Evaluation of Underground Water's Hydrochemicalfacies in Daoukro Area (Côte d'Ivoire)

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Abstract: ***The water, in relation with encountered lands, is loaded with various elements that will influence its quality and its mineralogical composition. This study aims to evaluate the hydrochemicalfacies and the origin of the mineralization of groundwater in the Daoukro region. The methodology adopted consisted in determining the various hydrochemicalfacies using the Pipper diagram. Statistical analyses were carried out to determine the origin of the Daoukro groundwater mineralization. The hydrochemical classification of water through the Piper diagram showed waters characterized by bicarbonate calcium facies with a slight tendency to migrate to the chloride-calcium facies. Normalized component analysis shows a positive correlation between conductivity, calcium, magnesium and bicarbonate. These correlations indicate a phenomenon of the dissolution of rocks and the hydrolysis of minerals related to remain time of rocks in the water.***

Keywords: hydrofacies, mineralization, water resources, Daoukro, Côte d'Ivoire

1. Introduction

Water is a vital element for the subsistence of any alive being. It is also a dominating factor for any socio-economic activity **[4]**. Daoukro belongs to the former cocoa buckle which knew a considerable economic expansion. The rainfall recessions of these last decades (1970-2002) involved a strong migration of the populations and the displacement of the "cocoa loop" towards the south-west region. This fall of the rainfall had also, as a consequence, a drying up of the majority of the water points as well as a significant fall of the piezometric level of the nap. The supply drinking water of the town of Daoukro and the large villages close to Daoukro is ensured by the systems of water conveyance of the SODECI (Distributive firm of Water of Côte d'Ivoire). The main towns of the region and certain localities, profit from the improved hydraulic systems. The other localities are supplied by the hydraulic system **[12]**. However, many water drillings of the villages are abandoned due to the recurring breakdowns, of natural drying up of the nape and deterioration of the quality of the water (metal taste, non-limpidaspect). Thus the present study aims to research the hydrogeochemical processes governing the composition of the water and to determine the origin of the mineralization of underground waters of Daoukro. To achieve these goals, the correlations between the various water parameters were established. The statistical analyses performed use the data of all the component analyses carried out during sampling campaigns.

2. Material and Methods

2.1. Study Area

The area of Daoukro is located in the region of N'ziComoé in the Center-East of Côte d'Ivoire (figure 1). It is situated between Western longitudes 3°29' and 4°34' and the Northern latitudes 6°55' and 7°32'. The department has a surface of 3745 km^2 and includes 4 cities (Daoukro, Ouéllé, Ettrokro and Ananda).

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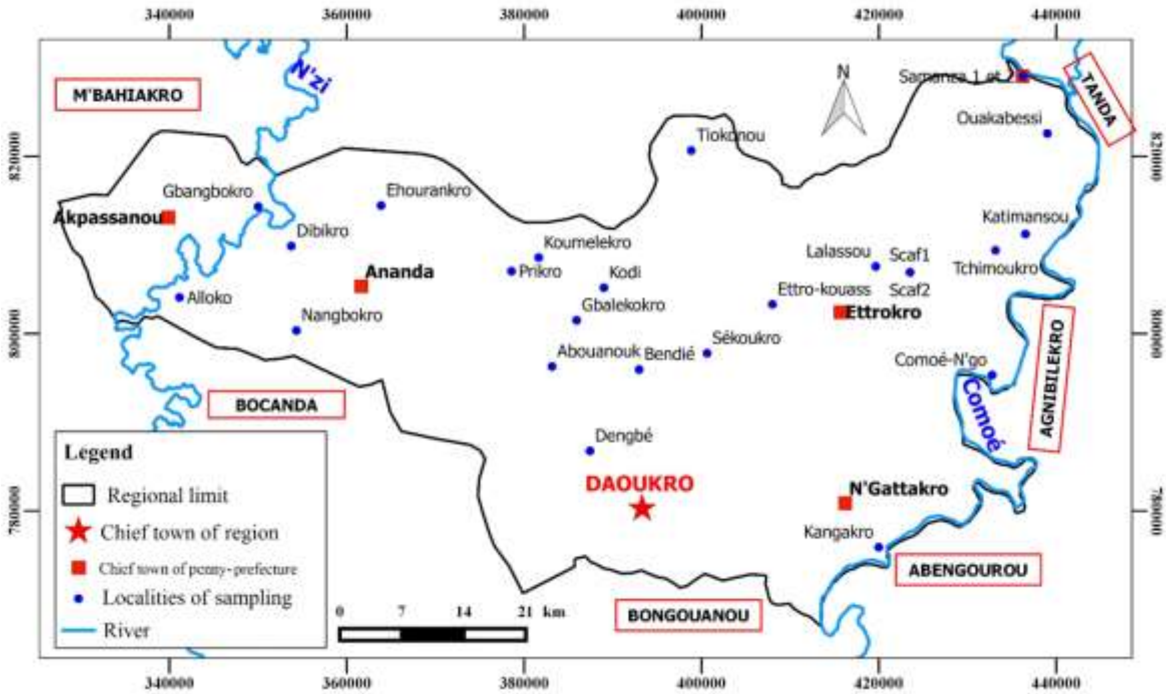

