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RESEARCH ARTICLE

Application of the Multivariate Statistical Analysis for Hydrogeochemical Assessment of Groundwater of Coastal Aquifer AQ1 of Pointe-Noire, Congo

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Abstract: The physicochemical quality of groundwater of one of the five aquifers of the coastal region of Pointe-Noire, aquifer AQ1 is the subject of this study. Water of 18 wells was taken during the year 2014. 13 variables were given in the water samples: pH, C.E, T, Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-, TDS and TH. The pH lies between 4.26 and 7.10. 88.88% of the wells have pH lower to 6.5, which show the acid character. 83.33% of analysed water are fairly mineral-bearing (C.E < 300 µS cm^{-1}). On the other hand 16.67% of these water wells (PU1, PU4 and PU17) present an accentuated mineralization. The multivariate statistical methods have been used in this study. Ascending hierarchical classification gave two groups of water well. Except for the temperature and pH, the other variables discriminate the two groups. The factorial analysis highlighted two factors which account for 80.61% of the total variance. The first factor (62.87%) shows the mineralization and the hardness water. The second factor (17.74%) highlights the dissolution of carbonated minerals of magnesium and the character slightly acid of water.

Keywords: Groundwater, Multivariate statistical analysis, Pointe-Noire Congo

Introduction

In the African countries, the access to the drinkable water resources is an economic problem and of major public health. Many areas of the continent exploit the underground sheets of water to satisfy the daily of the households, the industrial and agricultural needs.

In the particular case of Congo, the zone of the littoral of Pointe-Noire has two groundwater, one superficial and the other deep one confined. The problems arising from the exploitation of ancoastal aquifer are generally delicate for they associate the concept of quantity with that of quality. The intensive use of the natural resources and the increase in human activities generated serious problems on water quality groundwater[1,2].

However this quality can be faded when external substances come into contact with the aquifer. Such is the case of the even toxic undesirable substances which make subterranean water unsuitable for various uses in particular for the water use of drink.

The groundwater has physicochemical characteristics which are particular for it, such as the temperature, the color, the pH, conductivity and the content of major elements. These characteristics resulting from the natural environment are very variable. They depend on the geological nature of the ground from where they come and also of the reactive substances which they could have met during the flow. Thus the quantitative and qualitative composition of subterranean water out of suspended matter and dissolved, of mineral or organic nature, determines its quality[3].

Experimental

Presentation of the zone of study

The zone of study is the coastal sedimentary basin of Pointe-Noire, Congo located between the parallels 4° and Southern 5° and between the meridian lines 11° and 12° East, at the South-western end limited by the Atlantic Ocean (Figure 1). Its hydrogeology is structured in five aquifers[4] (Figure 2):

- Aquifer not very deep AQ-1 (not confined), contains an unconfined water, corresponding to the medium saturated with the most permeable layers and more draining sands of surface.
- Aquifer deep AQ-2 (confined) contains an Artesian deep confined water in certain places, corresponding to the most permeable layers of the series of the circuses (quaternary). It consists of sometimes silteux heterogeneous sands alternating with the levels mudstones.
- Aquifer deep AQ-3 (confined), contains a confined water corresponding to the most permeable layers of ferruginous sands, consisted of sometimes conglomeratic heterogeneous sands alternating with ferruginous concretions.
- Aquifer deep AQ-4 (confined) contains also a confined water, resting on a substratum not very permeable and limited by a not very permeable superstratum also, corresponding to the least permeable layers of the greso-dolomitic series of the cretaceous (secondary), consists of clayey sands and dolomitic aggregates.
- The aquifer potential AQ-5, is a confined water known as potential corresponding to the unit of the dolomite and the calcite of the calcaro-dolomitic series in which losses of circulation were observed in certain mining structural test drillings.

The present study relates to aquifer AQ1.

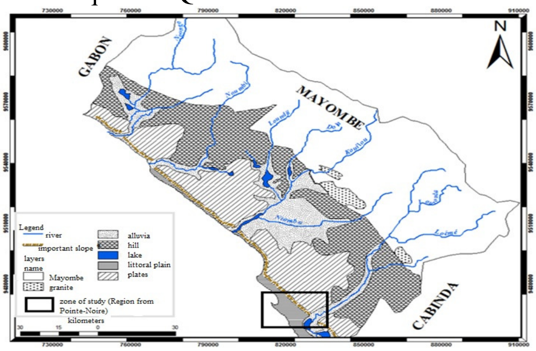

Figure 1. Geographical location of the coastal sedimentary basin[5]

