

Seasonal Groundwater Quality Variation in Brazzaville, Congo

Matini L.^{*1}, Tathy C.¹ and Moutou J.M.¹

Department of Exact Sciences, E.N.S, University Marien Ngouabi, B.P 69 Brazzaville, CONGO

Available online at: www.isca.in

(Received 29th August 2011, revised 21st October 2011, accepted 09th November 2011)

Abstract

Groundwater samples collected from southwestern Brazzaville, Congo, in rainy and dry seasons of the year 2008 were analyzed for pH, electrical conductivity, total dissolved solids, calcium, magnesium, sodium, potassium, chloride, sulfate, bicarbonate, fluoride, and nitrate to assess the seasonal variation of groundwater quality. The Results of the chemical analysis indicate that groundwater was characterized by Mg-Ca-HCO₃ facies in rainy season and Na-HCO₃ facies in dry season. In rainy season, silicate weathering was a dominant process, controlling the groundwater chemistry, followed by carbonate weathering and ion exchange; while in dry season silicate weathering was also the prime process over the governing of the groundwater quality followed by ion exchange and carbonate weathering. Leaching is the main contributor in rainy season.

Keywords: Groundwater quality, hydrochemical facies, hydrogeochemical processes.

Introduction

Suitability of groundwater for drinking, irrigation and industrial purposes depends upon its quality. Changes in groundwater quality are due to variation in climatic conditions, residence time of water, aquifer materials, and inputs from soil during percolation of water^{1,2,3}. Application of uncontrolled fertilizers and manure is one of the main sources of groundwater pollution, especially in developing countries, like Congo-Brazzaville, where domestic sewage contributes to pollute groundwater. Many hydrogeochemical processes have been highlighted in the control of the chemical composition of groundwater like carbonates and silicates weathering, ion exchange^{2,3,4,5}. In this study, an attempt is made to examine the controlling factors of hydrogeochemical processes for taking management measures for sustainable development.

Material and Methods

Study Area: The study area is located in southwestern Brazzaville between 15°13'53" and 15°14'10" East longitude, and 4°15'7.2" and 4°15'28.8" South latitude as shown in figure 1. The area is in the equatorial climate zone, with two seasons: rainy (October to May) and dry (June to September). Temperature varies from 25°C to 36°C in rainy season, while it is between 18°C and 24°C in dry season. The mean annual rainfall is 1470 mm. The vegetation is of savanna type (*Loutetia demeusi*) and presents a formation to sparse gramineous carpet, with a shrubby layer of *hymenocardia acida*.

Aquifer is shallow. Generally, the deep wells do not exceed 2 m depth. The main natural recharge to groundwater comes from precipitation (rainfall). Farming activities are present

around some water well sites and also agricultural activities near the river Mfilou, which flows in the study area. Belonging to the continental sedimentary basin of tertiary age, the southwestern Brazzaville is made of sedimentary deposits with recent alluvium formations covering the bed rock. These formations are also made of ochre sands or Batéké sands (silicate sandstones), which constitute the formation of Inkisi classically joined to the schisto-sandy group. The soil in the study area is also made of limestone, dolomite, tillite, arkoses, and mudstones⁶. The location of the water wells and spring water is shown in figure 1.

Sampling and Analysis: Twenty three samples of water wells and one sample of spring water were collected three times in rainy season (March to April, 2008). In dry season (July to August, 2008) twenty two samples of well water and one sample of spring water were also collected three times. They were analyzed for pH, electrical conductivity (EC), total dissolved solids (TDS), Ca²⁺, Mg²⁺, Na⁺, K⁺, Cl⁻, SO₄²⁻, HCO₃⁻, F⁻ and NO₃⁻ following standards methods⁷. Before water sampling, all the polyethylene bottles were cleaned and rinsed thoroughly with water to be analyzed. All reagents used were of analytical grade. Samples were unfiltered and the concentration of the different parameters could correspond to the total concentration if the groundwater was used by the consumers for drinking. Hydrogen ion concentration (pH), electrical conductivity (EC), total dissolved solids (TDS) were measured in situ using Consort C933 multi-parameters portable. Calcium (Ca²⁺) and magnesium (Mg²⁺) were analyzed titrimetrically using standard EDTA. Sodium (Na⁺) and potassium (K⁺) were determined by flame photometer; chloride (Cl⁻) was determined using standard AgNO₃ titration; sulphate (SO₄²⁻) was analyzed by nephelometric method; bicarbonate (HCO₃⁻)

was estimated titrimetrically from total alkalinity using HCl. Fluoride (F⁻) and nitrate (NO₃⁻) were determined by spectrophotometry.

Results and Discussion

All the data are summarized in table-1 to table-4 and the graphical representations are shown in figure-1 to figure-5.