Figure 1: Geographical situation of the region of Daoukro

The region of Daoukro have an equatorial climate of transition attenuated by an annual rainfall of1103 mm. The region is drained by two main rivers, the N'zi river in the West and the Comoé river in the East. The vegetation and the soil are favorable to the exports cultures, as well as for the food crops **[8]**. The landscape of the study zone is characterized by eburnean reliefs of flyschs forming small lengthened hills and with very weak slopes. From the geological view, the region is made up of antebirimean formations (gneisses soils), volcanogenic series, and intrusive sets (figure 2). The base rock of the region is primarily made up of chlorite schist (80%) and black schist (approximately 5%) **[19]**. One finds phyllite outcrops in certain rivers of the region. Phyllites are laminated crystalline schists. They include roof slates, sericitic and talcschist. Phyllites are more or less glossed metamorphic rocks, like roof slates and the sericiticschists.

The region has two types of aquifers which are alterites aquifers and fissured socleaquifers. The socle aquifers are developed in the crushed or fissured zones.

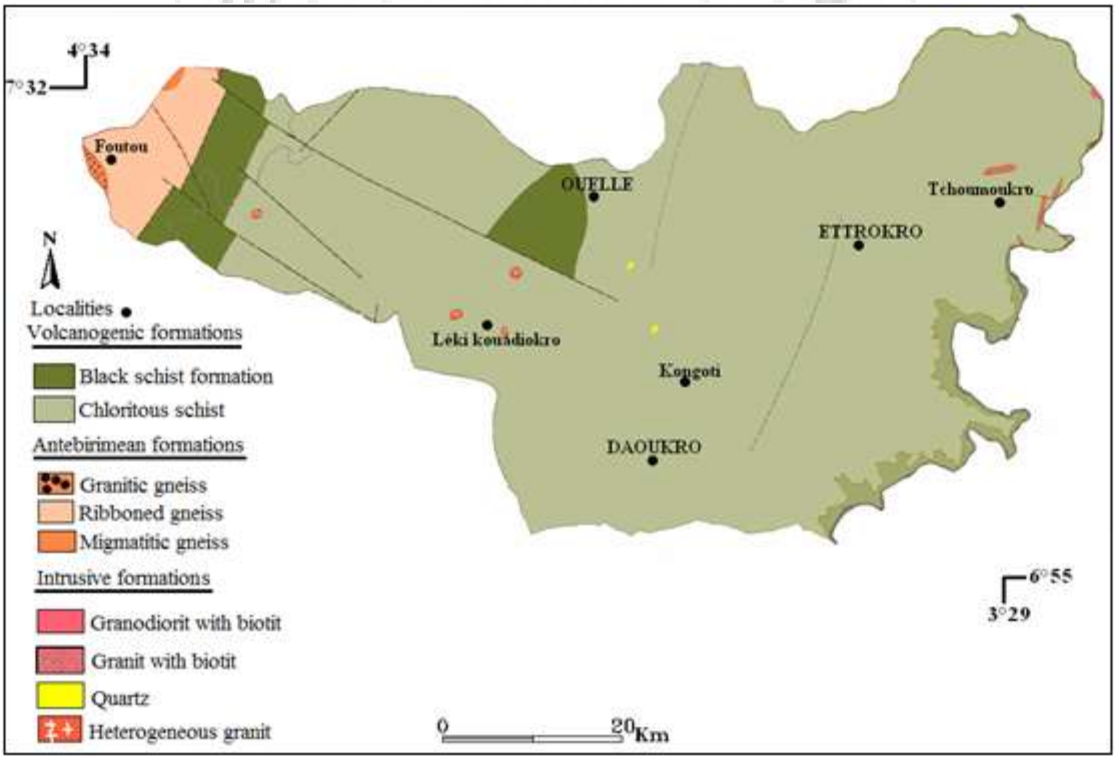

Figure 2: Geological map of Daoukro

2.2. Study Data

This study required the use of technical index card of 30 water drillings randomized on all the zone of study. AYSI multi-parameter was used to measure the conductivity in situ, the pH, the salinity, the dissolved oxygen and the temperature. Turbidity was measured using a turbid meter. The water samples were collected in polyethylene bottles of 1 liter and were conveyed at the laboratory of Abengourou. The chemical analysis of the water samples, was based on a certain number of chemical elements which are the bicarbonate, the calcium, the chlorine, the iron, the magnesium, the manganese and the nitrate. The data used in this study come from the local agricultural development project of the department of Daoukro. The realized drillings (HV and HVA) were a shutter of the local agricultural development project of Daoukro, Ouéllé and Ettrokro. These drillings were carried out by FORACO.