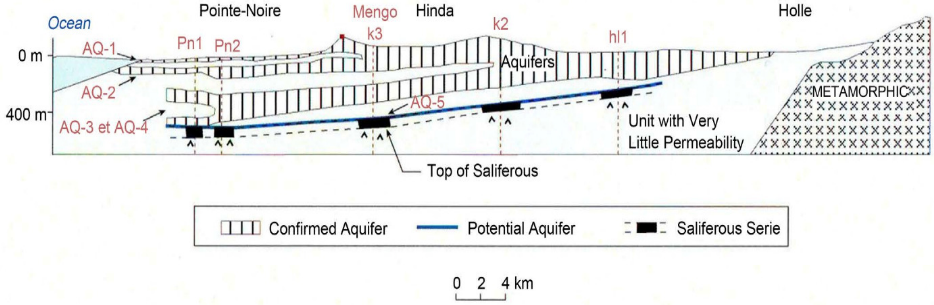

Figure 2. Coastal sedimentary aquiferous system[6]

The physicochemical analyses have been carried out on water of deprived wells of public use collecting the ground water of the complex hydrogeological of the area of Pointe-Noire, Congo. The taking away are carried out and conditioned in polyethylene bottles of 1 L. These bottles were cleaned with the nitric acid then to rinse with distilled water several times. On the ground the bottles were also rinsed with water to take. These taking away are carried out using an especially designed sampler. The device of sampling is carefully washed with the water distilled before each taking away. The near total of the water points of the aquifers is intended for the drinking water supply. To be used, water must meet certain standards which vary according to the type of use. The water samples intended for the chemical analyses were taken in eighteen (18) wells of the urban area of Pointe-Noire (Figure 2). These samples were taken from January in December 2014. The samples of the rain season take into account the following months: November in April 2014. The month of May 2014 is regarded as a transition between the rain season and the dry season[7].

The samples of the rainy season taken into account the following months: June in September 2014. For each analysis, physical parameters with knowing the pH, the temperature and electric conductivity are measured in situ using a pH-meter and of a conductometer of mark WTW 330. The water samples were immediately stored with 4 °C in a refrigerator containing of the ice, the analysis was carried out quickly with less of 24:00 after the taking away. The major elements calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), chloride (Cl^{-}), bicarbonate (HCO_3^{-}), sulphates (SO_4^{2-}) and total hardness were analysed in the laboratories of civil engineering of the Higher National Polytechnic School (ENSP), the Research institute in exact sciences and natural (IRSEN) and of the national company of water supply (SNDE). These analyses were carried out using a spectrophotometer by using the standardized traditional methods.

Results and Discussion

Physicochemical analyses

Tables 1 and 2 have the results of the physicochemical analysis of the samples in rainy season and dry season.

The temperature of water is an important climatic parameter which influences on many of other parameters. The temperature varies from 26.1 °C with 29.9 °C in rainy season with an average of 28.03 °C±0.94 °C and 26.12 °C with 28.63 °C in dry season with an average of 27.57 °C. The pH characterizes the concentration of a water or an aqueous solution in ions hydronium (H^{+}). The values of the pH of subterranean water vary from 4.10 and 7.10 in rainy season with an average of 5.92±0.58 and 5.06 to 7.00 in dry season with an average of 6.13, electric conductivity is the physical parameter which characterizes the conduction of the electric current by water. It varies in the sector between 20.5 µS cm^{-1} and 936.4 µS cm^{-1} in rain season des with an average 267.28±248.26 µS cm^{-1} and of 17.00 µS cm^{-1} to 697.00 µS cm^{-1} in dry season with an average of 176.94 µS cm^{-1}.

