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Groundwater Monitoring in the Gneisso-Basaltic Fractured Rock Aquiferous Formations of Kumba, Southwest Region Cameroon: Seasonal Variations in the Aqueous Geochemistry and Water Quality

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Abstract

The objective was to determine and monitor seasonal changes during four hydrological seasons: Wet season (September), Wetdry season (December), Dry season (March) and Drywet season (June) in the groundwater aqueous geochemistry and its domestic-agro-industrial quality using physicochemical parameters and hydrogeochemical tools: Temperature, Electrical Conductivity EC, pH, Total dissolved solids TDS, Ionic ratios, Gibbs diagrams, Piper diagrams Durov diagrams, total hardness H_T, Water quality index WQI, Sodium adsorption ratio SAR, Percent Sodium %Na, Kelly's Ratio KR, permeability index PI, Magnesium adsorption ratio MAR, Residual sodium carbonate RSC and Wilcox diagram. Field physicochemical parameters ranged from: Wet season; pH 3.9 - 6.9; Temperature, 23.3˚C - 29.1˚C; EC, 10 - 1900 µS/cm; TDS, 6.7 - 1273 mg/L; Wetdry, pH, 5.7 - 11.7; Temperature, 23.6˚C - 28.3˚C; EC, 1 - 1099 µS/cm, TDS, 0.67 - 736.33 mg/L; Dry pH, 5.7 - 13.1; Temperature, 26.3˚C - 30.2˚C; EC, 12 - 770 µS/cm, TDS, 8.04 - 515.9 mg/L and Drywet, pH, 4 - 7.4; Temperature, 25.8˚C - 30.7˚C; EC, 10 - 1220 µS/cm, TDS, 6.7 - 817.4 mg/L. Seventy-two groundwater samples, 18 per season were analysed. All ionic concentrations fell below acceptable World Health Organization guidelines in all seasons. The sequence of abundance of major ions are; Wet, $Ca^+ > Mg^{2+} > Na^+ = K^+ > NH_4^+$, $HCO_3^- > Cl^- > NO_3^- > SO_4^{2-} > HPO_4^{2-}$; Wetdry $Ca^+ > K^+ > Mg^{2+} > Na^+ > NH_4^+$, $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- > HPO_4^{2-}$; Dry $Ca^+ > K^+ > Mg^{2+} > Na^+ > NH_4^+$, $HCO_3^- > Cl^- >$

NO_3^- > SO_4^{2-} > HPO_4^{2-}; Drywet NH_4^+ > Ca^+ > K^+ > Mg^{2+} > Na^+; Cl^- > HCO_3^- > NO_3^- > SO_4^{2-} > HPO_4^{2-}. Groundwater ionic content was due to rock weathering and ion exchange reactions. $CaSO_4$ is the dominant water type in Wet and Wetdry seasons; followed by $CaHCO_3$, Na + K-Cl Wet, Ca-SO_4 and $CaHCO_3$ Wetdry; MgCl Dry and Drywet followed by CaCl, $CaHCO_3$ Dry and $CaSO_4$, $CaHCO_3$ Dry-Wet. The dominant hydrogeochemical facies are Ca-Mg-Cl-SO_4 followed by Na-K-SO_4 Wet and Ca-Mg- HCO_3^- in all other seasons. Ion exchange, Simple dissolution and uncommon dissolution are the processes determining groundwater character. The water quality indices; WQI, H_T, SAR, %Na, KR, PI, MAR,RSC and Wilcox diagrams, indicate that groundwater in Kumba is 80% - 100% excellent during the Drywet &Wet seasons, 5% - 10% unsuitable during the Wetdry & Dry seasons for domestic use while being excellent-good for Agro-Industrial uses in all other seasons. Physicochemical parameters in some areas exceeded permissible limits for drinking. All hydrogeochemical parameters vary with seasons and these variations show the impact of annual cycles of seasonal changes on the aqueous geochemistry of groundwater in Kumba.

Keywords

Groundwater Monitoring, Hydrogeochemical-Facies, Fractured Rock Aquifer, Groundwater-Quality, Kumba-Cameroon

1. Introduction

Kumba is situated between longitudes 9.39 - 9.49E and latitudes 4.605 - 4.675N Figure 1; is the administrative headquarters of Meme Division and economic capital of Southwest Region of Cameroon. It is at the center of one of the largest cocoa cash crop producing areas in the country.

1.1. Population

The population of Kumba is about 144,268 mostly farmers and business people from almost every ethnic group in Cameroon including: the Hausas (at Hausa Quarters), the Bamilekes (at Bamileke Quarters), the Bakossis (around Krammar and Anglican), the Metasat Meta quarters) and foreign nationals (especially neighboring Nigerians, like the Igbos at Igbo Quarters). The indigenes are the Bafawsat Kumba Town and the Balondos at Kake. The indigenous tribes constitute only a small percentage of the entire population. The main languages spoken are English; French with pidgin and dialects amongst the various ethnic groups (Akoachere & Ngwese, 2016).

1.2. Climate

Kumba generally has a hot and humid equatorial climate with two seasons: a short Dryseason of about 4 months (December to March) and a long rainy season

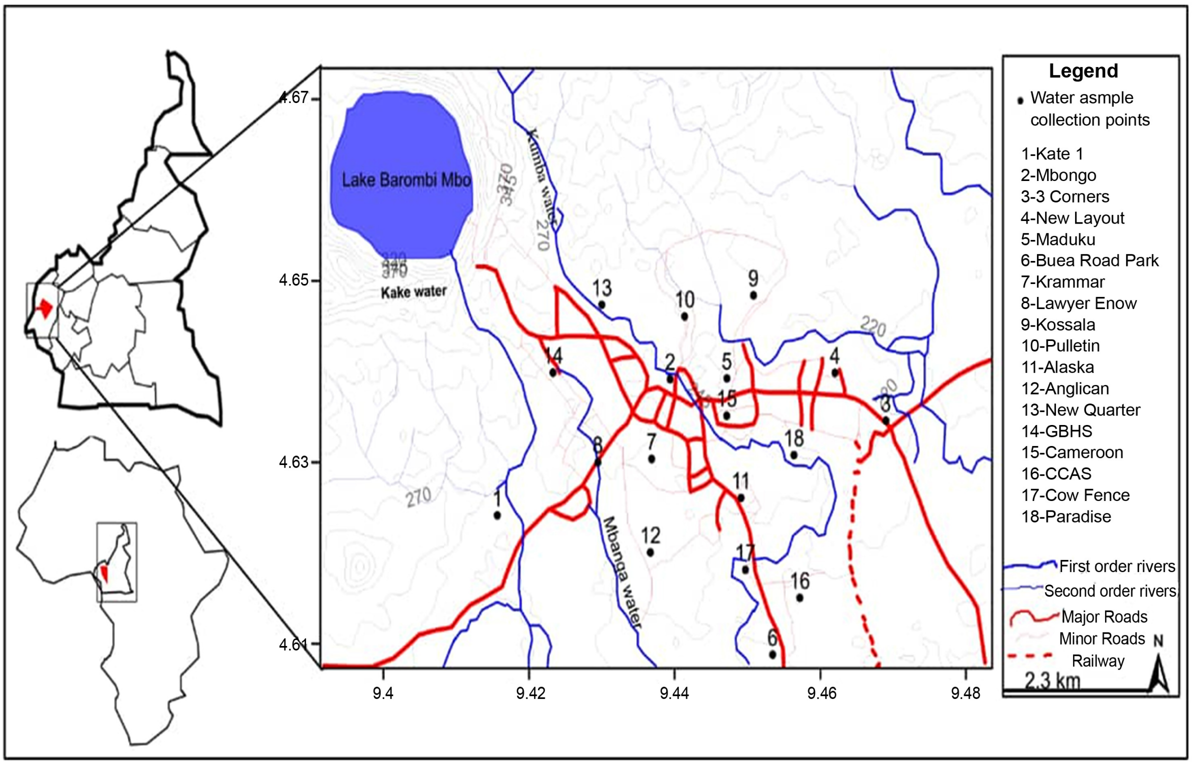

Figure 1. Location of measurements, tests and sampled points during the study in Kumba.

(April to November). Annual rainfall ranges from 2298 mm to 3400 mm. The average annual air temperature is 27˚C (Akoachere & Ngwese, 2016).

1.3. Vegetation

Kumba is located in the tropical rainforest with vegetation that varies from savannah to forest (around Lake Barombi Mbo). The evergreen and semi-deciduous forests contain economically important tree species (iroko, mahogany, obeche, ebony, padouk, tiama, framire, sapelline, makore and bobinga, etc.). The herbaceous layer is dominated by Pennisetumpurpureum and Imperatacylindrica with a ligneous cover that is heavily affected by human activity. The river valleys are covered with Indian bamboo (Bambousa species) whose stems are used for handicraft activities (Akoachere & Ngwese, 2016). Deforestation is the main cause of environmental degradation in Kumba. It arises from human activities, especially inappropriate farming practices (shifting cultivation), overgrazing, bush fires, poaching and illegal logging (Akoachere & Ngwese, 2016).

1.4. Soils

A wide variety of soils exist in Kumba including: clayey soils (earthy) around Kake, Mbonge Road, Kumba Town, Krammer and Anglican; gravelly soils (brick red) around Buea Road; sandy soils (pale yellow to earthy) around Kossala; and laterites (brick red) in almost every part of the town. Soils' grain-sizes range from coarsegrained to fine grained, poorly sorted to moderately well-sorted.

1.5. Surface Water

Kumba has numerous streams of small discharges (Kumba water, Kake water, Mbanga water), springs (including Cold spring and Mother Spring) and lake Barombi Mbo which constitutes a huge freshwater reserve.

