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Seasonal Variations in Groundwater of the Phreatic Aquiferous Formations in Douala City-Cameroon: Hydrogeochemistry and Water Quality

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Abstract

This study carried out in Douala City, was to determine the seasonal variations of groundwater, the influence of the rock formations on the groundwater solute chemistry and groundwater domestic-agro-industrial quality using hydrogeochemical tools and physicochemical parameters, Ionic ratios, Gibbs diagrams, Piper diagrams, Durov diagrams and water quality indices. From physicochemical parameters, in the rainy season, pH ranged from, 4.6 - 7.1; EC, 0.023 - 1.63 mS/cm, Temperature, 26.3˚C - 29˚C and TDS, 0.015 - 1.09 mg/L, and in the dry season pH ranged from 5 - 7.2, EC, 0.01 - 1.61 mS/cm, Temperature, 24.4˚C - 29.5˚C and TDS, 0.01 - 1.08 mg/L. Forty groundwater samples, 20 per season, wet and dry were analysed. The major ions fell below WHO acceptable limits for both seasons. The sequences of abundance of major ions were, $Ca^{2+} > K^{+} > Mg^{2+} > NH_4^{+} > Na^{+}$, $HCO_3^{-} > Cl^{-} > SO_4^{2-} > NO_3^{-} > HPO_4^{2-}$ in wet season and $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+} > NH_4^{+}$, $HCO_3^{-} > Cl^{-} > SO_4^{2-} > HPO_4^{2-} > NO_3^{-}$ in dry season. Ion-exchange, simple dissolution and uncommon dissolution processes determined groundwater character. Groundwater ionic content was as a result of ion exchange from rock-weathering. Water types are; MgCl and $MgHCO_3$ in both seasons. Hydrogeochemical facies are; Ca-Mg-Cl-SO_4, characteristic of groundwater some distance along its flow path and Ca-Mg-HCO_3, characteristic of freshly recharged groundwater from precipitation. The groundwater indices of Sodium Percent (% Na), Residual Sodium Carbonate (RSC), Kelley's ratio (KR), Sodium Adsorption Ratio (SAR), Electrical Conductivity (EC), Total Dissolved Solid (TDS), USSL and Wilcox index were determined, evaluated and found to be suitable for agro-industrial uses in all seasons.

Permeability Index (PI), Water quality index (WQI) and Magnesium Adsorption Ratio (MAR) were not suitable in some areas and in some seasons.

Subject Areas

Geochemistry, Hydrology

Keywords

Groundwater, Hydrogeochemistry, Seasonal Variations, Water Quality, Douala-Cameroon

1. Introduction

Douala situated between latitude 4.00 - 4.15 and longitude 9.65 - 9.95, is the economic capital of Cameroon in the Littoral Region hosts more than 80% of the industries in the Country. It is divided into districts: Akwa, Bassa, Bonaberi, Bonapriso, Bonanjo, Deïdo, NewBell, Akwa North, Madagascar, Yassa, Nyalla, Logbaba, Ndogsimbi, Ndokoti, Ndogpassi, Cite Sic, Logpom as in **Figure 1**. The city handles most of the country's major exports, such as palm oil, cocoa, coffee, timber, metals, fruits. Rivers, spring and wells represent the major sources of water supply to the inhabitants and animal population in the tropical zones and their pollution constitute serious health risks. According to [1], Douala rests directly on unconsolidated alluvial deposits, hosts the largest urban population in the country with a population density of 350 persons per km^2. Inadequate supply of pipe-borne water with only 65.000 persons connected out of 3 million inhabitants pushes the population to depend on groundwater. In Douala, groundwater is the major source of water supply for a large part of the population. The soils vary from yellow through brown to black freely drained sandy, ferralitic soils sandy at the base and sandy-clayey at the top soils [2]. Smaller tributaries like rivers Tongo, Bassa and Ngoua feed major rivers Wouri and Dibamba, which eventually empty in the Atlantic Ocean. The area is characterized by a hyper humid equatorial climate modified by the relief of Mt Cameroon with two seasons, a rainy (April to October) and a dry season (November to March) [3] [4]. Thirty years (1980-2011) of meteorological data from the national archive in Douala show that in the rainy season the average annual rainfall in the study area is 4000 mm/year, and the average monthly temperature is 33˚C according to [5].

Geologic Setting of the Study Area

The Douala Basin covers some 26,500 km^2. About 70% is located offshore, half of which is in deep water. The basin is mainly on- and off-shore Cameroon. To the west and southwest, it extends into the territorial waters of Equatorial Guinea. A number of geological features delimit the basin—The Cameroon Volcanic

Line to the northwest, the Pan African Fold Belt to the east and the Kribi Fracture Zone to the south. The basin is believed to extend westward up to the Gabon-Douala Deep Sea Basin. The Douala Basin is the northernmost of a series of basins located along the South Atlantic margin of Africa. The history of this basin began in Late Jurassic time as a series of northwest-southeast trending intra-cratonic rift basins formed in response to the separation of South America from Africa.

The successive Neocomian and Barremian sequences record two major phases of non-marine sedimentation and rifting, which culminated in the formation of a regional peneplain toward the end of the period. The Late Barremian peneplain was flooded by marine deposits of Aptian age that include thick sequences of salt. This early basin history is unrecorded in the Douala Basin as well as generally do not penetrate sediments older than Aptian. Nonetheless, the thick section below the level of Aptian penetration suggests that the non-marine successions recorded in the basins to the south are also present in the Douala Basin. Salt occurs in the southern part of the basin which is Cretaceous in age and is interpreted to be Aptian by analogy with its dated equivalent in Gabon. The main rock types in Douala City include; sandstones, limestone, shale, and alluvium [6] as in **Figure 2**. Regional stratigraphic and tectonics can be summarized in four main phases of evolution related to pre, syn and post-rift separation of Africa from South America [7].

2. Materials and Methods

2.1. Materials

The field materials and equipment used in the study are listed in **Table 1**.

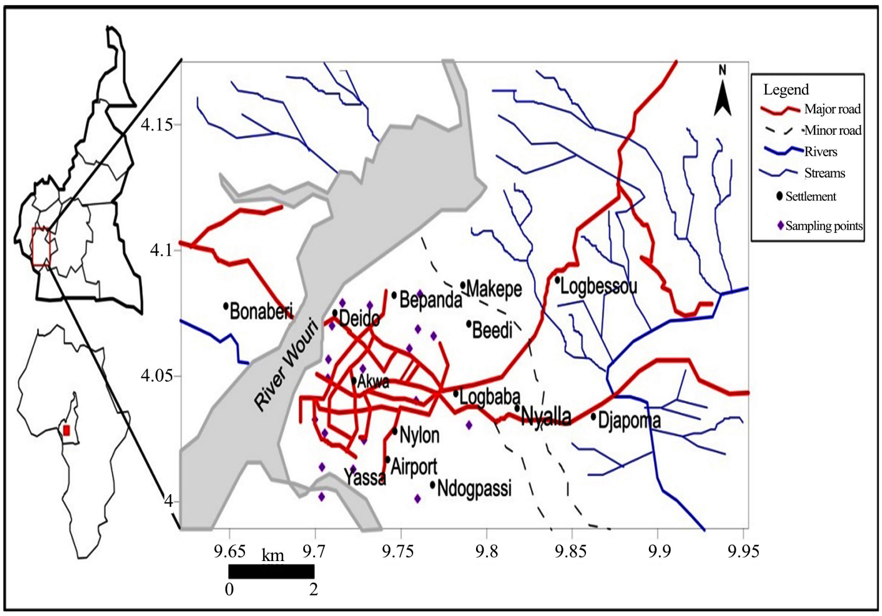

Figure 1. Location map of the study area showing field tested and sampling points.

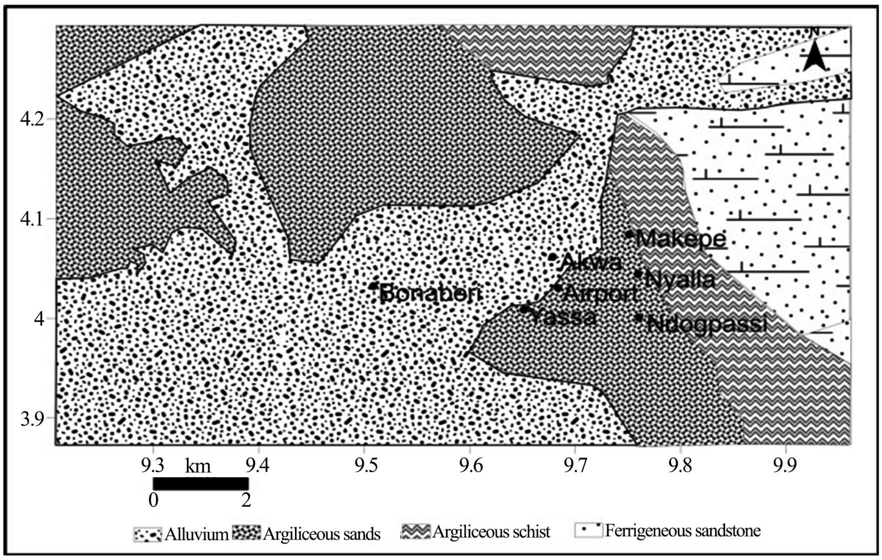

Figure 2. Geologic map of Douala and environs.

Table 1. Field equipment, specifications, and functions.

Equipment/Softwares	Specifications	Functions
Bike	Commercial bikes (Benskin)	To transport fieldworkers to wells
GPS	GARMIN GPSMAP 60CSx	To measure longitude, latitude, and elevation of wells
EC Meter	HANNA HI 98304/HI98303	To measure Electrical Conductivity of water.
pH Meter	HANNA HI 98127/HI98107	To measure the pH of water.
Water level indicator	Solinst Model 102M	To indicate static water levels of water in wells
Measuring Tape	Weighted measuring tape	Measurement of well diameter and depth.
Digital Thermometer	Extech 39240 (−50˚C to 200˚C)	To measure temperature of water
Total Dissolved Solid meter	Hanna HI 96301 with ATC	To measure Total dissolved solids in water
Water sampler	Gallenkampf 1000 ml	To collect well water sample from well
Sample bottles	Polystyrene 500 ml	To hold sample for onward transmission to laboratory
ArcGIS	Version 10.1	GIS Drawing sampling/Tests location maps
Global Mapper	Version 15	GIS Geolocation of wells
Surfer Golden Software	Version 12	GIS plotting contours for spatial distribution
AqQA/Aquachem	Version 1.5	For the analysis/interpretation of water chemistry

2.2. Methods

A reconnaissance survey was carried out to identify wells, springs, and streams in June 2016 as per [8]. Seasonal tests/measurements were carried out in September 2016 wet season and Dry season February 2017 respectively. 212 dug wells, were measured/tested *in situ* for: coordinates of wells, Surface elevation, Well water level, Dug wells depths, well diameter, Electrical conductivity (EC), pH, Total dissolved solids (TDS) and Temperature (˚C). Forty (40) groundwater samples 20 in wet and dry seasons were collected in a high density polyethylene (HPDE) 500 ml bottles sealed and sent to the laboratory as per sampling protocols; [9] [10] using the standard methods of [11] to analyze for:

1) Major cations in mg/L: Ca^{2+}, Mg^{2+}, Na^+, K^+ and NH_4^+;

2) Major anions in mg/L: HCO_3^-, Cl^-, SO_4^{2-}, HPO_4^{2-} and NO_3^-.