Table 1. Physicochemical composition of the water samples of well in rain season

Wells	T	pH	C.E	TDS	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	TH
PU1	28.1	6.3	936.4	697.2	28.4	7.6	161.5	7.8	18.8	90.2	80.4	302.4	10.3
PU2	28.6	5.3	363.3	111.2	4.7	2.9	20.6	2.2	43.9	12.4	0.3	23.9	2.7
PU3	27.7	4.9	550.8	268.7	10.9	4.3	54.6	14.3	12.2	46.7	36	88.9	4.7
PU4	28.1	6.1	542	396.8	16.6	2.5	99.7	7.6	14.5	77.6	41.2	137.4	5
PU5	27.1	5.8	255.8	193	3.2	3	50.1	3.5	9.7	34.4	2.1	87.1	2
PU6	26.8	5.7	481.9	192.8	7	4.3	39	2.5	45.8	27.3	1.6	65.3	3.7
PU7	28.5	6.1	115.2	96.5	3.3	0.2	24.2	2.2	6.1	19.1	0.3	40.9	1
PU8	29.5	5.4	72	42.7	1.8	1.1	11.4	0.5	6.3	17.4	0.5	3.6	1
PU9	28.4	6.3	30.2	74.3	0.8	3	14.7	1.1	48.6	4.2	0.5	1.4	1.2
PU10	29.3	6.3	69.8	70.2	5.6	4	5.8	1.8	46	2.3	0.8	3.7	3.2
PU11	28.3	5	92.1	79.2	3.4	1.4	14.8	3.4	43.7	10.7	0.5	1.3	1.3
PU12	28.6	6	261.9	196	4.8	2	46.4	4.3	6.1	26.2	2.2	103.9	2
PU13	27.7	6.6	86.7	59	6.5	3.4	4.5	0.4	36.5	7.2	0.5	0.1	3
PU14	27.7	6.1	28.9	18.8	1.5	0.6	3.3	0.2	6.5	3.7	2.6	0.4	1
PU15	26.1	7.1	132.2	99.5	9.8	7.2	4.8	0.7	66.6	5.2	5.1	0.1	5
PU16	26.5	5.9	335.7	246.5	12.1	0.1	60.2	2.7	6.1	44.8	8.4	112.1	3
PU17	28.5	6.1	435.6	330	21.1	3.1	67.3	4.5	24.4	35.5	38.6	135.8	6.5
PU18	29.1	5.6	20.5	17.7	1.2	0.4	3.2	0.3	6.8	3.3	1.8	0.5	0.5
Minimum	26.1	4.9	20.5	17.7	0.8	0.1	3.2	0.2	6.1	2.3	0.3	0.1	0.5
Maximum	29.5	7.1	936.4	697.2	28.4	7.6	161.5	14.3	66.6	90.2	80.4	302.4	10.3
Mean	28.03	5.92	267.28	177.23	7.93	2.84	38.12	3.33	24.92	26.01	12.41	61.60	3.17
Sd	0.94	0.55	248.26	169.28	7.54	2.16	41.20	3.55	19.77	25.56	22.09	78.91	2.46
WHO limits	25	6.5-8.5	300	500	75	30	200		300	250	150	10	300

Except pH, C.E (µS cm^{-1}), T (°C) and TH (mg$L^{-1}$$CaCO_3$), all the other parameters are expressed in mg/L

The nitrate concentrations in analysed water vary from 0.10 to 302.4 mg/L in rainy season with an average of 61.60 ±79.37 mg/L and 0.10 to 302.21 mg/L in dry season with an average of 61.8 mg/L.

The total hardness of the water attached mainly to the quantity of calcium varies from 0 °F with 10.3°F in rain season with an average of 3.17°F and 0°F with 10°F in dry season with an average of 3.44°F.

We notice that within sight of the values of the concentrations of these two tables that there is no significant evolution of the parameters during the two seasons. Table 2 presents the average variation of these parameters in dry season.

Figures 3 to 6 present the distribution of some parameters during the two seasons. For nitrates on Figure 2, only wells PU1, PU16 and PU17 show a high rate of concentration. 55.56% of these wells have a concentration which exceeds standard WHO of 10 mg/L. We also notice that there is no manifest seasonal evolution.

Table 2. Physicochemical composition of the water samples of well in dry season

Wells	T	pH	C.E	TDS	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	TH
PU1	28.31	6.60	936.75	697.00	28.28	7.03	161.57	7.78	18.34	90.47	80.93	302.21	10
PU2	28.60	5.63	415.16	108.00	4.20	2.80	21.28	2.10	39.55	13.01	0.50	24.42	6
PU3	26.57	5.06	554.10	289.00	14.85	4.75	54.65	13.58	14.40	48.28	39.30	98.63	6
PU4	27.05	6.53	542.08	406.00	17.33	2.91	100.44	7.35	19.08	78.68	41.30	139.03	6
PU5	28.20	6.65	258.40	213.00	3.60	3.38	53.30	3.53	22.75	36.76	2.15	87.40	2
PU6	26.80	6.38	486.68	201.00	8.69	4.65	40.85	3.65	44.18	30.18	1.84	66.63	4
PU7	27.55	6.35	119.95	90.00	2.19	0.68	23.65	2.55	6.88	20.50	0.78	32.58	1
PU8	28.05	5.48	74.55	46.00	1.18	1.13	11.90	0.73	7.78	18.18	0.86	3.83	1
PU9	26.84	6.28	34.80	23.00	1.28	1.05	4.04	0.65	7.40	6.34	1.73	0.35	1
PU10	27.51	6.36	72.23	70.00	5.34	3.58	6.54	1.73	46.05	1.74	0.89	3.83	3
PU11	27.87	5.88	95.83	75.00	2.10	1.18	15.60	3.75	38.00	11.48	0.98	1.55	1
PU12	28.63	6.10	264.18	196.00	4.80	2.00	46.40	4.30	6.05	26.20	2.20	103.90	2
PU13	27.71	6.60	89.23	59.00	6.50	3.40	4.50	0.40	36.30	7.20	0.50	0.10	3
PU14	27.70	6.20	30.00	20.00	1.60	0.60	3.75	0.20	6.33	4.25	2.50	0.90	1
PU15	26.12	7.00	135.23	99.00	9.80	7.20	4.80	0.70	65.60	5.20	5.10	0.10	5
PU16	26.52	5.90	338.25	247.00	12.14	0.10	60.21	2.70	6.06	44.80	8.40	112.11	3
PU17	28.53	6.10	438.78	329.00	21.10	3.10	67.30	4.50	23.20	35.50	38.60	135.80	7
PU18	27.66	5.31	19.73	17.00	0.99	0.34	3.56	0.12	6.25	3.33	2.19	0.13	0
Minimum	26.12	5.06	19.73	17.00	0.99	0.10	3.56	0.12	6.05	1.74	0.50	0.10	0
Maximum	28.63	7.00	936.75	697.00	28.28	7.20	161.57	13.58	65.60	90.47	80.93	302.21	10
Mean	27.57	6.13	272.55	176.94	8.11	2.77	38.02	3.35	23.01	26.78	12.82	61.86	3.44
Sd	0.77	0.51	249.36	173.36	7.83	2.14	41.66	3.42	17.90	25.68	22.31	79.37	2.71
WHO limits	25	6.5-8.5	300	500	75	30	200		300	250	150	10	300

