

## Hydrochemistry of Groundwater in the Aquifer AQ-2 in Pointe-Noire, South-West Congo-Brazzaville

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**Abstract:** The hydrochemistry of groundwater from aquifer AQ-2 exploited by the National Company of Water supply (NCWD) located at Pointe-Noire, south-west of Congo-Brazzaville was evaluated for drinking water. Eleven piezometers were sampled. The physical parameters (pH), Electric Conductivity (EC), Total Dissolved Solids (TDS) as well as the concentrations in major ions  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{HCO}_3^-$  are within the WHO prescribed limits for drinking water. Two chemical facies are predominant mixed cations  $\text{HCO}_3^-$  (36.36%) and  $\text{Ca-Mg-HCO}_3^-$  (27.27%). Water-rock interaction characterized by the dissolution of carbonates and silicates plays a primordial role in the chemical composition of the groundwater. The Na/K ratio makes it possible to classify the piezometers in three groups which were also revealed by hierarchical cluster analysis. The hydrochemical study of the aquifer AQ-2 showed that the major cations and anions, the pH, electric conductivity, the total dissolved solids, total alkalinity and the total hardness which characterize the chemical composition of the tablecloth are within the limits allowed for the drinking water according to standards WHO.

**Key words:** Hydrochemistry, aquifer, chemical facies, cluster analysis, pH, tablecloth

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### INTRODUCTION

Water quality is of great importance in human life. The aquifers constitute groundwaters tanks of a vital need for the human. Groundwaters are the subject of several studies related to their quality (Aris *et al.*, 2007). In Pointe-Noire, harbour city and economic capital located at the south-west of Congo, the principal source of supply water for human consumption is a tablecloth of deep sands exploited by the National Company of Water Distribution (N.C.W.D).

The demographic growth and the industrial activity make that this water resource is more and more exploited. In order to maintain a long-lasting development, the quality of the water resource must be acceptable. The geochemistry of the coastal aquiferous systems such as the case of Pointe-Noire tablecloth is an effective means which permits to control the salinisation. The objective of this study is to evaluate the hydrochimy of tablecloth AQ-2 of Pointe-Noire and to determine the hydrogeochemical process which controls its composition.

### MATERIALS AND METHODS

**Presentation of area study:** The area of Pointe-Noire which is chosen for this study is located on the Atlantic coast of central Africa at the south-western extremity of Congo-Brazzaville and its geographical co-ordinates lie between the meridian lines  $11^{\circ}30'$  and  $12^{\circ}$  East and parallels  $4^{\circ}30'$  and  $5^{\circ}$  South (Fig. 1). Its surface which is approximately about 15.660 ha spread out within a radius of 15 km.

Presenting a dominating geographical position to which it owes its most characteristic features, the studied area is an ideal zone of the contact ocean-continent where the effects of the marine currents and mass of Atlantic maritime air were announced. Annual precipitations are relatively moderate on average 1200 mm compared to the whole of the country. The average temperatures range between  $22.2$  and  $28^{\circ}\text{C}$  with weak thermal variations. Belonging to the coastal sedimentary basin of cretaceous and tertiary age, the area of Pointe-Noire is covered by formations with ages plio-pleistocenes formations other than the series of circuses