Ionic ratio for indicative elements is a useful hydrogeochemical tool to identify source rock of ions and formation contribution to solute hydrogeochemistry [12]. These were used in this study.

Gibbs Diagram is a plot of $Na^+/\left(Na^+ + HCO_3^- Ca^{2+}\right)$ and $Cl/\left(Cl + HCO_3^-\right)$ as a function of TDS is widely employed to determine the sources of dissolved geochemical constituents. These plots reveal the relationships between water composition and the three main hydrogeochemical processes involved in ions acquisition; Atmospheric precipitation, rock weathering or evaporation crystallisation.

Pipers Diagram is a graphical representation of the chemistry of water sample on three fields; the cation ternary field with Ca, Mg and Na + K apices, the anion ternary field with HCO_3, SO_4 and Cl^- apices. These two fields are projected onto a third diamond field. The diamond field is a matrix transformation of the graph of the anions [sulphate + chloride]/Σ anions and cations [Na + K]/Σ cations. This plot is a useful hydrogeochemical tool to compare water samples, determine water type and hydrogeochemical facies [13]. This has been used here for these purposes.

Durov diagram is a composite plot consisting of two ternary diagrams where the milliequivalent percentages of cations are plotted perpendicularly against those of anions; the sides of the triangles form a central rectangular binary plot of total cation vs. total anion concentrations. These are divided into nine classes by [14] which give the hydrogeochemical processes determining the character of the water types in the aquiferous formation [13].

WQI was calculated by adopting Weighted Arithmetical Index method considering thirteen water quality parameters (pH, EC, TDS, total alkalinity, total hardness, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, NO_3^-, NH_4^+) in order to assess the degree of groundwater contamination and suitability using indices and formulae in **Table 2**.

For Agro-industrial suitability the following parameters were used; sodium adsorption ratio SAR, permeability index PI, Magnesium adsorption ratio MAR, percent sodium %Na, Kelly's ratio KR and Residual sodium carbonate RSC and

Wilcox Diagram (Table 2).

The following softwares: Surfer 12, Global mapper 11 and AqQA 1.5 AGIS 10.3 were used for data presentation, interpretation, and analysis.

3. Results and Interpretation

3.1. Physicochemical Parameters

The physicochemical parameters of groundwater in Douala: Temperature, pH, EC and TDS for 212 wells evaluated as demonstrated in Table 3. All physicochemical parameters vary with seasons indicating seasonal influence on the phreatic aquifer.

Table 2. Indices used in the calculation of water quality and irrigation water quality.

	Formula	Reference
Percentage of Sodium	$\%\mathrm{Na} = \frac{\mathrm{Na}^+ + \mathrm{K}^+}{\mathrm{Na}^+ + \mathrm{K}^+ + \mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}} \times 100$	[15]
Kelly's Ratio	$\mathrm{KR} = \frac{\mathrm{Na}^+}{\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}}$	[16]
Magnesium Adsorption Ratio	$\mathrm{MAR} = \left(\frac{\mathrm{Mg}^{2+}}{\mathrm{Mg}^{2+} + \mathrm{Ca}^{2+}}\right) \times 100$	[17]
Total Hardness	$\mathrm{TH}(\mathrm{CaCO_3})\,\mathrm{mg/L} = 2.5\mathrm{Ca}^{2+} + 4.1\mathrm{Mg}^{2+}$	[18]
Residual Sodium Carbonate	$\mathrm{RSC} = \left(\mathrm{CO_3} + \mathrm{HCO_3} - (\mathrm{Ca} + \mathrm{Mg})\right)$	[19]
Sodium Adsorption Ratio	$\mathrm{SAR} = \frac{\mathrm{Na}}{\sqrt{\frac{\mathrm{Ca} + \mathrm{Mg}}{2}}}$	[20]
Permeability Index	$\mathrm{PI} = \frac{\left((\mathrm{Na} + \mathrm{K}) + \sqrt{\mathrm{HCO_3}}\right) \times 100}{\mathrm{Ca} + \mathrm{Mg} + \mathrm{Na} + \mathrm{K}}$	[21] [25]
Water Quality Index	$\mathrm{WQI} = \sum_{i=1}^{n} W_i q_i \left[\sum_{i=1}^{n} W_i\right]^{-1}$	[22]

Table 3. Basic Statistics of the physicochemical parameters in groundwater, for both the wet season and dry seasons.

Parameters	Wet				Dry			
	Min	Max	Mean	Std.	Min	Max	Mean	Std.
T (˚C)	26.3	29	27.4	0.51	24.4	29.6	28.52	0.66
PH	4.6	7.1	6.13	0.57	5.5	7.2	6.35	0.51
EC (mS/cm)	0.02	1.63	0.5	0.29	0.01	1.61	0.36	0.28
TDS (mg/L)	0.01	1.09	0.33	0.19	0.01	1.08	0.24	0.19

3.1.1. Water Level Fluctuations

Depth-to statues water values (m) of groundwater in Douala ranged from 0.12 - 10.13 in the Wet season and 0.32 - 8.2 in the dry season as in Figure 3.

3.1.2. Groundwater Flow Direction

Groundwater flows towards the central parts of the study area during the wet season and dry season but during the dry season some water flows towards the Northwestern part as in Figure 4.

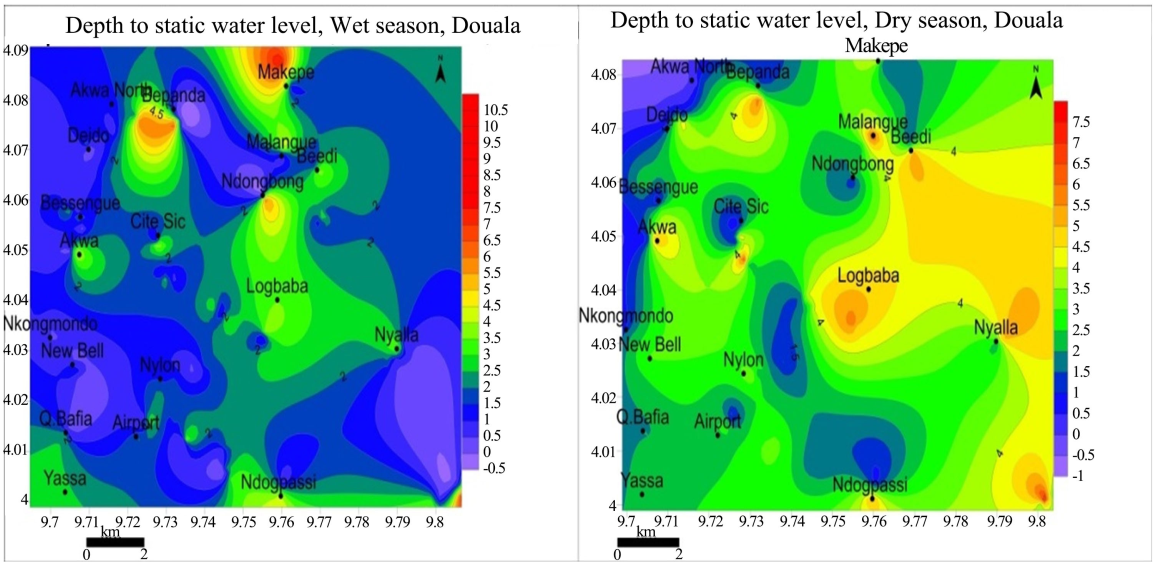

Figure 3. Depth to static water level in Douala; note highwater level is recorded during the wet season than in the dry season. High values are at Makepe and Bepanda in the wet season with high values at Logbaba and Nyalla during the dry season. Low values are at Airport, Nkongmondo and Akwa North for both seasons.

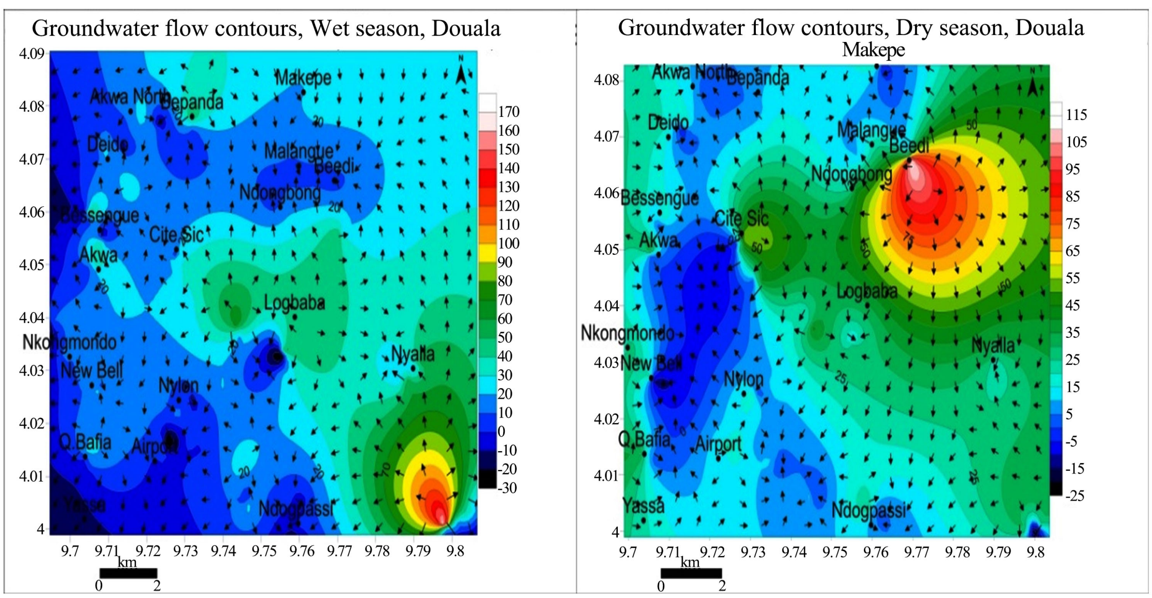

Figure 4. Groundwater flow direction in Douala indicating that water flows towards the Central part of the study area that is towards Malengue, Beedi, and Ndongbong in the wet season but during the dry season some water flows towards Northwestern parts indicating that it is a recharge zone.