Except pH, C.E (µS cm^{-1}), T (°C) and TH (mgL^{-1}$CaCO_3$), all the other parameters are expressed in mg/L

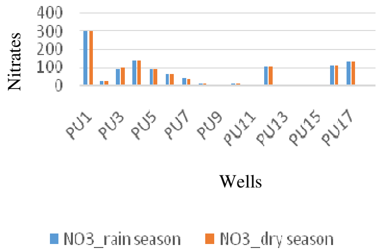

Figure 3. Distribution of the concentration of the ions nitrates

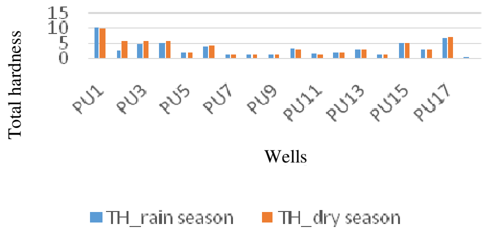

Figure 4. Distribution of total hardness

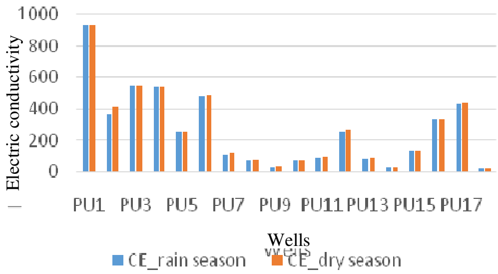

Figure 5. Distribution of electric conductivity

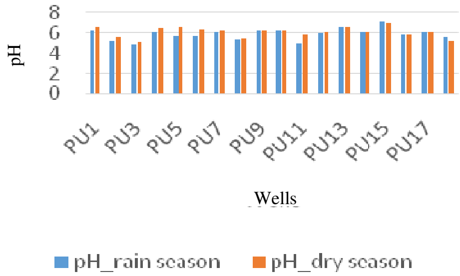

Figure 6. Distribution of the pH

Table 3. presents the monthly median values (January in December 2014)

Wells	T	pH	C.E	TDS	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3	Cl^{-}	SO_4^{2-}	NO_3^{-}	TH
PU1	28.2	6.4	936.5	697	28.4	7.4	161.5	7.8	18.4	90.3	80.5	302.4	11
PU2	28.6	5.4	388.8	109	4.5	2.8	20.8	2.2	41.7	12.7	0.4	24.1	2
PU3	27.3	5	551.9	276	12.4	4.5	54.6	14.1	14.6	47.2	37.1	91.5	5
PU4	27.7	6.3	542	400	16.9	2.6	100	7.5	16.3	78	41.3	137.9	5
PU5	27.6	6.1	256.5	201	3.4	3.1	51.2	3.5	15.5	35.1	2.1	87.1	2
PU6	26.9	5.9	483.5	195	7.8	4.4	39.6	2.9	44.2	28.3	1.7	65.8	4
PU7	28.2	6.2	116.9	96	3.2	0.4	24.2	2.3	6.3	19.7	0.4	39.2	1
PU8	29	5.5	72.9	44	1.6	1.1	11.6	0.6	7.2	17.7	0.6	3.7	1
PU9	27.9	6.4	31.8	53	1	2.2	10.2	1	32	4.9	1	1	1
PU10	28.7	6.3	70.5	70	5.5	3.7	6.1	1.8	46.2	2	0.8	3.8	3
PU11	28.1	5.3	93.6	78	3	1.3	15.1	3.5	41.7	11	0.6	1.4	1
PU12	28.6	6	262.7	196	4.8	2	46.4	4.3	5.9	26.2	2.2	103.9	2
PU13	27.7	6.6	87.6	59	6.5	3.4	4.5	0.4	36.4	7.2	0.5	0.1	3
PU14	27.7	6.1	29.2	19	1.5	0.6	3.4	0.2	6.5	3.7	2.5	0.6	1
PU15	26.1	7	133.3	99	9.8	7.2	4.8	0.7	66.1	5.2	5.1	0.1	5
PU16	26.5	5.9	336.6	246	12.1	0.1	60.2	2.7	5.8	44.8	8.4	112.1	3
PU17	28.5	6.1	436.7	330	21.1	3.1	67.3	4.5	23.7	35.5	38.6	135.8	7
PU18	28.6	5.5	20.3	17	1.1	0.4	3.3	0.2	6.6	3.2	2	0.3	0
Minimum	26.1	5	20.3	17	1	0.1	3.3	0.2	5.8	2	0.4	0.1	0
Maximum	28.6	6.4	936.5	697	28.4	7.4	161.5	7.8	18.4	90.3	80.5	302.4	11
Mean	27.88	6.00	269.52	176.94	8.03	2.79	38.04	3.34	24.17	26.26	12.54	61.71	3.17
Sd	0.79	0.50	248.77	170.71	7.62	2.13	41.37	3.51	18.20	25.61	22.15	79.02	2.71
WHO limits	25	6.5-8.5	300	500	75	30	200		300	250	150	10	300