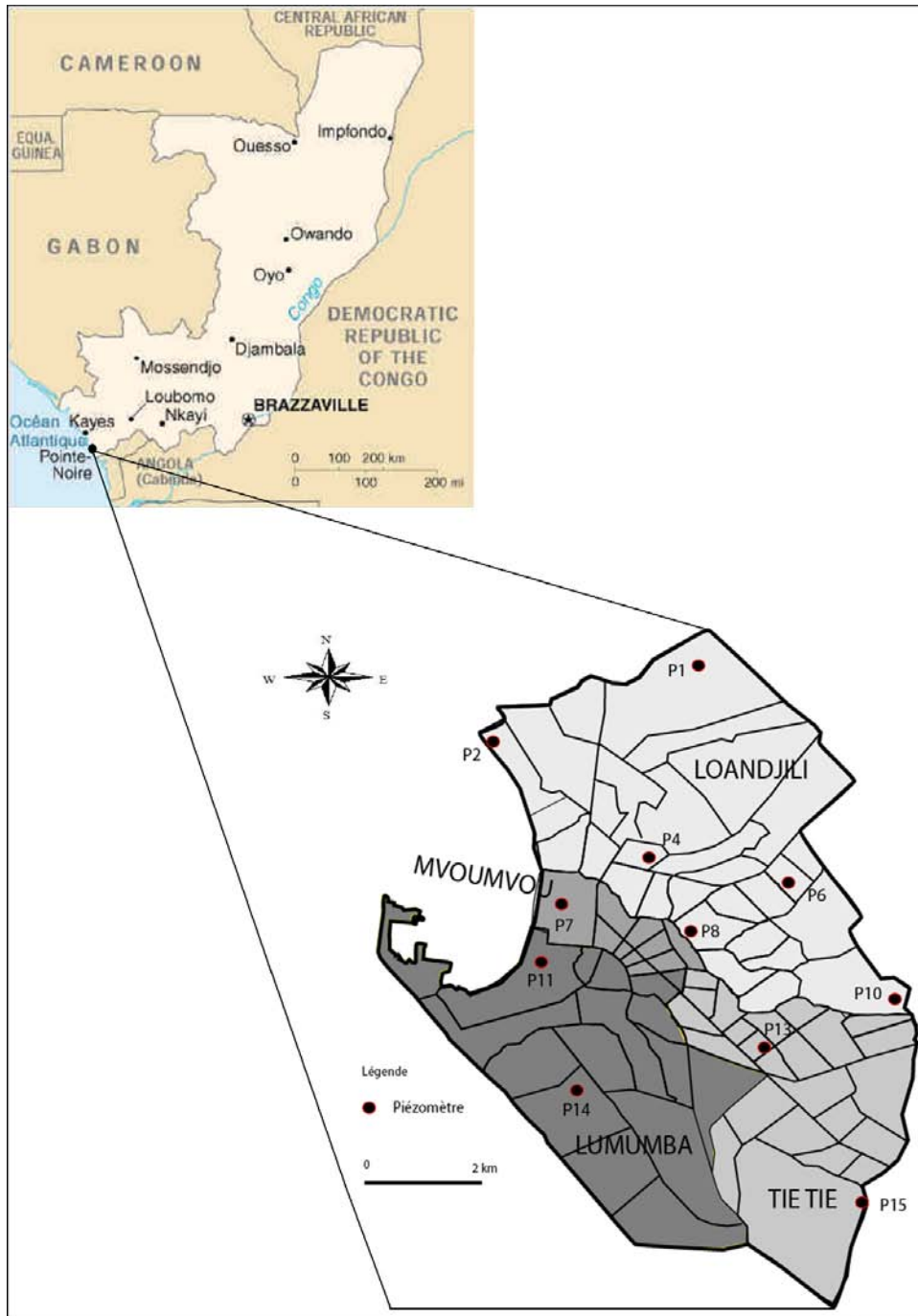


Fig. 1: Localization of the piezometers in the domain study

(Fig. 2) made of very permeable sands including multiple resistant horizons. The classification of FAO arranges the grounds of the region of Pointe-Noire in the Ferralic Arenosols group with a sandy texture (80-90%) on >1 m.

The aquiferous tank of Pointe-Noire is of deep sands type belonging to the category of the permeable layers to

semi permeable which endows it with the potentiality in drinking water provisioning. The present study concerns one of the two higher aquifers, aquifer AQ-2, the most exploited of the region (Fig. 3).

**Experiment:** To characterize the chemical composition of aquifer AQ-2, 11 piezometers of N.C.W.D whose

ETAGES	FORMATIONS	LITHOLOGIE	EPAISSEUR
PLIO-IV	Série des Cirques		
MIOCENE	F. Argilo-Sableuse de Paloukou		~ 800 m
EOCENE PALEOCENE-SENONIEN	Marnes de Madingo Siltis d'Emeraude		~ 600 m
TURONIEN	Dolomies de Loango		~ 100 m
CENOMANIEN	Silto-agileux de Likouala Grès de Tchala		300 à 500 m
ALBIEN	F. des Carbonates de Sendji		100 à 1 300 m
APTIEN	F. Salifère de Loémé		> 1 000 m
	Sables de chéla		15 à 60 m
NEOCOMIEN BARREMIEN	Carbonates de Toca F. Argiles de Pointe-Indienne		> 800 m
	F. Marnes de Pointe-Noire		300 à 700 m
NEOCOMIEN	F. des Grès de Djéno		300 à 1 000 m
	F. Marnes de Sialivakou		130 à 800 m
	F. des Grès de Vandji		50 à 800 m
PRECAMBRIEN	Socle		

Fig. 2: Cross section of the lithostratigraphic column of Pointe-Noire

localization is shown in Fig. 1 were sampled. Sampling was carried out during the dry season (July and August, 2009). The hydrochimie of groundwater was essentially based on the determination of the basic parameters which are pH, temperature, Electric Conductivity (EC), Total Dissolved Solids (TDS), Calcium ( $\text{Ca}^{2+}$ ), Magnesium ( $\text{Mg}^{2+}$ ), Sodium

