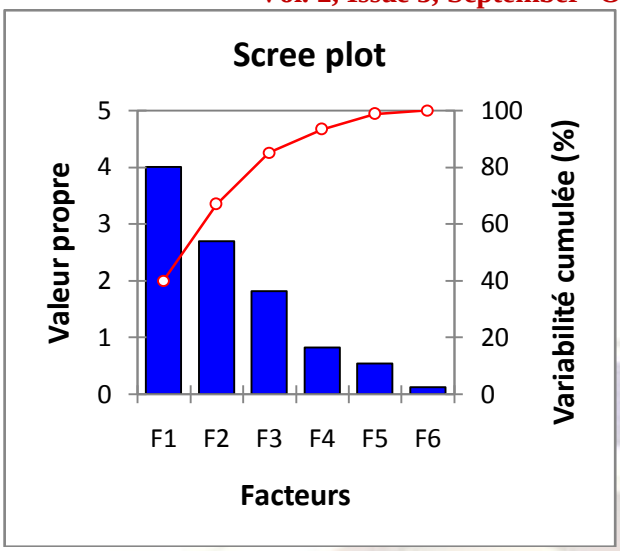


Figure 4: diagram of the appropriate values

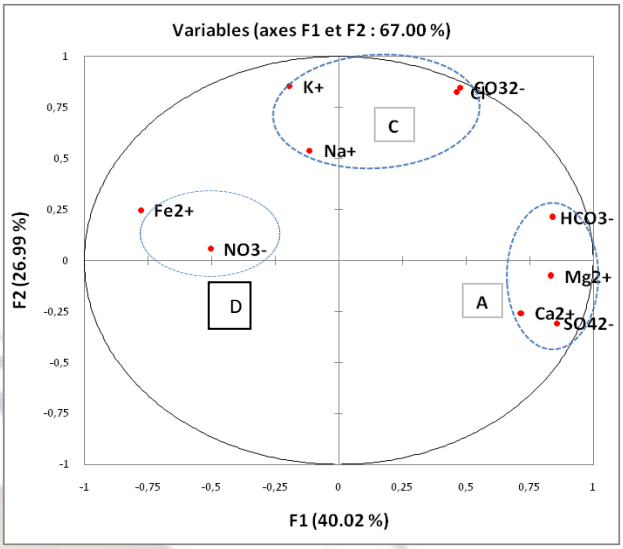
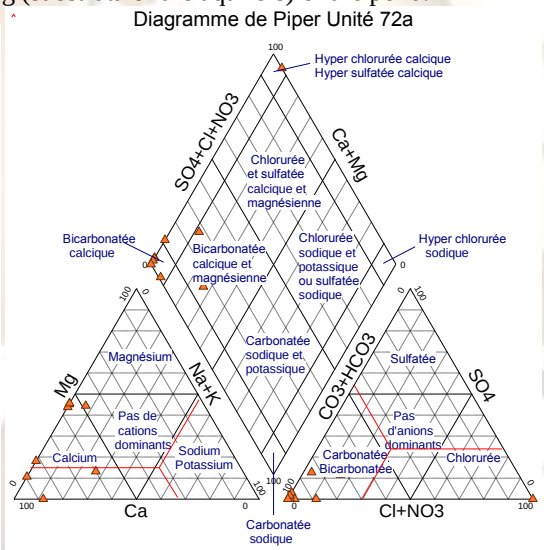