Ionic composition: Chemical composition of the groundwater samples collected in the study area during rainy season and dry season is presented in tables 1 and 2, respectively. In rainy season, groundwater showed acidic

nature, with pH values between 3.40 and 5.93. Electrical conductivity (EC) varied from 96.56 to 459.80 μS/cm, total dissolved solids (TDS) from 51.26 to 244.80 mg/L. The concentration (mg/L) of individual ions varied as Ca²⁺ from 9 to 38; Mg²⁺, 6 to 30; Na⁺, 69 to 264.5; K⁺, 3 to 11.5; Cl⁻, 2 to 47; SO₄²⁻, 6 to 14; HCO₃⁻, 12.20 to 91.50; F⁻, 0.12 to 1.18 and NO₃⁻, 0.61 to 2.70. The chemical composition reflects a low mineralization of the groundwater. The values of pH and NO₃⁻ concentration are almost the same in both seasons as shown in table 3. The other parameters had a decrease trend in dry season compared to rainy season.

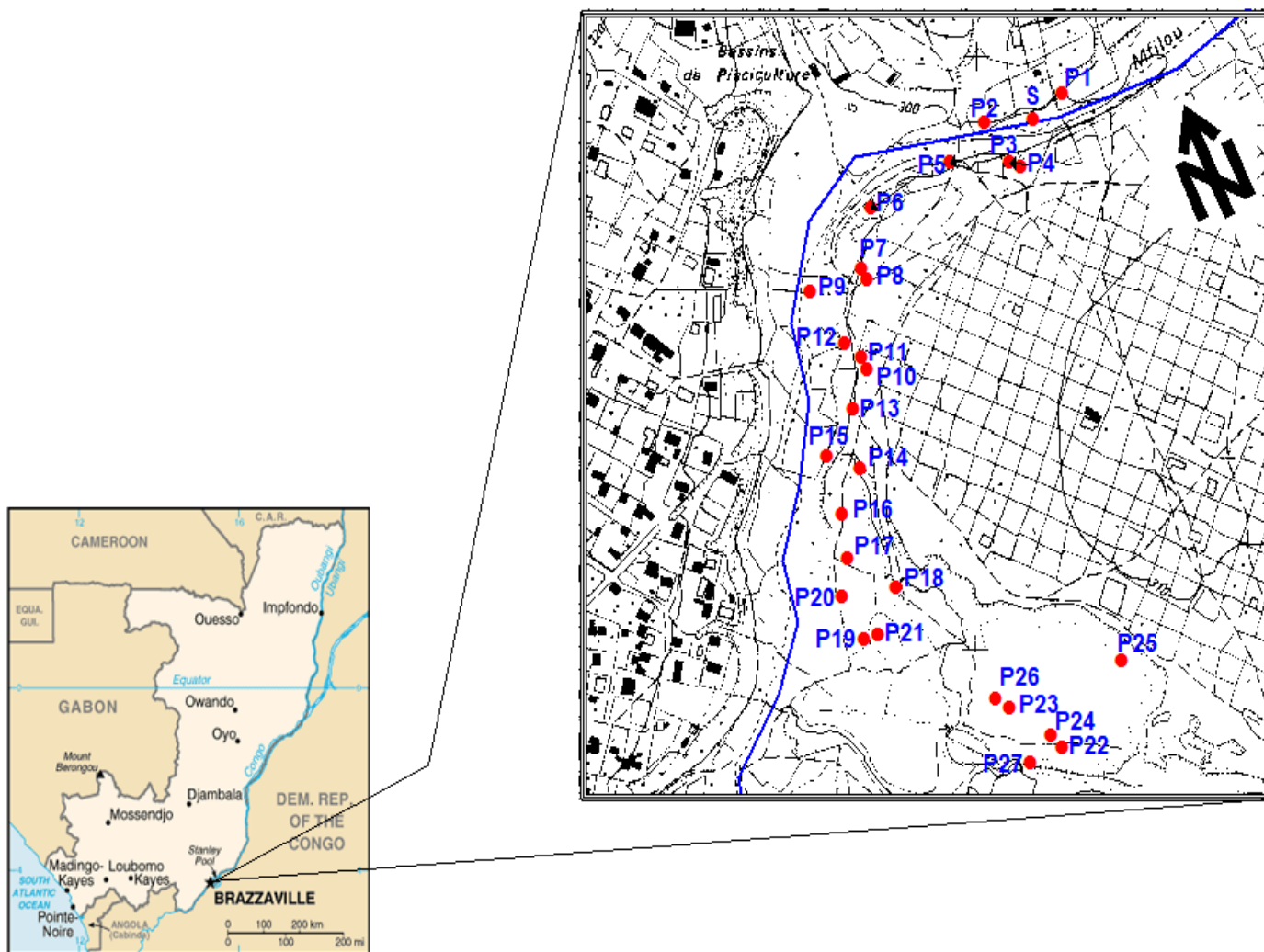


Figure-1
Location of the water points in the study area (P: well water, S: spring water)