1.6. Geology

Kumba is situate in the Kumba Plain, a grabben intercalated between the strato-volcanoes of Mt Cameroon and MtsRumpi (Sehar et al., 2011), at the northwestern edge of the Douala Basin **Figure 2**. The Cameroon Line (CL) is an alignment of Tertiary-to-Recent alkaline volcanoes, plutons and grabbens extending over more than 1600 km stretching from the Atlantic oceanic island of Annobon through the Gulf of Guinea and within the African continent (Parihar et al., 2012).

The Douala basin probably formed from a Precambrian cratonisation, granitisation and sedimentation phase followed by the Pan-African orogenesis, the Afro-Brazilian depression (the site of the future Cameroon Atlantic basin) with epi-continental sedimentation which may have begun during the lower Cretaceous discordant Cretaceous to Pliocene sediments on the Precambrian Pan-African basement and covered in some areas by Miocene sedimentation and volcanism (Loko et al., 2013). The geology of the Kumba Plain (Kumba Volcanic Field) is controlled by three main volcanic activities (which probably occurred between the Eocene and 1Ma ago). These include: old basaltic lavas covering the entire plain; cinder cones and phreatomagmatic units; and short vesicular basaltic lava flow (Prasad et al., 2014). There are 4 maars in the Kumba Plain. These

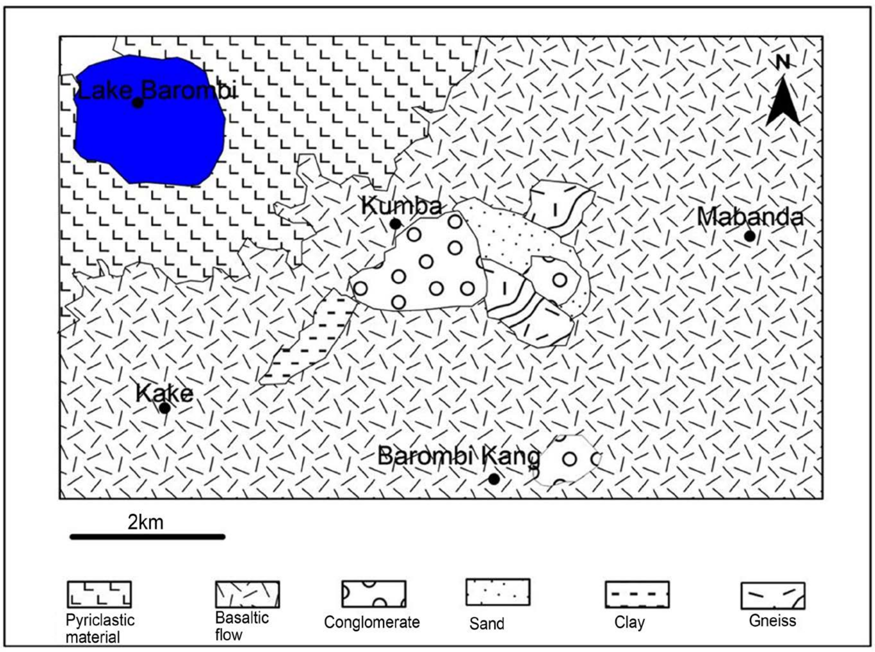

Figure 2. The Geology of Kumba: Made up of six major geologic formations Basalt, Conglomerate, Basalt, Pyroclasites, sand and Clay.

include: the Barombi Mbo, Barombi Koto, Mbwadong and Dissoni Maars, with the first two occupied by Lakes Barombi Mbo and Lake Barombi Koto. Based on the composite fragments contained in the Barombi Mbo Maar (BMM) pyroclastic deposits, it is likely that the maar cuts through a geological succession composed by granite gneissic formations, sandstones, and basaltic lava flows; the same formations that make up the *Kumba Volcanic Field* (Al-Khatib & Arafat, 2009) (**Figure 2**).

Volcanic formations of the plain have been emplaced over Panafrican metamorphic formations intruded by granitoids and locally covered by Cretaceous continental sandstones. They commonly enclose mantle peridotite xenoliths (Nagarnaik & Patil, 2012). Conglomerates outcrop at the Buea Road area. They are poorly sorted; containing grains ranging from clays to boulders, with intense weathering. Fine grained sandstones (pale yellow to earthy in color) outcrop around Kossala. Pyroclastic materials from ash to bombs (mostly ash) outcrop at the BMM. Lava flow structures outcrop at some parts of Kake water and Kumba Water (at Buea Road) river beds, and rounded basaltic boulders (both massive and phorphyritic) along the banks of Kumba Water (up to several meters away from the river in some places) at Up-station to Ntchako Street and around Kake Water at Ekoka Falls. Gneisses outcrop at Fomenky Street (Buea Road), Osheami quarter, three corners, Farm road and Solar quarters (Fiango).

1.7. Hydrogeology

Weathered basement (regolith), fractured-gneiss, basalts, pyroclastics and recent alluvium are the aquiferous formations in the area. Saturated hydraulic conductivities of the aquiferous formations range from 2.88E-08 to 1.60E-06 m/d (Akoachere & Ngwese, 2016), groundwater velocities from 1.96E+01 to 6.34E+02 m/d (Akoachere & Ngwese, 2017), first estimates of well yields from 4.6E-01 to 2.28E+01 m/d (Akoachere & Ngwese, 2016) and the hydraulic conductivities of the vadose zone from 7.96E+02 to 3.27E+04 m/d. and stream discharges 1.79E+05 to 9.13E+05 m^3/d (Ayuk & Mesode, 2017).

2. Methods and Procedures

2.1. Methods

A detailed field program of bore well data acquisition; field hydrogeological measurement/tests, sampling and laboratory analysis of collected groundwater samples was conducted in Kumba using appropriate equipment and softwares **Table 1**, ISO 5667 1 (International Organization for Standardization, 2006), ISO 5667-11 (International Organization for Standardization, 2009), ISO 5667-3 (International Organization for Standardization, 2003) and Barcelona et al. (1985).

Determination of indices for suitability of groundwater for Agro-Industrial uses was done using formulae in **Table 2**.

1) Ionic ratio for indicative elements is a useful hydrogeochemical tool to identify source rock of ions and formation contribution to solute hydrogeochemistry (Hounslow, 1995). These were useful in this study.

Table 1. Field Equipment, Softwares, their specifications and functions.

Equipment/Softwares	Specifications	Functions
Bike	Commercial bikes (Bensikin)	To transport fieldworkers to wells
GPS	Garmin GPS map 60 CSx	To measure longitude, latitude and elevation
EC Meter	Hanna HI 98,304/HI 98,303	To measure Electrical Conductivity of water.
pH Meter	Hanna HI 98,127/HI 98,107	To measure pH of water.
Water level indicator	Solinst Model 102M	To indicate static water levels of wells
Measuring Tape	Weighted measuring tape	Measurement of well diameter and depth.
Digital Thermometer	Extech 39,240 (−50˚C to 200˚C)	To measure temperature of water
Water sampler	Gallenkampf 1000 ml	To collect well water sample from well
Sample bottles	Polystyrene 500 ml	To hold sample for 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 15	For the analysis/interpretation of chemistry

Table 2. Formulae for the determination for indices/parameters for water quality assessment Kumba.

Indices	Formula	Reference
Percentage Sodium	$\%\mathrm{Na}=\frac{\mathrm{Na}^{+}+\mathrm{K}^{+}}{\mathrm{Na}^{+}+\mathrm{K}^{+}+\mathrm{Ca}^{2+}+\mathrm{Mg}^{2+}}\times 100$	(Wilcox, 1955)
Kelly Ratio	$\mathrm{KR}=\frac{\mathrm{Na}^{+}}{\mathrm{Ca}^{2+}+\mathrm{Mg}^{2+}}$	(Kelley, 1940)
Magnesium Absorption Ratio	$\mathrm{MAR}=\left(\frac{\mathrm{Mg}^{2+}}{\mathrm{Mg}^{2+}+\mathrm{Ca}^{2+}}\right)\times 100$	(Szaboles & Darab, 1964)
Total Hardness	$\mathrm{TH}\ (\mathrm{CaCO_3})\ \mathrm{mg/L}=2.5\ \mathrm{Ca}^{2+}+4.1\ \mathrm{Mg}^{2+}$	(Todd, 1980)
Residual Sodium Carbonate	$\mathrm{RSC}=\left(\mathrm{CO_3}+\mathrm{HCO_3}-\left(\mathrm{Ca}+\mathrm{Mg}\right)\right)$	(Eaton, 1950), (Raghunath, 1987)
Sodium Absorption Ratio	$\mathrm{SAR}=\frac{\mathrm{Na}}{\sqrt{\frac{\mathrm{Ca}+\mathrm{Mg}}{2}}}$	(Richard, 1954)
Permeability Index	$\mathrm{PI}=\frac{\left(\left(\mathrm{Na}+\mathrm{K}\right)+\sqrt{\mathrm{HCO_3}}\right)*100}{\mathrm{Ca}+\mathrm{Mg}+\mathrm{Na}+\mathrm{K}}$	(Doneen, 1962)
Water Quality Index	$\mathrm{WQI}=\sum_{n}^{i=1}W_i q_i\left[\sum_{i=1}^{n}W_i\right]^{-1}$	(Sisodia & Moundiotiya, 2006)

Gibbs Diagram is a plot of $Na^+/Na^+ + HCO_3^- Ca^{2+}$) and $Cl^-/(Cl + HCO_3^-)$ as a function of TDS are widely employed to determine the sources of dissolved geochemical constituents (Gibbs, 1970). These plots revealed the relationships between water composition and the three main hydrogeochemical processes involved in ions acquisition; Atmospheric precipitation, rock weathering or evaporation crystallisation over the four seasons.

2) 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 es ,the anion ternary field with HCO_3, SO_4 and Cl^- apices. These two fields are projected onto a third diamond field (Piper, 1944). 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 (Langguth, 1966). This has been used here for these purposes in the four seasons.