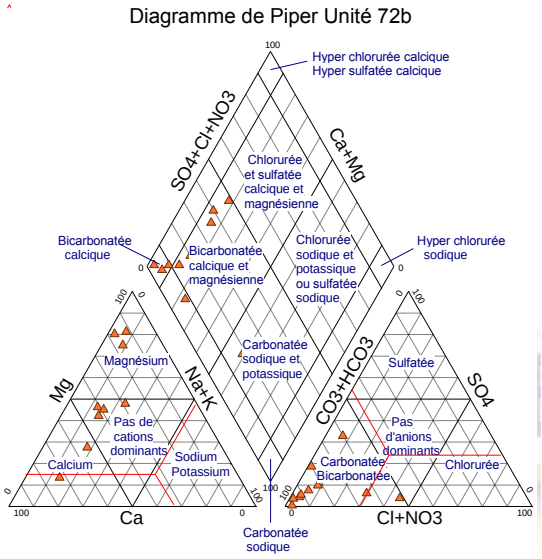
Figure 5: circle of correlation

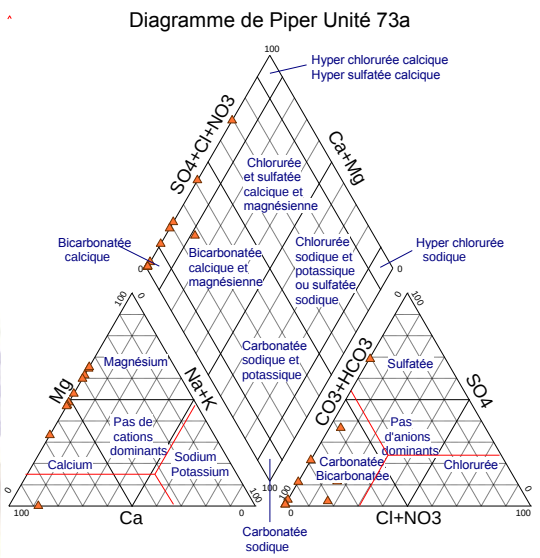
3- The chemical facies:

The graphic shows the major elements in the water allowed to lessen the chemical facies of every hydro geologic unit (figure. 6) and of the whole pond (fig. 7). These facies facilitate the description of the quality of underground waters and the geologic understanding (substrata of the aquifers) of the pond.

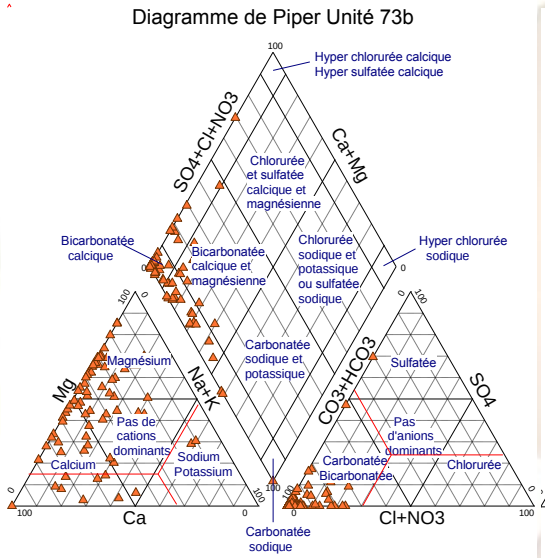


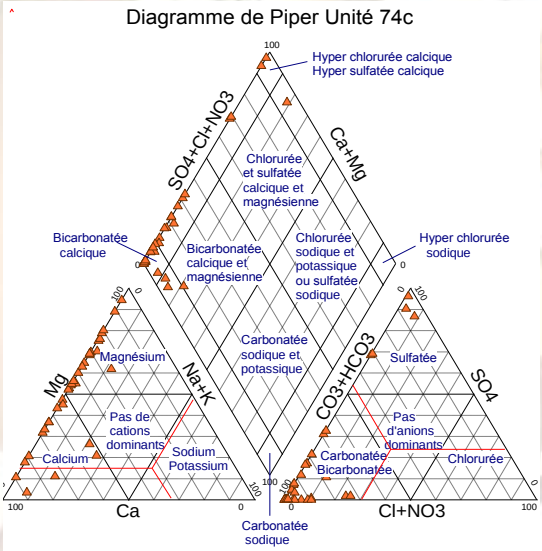
Bicarbonated calcic; calcic bicarbonated and magnesian; carbonated sodic and potassium
Bicarbonated calcic; Bicarbonated calcic and magnsian