( $\text{Na}^+$ ), Potassium ( $\text{K}^+$ ), Chloride ( $\text{Cl}^-$ ), Sulphate ( $\text{SO}_4^{-2}$ ), bicarbonate ( $\text{HCO}_3^-$ ), Total Hardness (TH) and Total Alkalinity (TA). The water samples were taken in polyethylene bottles of one liter capacity initially washed with nitric acid 1 M and distilled water. On the site, the bottles were washed three times with water to be analyzed

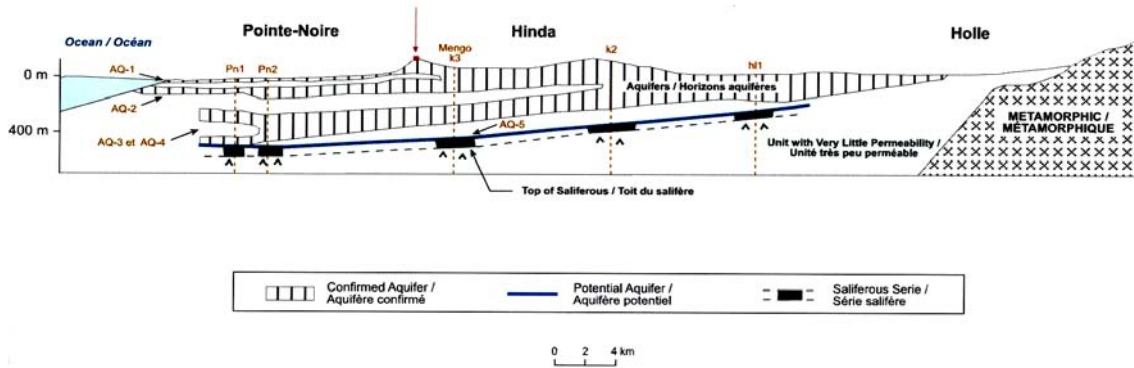


Fig. 3: Vertical cross section of the multi-layer aquiferous system of Pointe-Noire

then transported to the laboratory in a refrigerator at the temperature of 4°C. The measurement of the pH, Electric Conductivity (EC) and the Total Dissolved Solids (TDS) was made on the ground using the multi standard parameter Consort C933. The determination of the concentrations in cations and major anions was made according to the standardized methods (APHA/AWWA, 1995). The statistical data processing was made with the software Statistica 7.1. The distribution of electric conductivity was represented using the software Surfer 8.0.

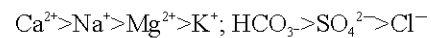
## RESULTS AND DISCUSSION

The chemical composition of the water samples taken on the level of the 11 piezometers and the descriptive statistics of the studied parameters are shown, respectively in Table 1 and 2. The pH of the water samples varies between 5.9 and 7.2 with an average of 6.73. The values of pH of the samples collected in the piezometers P4 (LOANDJILI) and P15 (MPAKA) are <6.5 which is the WHO lower limiting value (WHO, 2004) for the drinking water. Concerning the water samples from the other piezometers, the value of the pH is within the acceptable limits for the drinking water (6.5-8.5). Electric conductivity varies between 27 and 685  $\mu\text{S cm}^{-2}$  with an average of 225.75  $\mu\text{S cm}^{-2}$ . The water samples of the piezometers P15 and P11, respectively have the lowest and highest electric conductivity. Figure 4 shows the distribution of electric conductivity in the zone of study. One observes an increase of the latter from the south-east to the west of the zone of study which is closer to the sea. The total dissolved solids present values varying between 41.16 and 229.1  $\text{mg L}^{-1}$ . The average value of the total dissolved solids is 104.84  $\text{mg L}^{-1}$ . The TDS values are within the acceptable limits of WHO for drinking water because they

are <500  $\text{mg L}^{-1}$  (WHO, 2004). Low values of electric conductivity and the total dissolved solids are explained by the nature of the aquifer which is sandy.

Concentrations in major cations  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$  vary, respectively between 4.67-49, 0.7-60.48, 0.94-135.9, 2.2-7.1  $\text{mg L}^{-1}$ . The average values in major cations are respectively 25.08, 16.76, 43.64 and 4.03  $\text{mg L}^{-1}$ . As for the major anions ( $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{HCO}_3^-$ ), their concentrations vary, respectively between 0.8-7.3, 2.47-18, 15.13-61  $\text{mg L}^{-1}$  with a respective average value of 3.2, 14.31 and 35.64  $\text{mg L}^{-1}$ . The concentrations in major cations and anions are all within the acceptable limits for the drinking water (WHO, 2004).