Except pH, C.E ($\mu S\ cm^{-1}$), T (°C) and TH ($mgL^{-1}CaCO_3$), all the other parameters are expressed in mg/L

Associations between the monthly median values of the parameters were given starting from a matrix of correlation (Table 4).

Table 4. Correlation matrix of the monthly median values

Parameter	T	pH	C.E	TDS	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	NO_3^{-}	TH
T	1.00												
pH	-0.32	1.00											
C.E	-0.15	-0.06	1.00										
TDS	-0.10	0.12	**0.94**	1.00									
Ca^{2+}	-0.17	0.23	**0.86**	**0.92**	1.00								
Mg^{2+}	-0.33	0.42	**0.56**	**0.53**	**0.59**	1.00							
Na^{+}	-0.06	0.08	**0.92**	**0.99**	**0.87**	0.42	1.00						
K^{+}	-0.11	-0.33	**0.74**	**0.68**	**0.60**	0.36	**0.66**	1.00					
HCO_3^{-}	-0.31	0.35	-0.08	-0.17	0.00	**0.59**	-0.28	-0.20	1.00				
Cl^{-}	-0.13	0.01	**0.90**	**0.95**	**0.82**	0.35	**0.97**	**0.73**	-0.33	1.00			
SO_4^{2-}	-0.01	0.08	**0.86**	**0.93**	**0.92**	**0.53**	**0.90**	**0.71**	-0.17	**0.86**	1.00		
NO_3^{-}	-0.04	0.10	**0.90**	**0.98**	**0.87**	0.42	**0.98**	**0.63**	-0.30	**0.93**	**0.88**	1.00	
TH	-0.21	0.31	**0.85**	**0.89**	**0.96**	**0.77**	**0.81**	**0.57**	0.16	**0.74**	**0.89**	**0.82**	1.00

Significant correlations marked to $p < 0.05$ (N=18 observations)

Correlation matrix

In this hydrochemical study, the relation between the variables or descriptors chemical has been established by calculating the matrix of correlation in order to include/understand association between these variables. As it's shown on Table 4, the variables Ca^{2+}, Na^{+}, Cl^{-} and SO_4^{2-} are very strongly correlated with the TDS (R > 0.9). K^{+} and Mg^{2+} are fairly correlated with the TDS (r=0.68 and 0.53). C.E and TDS are strongly correlated positively, which shows that the dissolved total solids translate electric conductivity correctly. In addition, the chemical variables Na^{+} and K^{+} present a good correlation with Cl^{-} and SO_4^{2-}, which supposes the presence of chlorides and sulphates of these two major cations in the aquifer. The positive correlation between NO_3^{-} and the captions Ca^{2+} (r =0.87), Na^{+} (r=0.98), K^{+} (r=0.63) supposes a contamination of water by organic matter[8]. The null correlation between Ca^{2+} and HCO_3^{-} shows the absence of carbonates in the aquifer.

Multivariate statistical analysis

The multivariate statistical analysis of the data describes the whole of the variables taken overall and to extract the essence of information from it. These statistical analyses are the best and are often the only effective solution to analyse a great mass of information generated starting from the hydrochemical data of the groundwater[9-11]. In order to better interpret the hydrochemical variables of unconfined water AQ1, ascending hierarchical classification (HCA) and the analysis in principal components (ACP) were carried out by using the software of statistical analysis STATISCA 7.1[12].