3) 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 (Durov, 1948). These are divided into nine classes which give the hydrogeochemical processes determining the character of the water types in the aquiferous formation (Lloyd & Heathcoat, 1985; Langguth, 1966).

4) 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 over the period of the four seasons (**Table 2**) (Sisodia & Moundiotiya, 2006).

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.

The following Softwares; Surfer 12, Global mapper 11 and AqQA 1.5 AGIS 10.3 were used as platforms for data presentation, data interpretation and data analysis.

2.2. Procedures

A field visit was done using hydrogeological traverse field mapping to determine appropriate hand-dug wells, boreholes, springs and streams. Kumba was divided into zones and work was carried out in four hydrogeological seasons; Wet season, September; Wetdry season, December; Dry season, March and DryWet season, June. GIS platforms were used to analyze field data for the creation of sample location, drainage and water level contour maps. All equipment used were calibrated according to manufacturer's specifications.

Temperature, pH, Electrical conductivity Temperature, pH and electrical conductivity were measured onsite for 450 representative hand-dug wells during the four seasons: 1800 measurements for each of the four parameters. At each hand-dug well, a sample was collected and the Temperature, EC, pH and TDS meters were measured. 18 spatially representative groundwater samples were collected for four seasons: 72 water samples from; Kake 1, Mbongo Str., 3 Corners, New Layout, Maduku Str., Park, Krammar, Lawyer Enow, Kossala, Pulletin Str., Alaska Str., Anglican, New Quarter, GBHS, Cameroon Str., CCAS, Cow Fence and Paradise Str were analyzed.

At each hand-dug well, a clean polyethylene bottle was rinsed thrice with well water and then filled to its brim.

The 73 (18 per season plus one rain) samples were collected in 500ml containers, sealed and sent to the Institute of Agricultural and one Research and Development-I.R.A. Dusing the standard methods (APHA, 1995) 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^-.

To fully understand the relationship between the geology of the area and groundwater, hydrogeochemical tools were used such as ionic ratios, Gibbs Diagrams, Piper diagrams and Durov diagrams. For domestic agro-industrial water quality; Percent Sodium %Na, Kelly's Ratio KR, permeability index PI, Magnesium adsorption ratio MAR, Residual sodium carbonate RSC and Wilcox diagram. These were done for four seasons to determine the seasonal variations in these aquiferous formations.

3. Results and Discussions

1) Physicochemical Parameters

The field measured physicochemical parameters of groundwater Kumba are, Temperature, pH, EC and TDS **Table 3**.

The individual parameters are discussed below.

2) Depth to Water Level

Well diameters range from 0.6 - 1.5 m, well depths from 1 - 18 m. The wells have depth to water levels ranged from 0.02 m - 11 m in Wet season, 0.6 m - 11.66 m Wetdry season and 0.5 m - 11.48 m Drywet season **Figure 3**. The depth to water varies with the seasons and the water table is lowest during the Dry season. Most wells with depths less than eight meters in most areas were dry with a few centimeters of water at during this period; a reason for the absence of Dry season depth to water and groundwater level contours. In some wells during the Wet season, the water table is at the surface with an exceedingly high pollution potential as run off fills the wells with all kinds of runoff loads. Especially so, since many wells are poorly constructed (Ayuk & Mesode, 2017).

3) Groundwater Level Contours

From elevation and depth to water level, the groundwater contours were drawn with equipotential vectors simulating groundwater flow lines and flow direction **Figure 4**. Groundwater flows from the central slightly elevated Kumba plain to the surrounding areas radially outwards in a topography driven piston flow typical of phreatic aquiferous formations.

4) Temperature

The seasonal groundwater temperatures ˚C range from 23.3 - 29.1 in the Wet; 23.6 - 28.3 Wetdry; 26.3 - 30.2 Dry and 25.8 - 30.7 Drywet, **Figure 5**. There is a general increase from Wet to Dry season in rhythm with air temperature variations typical of phreatic aquiferous formations. Groundwater temperatures varied over the seasons with a peak of 30.7˚C in the Drywet season.

5) pH

pH ranges from 3.9 - 6.9 in the Wet season, 5.7 - 11.7 Wetdry season, 5.7 - 13.1 Dry season and 4 - 7.4 Drywet season. pH is strongly acidic to peralkaline in Wet and Drywet seasons and strongly acidic to strongly alkaline in Wetdry to Dry seasons Figure 6. Mean pH were slightly acidic in the Wet, neutral in the Wetdry, peralkaline in the Dry and slightly acidic in the Drywet seasons.

Table 3. Seasonal variations and basic Statistics of physicochemical parameters of groundwater in Kumba.

	Wet				Wetdry				Dry				Drywet			
	Min	Max	Mean	Std	Min	Max	Mean	Std	Min	Max	Mean	Std	Min	Max	Mean	Std
T (˚C)	23.3	29.1	26.78	0.61	23.6	28.3	27.01	0.49	26.3	30.2	27.32	0.51	25.8	30.7	27.62	0.62
pH	3.9	6.9	5.22	0.50	5.7	11.7	7.03	0.96	5.7	13.1	7.91	1.58	4	7.4	5.46	0.55
EC (mS/cm)	0.01	1.27	0.16	0.15	0.01	0.74	0.15	0.13	0.01	0.52	0.12	0.11	0.01	0.82	0.15	0.15
TDS (mg/L)	0.07	12.73	1.59	1.54	0.01	7.36	1.50	1.31	0.08	5.16	1.24	1.06	0.07	8.18	1.54	1.46

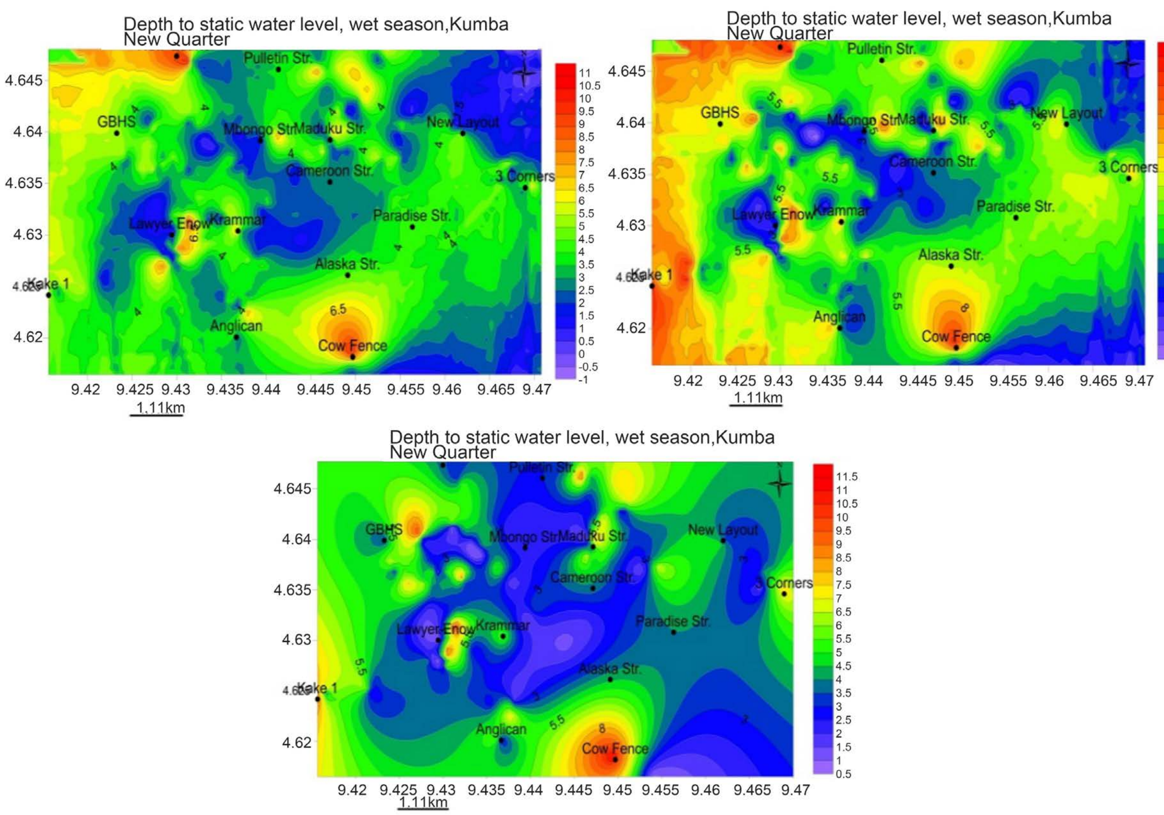

Figure 3. Groundwater level contours during four hydrogeological seasons Kumba. Most wells were dry in the Dry season as such there was no representative data for this season.