The composition relating to a cation or anion was expressed as a percentage of  $\text{meq L}^{-1}$  of the total of the cations or the anions (Fig. 5). The order of prevalence of the cations and anions expressed as a percentage of  $\text{meq L}^{-1}$  based on the average calculated with the whole of the wells is respectively:



From Fig. 5 one notices also an excess of the cations  $\text{Ca}^{2+} + \text{Mg}^{2+}$  compared to the cations  $\text{Na}^+ + \text{K}^+$ . The Total Alkalinity (TA) due primarily to the ions bicarbonates ( $\text{HCO}_3^-$ ) varies between 12.4 and 50  $\text{mg L}^{-1} \text{CaCO}_3$ . As for Total Hardness (TH) due to the ions  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  it varies between 14.54 and 371.41  $\text{mg L}^{-1} \text{CaCO}_3$  with an average value of 131.64  $\text{mg L}^{-1} \text{CaCO}_3$ . The low values of Total Hardness (TH) as those of the total dissolved solids make it possible to classify water of aquifer AQ-2 as being soft (Ravindra and Gark, 2007).

The geochemical evolution of groundwater being studied can be understood by plotting the diagram of Piper (Fig. 6). In the diagram of the cations one observes piezometers in the medium of the triangle not presenting

Table 1: Chemical composition of water samples in Pointe-Noire

Code	Locate	pH	CE	TDS	T	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	HCO <sub>3</sub> <sup>-</sup>	TA	TH
P1	TCHIALI	6.8	69.6	41.16	26.0	6.00	3.60	0.94	2.20	2.5	8.00	28.06	23.00	29.81
P2	CORAF	6.7	68.4	43.12	26.2	6.20	3.48	1.45	2.41	1.9	8.61	30.02	24.61	29.81
P4	LOANDJILI	5.9	35.8	54.38	26.9	4.67	0.70	12.27	2.90	3.9	12.00	32.94	27.00	14.54
P6	NKOUKOU	6.6	29.3	47.13	26.6	19.40	0.96	16.06	5.00	1.2	9.52	15.13	12.40	52.40
P7	ORSTOM	7.0	621.0	126.50	26.3	35.60	16.31	38.16	3.02	3.9	32.00	47.64	39.05	156.06
P8	MATENDE	6.6	29.7	53.21	26.0	11.90	0.96	2.67	3.60	1.7	6.87	28.06	23.00	33.67
P10	VOUNGOU	7.2	30.2	229.10	26.8	49.00	60.48	159.00	7.10	1.4	16.90	22.31	18.29	371.41
P11	CERCLE	7.2	685.0	140.00	26.8	38.00	17.00	35.52	3.70	4.9	35.00	61.00	50.00	164.89
P13	MBOUKOU	6.6	280.2	49.10	26.8	20.08	0.89	12.73	2.70	0.8	2.47	31.72	26.00	53.80
P14	BRASCO	7.0	607.0	140.80	26.8	43.00	20.00	65.34	6.10	7.3	8.00	46.36	38.00	189.73
P15	MPAKA	6.4	27.0	228.90	26.0	42.00	60.00	135.90	5.60	5.7	18.00	48.80	40.00	351.95
	WHO guides value	6.5-8.5	300.0	500.00	25.0	75.00	30.00	200.00	-	250.0	150.00	300.00	-	300.00

Excepted pH, EC ( $\mu\text{S cm}^{-1}$ ), T ( $^{\circ}\text{C}$ ), TA ( $\text{mg L}^{-1} \text{CaCO}_3$ ) and TH ( $\text{mg L}^{-1} \text{CaCO}_3$ ), all other parameters are expressed in  $\text{mg L}^{-1}$

Table 2: Descriptive statistics of the parameters

Parameters	Minimum	Maximum	Average	SD	Variance
pH	5.90	7.20	6.73	0.38	0.14
CE	27.00	685.00	225.75	274.85	75544.19
TDS	41.16	229.05	104.84	73.02	5332.09
T	26.00	26.90	26.47	0.37	0.14
Ca <sup>2+</sup>	4.67	49.00	25.08	16.81	282.52
Mg <sup>2+</sup>	0.70	60.48	16.76	22.69	515.05
Na <sup>+</sup>	0.94	159.03	43.64	55.11	3037.19
K <sup>+</sup>	2.20	7.10	4.03	1.66	2.74
Cl <sup>-</sup>	0.80	7.30	3.20	2.11	4.44
SO <sub>4</sub> <sup>2-</sup>	2.47	35.00	14.31	10.48	109.73
HCO <sub>3</sub> <sup>-</sup>	15.13	61.00	35.64	13.57	184.27
TA	12.40	50.00	29.21	11.13	123.80
TH	14.54	371.41	131.64	129.42	16749.14