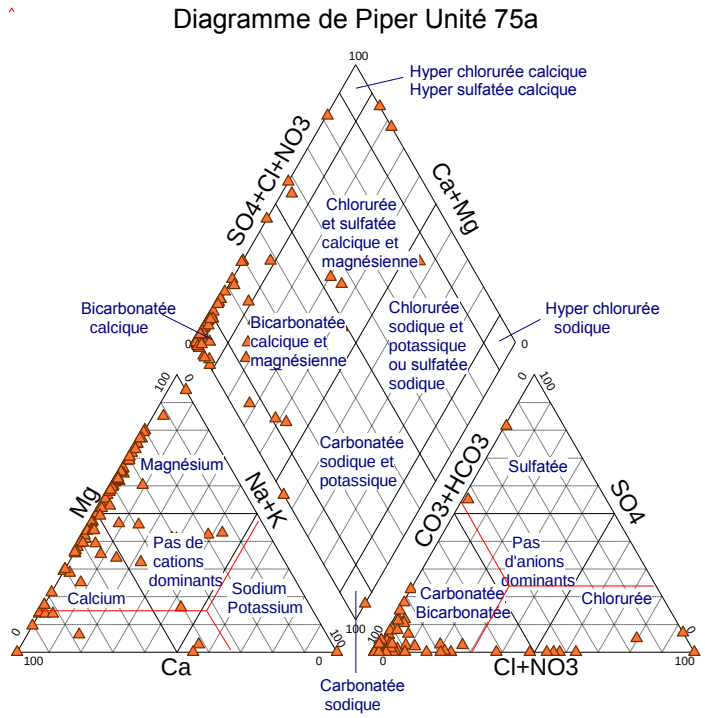


Bicarbonated calcic; calcic Bicarbonated calcic and magnesian
Calcic Bicarbonatée; calcic Bicarbonatée and magnésien; calcic Sulfate and calcic Chloride





Calcic Bicarbonatée; calcic Bicarbonatée and magnésien; calcic Sulfate and calcic Chloride; carbonated sodic and potassium.
Calcic Bicarbonatée; calcic Bicarbonatée and magnésien; hyper Calcic and hyper Sulfate Chlorinates calcic.



Calcic Bicarbonatée; carbonated sodic; calcic Bicarbonatée and magnésien; calcic Sulfate and calcic Chloride; chlorinated and treated with copper sulphate calcic and magnésienne