2.3. Ground water facieschemical analysis

The study of the origin of the major elements is based on the hydrochemical analyses. The hydrochemical study required the use of the Piper diagram for the characterization of the hydrofacies of the department of Daoukro. This diagram is very frequently used and gives very good results [**16, 17, 7**]. Indeed, these facies depend on the lithology, the kinetics of the solution and the diagrams of flow of the aquifer [**3**]. The known of these major hydrofacies will contribute to the determination of the uses of these water points which can be for the agriculture, the industry or the drinking water [**7**].

2.4. Statistical Analyses

The statistical tests were carried out to determine the correlations between the biogenic salts of the ground waters. Initially a simplified analysis of the studied parameters in comparison with the standards of the O. M. S was made. Then the study of the typology of waters was carried out using a Normalized Principal Component Analysis (ACPN). The ACP STATE is a statistical method (initially descriptive statistics) the purpose of which is to understand and visualize how the effects of isolated phenomena were linked [**5**]. It is a methodology largely used to interpret the hydrochemical data [**9, 20**]. The values, the factorial cards and the circles of correlations were obtained with the software Statistica 7. 1.

3. Results

The physical and chemical parameters were the pH, the conductivity, the dissolved oxygen, the nitrates, the nitrites, the calcium, the magnesium, the iron, the manganese, the chlorides ions, the bicarbonate, the turbidity and the color.
The pH of waters is close to 7. It varies between 6, 11 and 7, 10 with an average of 6, 80.
Conductivity varied between 195 µS/cm and 860 µS/cm with an average of 445, 6µS/cm.
73 PC of sampled drillings have an electric conductivity higher than the reference value of WHO which is of 300 µS/cm. Certain drilling waters are slightly mineralized with a conductivity ranging between 195 µS/cm and 198 µS/cm. These water points represent 7, 69 PC of the analyzed samples. The strong values of conductivity varying between 592 µS/cm and 840 µS/cm were obtained with 19, 23PC of drillings.

The dissolved oxygen rate varies between 6, 6 mg/l and 7, 2 mg/l with an average of 6, 72 mg/l. The deep nap generally have a rate of dissolved oxygen low because of the weak contact water-atmosphere. The analysis of the dissolved iron (Fe^{2+}) contents of the drillings water shows a variation which oscillates between 0, 01 mg/l and 0, 65 mg/l with an average of 0, 04 mg/l. Iron is naturally in the aquifer but the concentrations, in underground waters, can increase because of the anthropic activities (drilling, well).

The analysis of the composition in major ions and their distributions in the diagram of Piper (figure 3) highlight the calcic bicarbonatedfacies for all the water points except for those of Ehourankro locality with calcic chlorinated facies.
Water of the region of Daoukro is characterized by a predominance of bicarbonate ions compare tochlorides ions. Calcium (Ca^{2+}) constitutes the mostabundant cation.