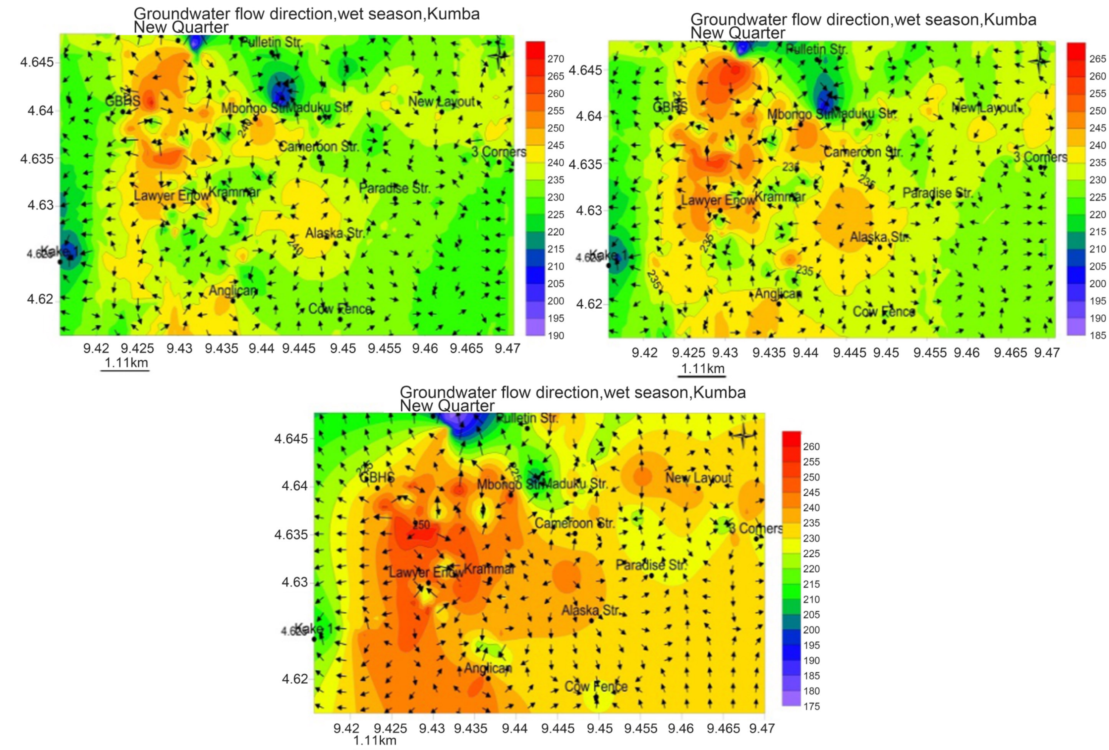

Figure 4. Spatial variation of Flow direction during four hydrogeological seasons, groundwater flows from the central slightly elevated Kumba plain to the surrounding areas radially outwards in a topography driven piston flow.

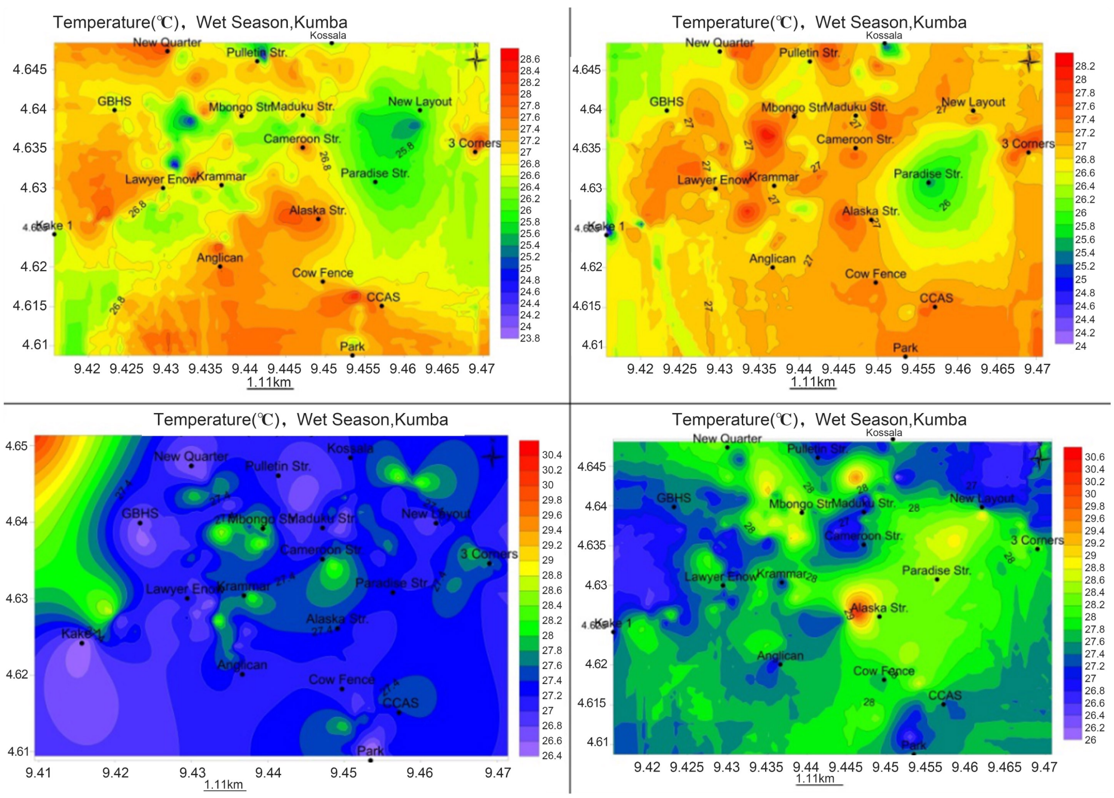

Figure 5. Spatial variation of Temperature values during four hydrogeological seasons. Highest Temperature was registered in Wetdry season.

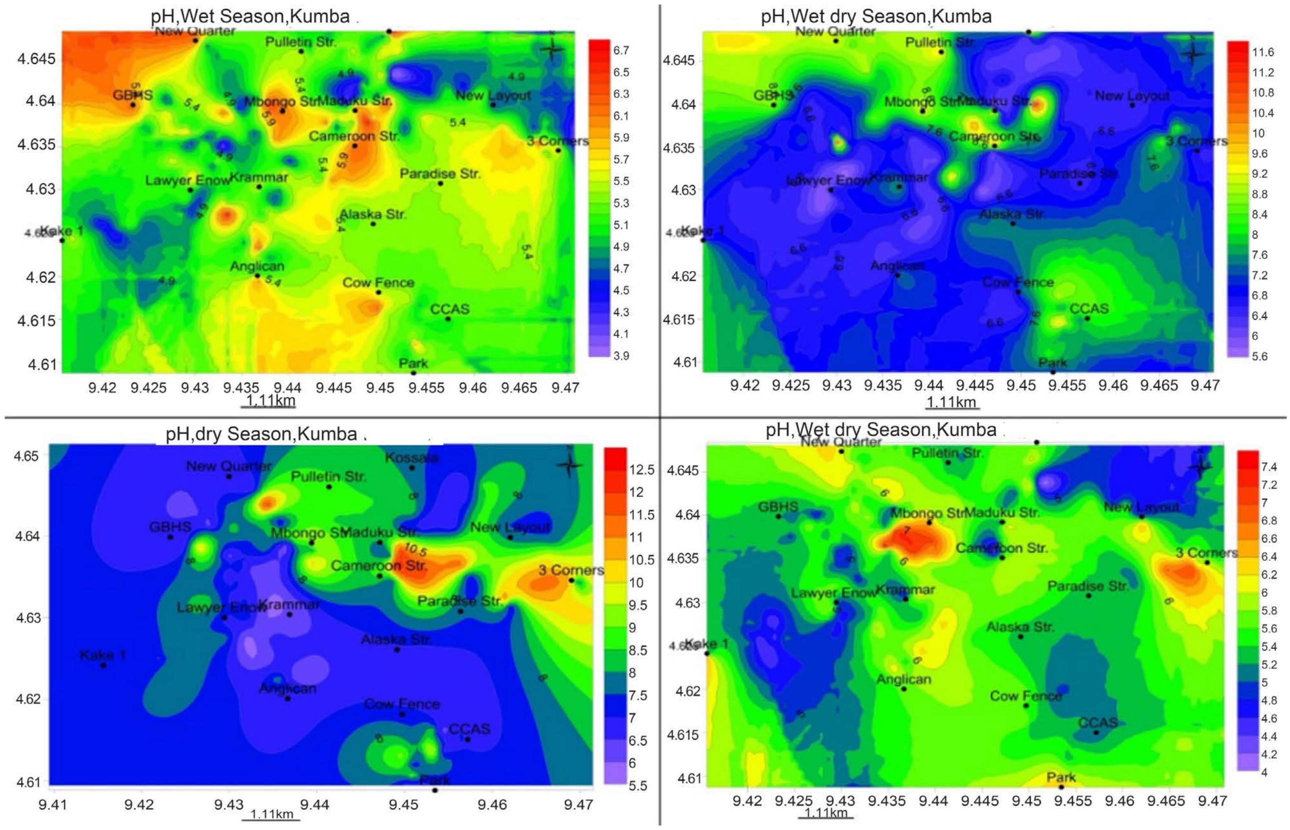

Figure 6. Spatial variation of pH values during four hydrogeological seasons. pH is strongly acidic to peralkaline in Wet and Drywet seasons and strongly acidic to strongly alkaline in Wetdry to Dry seasons.

6) Electrical Conductivity (EC)

The EC mS/cm values ranged between 0.01 - 1.90 in the Wet season, 0.01 - 1.10 Wetdry season, 0.012 - 0.77 Dry season and 0.001 - 1.22 in the Drywet season **Figure 7**. The very low values of electrical conductivity are due to low solute concentration of groundwater. The EC varied with seasons with a peak of 30.7 in the Drywet season.

7) Total Dissolved Solids

TDS ranged from 0.007 - 1.27 in the Wet season, 0.007 - 0.74 Wetdry season, 0.02 - 0.52 Dry season and 0.006 - 0.82 in the Drywet season **Figure 8**, maximum in all seasons around Maduka Str. and Cameroon Str.