3.1.3. Temperature

Temperature values ˚C ranged from 26.3 - 29 in the wet season and 24.4˚C - 29.6˚C in the dry season as in Figure 5.

3.1.4. pH

The pH value of the groundwater samples in the study area ranged from 4.6 - 7.1 in the wet season and 5 - 7.2 in the dry season as in Figure 6. This clearly shows that the groundwater in the study area is acidic to alkaline.

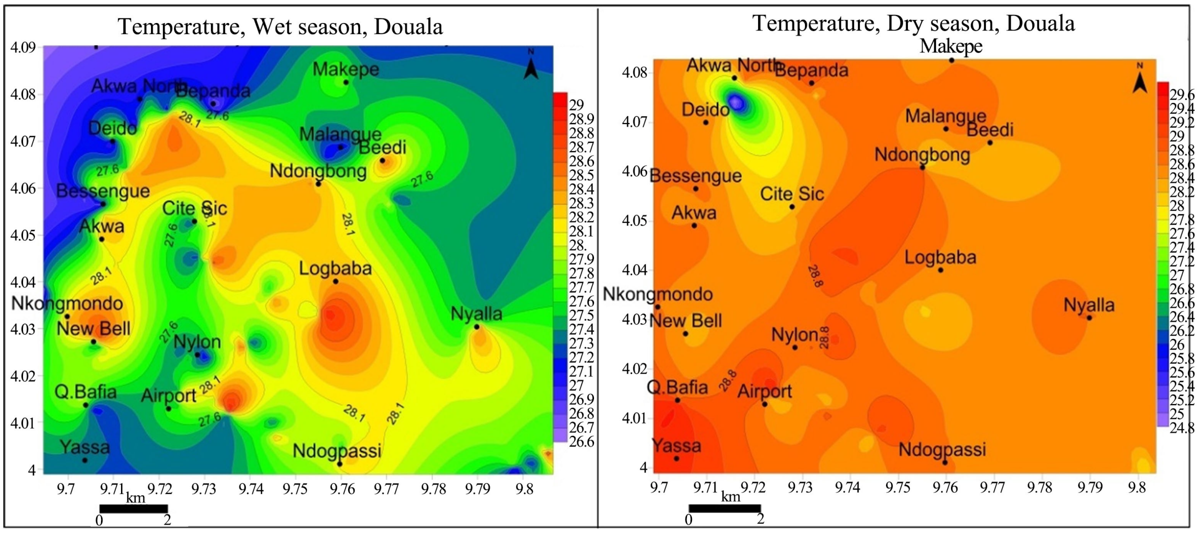

Figure 5. Variation of Douala groundwater temperature; temperatures are generally higher in the dry season and lower in the wet season. High temperatures are in Logbaba, New Bell and Beedi while low values are at Akwa North and Malangu in the wet season and during the dry season, the highest values are found Yassa and Bepanda.

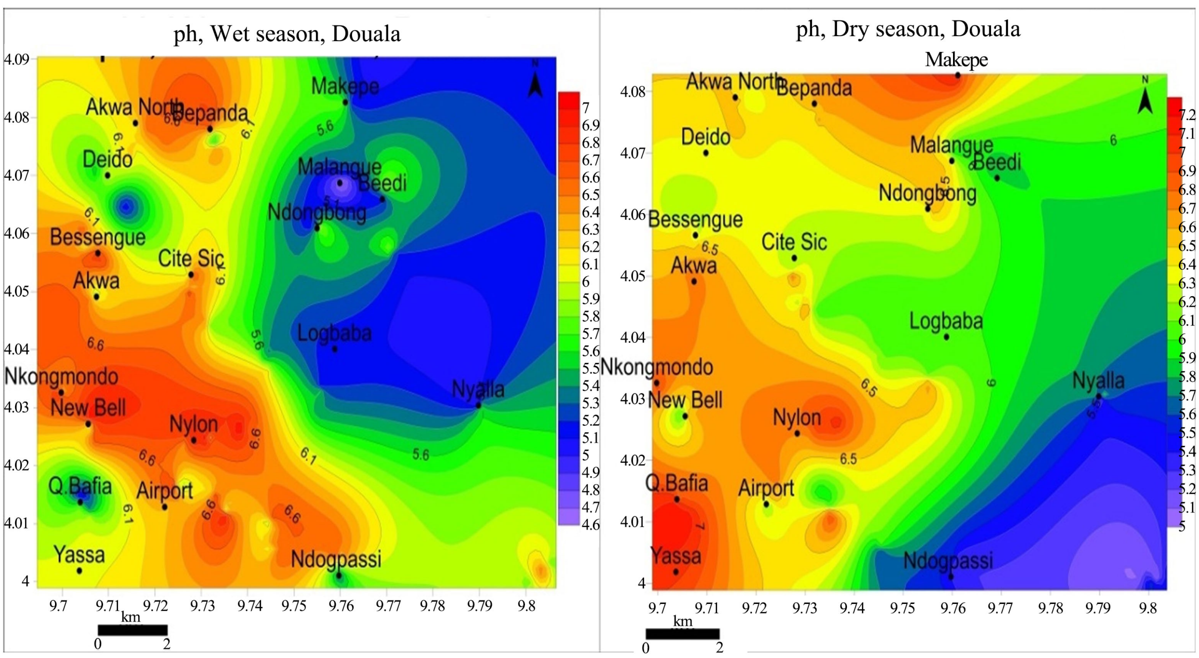

Figure 6. Spatial variation of pH; note decrease in pH values wet season around Nyalla and Logbaba while in the dry seasons the pH values increases around QuatierBafia, Yassa and Makepe.

3.1.5. Electrical Conductivity

The EC ranges from 0.02 - 1.63 mS/cm during the wet season and 0.01 - 1.61 mS/cm during the dry season as in Figure 7. The high electrical conductivity is due to high solute concentration in water.

3.1.6. Total Dissolved Solids (TDS)

The total dissolved solids range from 0.02 - 1.09 mg/L in the wet season and 0.01 - 1.08 mg/L in the dry seasons in Figure 8.

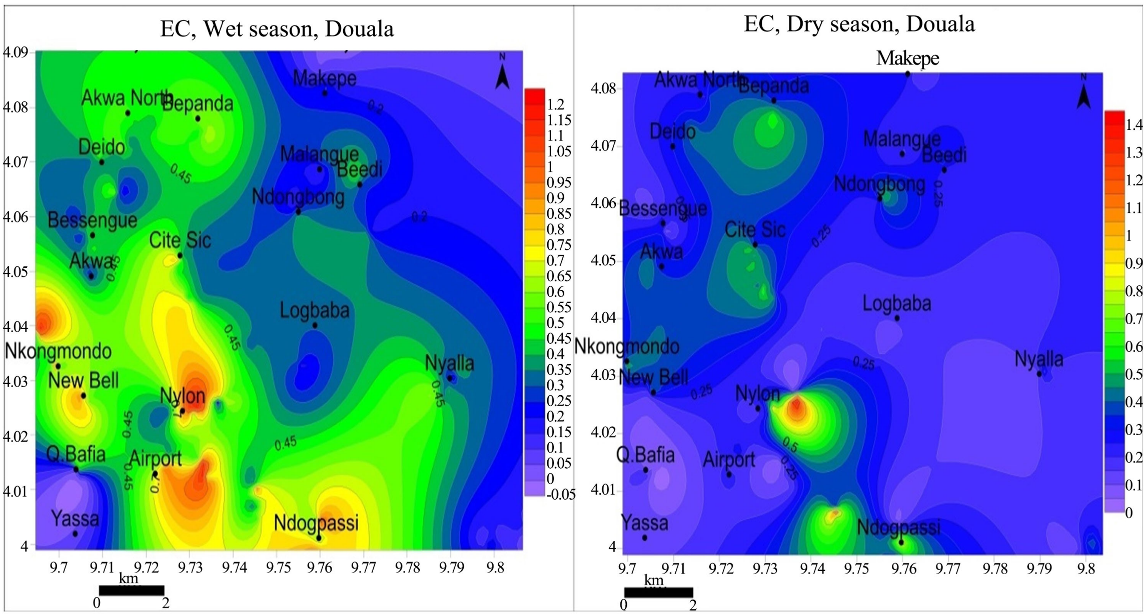

Figure 7. Spatial variation of Electrical Conductivities (mS/cm); EC is at maximum in the wet season and minimum in the dry season.

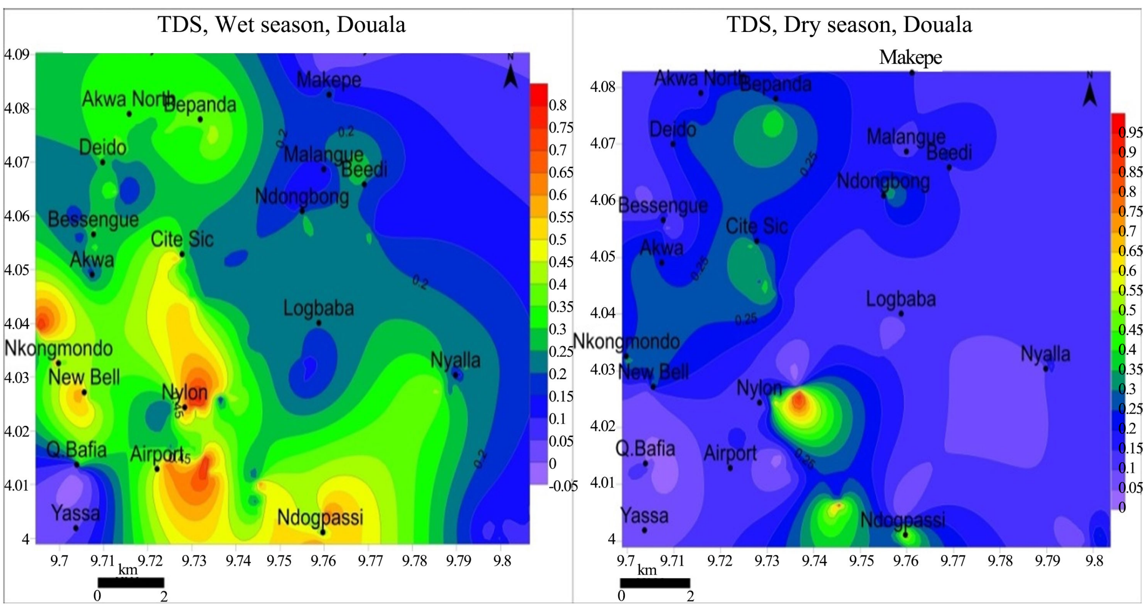

Figure 8. Spatial variation of total dissolved solids mg/L in Douala during wet and dry season. TDS is highest in the wet season and lowest in the dry season. In the wet season, the highest value is at Nylon and Airport.