Table -1
Chemical composition of groundwater in rainy season 2008

CODE	pH	EC	TDS	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	Cl ⁻	SO ₄ ²⁻	HCO ₃ ⁻	F ⁻	NO ₃ ⁻
S	3.40	96.56	51.26	9	12	10.00	3.0	9.0	6	36.60	0.40	0.61
P1	3.87	174.51	92.13	18	17	9.00	8.8	21.0	8	73.20	0.59	b.d.l
P2	4.87	120.96	64.32	14	19	10.10	4.5	17.0	6	73.20	0.30	1.20
P3	5.22	158.26	83.96	12	10	5.26	3.3	12.0	9	48.80	0.27	0.97
P4	4.01	120.46	64.13	17	13	25.32	4.7	14.0	9	24.40	0.42	1.02
P6	4.82	184.32	97.82	19	12	24.42	11.2	19.0	10	19.52	0.52	2.51
P8	4.84	154.66	82.10	35	17	27.09	6.9	4.0	14	91.50	0.27	1.22
P9	4.68	150.60	26.86	17	14	22.37	5.7	10.0	12	32.94	0.35	1.04
P10	4.03	169.56	90.06	22	10	22.21	8.2	12.0	9	30.50	0.50	1.57
P11	4.53	148.82	79.04	35	14	20.15	4.7	7.0	13	87.84	0.42	0.99
P12	4.27	178.60	94.84	23	11	28.86	11.2	5.0	10	39.04	0.57	1.17
P13	4.72	170.42	90.50	38	30	87.40	40.0	11.0	8	61.00	1.18	1.00
P14	3.94	175.18	93.18	21	12	11.47	7.0	7.0	11	69.54	0.33	2.00
P15	3.90	173.76	92.32	18	9	4.84	5.4	5.0	8	68.32	0.39	2.14
P16	3.55	166.50	88.51	19	8	24.00	5.2	4.0	13	15.86	0.30	2.20
P17	4.53	231.80	123.40	17	7	21.98	5.0	2.0	14	12.20	0.23	2.08
P19	5.49	233.80	124.20	16	6	20.61	4.5	2.0	8	17.08	0.14	2.70
P21	5.08	248.00	131.80	15	7	28.13	5.0	27.0	11	14.64	0.30	0.99
P22	5.15	358.80	191.40	16	12	14.89	9.5	28.0	12	14.64	0.47	1.03
P23	5.93	357.20	189.80	18	7	8.12	4.0	22.0	10	17.08	0.19	1.47
P24	5.66	314.60	167.00	19	19	15.66	5.2	47.0	11	14.64	0.16	0.99
P25	5.46	363.60	194.20	24	14	264.5	11.5	3.0	1	12.20	0.12	0.82
P27	5.63	459.80	244.80	22	8	15.27	7.0	23.0	9	19.52	0.18	1.00

All the parameters are expressed in mg/L, except pH (unit), and EC (µS/cm)
 b.d.l: below detection limit

Table-2
Chemical composition of groundwater in dry season 2008

Code	pH	EC	TDS	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	Cl ⁻	SO ₄ ²⁻	HCO ₃ ⁻	F ⁻	NO ₃ ⁻
S	3.40	83.98	44.72	13	11	57.5	2.5	8	5	37.82	0.36	0.55
P1	3.49	283.20	150.20	16	13	200.1	8.7	19	6	69.54	0.50	1.25
P2	3.58	63.86	33.92	11	15	98.9	4.3	14	4	68.32	0.29	0.97
P3	3.60	144.00	76.36	10	8	69.0	3.0	10	6	46.36	0.18	1.07
P4	4.88	147.54	78.50	15	11	92.0	4.0	12	7	23.18	0.40	1.00
P6	4.04	186.60	99.18	17	10	253.0	11.0	17	11	17.08	0.49	2.47
P8	3.81	190.48	101.16	31	15	142.6	6.2	2	12	85.40	0.25	1.20
P9	4.85	53.58	28.50	14	12	128.8	5.6	10	11	30.50	0.33	1.00
P10	4.09	176.96	93.82	8	9	184.0	8.0	12	7	26.84	0.48	1.50
P11	4.06	151.72	80.58	32	12	103.5	4.5	6	12	86.62	0.39	0.96
P12	4.52	200.72	106.28	20	9	232.3	10.1	3	8	35.38	0.51	1.14
P13	4.83	180.46	95.92	12	9	94.3	4.1	10	8	48.80	1.16	1.27
P14	4.89	164.32	87.12	20	10	161.0	7.0	7	9	67.10	0.3	2.00
P15	4.29	182.40	96.96	16	8	124.2	5.4	6	10	65.88	0.29	2.06
P16	3.78	195.26	103.48	16	5	115.0	5.0	4	11	12.20	0.27	2.20
P17	4.85	164.82	87.56	15	6	115.0	5.0	2	10	8.54	0.3	2.01
P19	5.82	183.12	97.12	14	3	92.0	4.0	1	5	14.64	0.11	2.20
P21	5.27	167.82	89.14	13	7	92.0	4.0	25	9	12.2	0.28	0.87
P22	5.43	226.60	119.80	16	5	92.0	4.0	20	7	13.42	0.40	1.00
P23	6.24	197.16	105.14	16	7	73.6	3.2	20	8	14.64	0.15	1.40
P24	5.94	180.48	95.70	20	9	115.0	5.0	42	9	10.98	0.15	0.96
P27	6.37	194.46	103.50	19	6	117.3	5.1	20	7	17.08	0.16	0.97