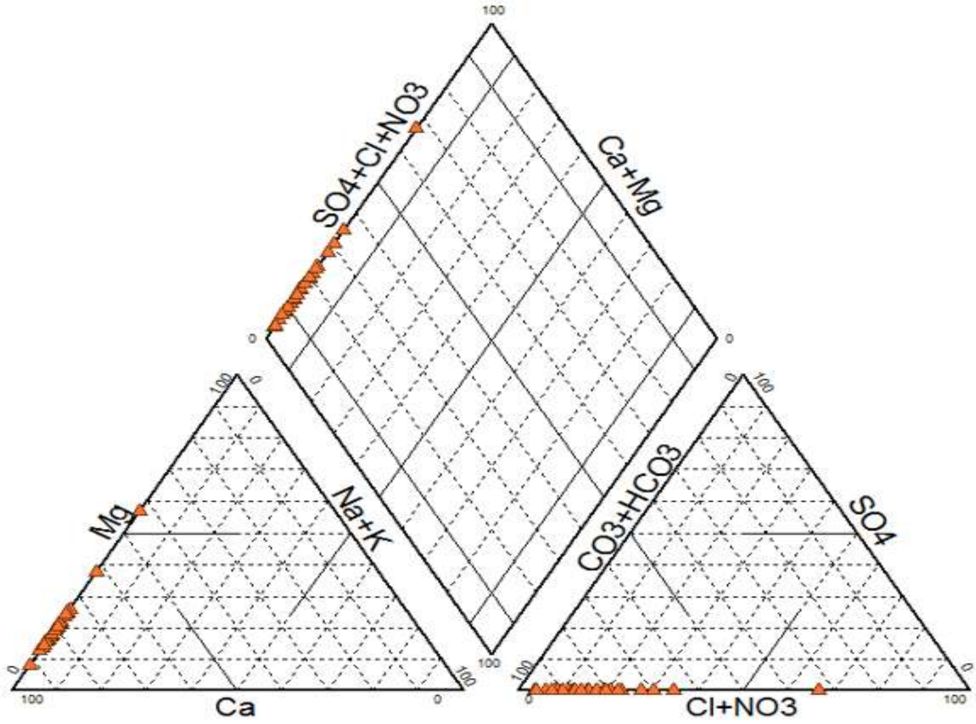

Figure 3: Diagram of Piper:hydrochemicalfaciesof ground water of Daoukro

A principal component (ACP) analysis was made in order to determine the origin of the concentrations observed in the various samples. The analyzed variables are the pH, the conductivity, the dissolved oxygen, the nitrates, the calcium, the magnesium, the iron, the manganese, the chlorideions, the bicarbonate, the turbidity and the color. The elementary statistics of variables are given in table I. This table presents as a whole a weak variation of the contents with often weak standard deviations compared to the average. However the contents of chloride ions are characterized by a great variation with a standard deviation in the same order than the average 39, 01 (± 27) mg/l. The analysis of table 1 shows that the bicarbonate and the calcium with respective averages of 198, 25 mg/l and 24, 85 mg/l constitute the essential elements of the total mineralization of the ground waters of the area. One also notes the presence of the chlorides ions in all the drillings sampled with rates going up to 85 mg/l. These high percentages of chlorides find their origin in the schistous formations which constitute the substratum of the nap in this area. The other ions present have weak concentrations. Water of the area thus has a chemical heterogeneity as a whole.

Table 1: Elementary statistics of the studied variables

Variables	*Number*	*Average*	*Standard-déviation*	*Minimum*	*Maximum*
pH	26	6, 81	0, 13	6, 11	7, 01
Cond	26	441, 45	185, 64	195	840, 00
Cl^-	26	39, 01	27, 47	7, 09	85, 10
Fe	26	0, 04	0, 07	0	0, 65
O_2 dis	26	6, 73	0, 10	6, 6	7, 20
NO_3^-	26	0, 03	0, 10	0	9, 20
Mn^{2+}	26	0, 01	0, 03	0	0, 50
Ca^{2+}	26	24, 85	15, 84	8, 016	78, 76
Mg^{2+}	26	5, 35	0, 89	1, 45	13, 61
HCO_3^-	26	198, 25	67, 28	73, 2	469, 70
turb	26	0, 56	0, 42	0, 3	2, 43
Coul	26	7, 89	4, 24	5	25, 00

The significant links which exist between the various parameters are given by the matrix of correlation (Table 2).

Table 2: Correlation Stamp

	pH	**Cond**	**Cl-**	**Fe 2+**	**O2 dis**	**NO3-**	**Mn2+**	**Ca2+**	**Mg2+**	**HCO3-**	**turb**	**Coul**
pH	1											
Cond	0,31	1										
Cl-	-0,11	0,43	1									
Fe 2+	-0,38	-0,22	-0,12	1								
O2 dis	0,11	0,32	-0,15	**-0,61**	1							
NO3-	-0,29	-0,04	0,20	0,13	-0,15	1						
Mn2+	-0,30	-0,28	-0,17	0,45	0,04	0,07	1					
Ca2+	0,13	**0,75**	0,16	0,02	0,22	0,16	-0,16	1				
Mg2+	0,08	**0,50**	-0,19	0,00	0,41	0,01	-0,09	**0,62**	1			
HCO3	0,24	**0,70**	-0,13	-0,01	0,32	-0,11	-0,14	**0,55**	**0,50**	1		
turb	0,29	-0,20	-0,05	0,02	-0,34	-0,10	0,05	-0,29	-0,02	-0,24	1	
Coul	0,27	-0,08	-0,02	0,22	-0,47	-0,12	0,08	-0,17	0,01	-0,10	**0,94**	1

In fat, significant values (except diagonal) with the threshold alpha=0, 050 (bilateral test)

The matrix of correlation (table 2) shows the various correlations between the studied physicochemical parameters. This matrix highlights significant correlations between conductivity and calcium (R= 0, 75), conductivity and magnesium (R = 0, 50) and conductivity and the bicarbonate (R = 0, 70). The correlation matrix also reveals correlations between bicarbonate and calcium (0, 55), bicarbonate and magnesium (R= 0, 50) and between magnesium and calcium (R = 0, 62). One also notes a correlation between dissolved oxygen and iron and turbidity and color. Dissolved Oxygen is in fact the quantity of oxygen present in the water at a given temperature and iron oxidizes itself in the presence of oxygen.