3.2. Chemical Parameters of Groundwater

The results of the chemical analysis varied in both seasons as shown in Table 4(a) and Table 4(b). Wet season the trend was $Ca^{2+} > Mg^{2+} > K^+ > NH_4^+ > Na^+$ for cations and $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- > HPO_4^{2-}$ for anions.

Dry season: The trend was $Ca^{2+} > Mg^{2+} > K^+ > Na^+ > NH_4^+$ for cations and $HCO_3^- > Cl^- > SO_4^{2-} > HPO_4^{2-} > NO_3^-$ for anions.

Table 4. (a) Results of chemical analysis during wet season; (b) Results of chemical analysis during dry season.

(a)

Wet Season (mg/L)											
SN	Location	Na^+	K^+	Ca^{2+}	Mg^{2+}	NH_4^+	HCO_3^-	NO_3^-	SO_4^{2-}	CL^-	HPO_4^{2-}
1	Quartier Bafia	0	1.25	0	1.25	0	67.1	11.1	3.23	2	0
2	Airport	0.51	5.81	12.4	7.43	0	89.67	6.59	17.87	26	0
3	Nylon	2.24	30.65	90	12.98	0	121.39	6.75	22.5	110	0.17
4	Ndogpassi 1	2.3	26.95	83.8	20.76	0	200.69	8.61	27.5	106	0.17
5	Ndogpassi 3	1.66	21.68	55.8	18.71	0	216.55	7.67	23.62	46	0
6	Yassa	0.23	2.81	0	2.11	0	0	10.11	2.53	6	0.93
7	Nyalla	0.23	2.46	0	1.5	0	0	3.31	3.09	24	0
8	Logbaba	0.41	4.76	3.1	7.1	5.39	0	5.39	5.8	20	0
9	Cite Sic	0.83	10.06	24.8	1.84	7.64	0	5.69	6.69	42	0.51
10	Ndongbong	0.74	8.58	18.6	14.1	14.2	0	4.43	8.61	36	0
11	Beedi	0.51	6.01	12.4	11.31	7.1	0	4.89	7.62	26	0
12	Malangue	0.28	3.16	3.1	2.71	0	0	4.04	1.92	28	0
13	Makepe	0.41	7.41	18.62	3.88	0	10.37	5.02	9.17	10	0
14	Bessengue	0.55	7.41	12.4	2.06	1.44	45.75	3.95	9.87	24	0
15	Akwa	0.74	8.46	18.6	4.9	4.76	71.37	2.58	11.37	48	0
16	Akwa North	0.05	1.76	0	1.76	0	20.13	4.55	2.9	6	0
17	Deido	0.64	7.22	15.6	14	4.34	0	3.92	2.62	42	3.06
18	NkongMondo	1.06	12.68	34.2	10.51	0	87.23	6.29	11.27	32	0
19	New Bell	1.43	17.08	46.6	32.09	0	73.81	5.99	27.55	48	0.25
20	Bonamoussadi	0	0.2	0	1.51	0	33.55	2.24	2.34	4	0
	min	0	0.2	0	1.25	0	0	2.24	1.92	2	0
	max	2.3	30.65	90	32.09	14.2	216.55	11.1	27.55	110	3.06
	mean	0.74	9.32	22.50	8.63	2.24	51.88	5.66	10.40	34.3	0.25
	std	0.68	8.52	26.98	8.26	3.86	65.89	2.34	8.69	29.25	0.700

(b)

Dry Season (mg/L)											
SN	Location	Na^+	K^+	Ca^{2+}	Mg^{2+}	NH_4^+	HCO_3^-	NO_3^-	SO_4^{2-}	CL^-	HPO_4^{2-}
1	Quartier Bafia	0.24	2.39	16	14.25	0	144.3	0	0	0	0
2	Airport	0.65	5.9	15	34.51	0	74.84	0.01	17.33	8	0
3	Nylon	1.54	28.45	95	41.17	0	142.3	0.01	19.84	63	0.01
4	Ndogpassi 1	1.3	27.13	98.3	24.1	0	130	0.02	21.88	52	0.01
5	Ndogpassi 2	1.25	20.24	80.2	26.71	0	153.71	0	20.45	18	0
6	Yassa	0.51	3.44	14	16.94	0	148.84	0.03	0.65	0	0.42
7	Nyalla	0.52	4.03	13	14	0	132.11	0	0.04	23	0
8	Logbaba	0.62	6.23	25.01	35.19	0.13	100	0.01	0.41	15	0
9	Cite Sic	0.91	11.65	20.25	23.04	0.11	0	0.03	0.54	18	0.32
10	Ndongbong	0.64	7.81	15.14	12.64	0.25	0	0.02	1.35	17	0
11	Beedi	0.41	5.11	5.77	6.88	0.12	0	0	1.25	10	0
12	Malangue	0.35	5.21	23.41	12.44	0	9	0	0	12	0
13	Makepe	0.64	10.05	20.34	14.52	0	0	0	9.45	3	0
14	Bessengue	0.68	11.14	15.09	4.85	0	0	0.01	11.01	8	0
15	Akwa	0.96	10.24	20.23	7.09	0.11	19.24	0.01	10.11	35	0
16	Akwa North	0.1	2.79	18	2.35	0	24.15	0	0	2	0
17	Deido	0.45	6.13	15.94	14.17	0.13	18.99	0	0	32	2.77
18	NkongMondo	1	11.45	32.04	9.44	0	160.24	0.02	11.03	24	0
19	New Bell	1.8	18.04	48.24	35.03	0	162.84	0.01	24.03	12.31	0.12
20	Bepanda	0.39	0.34	13	15.09	0	0	0.01	0	0	0
	min	0.1	0.34	5.77	2.35	0	0	0	0	0	0
	max	1.8	28.45	98.3	41.17	0.25	162.84	0.03	24.03	63	2.77
	mean	0.75	9.89	30.20	18.22	0.04	71.03	0.01	7.47	17.62	0.18
	std	0.44	7.91	27.84	11.22	0.07	68.63	0.01	8.86	17.04	0.62

3.3. Mechanism Controlling Water Chemistry

3.3.1. Ionic Ratios of Groundwater in Douala

18 ionic ratios in groundwater were used to deduce formation inputs in Douala, as shown in Table 5.

11 out of the 18 (61.1%) ionic ratios calculated gave indices indicating rock weathering of formations as a source of solute concentration in the groundwater while nitrate ratio indicates no anthropogenic contribution and sulfate indices indicates no oxidation of sulfides. Ca is sourced from gypsum while Na is sourced from halite-albite and ion exchange. Mg is contributed by dolomite dissolution, calcite precipitation or saltwater. There is no plagioclase weathering. High indices values are found in the following localities Logbaba, Bepanda, Cite sic and Akwa North.

Table 5. Ionic ratios for wet and dry seasons with determined formation input.

Ionic ratio	Wet	Dry	Comment	Interpretation
SO_4/Cl	0.06 - 1.62	0 - 3.15	high	Additional sources of SO_4 from weathering of sulfates
Na/Cl	0.00 - 0.04	0 - 0.21	low	No Na-adsorption during freshening and a little silicate weathering
Mg/Cl	0.04 - 0.67	0 - 4.84	high	Cation-exchange and silicate weathering of sandstones.
Na/HCO_3	0.00 - 0.04	0 - 0.05	high	Substantial weathering of Na-feldspar or other Na-silicates
Ca/HCO_3	0.00 - 1.80	0 - 2.60	high	Calc-carbonate dissolution or Calc-silicate weathering
Ca/SO_4	0.00 - 4.00	3.84 - 61	high	Gypsum dissolution present
Ca/Mg	0.00 - 13.48	0 - 7.66	high	Cation-exchange of weathering of silicate rocks.
Ca + Mg/Na + K	0.00 - 7.55	0.00 - 38.48	high	Carbonate weathering
HCO_3/ΣAnions	0.00 - 0.11	0.00 - 0.08	high	Weathering reactions and input of dissolved species in recharge area
NO_3/ΣAnions	0.00 - 0.01	0.00 - 0.00	very low	No anthropogenic contribution
SO_4/ΣAnions	0.00 - 0.01	0.00 - 0.01	very low	No oxidation of sulphides.
Mg/Ca	0.00 - 2.29	0.00 - 4.84	low	Weathering of Silicate rocks
Na/Na + Cl	0.00 - 0.04	0.01 - 1.00	high	Sodium source other than halite-albite, ion exchange
Mg/Ca + Mg	0.07 - 1.00	0.12 - 0.7	high	Dolomite dissolution, calcite precipitation or saltwater
Ca /Ca + SO_4	0.00 - 0.86	0.46 - 1.00	high	Calcium source other than gypsum
Ca + Mg/SO_4	0.39 - 11.30	0.00 - 675		
Na + K − Cl/Na + K − Cl + Ca	0.10 - 1.00	−0.61 - 0.61	high	Plagioclase weathering unlikely
Cl/ΣAnions	0.00 - 0.16	0.00 - 0.04	low	Rock weathering

3.3.2. Gibbs Diagrams of Groundwater in Douala

The Gibbs diagrams were used. All samples plot in the rock-weathering dominance for both seasons. This indicates the mechanism contributing solute to groundwater in Douala is rock-weathering as in Figure 9.

3.3.3. Groundwater Types

The diamond field of piper diagram has further been divided into seven fields classifying water types and designated with alphabets from A to G according to [13]. Using this classification, the water from the study area is distinguished into the A, B, and C categories. The D, E, F, and G water types are absent. In the rainy season; Category A, 2 samples 10%; characterized by normal earth alkaline water with prevailing bicarbonate. Category B, 4 samples 20% are characterized by normal earth alkaline water with prevailing bicarbonate and sulfate or chloride, Category C, 8 samples 40% are characterized by earth alkaline water with prevailing sulfate or chloride Category D, 2 samples 10% are characterized by earth alkaline water; increased portions of alkalis; prevailing HCO_3^- and Category E, 4 samples 20% are characterized by earth alkaline water with added portions of alkalis with prevailing chloride as seen in **Figure 10**.

In the dry season; Category A, 10 samples 50% characterized by normal earth alkaline water with prevailing bicarbonate. Category B, 2 samples 10% are characterized by normal earth alkaline water with prevailing bicarbonate and sulfate or chloride, Category C, 7 samples 35% are characterized by earth alkaline water with prevailing sulfate or chloride and Category E 1 sample 5% are characterized by earth alkaline water with added portions of alkalis with prevailing chloride as in **Figure 10**. The dominant water types are Category C, 40%; Normal earth alkaline water; prevailing SO_4^{2-} or Cl^- in the wet season and Category A, 50%; Normal earth alkaline water; prevailing HCO_3^- in the dry season. The water types in Douala groundwater are MgCl and $MgHCO_3$ for both seasons seen in **Table 6**.