All the parameters are expressed in mg/L, except pH (unit), and EC (µS/cm)

Table-3
Descriptive statistics and T-test of groundwater parameters

Parameter	Rainy season			Dry season			Statistical Test	
	Mean	S.D	C.V	Mean	S.D	C.V	T-test calculated	R
pH	4.70	0.71	0.15	4.66	0.90	0.19	0.166	N
EC	211.38	92.74	0.43	167.89	49.86	0.29	1.947	S
TDS	110.16	52.10	0.46	89.14	26.42	0.29	1.696	S
Ca ²⁺	19.96	7.08	0.03	16.78	5.76	0.34	1.649	N
Mg ²⁺	12.50	5.28	0.47	9.13	3.11	0.33	2.595	S
Na ⁺	148.10	56.39	0.38	130.70	56.97	0.42	1.029	N
K ⁺	7.90	7.28	0.35	5.68	2.48	0.42	1.358	N
Cl ⁻	13.23	10.74	0.41	11.74	9.70	0.81	0.488	N
SO ₄ ²⁻	9.58	2.90	0.90	7.96	2.74	0.34	1.924	S
HCO ₃ ⁻	40.11	26.77	0.80	35.43	26.42	0.73	0.590	N
F ⁻	0.38	0.22	0.30	0.34	0.22	0.62	0.610	N
NO ₃ ⁻	1.32	0.64	0.48	1.34	0.54	0.40	-0.113	N

SD: Standard Deviation, C.V: Coefficient of Variation, R: Result, N: Non-significant, S: Significant (in bold)

For example, EC increases 1.26, TDS 1.24, Ca 3.18, Mg 1.37, Na 1.13, K 1.39, Cl 1.13, SO₄ 1.20, HCO₃ 1.13 and F 1.12 times higher in rainy season than in dry season. This reflects a seasonal variation in groundwater quality. The effect of seasonal variation on groundwater quality is mainly due to the influence of EC in terms of TDS, Mg²⁺ and SO₄²⁻ rather than other parameters. Similar results are also proved through *T*-test of significance as shown in table 3.

In rainy season, no cation exceeded 50% of the total cations (Tcations) in all the groundwater samples. The order of the relative abundance of major cations, expressed in percent of meq/L, was Mg²⁺ (36.74%) > Ca²⁺ (36.32%) > Na⁺ (18.53%) > K⁺ (8.4%) while that of the anions was HCO₃⁻ (52.27%) > Cl⁻ (31.24%) > SO₄²⁻ (16.49%). In dry season, the order was: Na⁺ (67.04%) > Mg²⁺ (20.58%) > Ca²⁺ (10.19%) > K⁺ (2.19%) for the cations and HCO₃⁻ (53.89%) > Cl⁻ (30.77%) > SO₄²⁻ (15.34%) for the anions. The concentration of earth alkalis elements (Ca and Mg) in dry season represents 28,5% of Tcations; this shows a low rock/water interaction in dry season. The compositional relations among the dissolved ions have been calculated by means of stoichiometric relations to assess the processes that result in water composition.

Stoichiometric relations: The ratios between dissolved ions (meq/L) are shown in table 4. The ratio (Ca²⁺ + Mg²⁺) / Tcations is ranged between 0.38 – 0.76 and 0.46 – 0.93 in rainy season and dry season, respectively. The ratios lower than 0.5 denotes the contribution of alkalis to Tcations. This is supported by (Na⁺ + K⁺) / Tcations ratio, which varied from 0.24 to 0.62 in rainy season and from 0.38 to 0.69 in dry season. Some groundwater samples have (Na⁺ + K⁺) / Tcations ratio equal or higher than 0.5 in both seasons, reflecting the contribution of cations via silicate weathering⁸. Indeed, the bedrock in the study area derives from sedimentary rocks which contain silicates. The weathering of silicates with carbonic acid (H₂CO₃) formed from interaction of atmospheric CO₂ with water or CO₂ coming from the decomposition of organic matter in the soil⁵, can be written as follows:

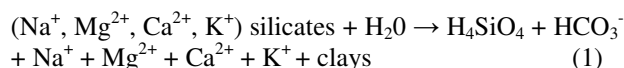


Table-4

Stoichiometric relations between the observed solutes in the groundwater samples

Ionic ratio	Range	
	Rainy season	Dry season
(Ca ²⁺ + Mg ²⁺) / T cations	0.38 - 0.76	0.46 - 0.93
(Na ⁺ + K ⁺) / T cations	0.24 - 0.62	0.38 - 0.69
Ca ²⁺ / Mg ²⁺	0.44 - 1.76	0.44 - 2.80
Na ⁺ / Cl ⁻	0.51 - 31.71	0.28 - 24.14
HCO ₃ ⁻ / Na ⁺	0.07 - 2.96	0.02 - 9.50
Na ⁺ / Ca ²⁺	0.45 - 2.65	0.33 - 3.28
Na ⁺ / (Na ⁺ + Cl ⁻)	0.34 - 0.97	0.22 - 1.00