The factorial plans analysis (figure 4) reveals a correlation between physicochemical parameters of studied water and highlights regrouping variables. Thus, the F_1 factor in the factorial plans F_1-F_2 and F_1-F_3 gather bicarbonate ions, calcium, magnesium and conductivity in its positive part. The F_1 factor reveals the existence of rocks dissolution phenomenon by considering the combination of those parameters around this axis. The F_1 factor also gathers the iron and the manganese. The F_2 factor gathers turbidity and the color in it negative part. The F_2 factor also carries nitrate and slightly chlorides ions in it positive part. This factor expresses the infiltrations of surface as well as the water pollution by the anthropic activities.

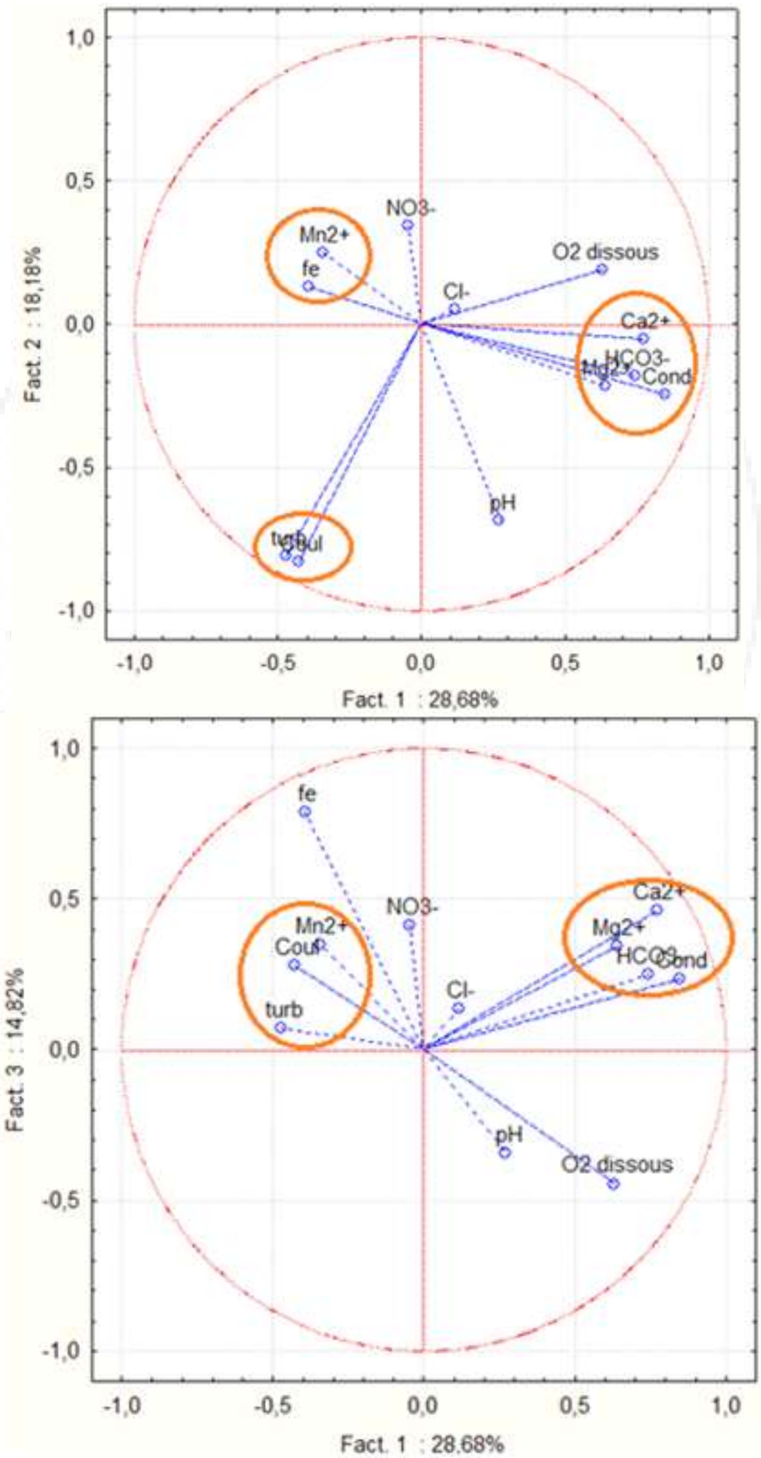

Figure 4: Circles of correlations F_1-F_2 and F_1-F_3

The Daoukro drillings factorial plans analysis (Figure 6) makes it possible to range waters in four (4) classes.