Table 6. Classification of Douala groundwater based on Piper diagram [13] to depict water types and hydrogeochemical facies.

Class	Water Types	Wet		Dry	
		No	%	No	%
A	Normal earth alkaline water with prevailing bicarbonate	2	10	10	50
B	Normal earth alkaline water with prevailing bicarbonate and sulfate or chloride	4	20	2	10
C	Normal earth alkaline water with prevailing Sulfate or Chloride	8	40	7	35
D	Earth alkaline water; increased portions of alkalis; prevailing HCO_3^-	2	10		
E	Earth alkaline water with added portions of alkalis with prevailing chloride	4	20	1	5
Cations field					
1	Calcium rich	8	40	8	40
2	Magnesium rich	12	60	12	60
Anion Field					
4	Bicarbonate rich	8	40	12	60
5	Chloride rich	12	60	6	30
6	Sulfate rich			2	10
	Hydrogeochemical facies				
Field I	$Ca\text{-}Mg\text{-}Cl\text{-}SO_4$	14	70	7	35
Field IV	$Ca\text{-}Mg\text{-}HCO_3$	6	30	13	65

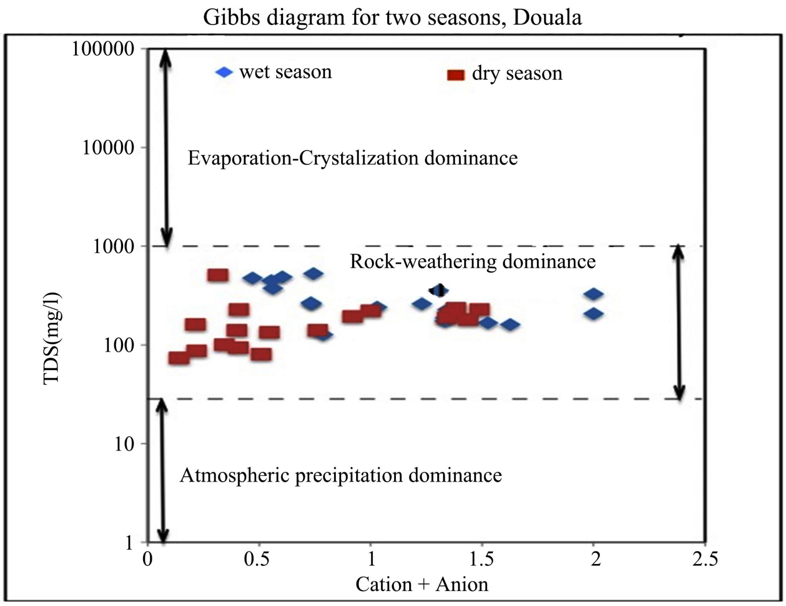

Figure 9. Gibbs diagram for Douala groundwater [23]: In both the wet and dry season all samples plot in the rock-weathering dominance field indicating that rock weathering is the mechanism controlling chemical composition of groundwater in the study area.

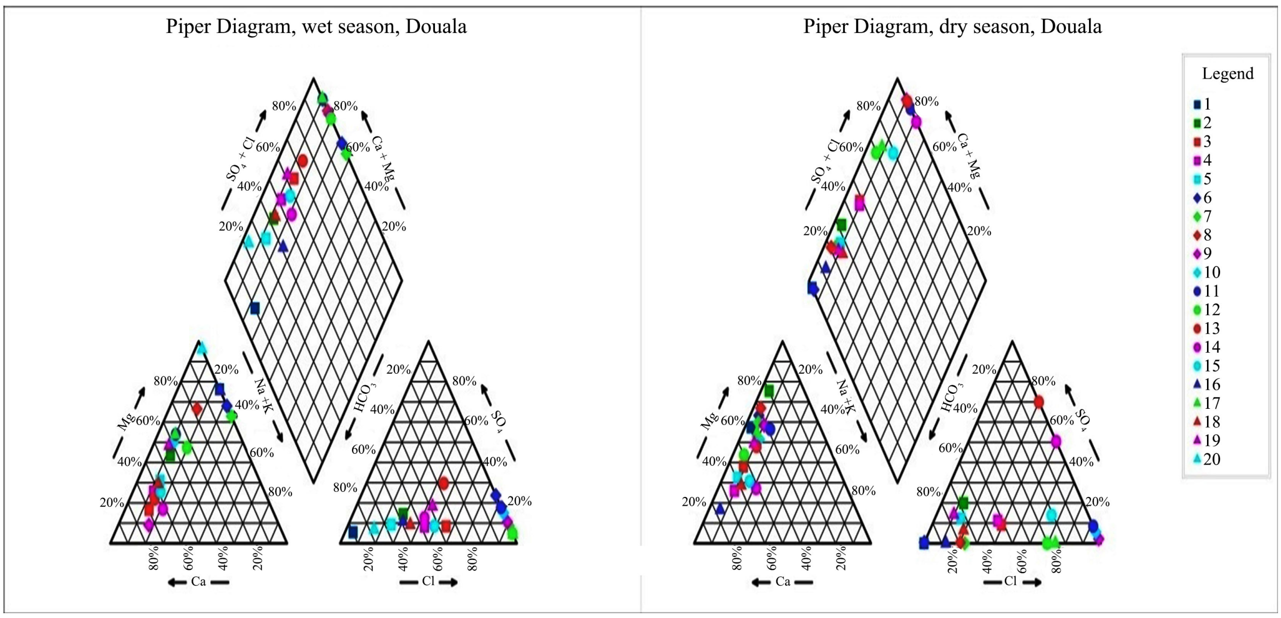

Figure 10. Piper's diagrams [24] for Douala groundwater samples.

Diamond field I: Ca-Mg-Cl-SO_4 hydrogeochemical facies has 14 samples, 70% in the rainy and 7 samples, 35% in the dry season. Field IV, Ca-Mg-HCO_3 hydrogeochemical facies has 6 samples, 30% in the rainy and 13 samples, 65% in the dry season. No samples plotted on field II and field III in both seasons [13].

3.3.4. Hydrogeochemical Facies

From Piper's diagrams, the field I: Ca-Mg-Cl^--SO_4 hydrogeochemical facies has 14 samples, 70% in the rainy and 7 samples, 35% in the dry season demonstrating the dominance of alkaline earths over alkali Ca + Mg > Na + K and strong acidic anions over weak acidic anions. Field IV, Ca-Mg-HCO_3hydrogeochemical facies has 6 samples, 30% in the rainy and 13 samples, 65% in the dry season as shown in Table 7. This facies is characteristic of freshly recharged groundwater that has equilibrated with CO_2 and soluble carbonate minerals under open system conditions in the vadose zone typical of shallow groundwater flow systems in crystalline phreatic aquifers.

No samples plotted on field II and field III.

3.3.5. Durov Diagrams

Based on the classification of [14]: Six classes of processes occur in the rainy season; Class 1 recharging waters: 10 samples, 50%; Class 2 ion exchange water: 5 samples, 15%; Class 3 ion exchange water: 1 sample, 5%; Class 4: mixed water or water exhibiting simple dissolution: 7 samples, 35%, Class 5 simple dissolution or mixing: 4 samples, 20% and Class 6 probable mixing or uncommon dissolution influences: 2 samples, 10% respectively as shown in Table 7. Six classes of processes occur in the dry season: Class 1 recharging waters: 1 sample 5%; Class 2 ion exchange water: 2 sample 10%; Class 3 ion exchange water: 3 samples 15%; Class 46 30% mixed water or water exhibiting simple dissolution may be indicated; Class 5 simple dissolution or mixing: 1 sample 5%; Class 6 probable mixing or uncommon dissolution influences: 7 samples 35% respectively as in Figure 11. There are no Classes 7, 8 and 9 in both seasons.

Table 7. Classification of Water based on Durov diagram.

		Wet		Dry	
SN	Description of Water Types	No	%	No	%
1	HCO_3 and Ca dominant, frequently indicates recharging waters in limestone, sandstone, and many other aquifers	1	5	1	5
2	This water type is dominated by Ca and HCO_3 ions. Association with dolomite is presumed if Mg is significant. However, those samples in which Na is significant, an important ion exchanged is presumed	5	25	2	10
3	HCO_3 and Na are dominant, normally indicates ion exchanged water, although the generation of CO_2 at depth can produce HCO_3 where Na is dominant under certain circumstances	1	5	3	15
4	SO_4 dominant, or anion discriminant and Ca dominant; mixed water or water exhibiting simple dissolution may be indicated.	7	35	6	30
5	No dominant anion or cation, indicates water exhibiting simple dissolution or mixing	4	20	1	5
6	SO_4 dominant or anion discriminate and Na dominant; is water type that is not frequently encountered and indicates probable mixing or uncommon dissolution influences.	2	10	7	35

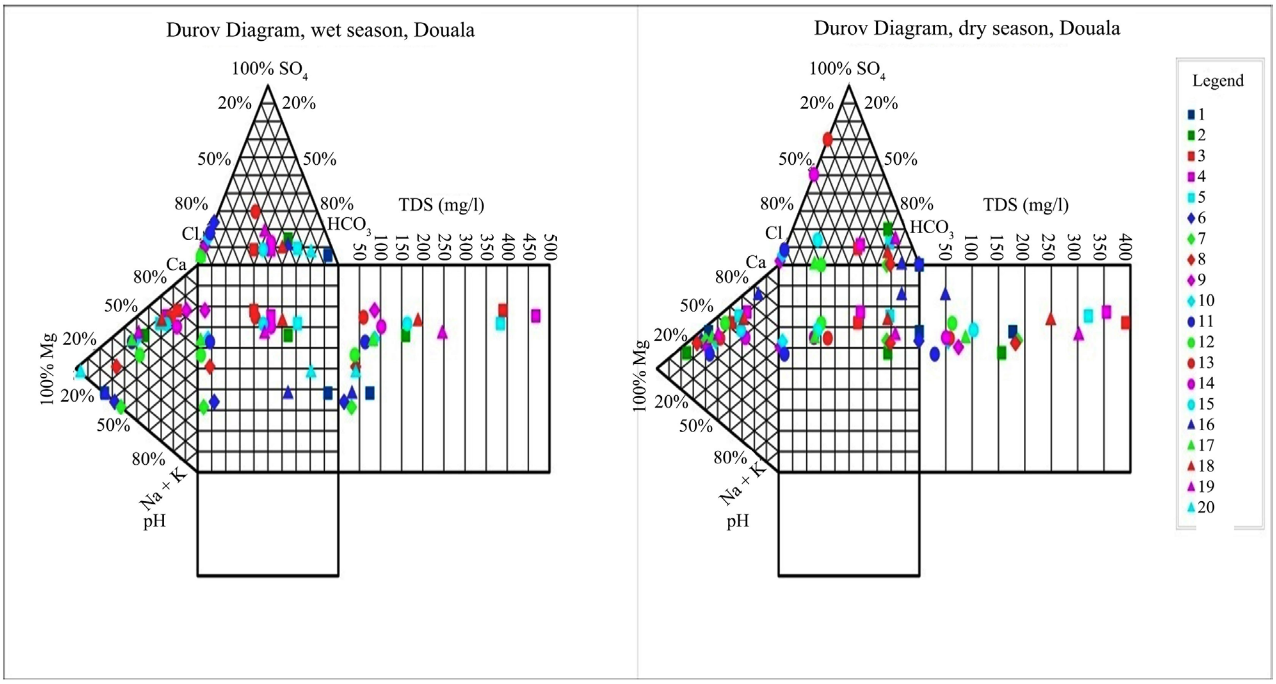

Figure 11. Durov diagrams of Douala groundwater: Six classes of processes occur in the wet and dry seasons each.