Another source of major cations, such as Ca²⁺ and Mg²⁺, in groundwater can be the weathering of calcium and magnesium minerals³. The nature and the extent of water/rock interaction were assessed by plotting some relations between major ions. The relation between Ca and Mg in the groundwater samples shows that the Ca²⁺/Mg²⁺ ratio ranged between 0.44 and 1.76 in rainy season and between 0.44 and 2.80 in dry season. High ratio in dry season can be explained by a high residence time of water in the aquifer, which favours the weathering process. The ratio of Ca²⁺/Mg²⁺ less than 1 explains that groundwater is more enriched in Mg²⁺ and the ratio higher than 1 explains the increasing of Ca²⁺ in relation with Mg²⁺ in the groundwater.

The Na-Cl relationship has often been used to identify the reasons of salinity in groundwater^{10,11}. In rainy season, groundwater samples had Na⁺/Cl⁻ ratio ranged from 0.51 to 31.71, while it varied from 0.28 to 24.14 in dry season. A Na⁺/Cl⁻ ratio equal to 1 is attributed to the dissolution of NaCl while a ratio greater than 1 reflects a release of Na⁺ from silicate weathering^{12,13}. None of groundwater samples had a Na⁺/Cl⁻ ratio equal to 1 in both seasons. Some groundwater samples (P3, P21, P23, P24 and P25) had a Na⁺/Cl⁻ ratio less than 1 in both seasons, allowing to conclude that the reduction of sodium concentration may be due to ion exchange^{3,14,15}. In the two seasons, Na⁺/Cl⁻ ratio varied spatially, and the increase in Na⁺ concentration was not associated with an increase in Cl⁻ concentration. That supports a cation exchange process^{16,17}. The low concentrations of Na⁺ and Cl⁻ in groundwater suggest that the dissolution of halite is not important in the regulation of Na⁺ in groundwater⁴.

Other sources of Na⁺ and Cl⁻ in the groundwater of the study area may be domestic wastewater¹⁴, which is usually enriched in Na⁺ relatively to Cl⁻. In rainy season, the groundwater samples P1, P6, P12, P22 and P25 have a concentration of Na⁺ higher than the permissible limit (200 mg/L) of WHO for drinking purpose. A higher concentration of Na⁺ in drinking water may be a risk for a person suffering from cardiac, renal, and circulatory diseases¹⁸.

Ion exchange can be a source of sodium in the groundwater by releasing of Na⁺ from clay products. In order to confirm the ion exchange process taking place, Na⁺/Ca²⁺ and Na⁺/(Na⁺ + Cl⁻) ratios are also computed. In the study area, the groundwater shown Na⁺/Ca²⁺ ratio between 0.45 – 2.65 and 0.33 – 3.28 in rainy season and in dry season, respectively. This ratio was higher than 1 in 52.17% and 39.13% of the groundwater samples in rainy season and dry season, respectively.

The ion exchange process was also highlighted by Na⁺/(Na⁺ + Cl⁻) ratio, which varied in the range 0.34 – 0.97 and 0.22 – 1.00 in rainy season and in dry season, respectively. A ratio of Na⁺/(Na⁺+Cl⁻) was higher than 0.5 in 83.33% and 60.87% respectively in rainy and dry season groundwater samples, suggesting clearly that ion exchange process occurred.

The ratio $\text{HCO}_3^-/\text{Na}^+$ can also be used to assess the weathering process^{3,5} that occurs in groundwater. When the $\text{HCO}_3^-/\text{Na}^+$ ratio is greater than 1, carbonate weathering occurs, while a ratio less than 1 allows the conclusion that silicate weathering occurs. In both seasons, silicate weathering appears to be the main weathering process controlling the groundwater chemistry. Taking in account $\text{HCO}_3^-/\text{Na}^+$ ratio, 66.66% and 33.34% of groundwater samples characterize silicate and carbonate weathering in rainy season, respectively, and 60.87% and 39.13% in dry season, respectively. This also supports the silicate weathering. On the whole, the groundwater samples have the concentration of Na^+ higher than that of K^+ in the two seasons as shown in tables 1 and 2, because of the greater resistance of K^+ to chemical weathering and its adsorption on clay minerals^{5,8}.