predominance (P1, P2, P7, P10, P11, P14 and P15). On the other hand the piezometer P4 presents a predominance in Na<sup>+</sup>, the piezometers P6, P8 and P13 present a predominance in Ca<sup>2+</sup>. In the diagram of the anions, all the piezometers are close to the bicarbonated pole except P10 which does not present predominance. The analyzed water samples set out again in the zones of following chemical facies: mix cations HCO<sub>3</sub> (Ca-Na-HCO<sub>3</sub>, Na-Ca-HCO<sub>3</sub>, Na-Mg-HCO<sub>3</sub>) accounting for 36.37% of the total of the piezometers, Ca-HCO<sub>3</sub> (27.27%), Ca-Mg-HCO<sub>3</sub> (18.18%), Na-HCO<sub>3</sub> and Na-Mg-HCO<sub>3</sub>-SO<sub>4</sub> representing each one 9.09% of the piezometers (Table 3). The meteoric influence of water S is clear in the studied tablecloth.

The hydrochimy of the tablecloth was also characterized by various ionic ratios (Table 3). The Ca/Mg ratio is characteristic of course of subsoil waters, variable between 0.42 and 13.54. The strongest values were observed in water of the piezometers P6, P8 and P13. This could be explained by a more significant time of residence on these piezometers.

The Na/Ca ratio varies between 0.14 and 2.82. For values <0.80, sodium impoverishment of groundwater being studied is very characteristic. The Na/K ratio is about 47 for sea water and <10 for rainwater. This report/ratio divides water of the piezometers into three

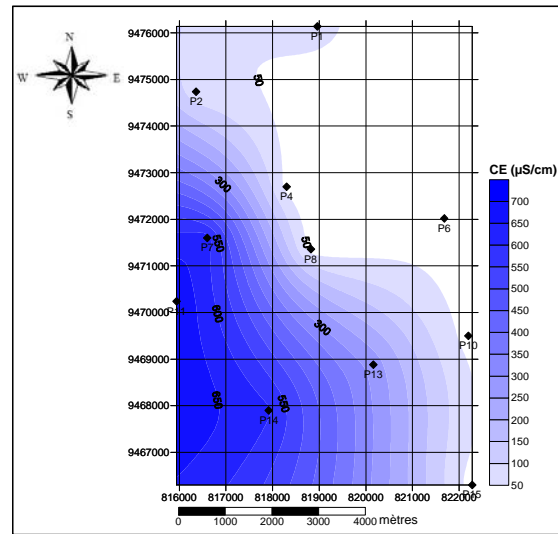


Fig. 4: Distribution of electric conductivity of water samples of the piezometers

groups: the first group is consisted of the piezometers P1, P2, P4, P6, P8 and P13 with a Na/K ratio <10 which shows the influence of rainwater. The water samples taken in these piezometers have the low values of the Total Alkalinity (TA) and of Total Hardness (TH); the second group is formed by the piezometers P7, P11 and P14 whose Na/K ratio in the water samples is slightly higher than that of rainwater.

The values of TA and TH are higher than those of the first group and lower than those of the third group; the third group gathers the piezometers P10 and P15 to which the Na/K ratio is lower or close with that to sea water. The values of TA and TH are highest in the zone of study. The Na/(Na+Cl) ratio is >1 in all the analyzed water samples. The values higher than 0.5 of this ratio represent the process of ionic exchange between Ca<sup>2+</sup> and Na<sup>+</sup> on