3.1. Chemical Properties of Groundwater

The sequence of abundance of major ions for four seasons are; Wet season Ca^{2+} > Mg^{2+} > Na^{+} > K^{+} > NH_4^{+}; HCO_3^{-} > Cl > NO_3^{-} > SO_4^{2-} > HPO_4^{2-}; Wetdry season Ca^{+} > K^{+} > Mg^{2+} > Na^{+} > NH_4^{+}, HCO_3^{-} > Cl > SO_4^{2-} > NO_3^{-} > HPO_4^{2-}; Dry season Ca^{+} > K^{+} > Mg^{2+} > Na^{+} > NH_4^{+}; HCO_3^{-} > Cl > NO_3^{-} > SO_4^{2-} > HPO_4^{2-} and Drywet season NH_4^{+} > Ca^{+} > K^{+} > Mg^{2+} > Na^{+}, Cl^{-} > HCO_3^{-} > NO_3^{-} > SO_4^{2-} > HPO_4^{2-}. From **Tables 4(a)-(d)**; Maduka Street, Cameroon Street and Mbongo Street have the highest cations/anions. Ca^{2+} and HCO_3^{-} are the most abundant in three seasons except for Drywetseason where

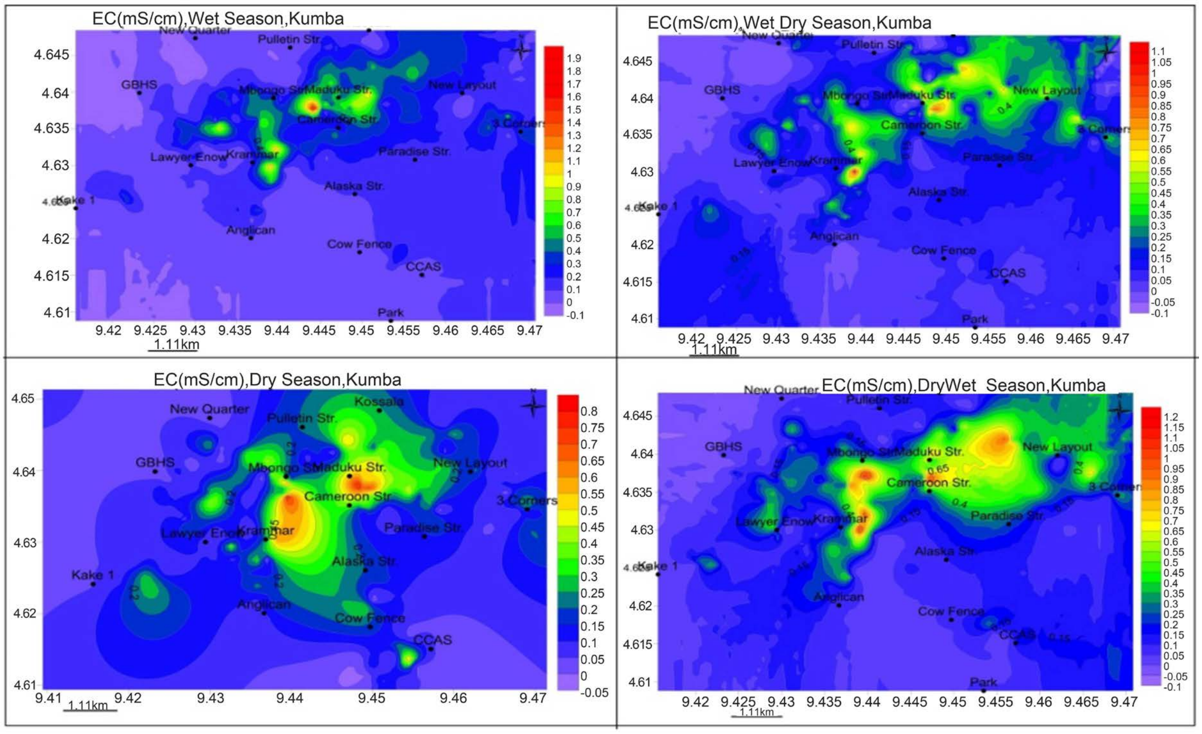

Figure 7. Spatial variation of Electrical Conductivity EC values during four hydrogeological seasons. EC values change with peak in the Wetseason and maximumaround Maduku Str. Kumba for all seasons.

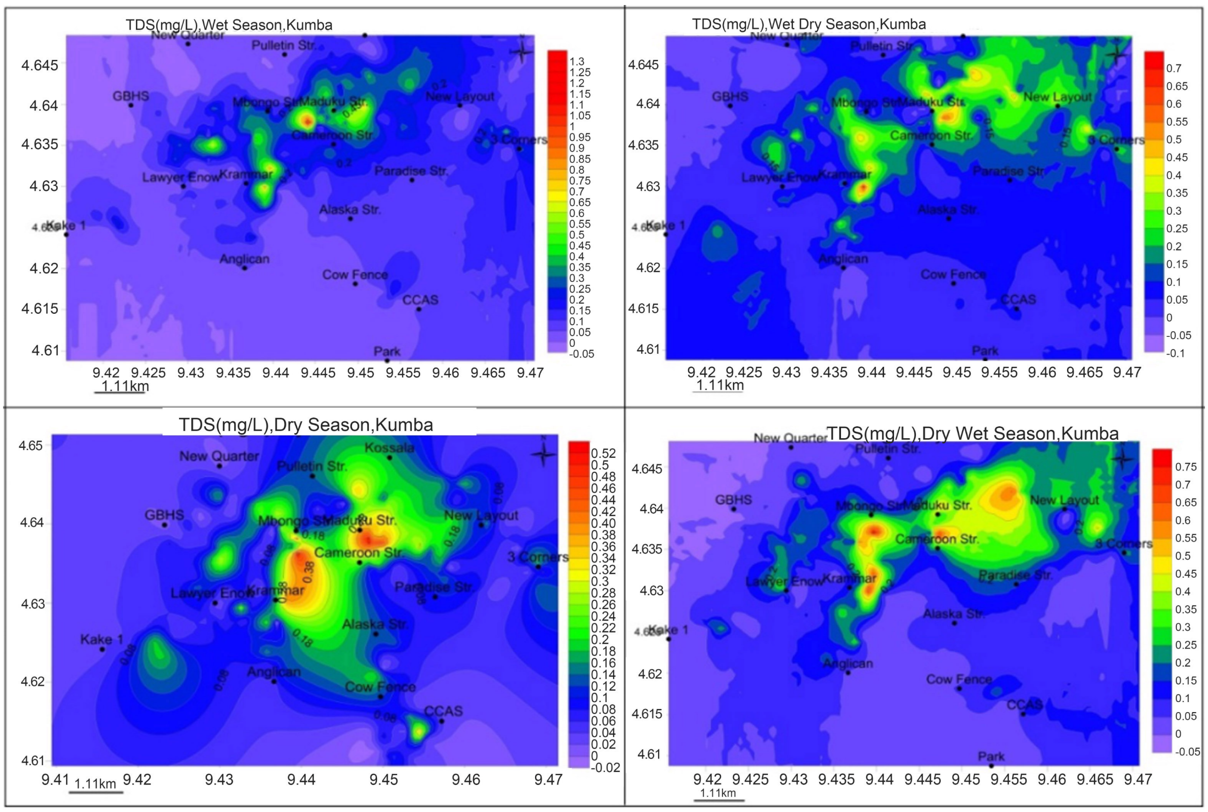

Figure 8. Spatial variation of Total Dissolved Solids during four hydrological seasons; TDS is maximum in the Wet season and peaks around Maduka Str. and Cameroon Str. in the center of Kumba for all seasons.

Table 4. (a) Results of chemical Analysis and basic statistics of groundwater for Wet season Kumba. The values of rainwater and groundwater are similar indicating connectivity typical of phreatic aquifers in fractured rock aquifers; (b) Results of chemical Analysis and basic statistics of groundwater for Wetdry season Kumba; (c) Results of chemical Analysis and basic statistics of groundwater for Dry season Kumba; (d) Results of chemical Analysis and basic statistics of groundwater for Drywet season Kumba.

(a)

Wet Season mg/L											
SN	Names	Na^+	K^+	Ca^{2+}	Mg^{2+}	NH_4^+	HCO_3^-	NO_3^-	SO_4^{2-}	CL^-	HOP_4^{2-}
1	Kake 1	0.00	0.00	0.00	0.00	0.00	3.66	0.00	1.42	10.00	0.00
2	Krammar	0.48	0.48	22.80	4.11	0.39	1.00	0.00	0.00	23.00	0.00
3	Lawyer Enow	0.03	0.03	0.00	0.00	0.31	6.10	0.23	0.67	7.00	0.06
4	Anglican	0.09	0.09	15.20	3.88	0.58	3.66	0.00	0.00	10.00	0.01
5	Mbongo Str.	1.04	1.04	37.80	4.21	0.65	52.46	5.48	0.57	37.00	0.01
6	New Quarter	0.00	0.00	11.40	4.00	0.65	3.66	0.00	0.21	2.00	0.01
7	GBHS	0.00	0.00	11.40	5.66	0.49	1.00	0.00	0.00	5.00	0.00
8	Park	0.00	0.00	0.00	0.00	0.48	1.22	0.00	0.00	7.00	0.00
9	CCAS	0.03	0.03	7.60	2.77	1.47	4.88	0.00	1.42	6.00	0.00
10	Cow Fence	0.00	0.00	7.60	4.31	1.25	0.00	0.00	0.00	7.00	0.00
11	Alaska Str.	0.03	0.03	19.00	5.51	0.41	1.22	0.00	0.00	9.00	0.00
12	Cameroon Str.	2.86	2.86	20.80	10.26	0.63	8.54	1.23	0.69	30.00	0.03
13	Paradise Str.	0.03	0.03	22.80	8.65	0.54	6.10	0.22	0.66	11.00	0.02
14	Kossala	0.17	0.17	3.80	2.71	0.45	3.66	0.00	1.08	10.00	0.00
15	Pulletin Str.	0.00	0.00	0.00	0.00	0.66	6.10	0.46	0.65	5.00	0.00
16	New Layout	0.39	0.39	11.40	2.06	0.61	6.10	0.00	0.64	28.00	0.06
17	Maduku Str.	1.63	1.63	60.60	20.51	0.20	31.72	4.45	5.23	47.00	0.00
18	3 Corners	1.24	1.24	56.80	10.59	0.65	21.96	2.87	0.63	31.00	0.02
19	Rain	0.09	0.29	4.20	18.86	0.02	7.76	0.00	0.84	3.0	0.00
	Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00
	Max	2.86	2.86	60.60	20.51	1.47	52.46	5.48	5.23	47.00	0.06
	Mean	0.45	0.45	17.17	4.96	0.58	9.06	0.83	0.77	15.83	0.01
	Std.	0.78	0.78	18.16	5.07	0.34	13.43	1.67	1.21	13.24	0.02