Ascending hierarchical classification (HCA)

According to Davis[13], ascending hierarchical classification (HCA) is a hierarchical technique of classification of the data which is largely applied in sciences of the Earth and which is often used in the classification of the hydrogeochemical data[9].

The main result of the HCA carried out on the 18 subterranean water samples is the dendrogram (Figure 7). For this study, the Euclidean distance was selected as the measurement of distance, or measures similarity between the sites of sampling. The sites of taking away with the greatest similarity are initially gathered. Then, of the groups of samples are joined with a mechanism of coupling and the stages are repeated until all the observations were classified.

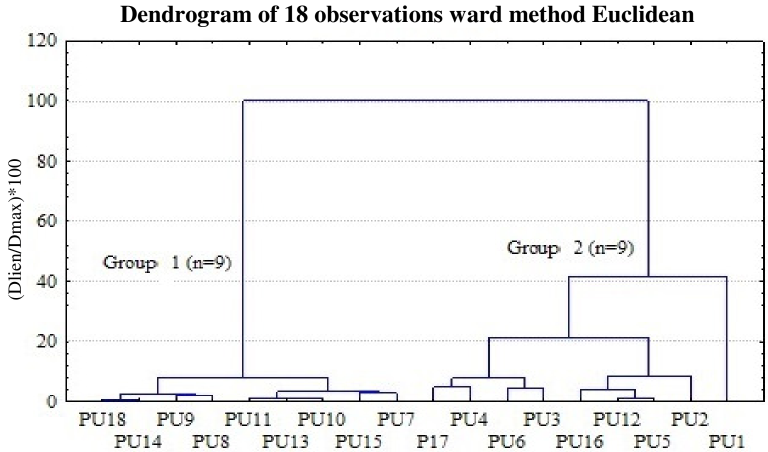

Figure 7. Dendrogram of 18 water wells

The regrouping in two groups or families of water gave the most satisfactory results (thus answering the objectives of the method of classification). The observation of the dendrogram applied to the 18 samples of the zone of study reveals some indications on the level of similarity between the samples (Figure 8). The samples coming from group 1, PU10 and PU11, PU8 and PU9, PU7 and PU15, PU14 and PU18 present a great similarity. In group 2, the water samples PU5 and PU12, PU3 and PU6, PU4 and PU17 present also a great similarity. Water of group 1 has the shortest distance from connection between them and thus, has the greatest resemblance compared to group 2. To describe the characteristics of each group of samples, the median values of the parameters used in this classification shown in the Figures 8a, b and c. All the parameters discriminate the two groups except for the temperature and of the pH.

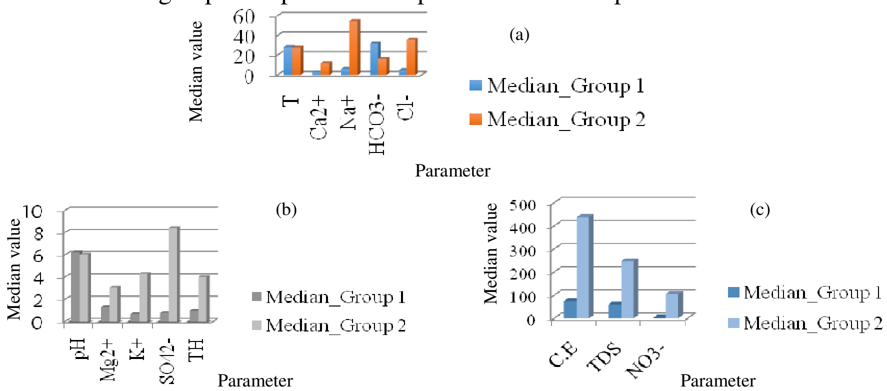

Figure 8. Comparison of the median values of the parameters between the two groups

Factorial analysis

The factorial analysis (AF) is one of the methods of analysis of the most used multidimensional data[13]. This multidimensional analysis of the data is a factorial and linear method which treats numerical characters (variable). It makes it possible to reduce the parameters while emphasizing those which are most determining. The component count to be kept is founded on the criterion of Kaiser[14], according to which the eigenvalues higher or equal to 1 are taken into account. The first F1 factor is that which expresses the strongest percentage of the original variance. The second F2 factor, independent of the first, which is that, expresses most of the residual variance and so on. The layout of the factorial weights is presented on Figure 9.