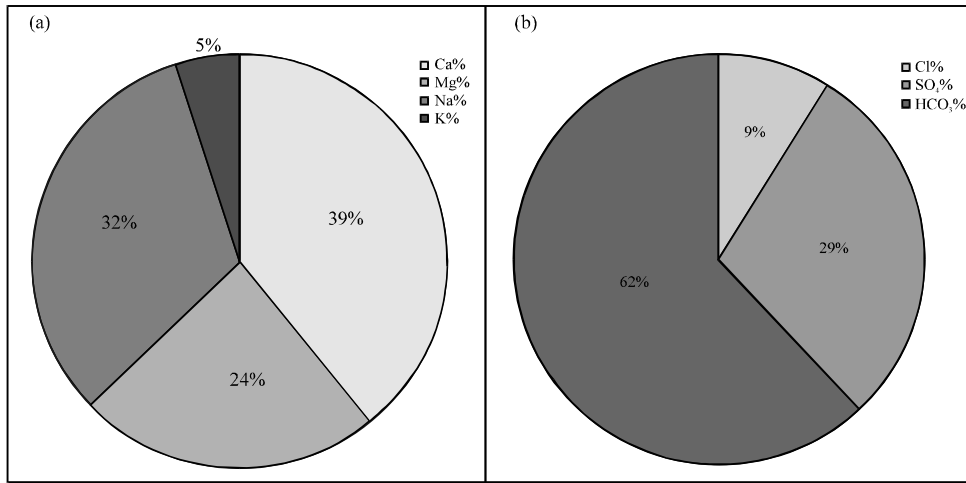


Fig. 5: Average composition in % meq L<sup>-1</sup> of the major cations (a) and major anions (b) of water in zone of study

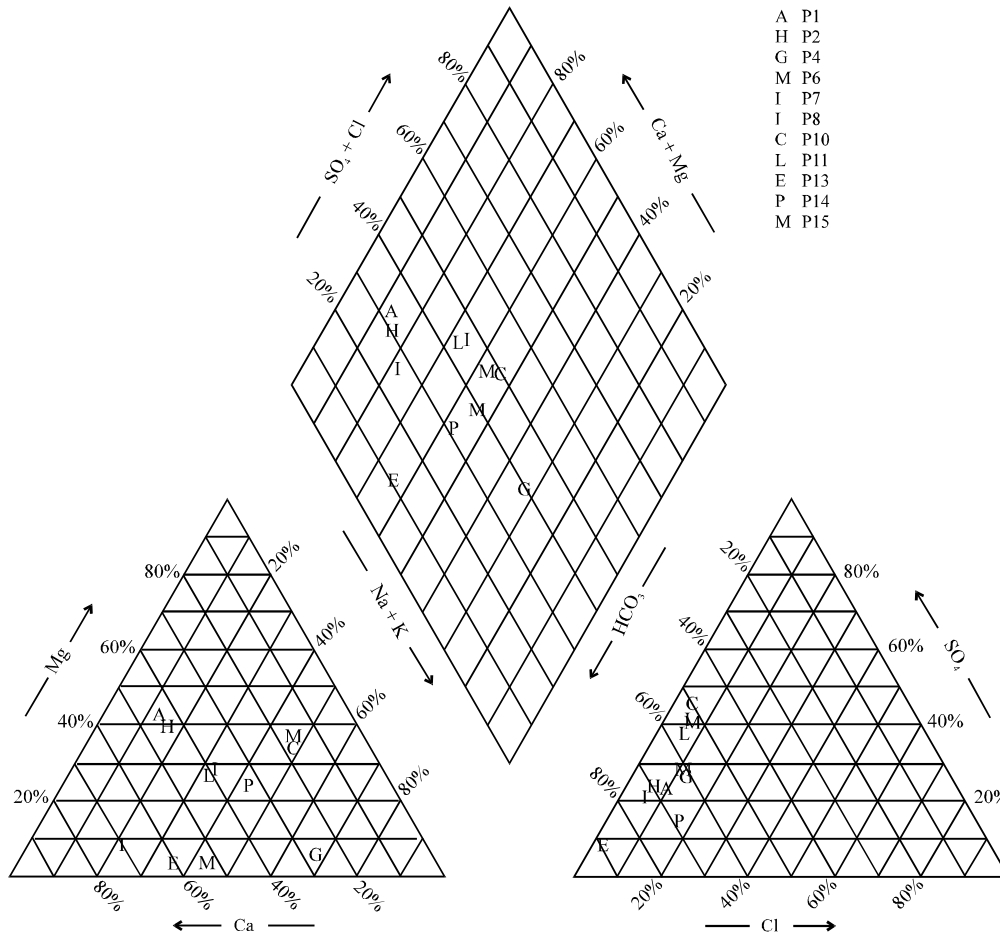


Fig. 6: Piper diagram of the water samples in zone study

the one hand and on the other hand between  $Mg^{2+}$  and  $Na^+$ . These cation exchanges are supported by the presence of argillaceous minerals (Subba *et al.*, 2006).