(b)

Wetdry Season mg/L											
SN	Names	Na^+	K^+	Ca^{2+}	Mg^{2+}	NH_4^+	HCO_3^-	NO_3^-	SO_4^{2-}	CL^-	HOP_4^{2-}
1	Kake 1	0.09	0.39	6.20	4.87	0.00	1.22	0.15	0.61	1.00	0.01
2	Krammar	0.81	8.97	30.80	0.59	0.10	2.44	0.17	0.00	21.00	0.04
3	Lawyer EnowStr	0.13	0.78	18.40	4.80	0.00	0.00	0.19	0.00	4.00	0.01
4	Anglican	0.35	1.95	18.40	4.38	4.32	2.44	0.11	0.00	10.00	0.04

Continued

5	Mbongo Street	0.85	12.09	30.80	0.59	0.30	23.18	0.38	0.00	25.00	0.05
6	New Quarter	0.16	0.39	0.00	1.32	0.42	1.22	0.27	0.56	0.00	0.01
7	GBHS	0.04	0.00	0.00	2.90	0.38	3.66	1.25	1.02	0.00	0.01
8	Park	0.00	1.17	12.20	10.48	0.45	3.66	0.22	1.39	6.00	0.04
9	CCAS	0.00	0.39	12.20	7.43	0.21	1.22	0.22	0.69	2.00	0.03
10	Cow Fence	0.16	0.39	18.40	1.81	0.38	1.22	0.22	0.23	5.00	0.01
11	Alaska Street	0.25	2.34	18.40	11.38	4.33	2.44	1.48	0.00	12.00	0.04
12	Cameroon Street	0.39	2.73	18.40	1.84	0.44	3.66	0.23	6.88	30.00	0.02
13	Paradise Street	0.39	0.39	6.20	14.87	0.00	0.00	4.34	1.32	13.00	0.01
14	Kossala	0.48	5.85	12.20	1.32	0.53	6.10	0.25	1.34	9.00	0.06
15	Pulletin Street	0.30	0.39	18.40	4.32	0.45	3.66	0.37	0.00	3.00	0.03
16	New Layout	0.85	7.02	18.40	5.26	0.00	2.44	5.14	6.88	36.00	0.01
17	Maduku Street	1.70	26.52	73.80	20.90	0.49	61.00	4.21	10.21	44.00	0.02
18	3 Corners Fiango	2.09	21.80	61.40	1.59	0.00	12.20	0.23	5.11	28.00	0.00
	Min	0	0	0	0.59	0	0	0.11	0	0	0
	Max	2.09	26.52	73.8	20.9	4.33	61	5.14	10.21	44	0.06
	Mean	0.50	5.20	20.81	5.59	0.71	7.32	1.08	2.01	13.83	0.02
	Std.	0.58	7.75	19.11	5.55	1.33	14.48	1.65	3.07	13.55	0.02

(c)

Dry Seasonmg/L											
SN	Names	Na^+	K^+	Ca^{2+}	Mg^{2+}	NH_4^+	HCO_3^-	NO_3^-	SO_4^{2-}	CL^-	HOP_4^{2-}
1	Kake 1	0.08	0.35	2.91	2.71	0.28	0	0	0.11	3	0.03
2	Krammar	0.68	10.45	29.12	0.59	0.34	0	0	0.41	25	0.01
3	Lawyer EnowStr	0.08	0.7	5.82	4.88	0.21	0	0	0.42	5	0.01
4	Anglican	0.16	1.4	2.91	2.71	0.38	0	0	0.21	8	0.1
5	Mbongo Str.	1.16	17.39	46.59	5.04	0.66	28.06	0.63	0.11	4	0.04
6	New Quarter	0.12	0.52	2.91	4.06	0.84	7.32	0.92	0.24	3	0.03
7	GBHS	0.08	0.18	2.91	2.68	0.11	0	0	0.22	1	0.1
8	Park	0.12	0.69	5.82	4.51	0.11	0	0.02	0.21	7	0.01
9	CCAS	0.16	0.87	2.91	4.32	0	0	0.04	0.33	7	0.01
10	Cow Fence	0.16	0.52	5.82	4.87	0.43	0	0	0.23	8	0.01
11	Alaska Str.	0.02	2.42	8.74	0.65	0	0	0.03	0.33	7	0
12	Cameroon Str.	1.36	15.13	43.68	5.21	0	68.32	6.21	5.88	86	0.3
13	Paradise Str.	0.2	0.52	2.93	2.68	0.33	0	0	0.23	11	0.01
14	Kossala	0.36	3.12	11.65	1.33	0.31	0	0	0.11	12	0
15	Pulletin Str.	0.12	0.35	2.92	2.7	0.41	0	0	0.31	1	0.1

Continued

16	New Layout	0.68	7.64	20.38	4.3	0.45	0	0	0.23	31	0
17	Maduku Str.	1.88	30.62	72.8	20.05	0	92.72	8.25	1.57	59	0.05
18	3 Corners	0.2	1.74	5.82	4.87	0.21	0	0	0.21	7	0
	Min	0.02	0.18	2.91	0.59	0	0	0	0.11	1	0
	Max	1.88	30.62	72.8	20.05	0.84	92.72	8.25	5.88	86	0.3
	Mean	0.42	5.26	15.37	4.34	0.28	10.91	0.89	0.63	15.83	0.05
	Std.	0.53	8.27	20	4.2	0.23	26.53	2.34	1.35	22.49	0.07

(d)

Drywet Season mg/L											
SN	Names	Na^+	K^+	Ca^{2+}	Mg^{2+}	NH_4^+	HCO_3^-	NO_3^-	SO_4^{2-}	CL^-	HOP_4^{2-}
1	Kake 1	0.13	0.37	3.6	2.98	0.28	0	0	0.15	5	0.01
2	Krammar	0.92	9.67	36.6	0.54	0.29	0	0.04	0.3	21	0
3	Lawyer EnowStr	0.3	1.29	3.6	6.03	0.33	0	0	0.38	6	0
4	Anglican	0.33	1.48	7.4	7.45	0.39	0	0.06	0.31	3	0.01
5	Mbongo Str.	0.46	7.29	40.2	32.94	3.53	0.51	0	0.12	8	0.01
6	New Quarter	0.21	0.9	0	6.11	0.81	9.45	0.32	0.12	6	0.02
7	GBHS	0.1	0	7.4	8.14	0.3	7.11	0.08	0.54	3	0.01
8	Park	0.23	0.55	3.6	0.45	3.84	0.41	0	0.19	9.3	0.02
9	CCAS	0.9	0.55	29.2	24	0	0	0.06	0.42	10	0.01
10	Cow Fence	0.23	0.37	7.4	5.43	0.46	0.17	0.04	0.34	10.1	0.03
11	Alaska Str.	0.26	2.57	3.6	0.62	0	0	0.04	0.33	8	0
12	Cameroon Str.	0.33	3.12	3.6	3.51	0	59.21	5.21	4.1	80	0.03
13	Paradise Str.	0.14	0.9	3.6	2.51	2.46	0.3	0	0.09	0	0.03
14	Kossala	0.25	2.93	7.4	0.42	0.4	0	0	0.11	11.94	0
15	Pulletin Str.	0.2	0	0	1.51	0.22	0	0	0.21	1.5	0.01
16	New Layout	0.13	7.87	11	0.03	0	0	0	0.12	24	0
17	Maduku Str.	2.44	33.42	61.4	0	80.2	7.14	0.56	1.44	51	0.03
18	3 Corners	0.1	1.29	36.6	31.43	0.11	0	0	0.12	8	0.01
	Min	0.1	0	0	0	0	0	0	0.09	0	0
	Max	2.44	33.42	61.4	32.94	80.2	59.21	5.21	4.1	80	0.03
	Mean	0.43	4.14	14.79	7.45	5.2	4.68	0.36	0.52	14.77	0.01
	Std.	0.56	7.86	17.82	10.59	18.76	13.94	1.22	0.95	20.05	0.01

NH_4^+ and Cl^- are most abundant. There is an increase of K^+ and Mg^{2+} ions as seasons change from Wet to Drywet.

3.1.1. Ionic Ratios of Groundwater

The ionic ratios of groundwater have been used to determine formation contribution to Kumba groundwater chemistry in Figure 9. The individual ionic ratios are analyzed per season and interpreted in Table 5.

The ionic ratios indicate groundwater in Kumba is affected to a great extent by silicate weathering mostly Ca-silicates and Mg-silicates from the minerals found in basalts with little weathering of Na-feldspar and Na-silicates, no Na-absorption, some Sulphate from external sources, no oxidation of sulphides and no anthropogenic contribution. Rock weathering and rainwater; increase in Wet, deplete in Dry Wet season. Some plagioclase weathering occurs in all seasons except Wet season with sodium source other than halite-albite, ion exchange and rainwater; silicate weathering of ferromagnesian minerals from the basalts but without gneiss weathering, ion exchange/Calcium removal and Calcium source from weathering of the basalts.