The ratio $(\text{HCO}_3^- + \text{SO}_4^{2-})/\text{Tanions}$, where Tanions indicates total anions, are ranged from 0.82 to 17.69 and from 0.11 to 0.97, in rainy season and in dry season, respectively. On the whole, the ratio $(\text{HCO}_3^- + \text{SO}_4^{2-})/\text{Tanions}$ is greater than 1, in rainy season. These values show an excess of bicarbonate and sulfate ions in rainy season, except for the groundwater sample P24, which shows a ratio lower than 1 (0.82). In dry season, the ratio $(\text{HCO}_3^- + \text{SO}_4^{2-})/\text{Tanions}$ in groundwater

samples are lower than 1. This denotes a deficit of HCO_3^- and SO_4^{2-} . The effect of the rain on the water/rock interaction is obvious.

Meanwhile $\text{Cl}^-/\text{Tanions}$ ratio is greater than 1 in all the groundwater samples in rainy season. In dry season, the ionic ratio $(\text{HCO}_3^- + \text{SO}_4^{2-})/\text{Tanions}$ is greater than the ratio $\text{Cl}^-/\text{Tanions}$ in some groundwater samples (S and P1- P19). This suggests that when there is lack of rain, the decomposition of organic matter by bacterial organisms in the soil would not provide the appropriate CO_2 to the rock/water interaction in dry season. The trend is reversed for the groundwater samples P21-P25 and P27 in which $\text{Cl}^-/\text{Tanions}$ ratio is greater than $(\text{HCO}_3^- + \text{SO}_4^{2-})/\text{Tanions}$ ratio.

Hydrogeochemical plots: The plot of $(\text{Ca}^{2+} + \text{Mg}^{2+})$ vs HCO_3^- given in figure 2, shows a positive correlation in rainy season ($r = 0.50$) and in dry season ($r = 0.64$), respectively. This implies that earth alkalis elements (Ca and Mg), may be derived from silicate and carbonate minerals. The mean concentration of HCO_3^- is the dominant anion in rainy season (40.11 mg/L) and in dry season (35.43 mg/L). That explains the low degree of water/rock interaction in the form of silicate weathering.

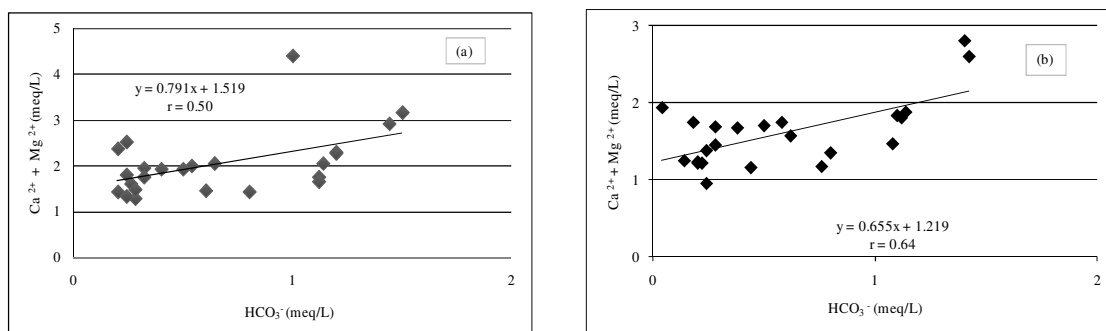


Figure-2
 Relation between $\text{Ca}^{2+} + \text{Mg}^{2+}$ and HCO_3^- in the groundwater
 (a) Rainy Season (b) Dry Season

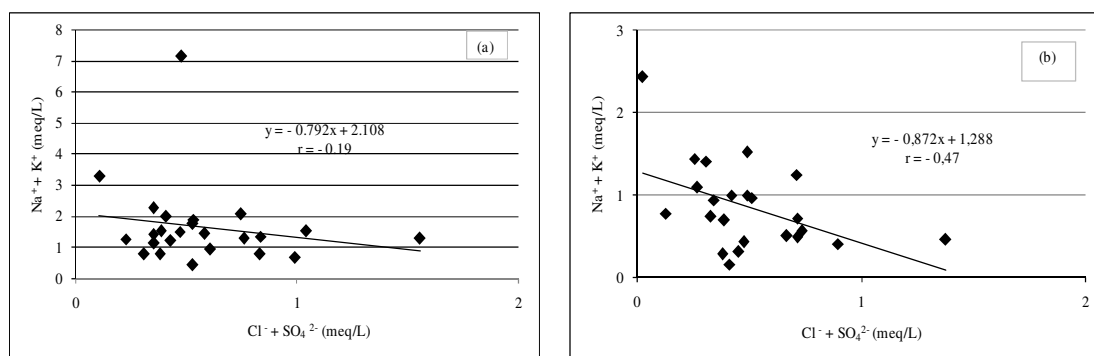


Figure-3
 Relationship between $\text{Na}^+ + \text{K}^+$ and $\text{Cl}^- + \text{SO}_4^{2-}$ in the groundwater
 (a) Rainy Season (b) Dry Season