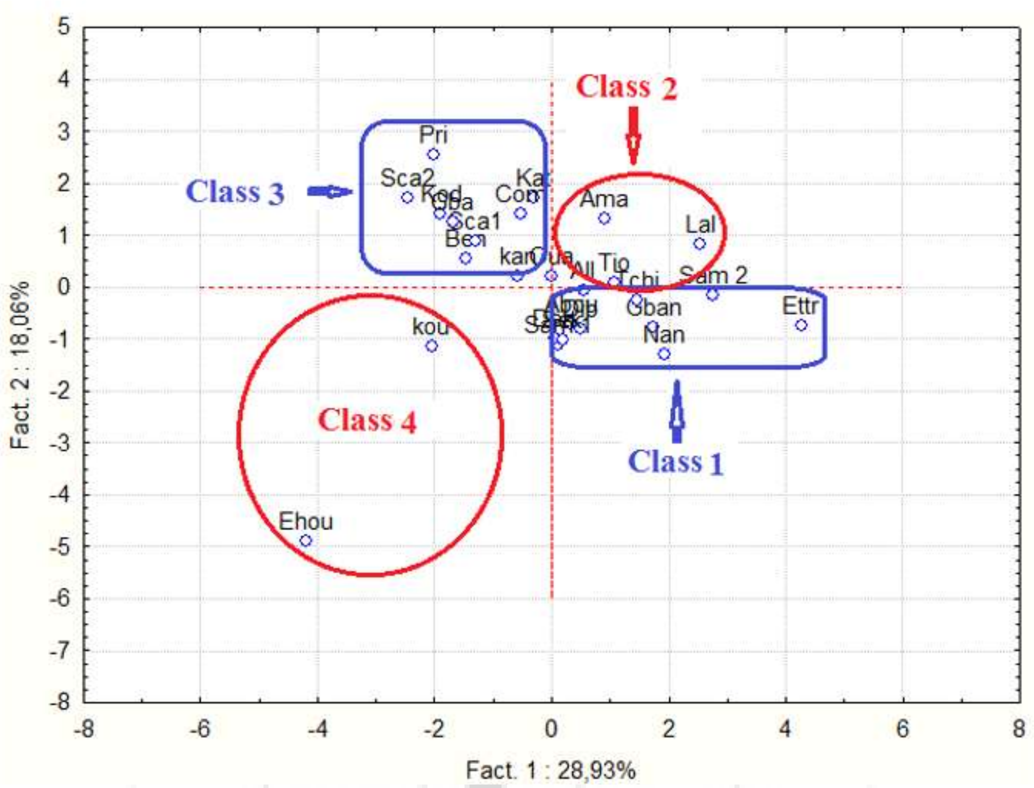

Figure 5: Daoukrodrillings factorial plans analysis

Class 1 (43PC) is characterized by drilling waters strongly mineralized and strongly affected by silicated minerals hydrolysis phenomenon. These water points are deep drillings which collect the fractured socle, characterized by low thicknesses of alterites. (Thicknesses of alterites ranging between 8 m and 20 m). The water of these drillings is rich in bicarbonates with contents varying between 256 mg/l and 469 mg/l. The rock contents in mineral salts are high (Ca^{2+}, Mg^{2+}, and Cl^{-}). The conductivity of drillings of this class varies between 456 µS/cm and 840 µS/cm. One primarily finds these drillings in the North-West and the North-East of the region of Daoukro (Dibikro, Nangbokro, Abouanoukpinkro, Allokokro, Gbangbokro, Samanza 1 and 2, Tchimoukro).

Class 2 includes water of fairly mineralized drillings (11, 5 PC) which also exploit the fissured aquifers of the region. One finds these waters in the localities of Lalassou, Tiokonou and Amanikro.

Class 3 includes water slightly mineralized (34 PC) with a low bicarbonate content. These deepdrillings (76 m -106, 5 m) have strong thicknesses of alterites (79 m - 103, 5 m). This class presents a mineralization influenced by the infiltration of rainfalls in the aquifers with high chloride ion content

Class 4 includes drilling waters slightly mineralized (7, 5 PC), low in bicarbonate and calcium. These water points are deep drillings of 80 m to 90 m without socle (which isn't collected with the fractured socle). One finds these water points in the localities of Ehourankro and Kouméléko.