3.1.2. Rock-Groundwater Interaction

From Gibbs diagram; 77.78% ionsin groundwater originate from rock-weathering dominance for Wet, Wetdry and Drywet seasons and 83.33% in Dry season originate from atmospheric precipitation dominance during the four seasons Figure 10 and Table 6. This reveals the weathering of the aquifer matrix as the primary process in the acquisition of ions while atmospheric precipitation is the secondary process controlling the hydrogeochemistry in Kumba. In the Dry season as precipitation reduces the rock weathering dominance increases from

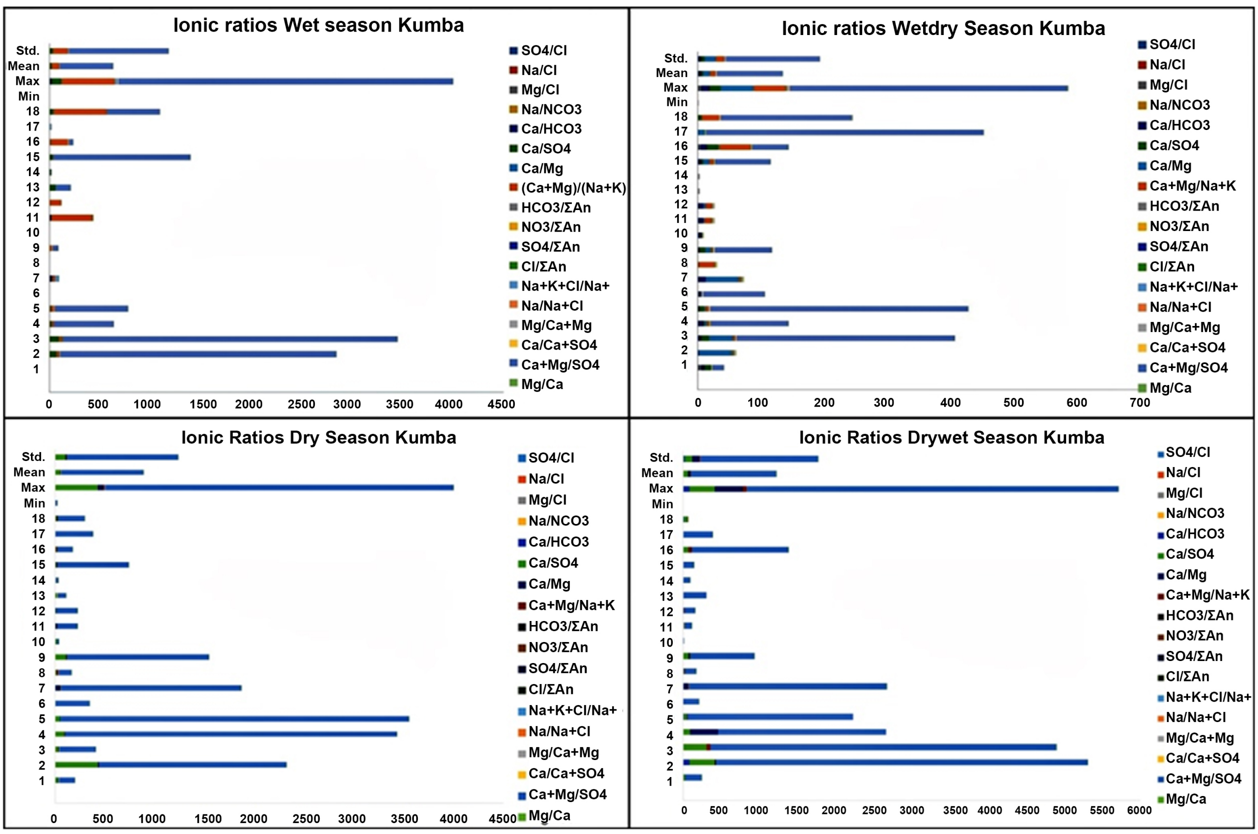

Figure 9. Cluster histograms of Ionic ratios and basic statistics of major elements in groundwater for four seasons in Kumba.

Table 5. Summary of the ionic Ratios for Wet, Wetdry, Dry, and Drywet seasons with inferred formation source types Kumba.

Ionic Ratio	Wet	Wetdry	Dry	Drywet	Interpretation
SO/Cl	0- 0.24	0 - 0.61	0.01 - 0.31	0 - 0.18	Sulphate reduction and suggests additional sources of Sulphate
Na/Cl	0 - 0.10	0 - 0.10	0 - 0.29	0 - 0.13	No Na-adsorption during freshening and absence of marine water.
Mg/Cl	0 - 2.0	0 - 4.87	0.02 - 2.70	0 - 4.12	Depict a cation-exchange and silicate weathering environment
Na/HCO	0 - 0.48	0 - 0.35	0 - 0.04	0 - 0.90	Low weathering of Na-feldspar or other Na-silicates.
Ca/HCO	0 - 22.80	0 - 12.62	0 - 1.66	0 - 78.82	Ca-silicate weathering from country rocks
Ca/SO	0 - 90.16	0 - 17.68	0 - 423.55	0 - 335.00	There is no gypsum dissolution in volcanic regions
Ca/Mg	0 - 8.98	0 - 52.20	0 - 49.36	0 - 366.67	Typical of coastal regions due to cation-exchange
Mg/Ca	0 - 524.17	0 - 50.33	0 - 13.72	0 - 48.94	Silicate weathering
(Ca + Mg)/(Na + K)	0 - 0.11	0 - 0.14	0 - 0.19	0 - 0.12	Occurrence of silicate weathering over carbonate weathering.
HCO_3^- /ΣAnions	0 - 0.01	0 - 0.01	0 - 0.02	0 - 0.01	Rainwater
NO_3/ΣAnions	0 - 0.01	0 - 0.02	0 - 0.01	0 - −0.01	No anthropogenicactivities.
SO_4/ΣAnions	0 - 1.0	0 - 0.95	0.12 - 0.99	0 - 0.99	No oxidation of sulphides.
Cl^-/ΣAnions	−10.26 - 31.53	−4.51 - 2.02	−21.11 - 11.76	−11.12 - 1.88	Rock weathering and rainwater; increase in Wet, deplete in DryWet season
$\frac{Na^+ + K^+ - Cl^-}{Na^+ + K^+ - Cl^- + Ca^{2+}}$	0 - 0.09	0 - 1.0	0 - 0.22	0 - 1.0	Some plagioclase weathering in all seasons except Wet season
$\frac{Na^+}{Na^+ + Cl^-}$	0 - 0.42	0.02 - 1.0	0.02 - 0.60	0 - 1.0	Sodium source other than halite-albite, ion exchange and rainwater
$\frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}}$	0 - 1.0	0 - 1.0	0.90 - 1.0	0 - 1.0	Silicate weathering of ferromagnesian minerals but no evidence of granitic weathering
$\frac{Ca^{2+}}{Ca^{2+} + SO_4^{2-}}$	0 - 3316.02	0 - 439.35	18.13 - 3489.27	0 - 4876.00	Ion exchange/Calcium removal and Calcium source from silicates
$\frac{Ca^{2+} + Mg^{2+}}{SO_4^{2-}}$	0 - 0.71	0 - 2.40	0.02 - 1.48	0 - 1.68	No dolomite at all, Dedolomitization

Table 6. Wet and Dry seasonal variations for cations plus anions in rock/groundwater interaction from Gibbs diagram, Kumba (Gibbs, 1970).

Rock-water Interaction	TDS mg/L	Wet		Wetdry		Dry		Drywet	
		No	%	No	%	No	%	No	%
Rock - Weathering Dominance	50 - 1000	14	77.78	14	77.78	15	83.33	14	77.78
Atmospheric Precipitation dominance	1 - 50	4	22.22	4	22.22	3	16.67	4	22.22

77.78% to 83.33% while atmospheric dominance reduces from 22.22% to 16.67% and vice versa. This causes a 5.55% increase in rock weathering dominance in the Dry season and a 5.55% increase in Atmospheric precipitation dominance in the rainy season. These variations in the aqueous geochemistry of the groundwater in Kumba are a direct consequence of hydrological changes.

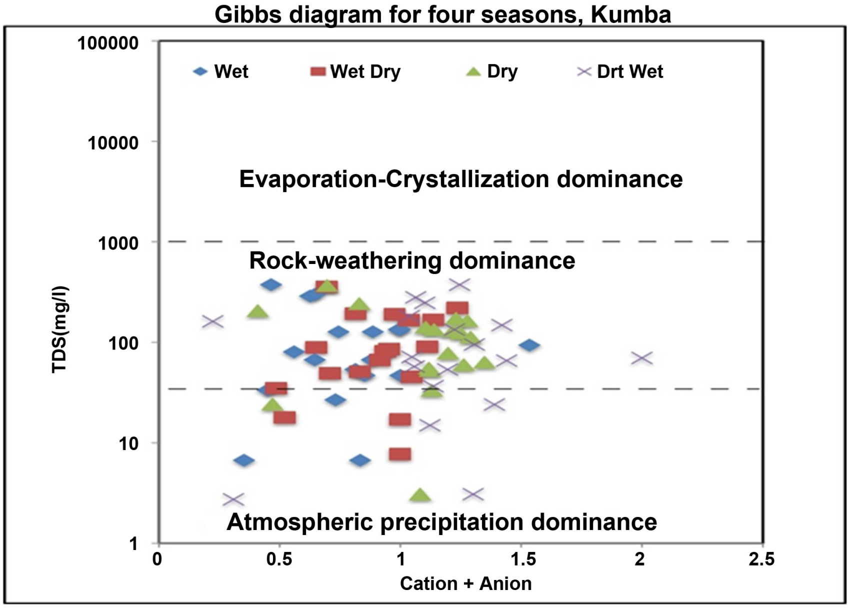

Figure 10. Gibbs Diagram Kumba indicating the interaction between aquifer formation and groundwater: Atmospheric precipitation was 4 samples 22.22% each, in the Wet, Wetdry and Drywet seasons and 3 samples 16.67% in Dry season. Rock-weathering was contributing 14 samples 77.78% each in the Wet, Wetdry and Drywet seasons and 15 samples 83.33% in Dry season.