The major ions could come mainly from the water and carbonated minerals interaction and/or the water and silicated minerals interaction. The Na/Cl ratio lies between

Table 3: Ionic ratios and chemical facies of the water samples

Code	Locate	Ca/Mg	Na/Ca	Na/K	Na/Na+Cl	Na/Cl	Chemical facies
P1	TCHIALI	1.00	0.14	0.72	1.07	0.58	Ca-Mg-HCO <sub>3</sub>
P2	CORAF	1.07	0.20	1.02	1.05	1.18	Ca-Mg-HCO <sub>3</sub>
P4	LOANDJILI	4.00	2.28	7.17	1.11	4.86	Na-HCO <sub>3</sub>
P6	NKOUIKOU	12.13	0.72	5.45	1.03	20.66	Ca-HCO <sub>3</sub>
P7	ORSTOM	1.31	0.93	21.43	1.11	15.10	Ca-Na-HCO <sub>3</sub>
P8	MATENDE	7.44	0.20	1.26	1.05	2.42	Ca-HCO <sub>3</sub>
P10	YOUNGOU	0.49	2.82	37.98	1.04	175.33	Na-Mg-HCO <sub>3</sub> -SO <sub>4</sub>
P11	CERCLE	1.34	0.81	16.28	1.14	11.19	Ca-Na-HCO <sub>3</sub>
P13	MBOUKOU	13.54	0.55	7.99	1.02	24.56	Ca-HCO <sub>3</sub>
P14	BRASCO	1.29	1.32	18.16	1.21	13.82	Na-Ca-HCO <sub>3</sub>
P15	MPAKA	0.42	2.81	41.14	1.16	36.79	Na-Mg-HCO <sub>3</sub>

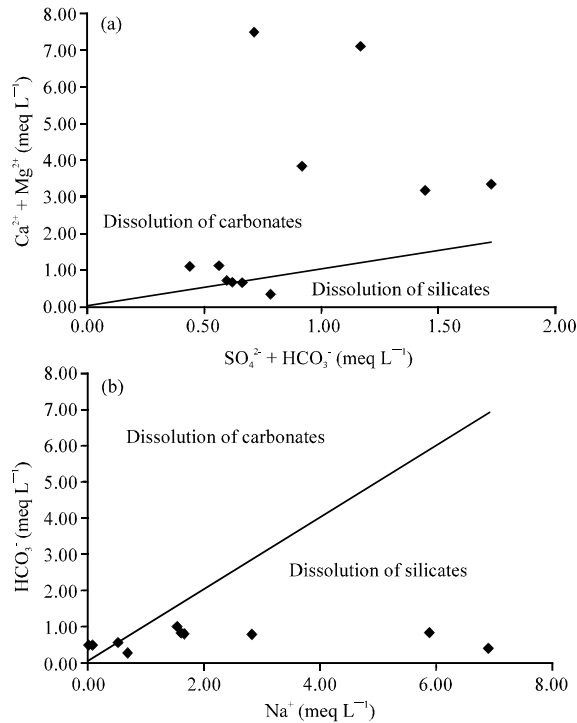


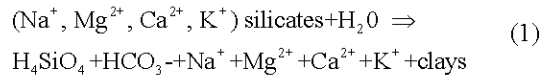
Fig. 7 a, b: Relation between Ca<sup>2+</sup> + Mg<sup>2+</sup> and SO<sub>4</sub><sup>2-</sup> + HCO<sub>3</sub><sup>-</sup>; HCO<sub>3</sub><sup>-</sup> and Na<sup>+</sup>

0.58 and 175.33. If sodium would come from the dissolution of halite, this ratio should be Equal to 1. However, it is >1 in 90.90% of the water samples which indicates that the principal source of sodium is the dissolution of the silicates (Meyback, 1987).

Bicarbonate ion HCO<sub>3</sub><sup>-</sup> is the major anion which prevails in this water. The presence of carbonated minerals in the zone of recharge and the chemical dissolution of silicates are the principal factors which support the increase in the concentration in bicarbonated ion in groundwaters (Elango *et al.*, 2003). Hydrochemical processes which control the chemical composition of the tablecloth namely dissolution of carbonates and silicates, ionic exchanges processes between cations were

evaluated starting from the relations between major cations and anions (Datta and Tyagi, 1996; Giridharan *et al.*, 2008; Jalali, 2007). These relations are illustrated on graphs whose straight line 1:1 makes it possible to delimit the dissolution field of carbonates from that silicates (Fig. 7 a, b).

The Fig. 7a shows that the majority of the water samples is above the straight line 1:1, this indicates that the dissolution of carbonates is the dominating process which provides the ions calcium and magnesium in the tablecloth. In addition to the dissolution of carbonates, the dissolution of silicates represented by the chemical Eq. 1 also contributes to increase the concentration in Ca<sup>2+</sup> and Mg<sup>2+</sup>:



The Fig. 7b shows that the dissolution of silicates is the process which controls the chemical composition of the tablecloth compared to sodium. The relation between (Na<sup>+</sup>+K<sup>+</sup>) and (Cl<sup>-</sup>+SO<sub>4</sub><sup>2-</sup>) (Fig. 8a) shows that Na<sup>+</sup> and K<sup>+</sup> present in the tablecloth neither come from salts such as the halite or sulphate of sodium, nor from potassium chloride or sulphate of potassium. This is also confirmed by the Fig. 8b which shows the regrouping of the piezometers.