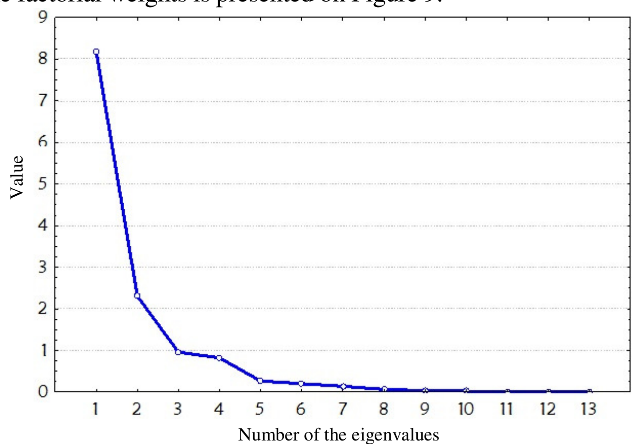

Figure 9. Layout of the eigenvalues

Two factors were extracted and count for 80.61% of the original variance. The F1 factor accounts for 62.87% of the total variance. It is strongly and positively correlated with variables C.E, TDS, Ca^{2+}, Na^{+}, Cl^{-}, SO_4^{2-} and NO_3^{-}(weight factorial > 0,9) and also correlated with TH (factorial weight 0.87) and K^{+} (factorial weight 0.77). The first factor represents mainly the mineralization of water and hardness (Table 5). The presence of nitrates in the F1 factor could translate a contamination of water by the organic matter coming from waste water[15]. The second F2 factor accounts for 17.74% of the original variance. It is correlated with variables HCO_3^{-}, Mg^{2+} and pH. It represents the dissolution of carbonated minerals of the magnesium whose pH of water controls dissolution[8]. The significant factorial weights are presented in fat in Table 5.

Table 5. Factorial weights of the variables

Code	Factor 1	Factor 2
T	-0.07	-0.57
pH	0.01	**0.73**
C.E	**0.95**	0.09
TDS	**0.99**	0.10
Ca^{2+}	**0.91**	0.28
Mg^{2+}	0.48	**0.77**
Na^{+}	**0.98**	-0.01
K^{+}	**0.77**	-0.15
HCO_3^{-}	-0.25	**0.83**
Cl^{-}	**0.95**	-0.07
SO_4^{2-}	**0.95**	0.08
NO_3^{-}	**0.97**	-0.01
TH	**0.87**	0.44
Eigenvalue	8.17	2.31
Total % variance	62.87	17.74
Cumulated %variance	62.87	80.61

Significant factorial weights in fat (> 0.7)

Table 6 presents the factorial scores of the water samples on the factors F1 and F2. More important is the value of the factorial score, more important is the process described by the factor corresponding to the level of the water points. Taking into consideration this table, well PU1 is atypical because it has a factorial score of 2.88 on F1. In addition, well PU15 has the highest factorial score (2.98) on F2.

Table 6. Factorial scores of the water samples

Code	Factor 1	Factor 2
PU1	2.88	0.64
PU2	-0.37	-0.19
PU3	1.10	-0.67
PU4	1.33	-0.19
PU5	0.01	-0.17
PU6	0.02	0.91
PU7	-0.45	-0.74

Contd.…

PU8	-0.61	-1.24
PU9	-0.86	0.32
PU10	-0.71	0.70
PU11	-0.64	-0.38
PU12	0.07	-0.84
PU13	-0.73	0.94
PU14	-0.83	-0.46
PU15	-0.68	2.98
PU16	0.35	-0.48
PU17	0.94	0.07
PU18	-0.82	-1.22

Figures 10 and 11 represent distribution of the factorial scores on the whole of the sampled water wells.

The process of mineralization of water and total hardness represented by the F1 factor is more important in wells PU1, PU3, PU4 and PU7. In the same way, the process concerned by the factor F2 (dissolution of carbonated minerals) is done more in a way accentuated in wells PU6, PU13 and PU15.