4. Discussion

The hydrochemical study reveal the prevalence of the calcic bicarbonate and magnesicfacies in ground waters of Daoukro region; while the calcic chlorinated facies only in the drilling water of Ehourankro is induced by a local pollution by worn water. The results obtained in this study are similar to those of many african researchers **[17, 13, 1, 14]** who worked on African ground waters (Morocco and Côte d'Ivoire). The dominant ions in the calcic bicarbonatedfacies are HCO_3^-, Ca^{2+} and Mg^{2+}. The origin of these ions in ground waters is attributed in the main case to the chemical and mineralogical constitution of the crossed rocks. And this mineralization of ground waters is controlled by the relation water-rock as indicates in the results of various statistical studies. The bicarbonates are primarily produced by the deterioration of silicates during the acquisition of the salt charge of water in the zone of ventilation **[14]**. Because of the dissolution of minerals contained in the rock or the soil, the chemical composition of the rock or the soil influences that of the crossed water **[17]**. From the geological approach, the region of Daoukro is composed of gneisses soils, volcano-sedimentary formations and intrusive sets **[19]**. The hydrolysis of such rocks rich in alkaline feldspars and acidic plagioclases for the migmatitic formations, explains the contents of the major ions in ground waters of Daoukro. The rocked socl of the area is primarily composed of chloritesschist (80PC). These schistous formations, which forms the socle of the aquifer studied, is the principal source of the strong Cl^- concentrations in ground waters. In these schists, the chloride, for a part, is probably contained in biotites, and is rejected into ground waters by the deterioration of these minerals **[13]**. The chlorides can have a magmatitic origin. They are present in mineral waters of recent volcanicity areas but also in very deep waters of the crystalline socle.

The matrix of correlation highlights significant correlations between conductivity and calcium (R= 0, 75), conductivity and magnesium (R= 0, 50) and conductivity and bicarbonate (R= 0, 70). The correlation of conductivity with these major ions accounts for the mineralization or the phenomenon of the minerals hydrolysis. According to **[7]**, the positive correlation between conductivity and these major ions is the consequence of the dissolution of the rocks related to the residence times.

Average turbidity is around 0, 46 NTU, this means that this water contains few suspended particles that is not the case of the drilling water of the locality of Ehourankro which has a high rate of suspended particle with a turbidity of 2, 43 NTU.

The factorial plans confirm the correlations between the physicochemical parameters of the studied water and highlights regroupings of variables around the axes F_1 and F_2. The F_1 factor reveals the existence of rocks dissolution phenomenon by considering the combination of the major ions around this axis. The F_1 factor also carries the iron and manganese. Iron (Fe) and manganese (Mn) are metal elements present together at the natural state in many types of rock. They come from the meteoritic deterioration of minerals and rocks which amphiboles, magnesia iron micas, sulphides iron, magnetites, oxides, carbonates, as well as ferruginous clay minerals **[15]**. Thus the contents of iron and manganese of ground waters of the area would come primarily from geological grounds **[15, 11]**. The F_2 factor expresses the surface infiltrations as well as the water pollution by the anthropic activities.

The drillings studied in the zone of Daoukro are rather deep because the strong thickness of alterites which covers the socle. The total depth varies between 31 m to 118 m with an average value of 75 m. the maximum depth (118 m) is reached in the locality of Dadiékro, with one water arrival whose flow is 13, 45 m^3/ h.

5. Conclusion

The hydrochemical study carried out highlight the prevalence of the bicarbonatedcalcic facies of the ground waters of the Daoukro zone except for the water point of the locality of Ehourankro which has a chlorinated calcic facies. The water of the area of Daoukro is characterized by a predominance of the bicarbonates ions on the chlorides ions. Calcium (Ca^{2+}) constitutes the most abundant cation. The pH of the water is close to 7. It varies between 6, 11 and 7, 10 with an average of 6, 80. Conductivity varies between 195 µS/cm and 860 µS/cm with an average of 445, 6µS/cm. The dissolved oxygen rate lies between 6, 6 mg/l and 7, 2 mg/l with an average of 6, 72. The mineralization of ground waters is controlled by the nature of the geological formations present in the area. Thus the principal ions result from the deterioration of the rocks and the hydrolysis of silicated minerals.

References

[1] Ahoussi KE, Soro N, Koffi YB, Soro G, Biemi J. 2010. Origine de la minéralisation des eaux des aquifères discontinus sous couvert forestier de la zone Sud de la Côte d'Ivoire : cas de la région d'Abidjan-Agboville. Int. J. Biol. Chem. Sci. 4(3): 782-797, DOI : http://ajol. info/index. php/ijbcs.

[2] Alayat H, Lamouroux C. 2007. Caractérisation physico-chimique des eaux thermo-minérales des monts de la Cheffia (extrême Nord-Est algérien). La Pressethermaleetclimatique, 144: 191199.

[3] Back W. (1966). Hydrochemicalfacies and groundwater flowpatern in northern part of Atlantic Coastal Plain. US Geological Survey Professional Paper 498-A.

[4] Ben YA. 2014. Evaluation des facies hydro-chimique des eaux souterraines de la région d'insalah (wilaya de tamanrasset).