Figure 6: diagram of Piper by hydrogeologic unit

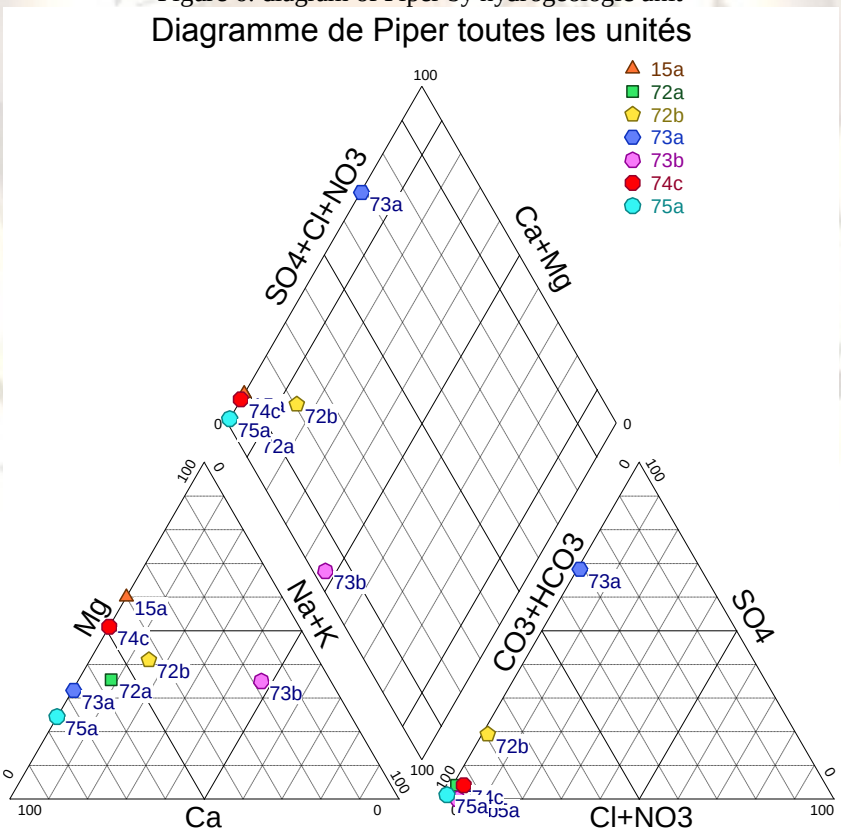


Figure 7: chemical facies of waters of Bani grit

Facies calcic and bicarbonated calcic and magnesian are found on the whole area of study. These waters are characterized by an ascendancy of the bicarbonated ions (HCO3-). These show that the basement of the area is rich in siliceous rock (siliceous stone wares with quartz seeds) and in carbonated rock (gritty or detrital lime stones and lime stone monumental mason or not monumental mason).

IV-2. Discussion

According to the hydro geologic nature of the studied zone; characterized by a cracked aquifer and a generalized aquifer; waters of surface are the only means to reload these tablecloths. The physical context of the aquifer shows that subterranean waters are semi connected but often even no connections. The refill of tablecloths stemming from the infiltration of waters of surface through networks of fissuring; besides the chemical reactions between the water and rocks confer on waters a mixture of chemical facies. Whose hydro chemical characterization it is difficult to make local with these waters.

The results obtained from the ACP of 258 samples analyses; allowed to loose (to kick away) the types (chaps) of water meet in the pond and the chemical facies of waters by hydro geologic sector.

The types of water are defined by the circle of correlation (figure 5); normal waters of the group A in opposition of waters to trend polluted by the group D and at the end salty waters of the group C. waters of the class C can join waters with acid taste if chlorides are dominant on the one hand; on the other hand, they can be salty with a rise in sodic ions.

The diagram of Piper has allowed the determination of the chemical facies of the hydro geological units. We notice that samples resulting from a unit present several chemical facies. The same case is met with the ACP for 47.97 % total slowness. The average values in the representation of the diagram give exactly the chemical facies by hydro geological units.

The drawback of the average values is that we work with reduced value group's , which do not make reference to the neither maximum nor minimum sample content. More, this method does not refer to the local sampling but to the whole unit.

One can make a comparison between the results obtained by that diagram and of the analysis of the main constituents. In hydro geological units, they are characterized by chemical facies bicarbonated calcic. That of the hydro geologic unit b is bicarbonated calcic and magnesian bicarbonated and carbonated sodic and potassium.

V- Conclusion and recommendation:

In gritty zone on the pond of Bani; the problem of water requirements remains a major concern. A sustainable solution of this problem can be based on subterranean waters from which the hydro chemical characterization of the zone is necessary. The present survey has allowed the revealing of the origin of waters (chemical facies by hydro geologic unit and led to the classification of the quality of waters according to the concentration of the constituents of chemical elements: good quality waters, salty waters and polluted waters. According to the chemical facies; polluted waters are very probably of anthropological origin with the presence of nitrates in more than 100 mg / l and some iron.

The major problem met during this study is the data processing. The hydro chemical data collected are not chronological. More, they are not connected with geographical address and phone number what brings back any difficult spatial analysis of these data. It is desirable that efforts be led to lessen the gaps in the base of the hydro chemical data of SIGMA.

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