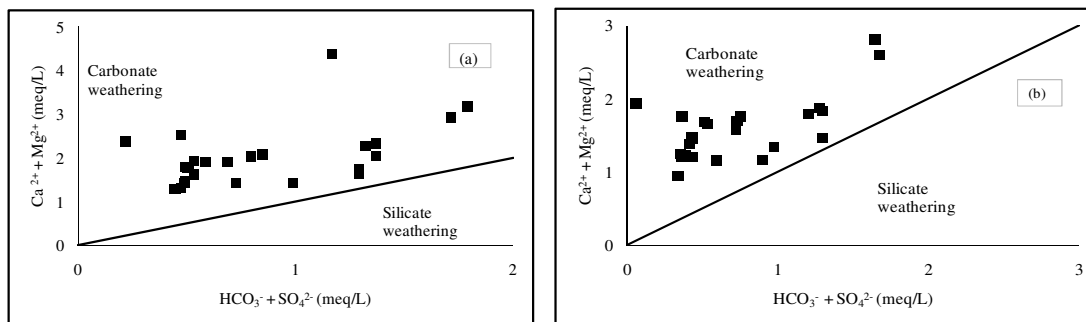


Figure-4
1:1 equiline diagram for carbonate weathering vs. silicate weathering processes
Relation between (Ca²⁺ + Mg²⁺) and (HCO₃⁻ + SO₄²⁻) (a) Rainy Season (b) Dry Season

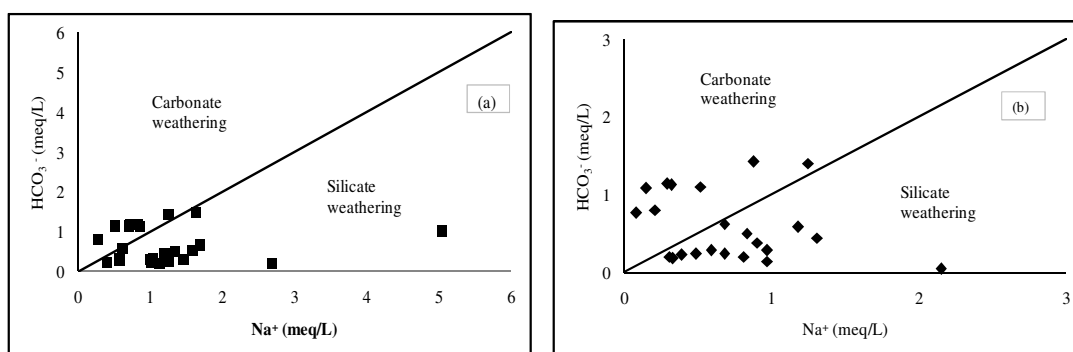


Figure-5
1:1 equiline diagram for carbonate weathering vs. silicate weathering processes
Relation between HCO₃⁻ and Na⁺ (a) Rainy season (b) Dry season

The plot of Na⁺ + K⁺ vs Cl⁻ + SO₄²⁻ given in figure 3, shows no significant positive correlation in rainy season and in dry season. The decrease in alkalis Na⁺ + K⁺ with a simultaneous increase in Cl⁻ + SO₄²⁻ reflects a non common source for these ions and suggests that the contribution of these ions from the soil salts could not be significant. Sulfate ions would proceed from the oxidation of pyrite⁹ FeS₂ as shown below: FeS₂ + 15/4 O₂ + 7/2 H₂O ↔ Fe(OH)₃ + 4 H⁺ + 2SO₄²⁻ (2)

This reaction would explain acidic nature of the groundwater. The decomposition of organic matter in the soil contributes also to the acidity of groundwater.

The plot (Ca²⁺ + Mg²⁺) vs (HCO₃⁻ + SO₄²⁻) in figure 4 shows that most groundwater samples are plotted above the equiline in both seasons. This indicates that carbonate weathering is the dominant process¹⁹ for the supply of Ca²⁺ to the groundwater. The plot HCO₃⁻ vs Na⁺ in figure 5 indicates that HCO₃⁻ ions are proceed from silicate and carbonate weathering. By order of magnitude, silicate weathering, carbonate weathering, and ion exchange process control the groundwater composition in rainy season. The magnitude of ion exchange process is greater in rainy season than in dry season. This can be due to the low intensity of silicate weathering supported by the percentage value of

groundwater samples sites in which silicate weathering occurs. Sources of chloride in groundwater of the study area could be domestic wastewater. In dry season, the chloride excess in the groundwater could be explained by the infiltration of domestic wastewater. Taking in account the scatter diagrams in figures 4 and 5, the silicate weathering is the main hydrogeochemical process, followed by carbonate weathering and ion exchange process in the groundwater of the study area. Because the chloride proceeds essentially from wastewater, and taking in account the geochemical processes, the results of this study uphold that in the year 2008, groundwater was characterized by Mg-Ca-HCO₃ facies in rainy season and Na-HCO₃ facies in dry season.