The presence of carbonates, sandstones, dolomites, marls announced in the lithography-stratigraphy of Pointe-Noire (Fig. 2) suggests that the dissolution of these minerals contributes to a significant degree to the increase of the concentration in ions Ca<sup>2+</sup>, Mg<sup>2+</sup> and Na<sup>+</sup>.

The statistical data processing by ascending hierarchical clustering also made it possible to gather the piezometers in three classes. These classes are not other than the three regroupings obtained starting from the ionic ratio Na/K in the water samples (Fig. 9).

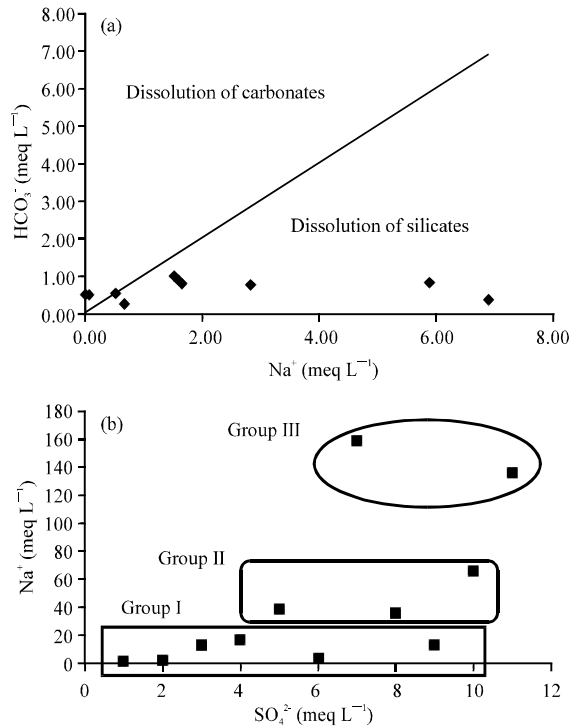


Fig. 8a, b: Relation between  $\text{Na}^+\text{K}^+$  and  $\text{Cl}^- + \text{SO}_4^{2-}$ ; Relation between  $\text{Na}^+$  and  $\text{SO}_4^{2-}$

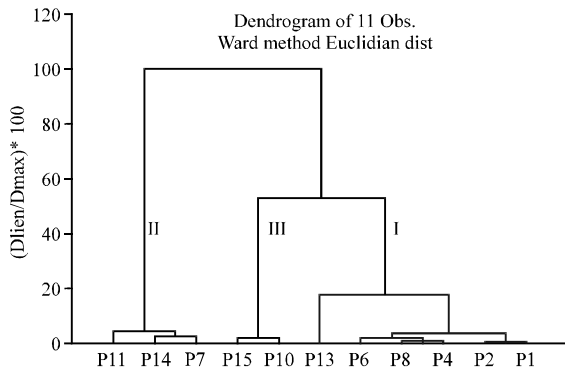


Fig. 9: Dendrogram of piezometers in study zone

**CONCLUSION**

The hydrochemical study of the aquifer AQ-2 whose aquifer is used by the national company of water distribution at Pointe-Noire in the south of Congo showed that the major cations and anions, the pH, electric conductivity, the total dissolved solids, total alkalinity and the total hardness which characterize the chemical composition of the tablecloth are within the limits allowed for the drinking water according to standards WHO. The hydrochemistry of the tablecloth in this aquifer varies in

relation to the various interactions water-rock. Do the hydrochemical characteristics of aquifer show a prevalence of the cations ( $\text{Ca}^{2+} + \text{Mg}^{2+}$ ) on ( $\text{Na}^+ + \text{K}^+$ ), of the ions bicarbonates  $\text{HCO}_3^-$  on the ions sulphates  $\text{SO}_4^{2-}$  and chlorides  $\text{Cl}^-$ . The ions bicarbonates come mainly from the dissolution of carbonated and silicated minerals.

While being based on the major components water of the tablecloth being studied corresponds to the chemical facies mixes cations- $\text{HCO}_3^-$  and  $\text{Ca-HCO}_3^-$  which account for 64% of the piezometers. The values of electric conductivity are relatively high in the south-west of zone study which lets suppose a probable influence of sea water on the chemical composition of water in this part of study zone.

The ratio  $\text{Na}^+/\text{K}^+$  allows a regrouping of the piezometers sampled in three groups which are confirmed by a statistical analysis of ascending hierarchical classification.

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