3.4. Water Quality

3.4.1. Domestic Water Quality

Ionic content of water in the study area was used to evaluate groundwater suitability for domestic use: The recommended values are of the [26] guidelines. The quality guidelines for drinking water have been specified by [26]. The suitability of groundwater in the study area based on the water quality index WQI and total hardness H_T have the values presented in Table 8.

3.4.2. Water Quality Index (WQI)

The guidelines for permissible concentrations of ions in groundwater [26] were used to calculate WQI values [27]. Water Quality Index WQI is considered the most effective tool to convey the water quality information in its simplest form to the public [28]. WQI values in Douala City ranged from −2.8 - 10.9 in the wet season and 8.8 - 81.5 in the dry season. Groundwater in Douala is excellent to very poor for domestic use as shown in Figure 12 and presented in Table 8.

3.4.3. Total Hardness

The total hardness of groundwater samples range from 5.13 - 294.62 mg/L in the wet season and 42.63 - 402.3 mg/L in the dry season as seen in Figure 13. 60% of groundwater in the study area can be classified as soft, 20% fell in the moderately hard category, and 20% in the wet season is hard water that may be a potential health risk factor whereas in the dry season 15% of groundwater in the study area can be classified as soft, 55% fell into the moderately hard category, 15% is hard water and 15% is very hard [29] as presented in Table 8.

3.5. Water Quality for Irrigational Use

The important parameters which determine the irrigation water quality of the study area.

Table 8. Water quality classifications: WQI, Hardness, SAR, USSL, PI, MAR, RSC and KR indices, Douala.

Water quality classifications: WQI, Hardness, SAR, USSL, PI, MAR, RSC and KR indices, Douala						
Class	Values	Quality	Wet		Dry	
			No	%	No	%
		WQI Classification				
1	0 - 25	Excellent	20	100	12	60
2	26 - 50	Good	0	0	4	20
3	51 - 75	Poor	0	0	3	15
4	76 - 100	Very poor	0	0	1	5
		Hardness Classification				
1	0 - 75	Soft	12	60	3	15
2	76 - 150	Moderately Hard	4	20	11	55
3	151 - 300	Hard	4	20	3	15
4	>300	Very Hard	0	0	3	15
		SAR Classification				
S_1	<10	Excellent	20	100	20	100
		USSL Classification				
C_1	101 - 250	Very Good	3	15	9	45
C_2	251 - 750	Good	16	80	10	50
C_3	751 - 2250	Doubtful	1	5	1	5
		PI Classification				
Class I	>75	Excellent	2	10	4	20
Class II	50 - 75	Good	13	65	16	80
Class III	25	Unsuitable	5	25	-	-
		MAR Classification				
1	<50	Suitable	9	45	8	40
2	>50	Unsuitable	11	55	12	60
		RSC Classification				
1	<1.25	Good	20	100	20	100
		KR Classification				
1	<1	Suitable	20	100	20	100

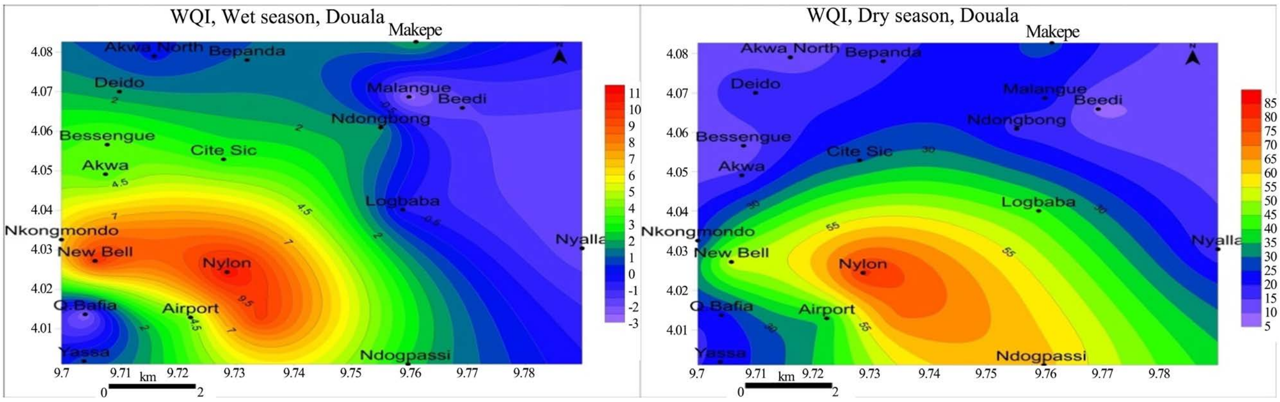

Figure 12. Spatial variation of water quality index during wet and dry seasons; note increase in WQI values during the dry season and decrease WQI values in the wet season.

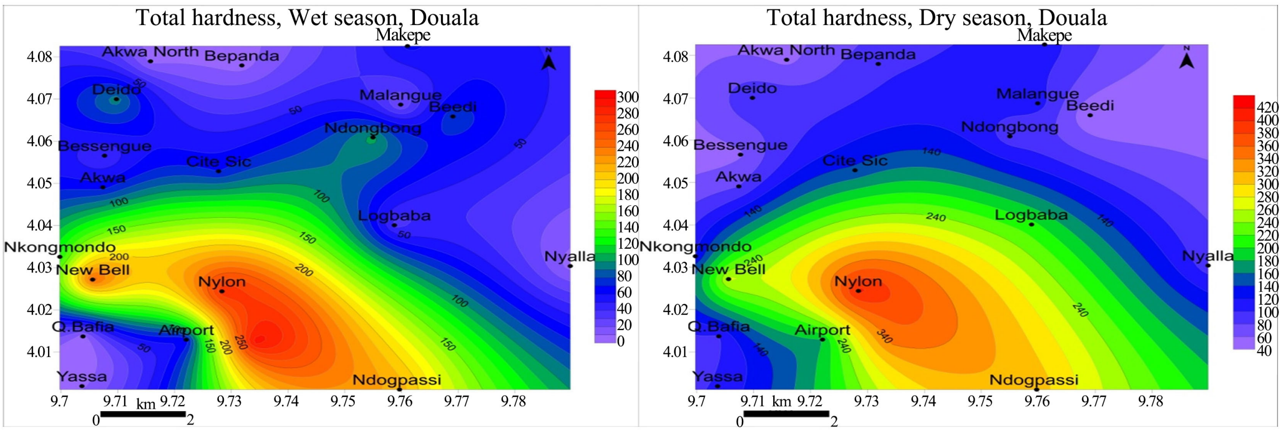

Figure 13. Spatial variation of total hardness in study area during wet and dry season; 60% of groundwater in the study area can be classified as soft.

3.5.1. Sodium Percent

Sodium along with carbonate forms alkaline soil; while sodium with chloride forms saline soil; both of these are not suitable for the growth of plants [30]. The quality classifications of irrigation water based on the values of sodium percentage [15] suggest that the groundwater of the study area is excellent-to-good and good-to-permissible category for both seasons as shown in Figure 14, indicating the water is suitable for irrigation.

3.5.2. Sodium Adsorption Ratio

The USSL Salinity Hazard Classification to crop irrigation is measured by the specific conductance [31]. SAR values ranged from 0.01 - 0.05 in rainy season and 0.0 - 0.06 during the dry season as seen in Figure 15. All the 20 groundwater samples fell in the S_1 class Table 8 for both rainy season and dry season considered suitable for irrigation. In the Wet season 3 samples 15% plotted in the very good field, 16 samples 30% potted in the good field and 1 sample 5% plotted in the doubtful field whereas during the dry season 9 samples 45% plotted in the very good field, 10 samples 50% plotted in the good field and 1 sample 5% plotted in the doubtful field as shown in Figure 16 and presented in Table 8.

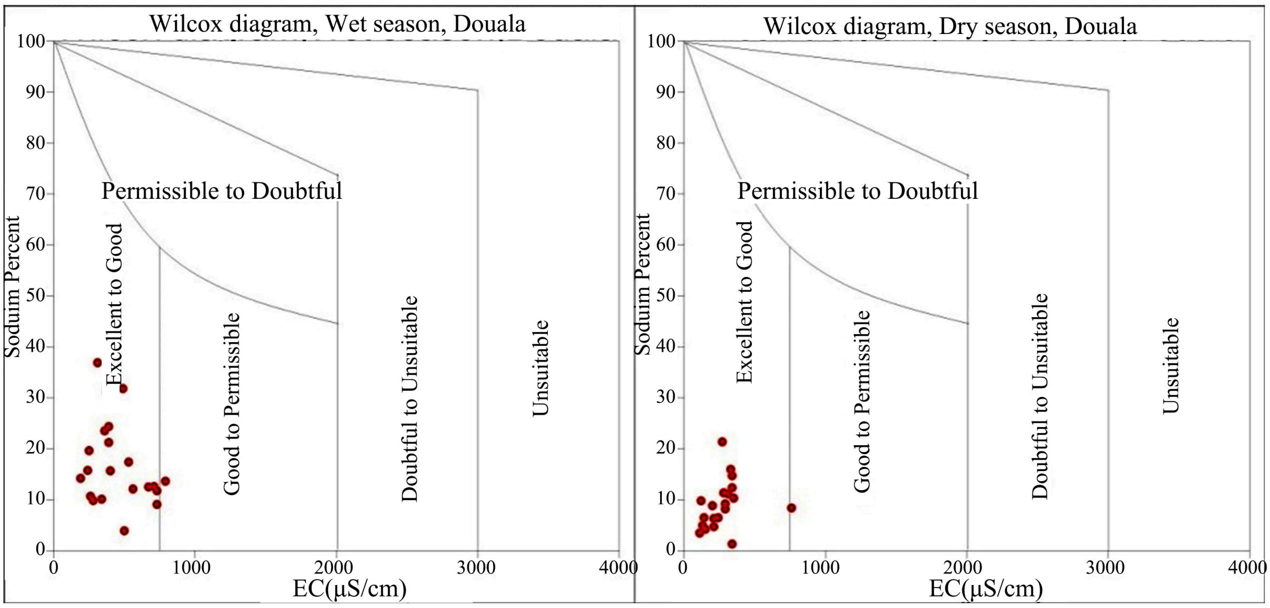

Figure 14. Wilcox diagram showing groundwater suitability for irrigation with all the water samples plotting in excellent to good and good to permissible fields in both wet and dry seasons indicating that the water is suitable for irrigation.