Conclusions

The seasonal variation of groundwater quality in the study area in the year 2008 has shown the facies Mg - Ca - HCO₃ in rainy season and Na - HCO₃ in dry season. The pH values reveal that the groundwater was acidic in nature. The amount of total dissolved solids was less than 300mg/L, indicating a “fresh environment”. Silicate weathering, carbonate weathering, and ion exchange have been identified as the hydrogeochemical processes controlling the chemical composition of groundwater in both seasons. The spread of

silicate weathering was more marked in rainy season than in dry season, and that of ion exchange process was more important in dry season. The bicarbonates derived mainly from silicate weathering. Chloride concentration in groundwater was partially due to dissolution of rock salts, irrigation return flow in the northern part of the study area and domestic wastewater. Seasonal effect has been observed on some parameters such as EC, TDS, Mg^{2+} and SO_4^{2-} .

Acknowledgements

The authors are sincerely thankful to Prof. N. Subba Rao, Department of Geology, Andhra University, Visakhapatnam – 530 003, India, for his suggestions in the preparation of the paper. They also thank Prof B. Evayoulou, ENS, University Marien Ngouabi, Brazzaville, Congo, for his remarks and suggestions.

References

1. Mitra B.K., Sasaki C., Enari K., Matsuyama N. and Fujita M., Suitability assesment of shallow groundwater for agriculture in sand dune area of northwest Honshu Island Japan, *Applied Ecology and Environmental Research*, **5(1)**, 177–188 (2007)
2. Giridharan L., Venugopal T. and Jayaprakash M., Evaluation of the seasonal variation on the geochemical parameters and quality assessment of the groundwater in the proximity of River Cooum, Chennai, India, *Environ Monit Assess*, **143**, 161–178 (2008)
3. Krishna Kumar S., Rammohan V., Rajkumar Sahayam J. and Jeevanandam M., Assessment of groundwater quality and hydrogeochemistry of Manimuktha River basin, Tamil Nadu, India, *Environ Monit Assess*, **159**, 341-351 (2009)
4. Mohsen Jalali, Hydrochemical identification of groundwater resources and their changes under the impact of human activity in the Chah basin in western Iran, *Environ Monit Assess*, **130**, 347–364 (2007)
5. Subba Rao N., Factors controlling the salinity in groundwater in parts of Guntur district, Andhra Pradesh, India, *Environ Monit Assess*, **138**, 327-341 (2008)
6. Moukolo N., Etat des connaissances actuelles sur l'hydrogéologie du Congo-Brazzaville, *Hydrogéologie*, **1-2**, 47-58 (1992)
7. APHA, Standards methods for the examination of water and waste-water, 20th Ed. American Public Health Association, Washington, DC., USA (1998)
8. Sarin M.M., Krishnaswamy S., Dilli K., Somayajulu B.I.K. and Moore W.S., Major-ion chemistry of the Ganga-Brahmaputra river system. Weathering processes and fluxes to the bay of Bengal, *Geochimica et Cosmochimica Acta*, **53**, 997–1000 (1989)
9. Banton O. and Bangoy Lumony, Hydrologie: Multiscience environnementale des eaux souterraines, Presses de l'Université du Québec/AUPELF (1997)
10. Magaritz M., Nadler A., Koyumdjisky H. and Dan N., The use of Na/Cl ratio to trace absolute sources in a semiarid zone, *Water Resources Research*, **17**, 602–608 (1981)
11. Sami K., Recharge mechanism and geochemical processes in a semi-arid sedimentary basin, Eastern Cape, South Africa, *Journal of Hydrology*, **139**, 27–48 (1992)
12. Stallard R.F. and Edmond J.M., Geochemistry of Amazon River: the influence of the geology and weathering environment on the dissolved load, *Journal of Geophysical Research*, **88**, 9671–9688 (1983)
13. Meybeck M., Global chemical weathering of surficial rocks estimated from river dissolved loads, *American Journal of Science*, **287**, 401–428 (1987)
14. Vengosh, A. and Keren R., Chemical modifications of groundwater contaminated by recharge of treated sewage effluent, *Journal of Contaminant Hydrology*, **23**, 347-360 (1996)
15. Rhodes A.L., Newton R.M. and Pufall A., Influences of land use on water quality of diverse New England watersheds, *Environmental Science and Technology*, **35**, 3640–3645 (2001)
16. Appelo C.A.J. and Postma D., Geochemistry, groundwater and pollution, 2nd Edition: A.A. Balkema Publishers, Leiden, The Netherlands (1993)
17. Wayland K. G., Long D.T., Hyndman D.W., Pijanowski B.C., Woodhams S. M. and Haack, Sh.K., Identifying relationships between base flow geochemistry and land use with synoptic sampling and R-Mode factor analysis, *Journal of Environmental Quality*, **32**, 180-190 (2003)
18. WHO, Sodium, chlorides and conductivity in drinking water. Regional Office for Europe, Copenhagen. *EURO Reports and Studies*, **2**, (1979)
19. Datta P.S. and Tyagi S.K., Major ion chemistry of groundwater in Delhi area: Chemical weathering processes and groundwater flow regimes, *Journal of the Geological Society of India*, **47**, 179–188 (1996)