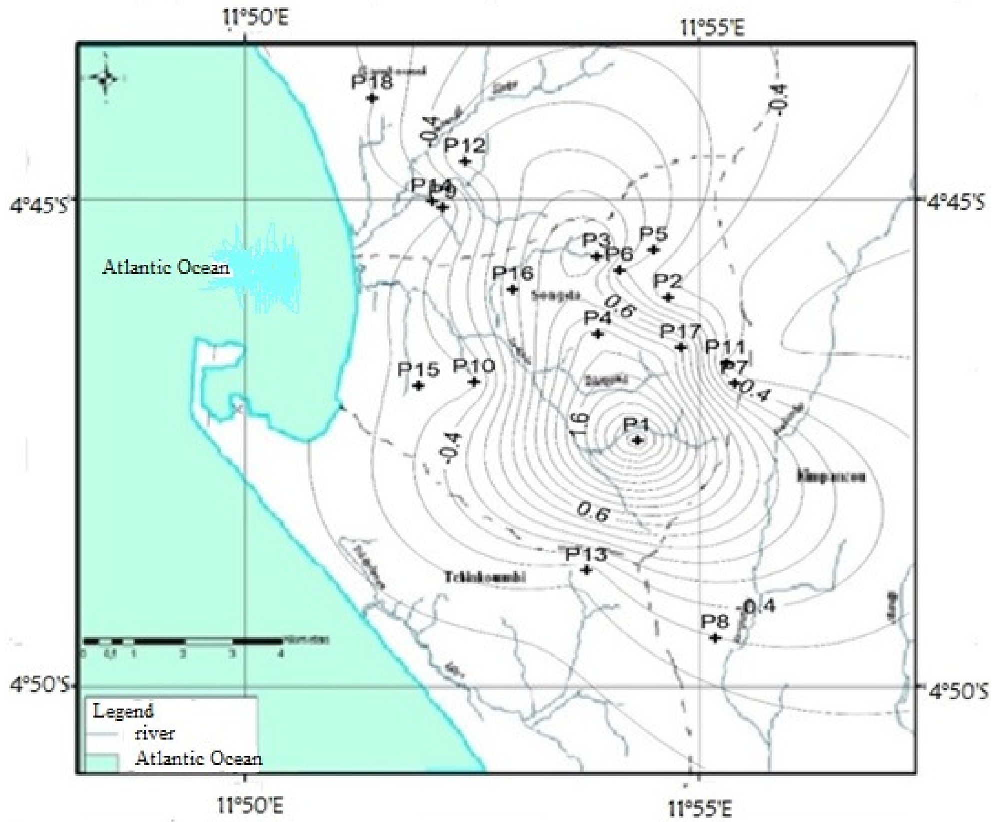

Figure 10. Distribution of the factorial scores on F1

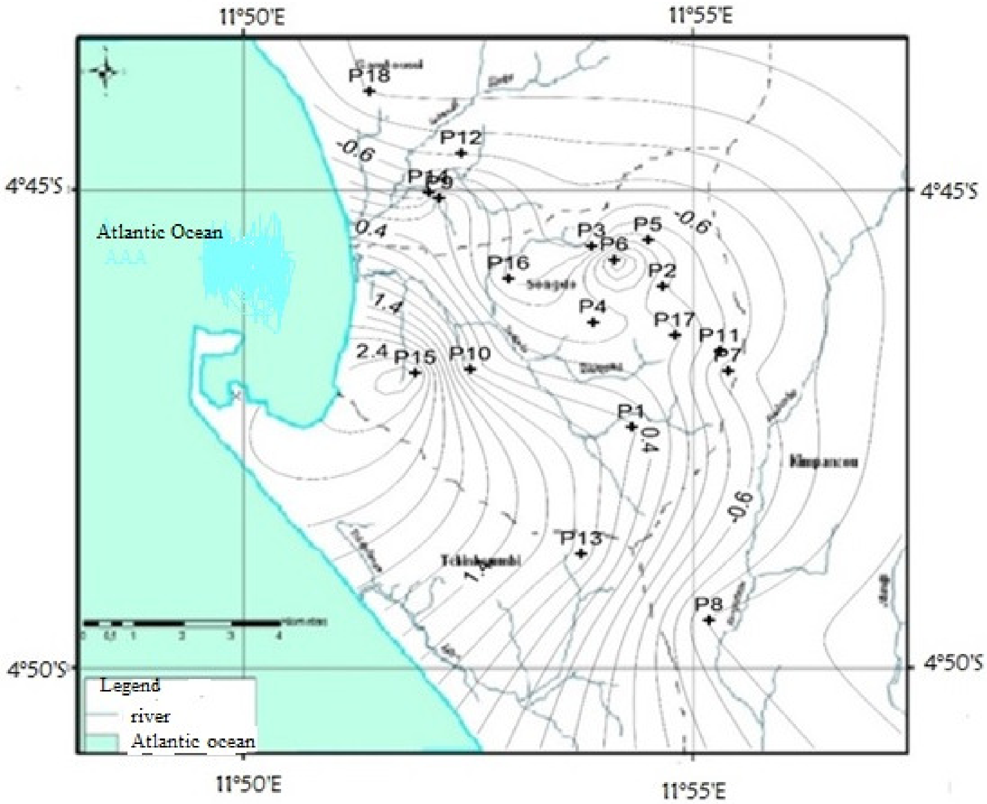

Figure 11. Distribution of the factorial scores on F2

Conclusion

The hydrochemical study of water of aquifer AQ1 of the zone of study showed the concentrations in major ions are within the limits for the drink water except for the nitrates whose concentrations exceed the limiting value of 10 mg/L for the drinking water including 55.56% of the water wells. This water is soft and is slightly acid. As a whole mineralization is weak except the well PU1 which is presented in the form of atypical.

Ascending hierarchical classification made it possible to gather the water wells in two groups which are discriminated by mineralization, total hardness, the contamination in ions nitrates. These discriminating parameters of two groups were highlighted by the factorial analysis.

The application of the multivariate statistical methods in this study showed their need on the description of the processes which control the chemical composition of studied water.

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