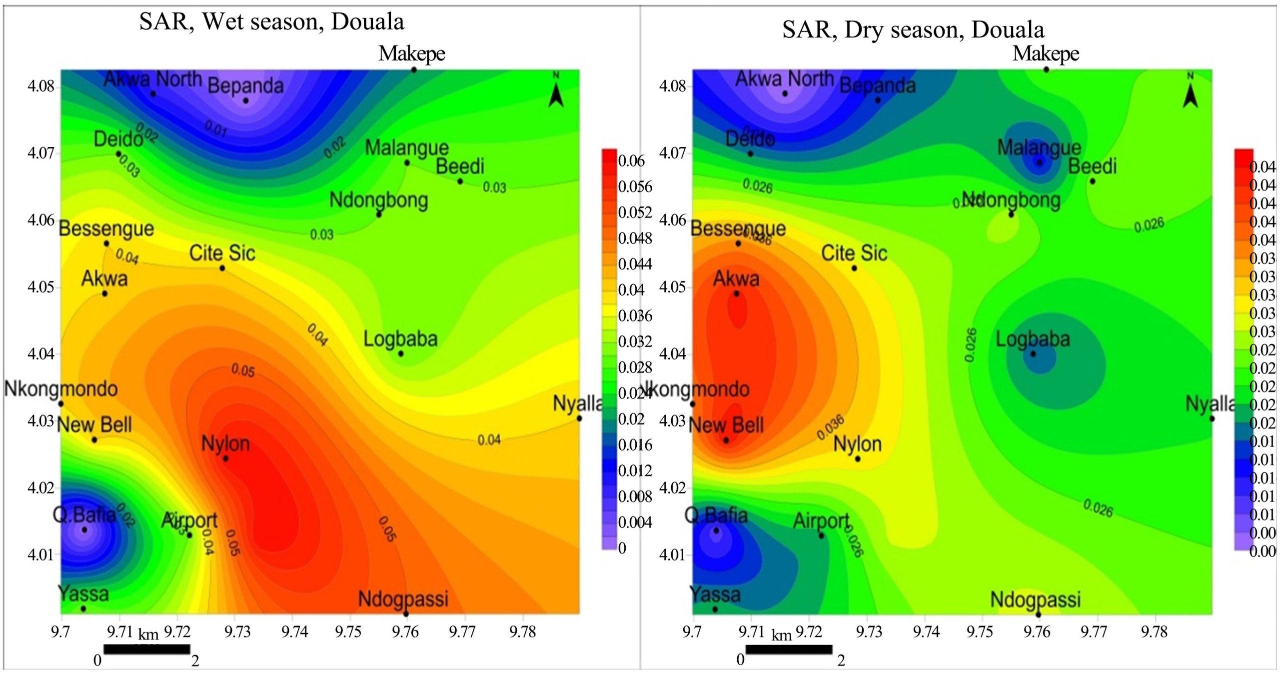

Figure 15. Spatial variation of Sodium adsorption ratio during wet and dry season; Note increase in SAR values during the dry season while in the wet season the SAR values decrease.

3.5.3. Permeability Index

The classification of irrigation waters has been attempted on the basis of permeability Index [21]. The groundwater samples of the study area fell in class-I, II, and III as per Doneen chart, the groundwater samples of the study area are of good quality for irrigation except for 5 samples that plotted in the class III field in the wet season as shown in **Figure 17** and presented in **Table 8**.

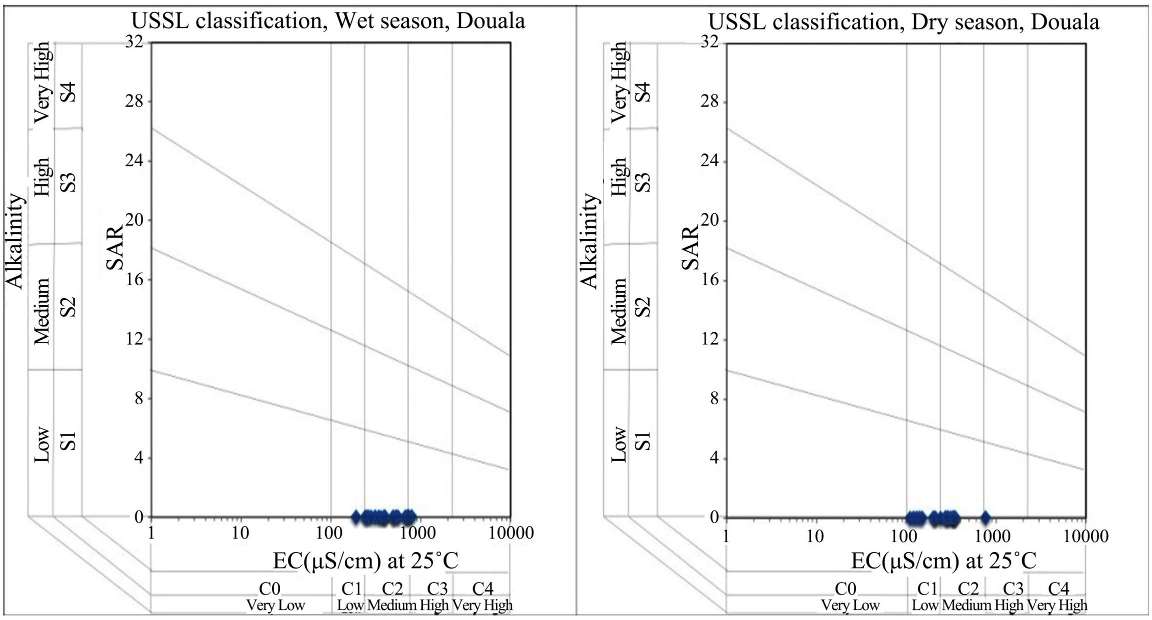

Figure 16. Residual Salinity Hazard classification, Douala; The S_1C_0, S_1C_1, and S_1C_2 make up the excellent, very good and good fields respectively. In the Wet season 3 samples 15% plotted in the very good field, 16 samples 30% potted in the good field and 1 sample 5% plotted in the doubtful field whereas during the dry season 9 samples 45% plotted in the very good field, 10 samples 50% plotted in the good field and 1 sample 5% plotted in the doubtful field.

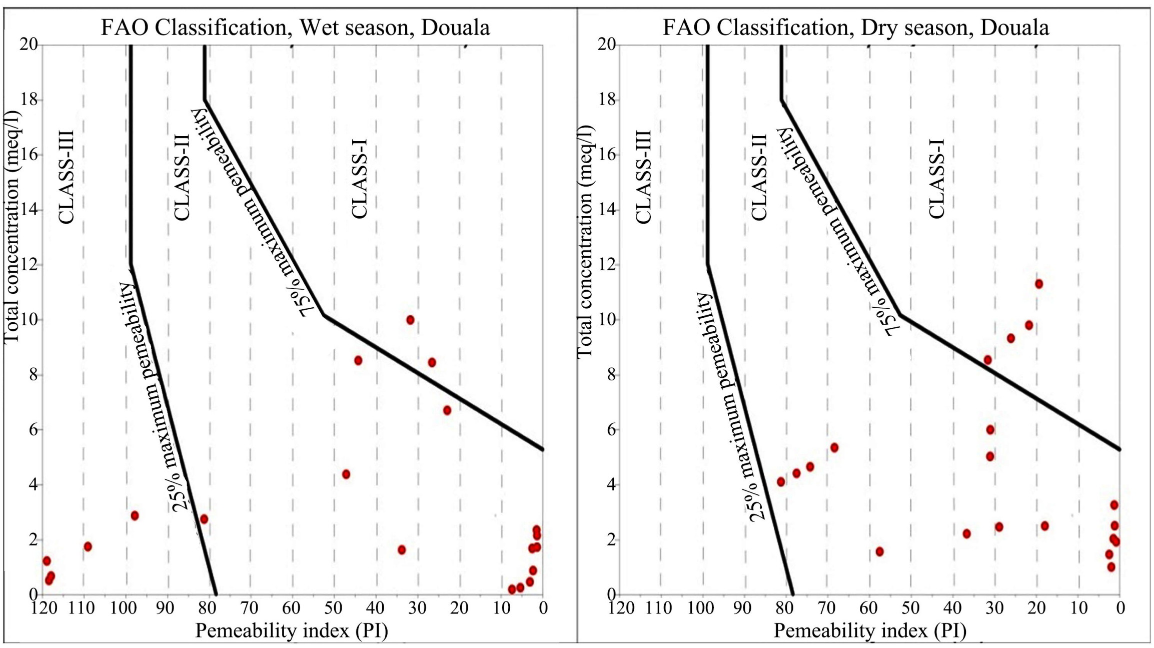

Figure 17. FAO classification of groundwater for irrigation indicating that the water is suitable for irrigation in the dry season. It is that the samples plot in class I and class II field with 5 samples plotting in the class III field during the wet season.

3.5.4. Magnesium Adsorption Ratio

Magnesium adsorption ratio values ranged from 11 - 100 in the wet season and 17.87 - 79.32 in the dry season as in Figure 18. Magnesium adsorption ratio less than 50% it is considered suitable for irrigation purpose. In the study area, 45% of the samples are suitable for irrigation during the wet season whereas 40% of the samples are suitable for irrigation during the dry season; 55% of the samples are unsuitable for irrigation during the wet season whereas 60% of the samples are unsuitable for irrigation during the dry season presented in Table 8.

3.5.5. Residual Sodium Carbonate

The RSC values ranged from −3.79 - 1 in the wet season and −5.38 - 0.38 in the dry season as in Figure 19. All the RSC values are <1.25 in the study area thus rendering the water suitable for irrigation in both seasons presented in Table 8.