[5] Caillez J. P et Pages. 1976**.** Introduction à l'Analyses des données. *SMASH*, *Paris*, 616 p.

[6] Dibi B, Inza D, N'go Y, Gone D. L. 2006. Origine et mécanisme de la minéralisation des eaux souterraines de la région de Dabou, Côte d'Ivoire. Apport de l'Analyse en Composantes Principales Normées. Bioterre, Rev. Inter. Sci. de la Vie et de la Terre. 5 (1): 5-16.

[7] Dibi B, Konan KS, Konan-Waidhet AB, Savané I, Gnakri D. 2014. Analysis of the impact of anthropic activities on the water chemistry of weathered layer aquifer of M'bahiakro locality (Center of Côte d'Ivoire). American Journal of Engineering Research (AJER). 3 (1) : 43-49, DOI : www. ajer. org.

[8] DCGTX (Direction et contrôle des grands travaux) (1995). "Projet local de développement agricole de Daoukro". DCGTx, Côte d'Ivoire, 147 p.

[9] El Asslouj J, Kholtei S, El Amrani-Paaza N, Hilali A. 2007**.** Impact des activités anthropiques sur la qualité des eaux souterraines de la communauté Mzamza (Chaouia, Maroc). *Rév. Sci. Eau,* **20**(3) : 306-321, DOI : 10. 7202/016505ar.

[10] Géomines Ltée (1982). Inventaire hydrogéologique appliqué à l'hydraulique villageoise. Minist. T. P. &Transp., Direct. Centr. Hydraul., République de Côte d'Ivoire, carte de Agnibilékrou, Cahier n°. 20, 30 p.

[11] Gronayes CC, Koffi PB, Kouamé KF, Kouakou BB. 2003. Identification de couloirs de cisaillement à partir de l'imagerie TM de landsat : Application à l'Archéen de Bloléquin (Ouest de la Côte d'Ivoire). Bioterre, 2: 218-221.

[12] Kanohin F. 2010. Evaluation des ressources en eau de surface et souterraine dans un contexte de variabilité climatique dans la région de Daoukro (Centre-Est de la Côte d'Ivoire). Thèse Unique, Université Abobo-Adjamé, 146 p.

[13] Krimissa, S., Michelot, J. L., Bouchaou, L., Mudry, J., et Hsissou Y. 2004. Sur l'origine par altération du substratum schisteux de la minéralisation chlorurée des eaux d'une nappe côtière sous climat semi-aride (Chtouka-Massa, Maroc). Comptes Rendus Geosciences 336, 1363-1369.

[14] Kouassi MA, AhoussiEK, KoffIBY, AKEYA, BiemiJ. 2012. Caractérisation hydrogéochimique des eaux des aquifères fissurés de la zone Guiglo-Duekoué (Ouest de

la Côte d'Ivoire). Int. J. Biol. Chem. Sci. 6(1): 504-518, http://ajol. info/index. php/ijbcs.

[15] Lasm T, Yao KT, Oga MS, Kouame KF, Jourda P, Kouadio KE, Baka D. 2008. Analysis of the physico-chemical characteristics of groundwater in proterozoic land region of the Tiassale area (Southern Côte d'Ivoire). European Journal of Scientific Research, 20(3): 526-543.

[16] Oga MS, Lasm T, Yao KT, Soro N, Saley MB, Kouassi D, Gnamba F. 2009. Caractérisation chimique des eaux des aquifères de Fracture: cas de la région de Tiassalé en Cote D'ivoire. European Journal of Scientific Research, 31 (1): 7287

[17] Sadek A. 2011. Hydrochimie et faciès géochimiques des eaux souterraines, Plaine de Bekaa. Hydrological Sciences Journal, **56**(2) : 334-348, DOI: 10. 1080/02626667. 2011. 559331.

[18] Tabouche N, Achour S. 2004. Etude de la qualité des eaux souterraines de la région orientale du Sahara septentrional algérien. Larhyss Journal, 3: 99-113.

[19] Tagini B. 1971. Esquisse structurale de la Côte-d'Ivoire. Essai de géotectonique régionale. Thèse de Doctorat d'Université de Lausanne (Suisse). *Bulletin, SODEMI, n° 5, 302p.*

[20] Yapo OB, Mambo V, Seka A, Ohou MJA, Konan F, Gouzile V, Tidou A. S, kouame KV et HouenouP. 2010. Evaluation de la qualité des eaux de puits à usage domestique dans les quartiers défavorisés de quatre communes d'Abidjan (Côte d'Ivoire) : Koumassi, Marcory, Port-Bouet et Treichville. Int. J. Biol. Chem. Sci. **4**(2) : 289-307, DOI : http://ajol. info/index. php/ijbcs