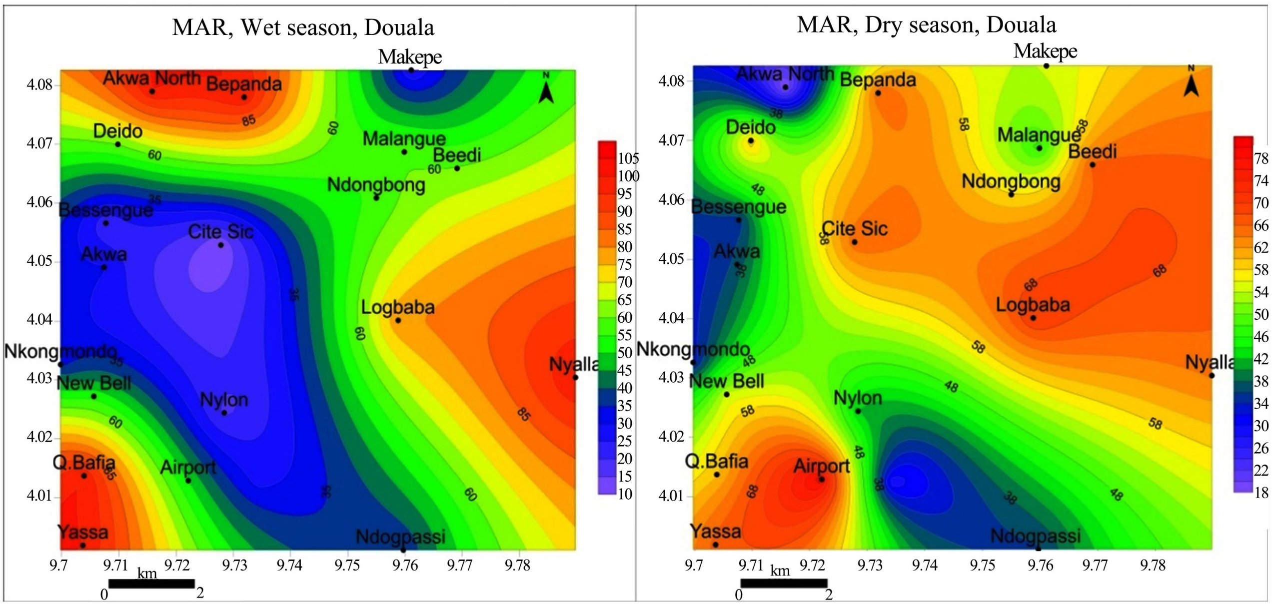

Figure 18. Spatial variation of Magnesium adsorption ratio in the study area during wet season and dry season; note increase in MAR values during the wet season while in the dry seasons the MAR values decrease at Akwa, Nkongmondo, and Ndogpassi.

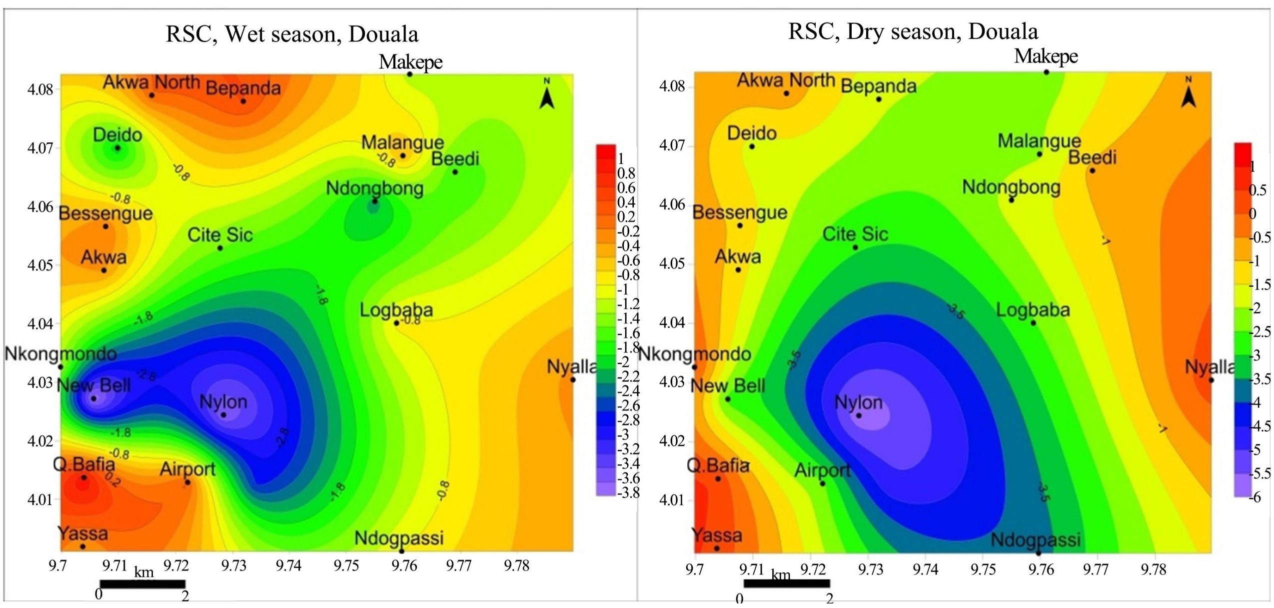

Figure 19. Spatial variation of Residual sodium carbonate in the study area during wet and dry season; note decrease in RSC values during the dry season while in the wet season the RSC values increases.

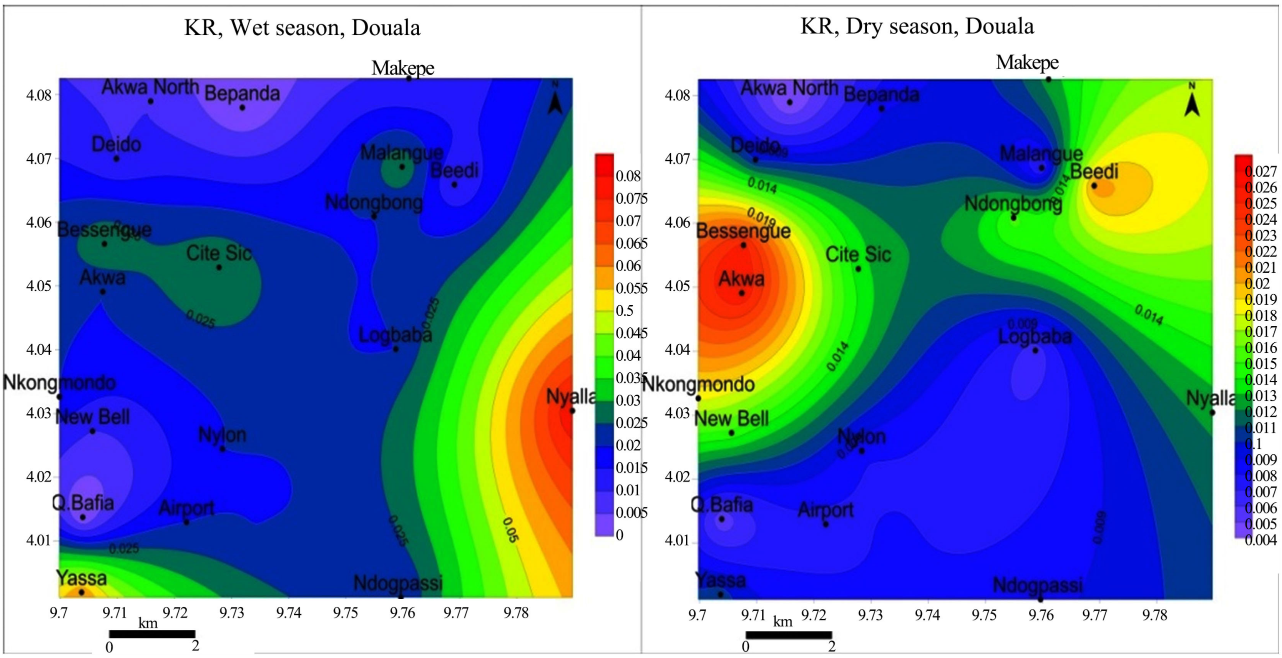

Figure 20. Spatial variation of Kelly's ratio during wet and dry season; note decrease in KR value during the dry season and increases in the wet season.

3.5.6. Kelly's Ratio

KR < 1 is considered suitable for irrigation and KR > 1 is unsuitable. During rainy season, KR values vary between 0.00 - 0.08 during the wet season and during the dry season the values vary between 0.00 - 0.03 as in Figure 20. All groundwater samples in Douala are suitable for irrigation for both seasons presented in Table 8.

4. Discussion

There is a seasonal variation of temperature, pH, EC, and TDS as such the groundwater is in hydraulic connectivity with the atmosphere indicative of a phreatic aquifer. All the major ions fell below acceptable limits for both seasons [26]. From the ionic ratios there are additional sources of SO_4 and silicate weathering possibly of the rocks in this area; weathering of Na-feldspar, other Na-silicates and Ca-carbonate dissolution or Ca-silicate weathering. Cation-exchange of the silicate rocks with the groundwater. Ironic ratio values for nitrate and sulfate are very low as such there are no anthropogenic contribution and no oxidation of sulphides. Solutes from weathering reactions and inputs of dissolved species in precipitation get into the aquifer indicating a recharge zone. From Gibbs diagram there is the dominance of rock-weathering indicating that rock weathering is the mechanism controlling groundwater chemistry in the area. From Durov diagrams the processes involved are; ion exchange, dissolution and simple mixing of groundwater. From Piper's diagrams, the dominant resultant hydrogeochemical facies are Ca-Mg-Cl-SO_4 and Ca-Mg-HCO_3 for both seasons. These facies are characteristic of freshly recharged groundwater that has equilibrated with CO_2 and soluble carbonate minerals under open system conditions in the vadose zone typical of shallow groundwater flow systems in phreatic aquifers.

5. Conclusions

From the above data synthesis, all physicochemical parameters vary with season indicating seasonal influence on all the phreatic aquiferous formations:

The pH indicates that groundwater is acidic to alkaline in all seasons.

All ionic concentrations fall below acceptable WHO limits in all seasons.

Groundwater in Douala is made up of two water types: $CaHCO_3$ and MgCl.

There are two hydrogeochemical facies: Ca-Mg-Cl-SO_4 hydrogeochemical facies characteristic of groundwater some distance along its flow path and Ca-Mg-HCO_3 hydrogeochemical facies characteristic of freshly recharged groundwater that has equilibrated with CO_2 and soluble carbonate minerals under open system conditions in the vadose zone typical of shallow groundwater flow systems in phreatic aquifers.

The Water Quality Index (WQI) for groundwater in Douala is excellent to very poor for domestic use.

The groundwater indices of Sodium Percent (% Na), Residual Sodium Carbonate (RSC), Kelley's ratio (KR), Sodium Adsorption Ratio (SAR), Electrical Conductivity (EC), Total Dissolved Solids (TDS), USSL and Wilcox index were determined, evaluated and found to be suitable for agro-industrial uses in all seasons.

Permeability Index (PI) and Magnesium Adsorption Ratio (MAR) were not suitable in some areas and in some seasons.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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