3.1.3. Groundwater Types

The diamond field of Piper's diagram was divided into seven classes A - G classifying water types and designated with alphabets from A to G Figure 11, (Piper, 1944). Using this Classification, water from Kumba falls into A, B, C, E, G categories Table 7. There is no Class D and F in all seasons and no Class A in Wet season; no Class E Wet, Wetdry and Dry seasons; and Class G Wetdry, Dry and Drywet seasons. In the Wet season: Class B; 2 samples, 11.11% are characterized by normal earth alkaline water with prevailing bicarbonate or chloride, Class C; 15 samples, 83.33% are characterized by Normal earth alkaline water; prevailing chloride and Class G; 1 sample, 5.56%; characterized by alkaline water with prevailing bicarbonate. In the Wetdry season: Class A; 2 samples, 11.11%; characterized by normal earth alkaline water with prevailing bicarbonate. Class B; 2 samples, 11.11% are characterized by normal earth alkaline water with prevailing bicarbonate or chloride and Category C; 14 samples, 77.78% are characterized by Normal earth alkaline water; prevailing chloride. In the Dry season: Category A; 1 sample, 5.56%; characterized by normal earth alkaline water with prevailing bicarbonate. Class B; 2 samples, 11.11% are characterized by normal earth alkaline water with prevailing bicarbonate or chloride and Class C; 15 samples, 83.33% are characterized by Normal earth alkaline water; prevailing chloride. In the Drywet season: Class A; 1 sample, 5.56%; characterized by normal earth alkaline water with prevailing bicarbonate. Class B; 2 samples, 11.11% are characterized by normal earth alkaline water with prevailing bicarbonate or chloride, Class C; 12 samples, 66.67% are characterized by Normal earth alkaline water;

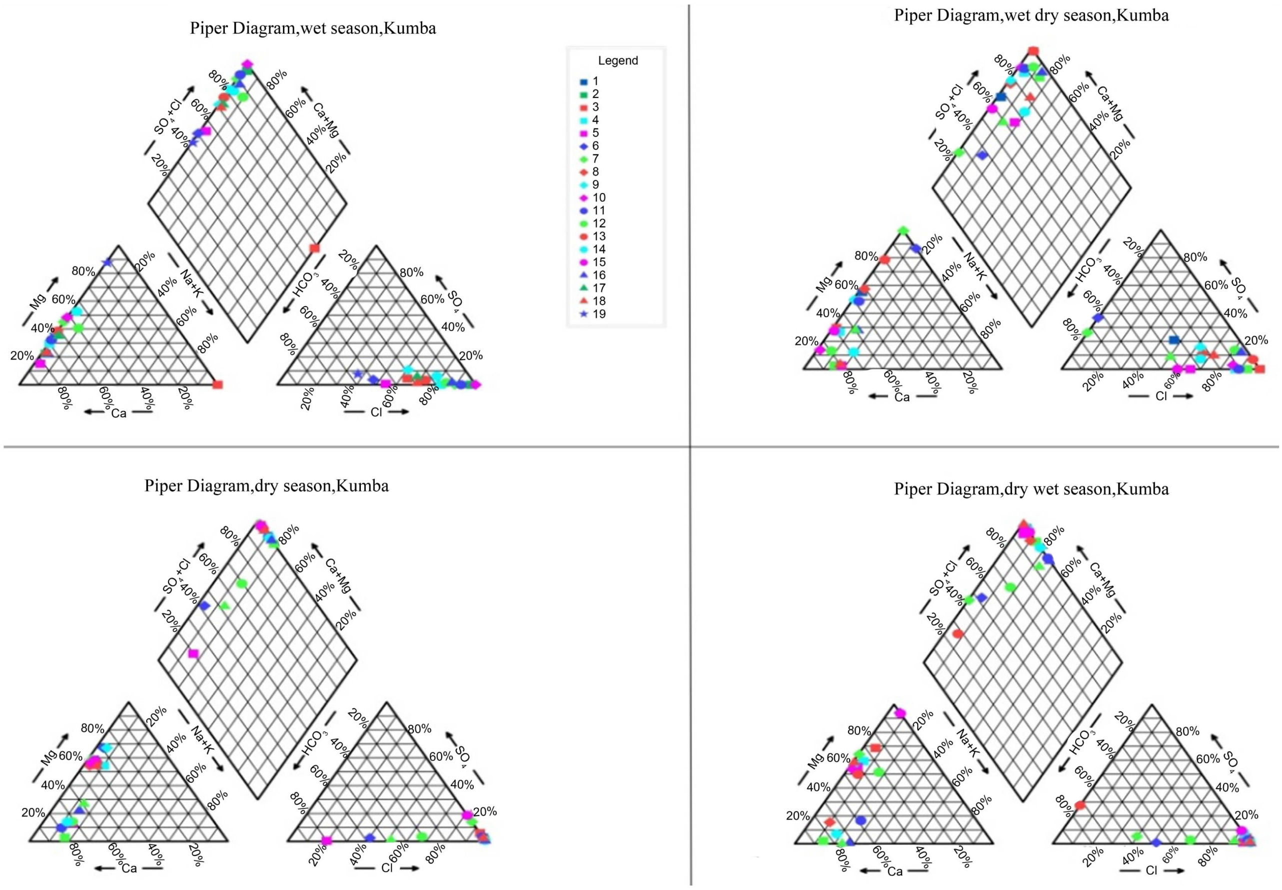

Figure 11. Piper's diagram (Piper, 1944) for 4 water types and 3 groundwater hydrogeochemical facies in Kumba; Field I: Ca-Mg-Cl-SO_4 hydrogeochemical facies is most dominant, 17 samples 94.44% in the Wet season, 16 samples 88.89% in the Wet-dry, Dry and Drywet seasons; Field II: Na + K-Cl, 5.56% in Wet season and Field IV: Ca - Mg - HCO_3, 11.11% in the other seasons. $CaSO_4$ is the dominant water type followed by $CaHCO_3$ and Na + K-Cl in Wet season. $CaSO_4$ and $CaHCO_3$ in the Wetdry, Dryand Drywet seasons; Na + K-Cl indicates input of sea spray in precipitation from the Atlantic Ocean nearby.

Table 7. Classification of groundwater and hydrogeochemical facies based on Piper diagram (Langguth, 1966; Lloyd & Heathcoat, 1985).

	Piper-Langguth Classification Kumba	Wet		Wetdry		Dry		Drywet	
Class	Characteristic-Water type	No	%	No	%	No	%	No	%
	Diamond Field								
A	Normal earth alkaline water; prevailing HCO_3^-	0	0	2	11.11	1	5.56	1	5.56
B	Normal earth alkaline water; prevailing HCO_3^- or Cl^-	2	11.11	2	11.11	2	11.11	2	11.11
C	Normal earth alkaline water; prevailing Cl^-	15	83.33	14	77.78	15	83.33	12	66.67
E	Earth alkaline water with added portions of alkalis with prevailing chloride	0	0	0	0	0	0	3	16.67
G	Alkaline water with prevailing bicarbonate	1	5.56	0	0	0	0	0	0

Continued

	Cation Field								
1	Ca-rich waters	16	88.89	13	72.22	7	38.89	6	33.33
2	Mg-rich waters	1	5.56	5	27.78	11	61.11	12	66.67
3	Na + K	1	5.56	0	0	0	0	0	0
	Anion Field								
4	HCO_3^- waters	1	5.56	2	11.11	2	11.11	2	11.11
6	Cl^- waters	17	94.44	16	88.89	16	88.89	16	88.89
	Hydrogeochemical facies								
Field I	Ca - Mg - Cl - SO_4	17	94.44	16	88.89	16	88.89	16	88.89
Field II	Na - K - Cl - SO_4	1	5.56	0	0	0	0	0	0
Field IV	Ca - Mg - HCO_3	0	0	2	11.11	2	11.11	2	11.11

prevailing chloride and Class E; 3 sample 16.67%; characterized by earth alkaline water, with added portions of alkalis with prevailing chloride. The dominant water types are Class B: 11.11%, Class C: 83.33% and Class G: 5.56%; Wetdry Category A, B: 11.11% and Class C: 77.78%; Dry Class A: 5.56%, Class B: 11.11% and Class C: 83.33% while in the Drywet season Wetdry Class A: 5.56%, Class B: 11.11%, Class C: 66.67% and Class E: 16.67%. From Table 7, $CaSO_4$ is the dominant water type in Wet and Wetdry seasons; this is followed by $MgHCO_3$; Na + K-Cl Wet season and MgCl; $MgHCO_3$Wetdry. The dominant water types for Dry and Drywet seasons are $CaSO_4$ and $CaHCO_3$.

3.1.4. Hydrogeochemical Facies

From the Piper's diagram Figure 11; Table 7, There are three hydrogeochemical facies: Field I: Ca – Mg – Cl - SO_4 hydrogeochemical facies is the most dominant, 17 samples 94.44% in the Wet season, 16 samples 88.89% in the Wetdry, Dry and Drywet seasons. This facies is characteristic of recently recharged groundwater at some distance along its flow path; regional flow. Field II: Na - K - SO_4 hydrogeochemical facies has 1 samples, 5.56% in the Wet season indicating the influence of precipitation from the Atlantic Ocean. Field IV: Ca - Mg - HCO_3 hydrogeochemical facies has 2 samples, 11.11% in the Wetdry, Dry and Drywet season, characteristic of freshly recharged groundwater that has equilibrated with CO_2 and soluble carbonate minerals under an open system condition in the vadose zone typical of shallow groundwater flow systems in crystalline phreatic aquiferous formations.

3.1.5. Hydrogeochemical Character of Kumba Groundwater

Based on the Durov diagram Figure 12, the Lloyd and Heathcoat classification Table 8 gave three classes in the Wet season; Class-1: Recharging groundwater; 14 samples, 66.67%; Class-2; Ion exchange; 3 samples, 16.67% and Class-8: reverse ion exchange, 1 sample, 5.56%. Four classes occur in Wetdry; Class-1: Recharging groundwater; 10 samples, 55.56%; Class-2; Ion exchange; 4 samples,

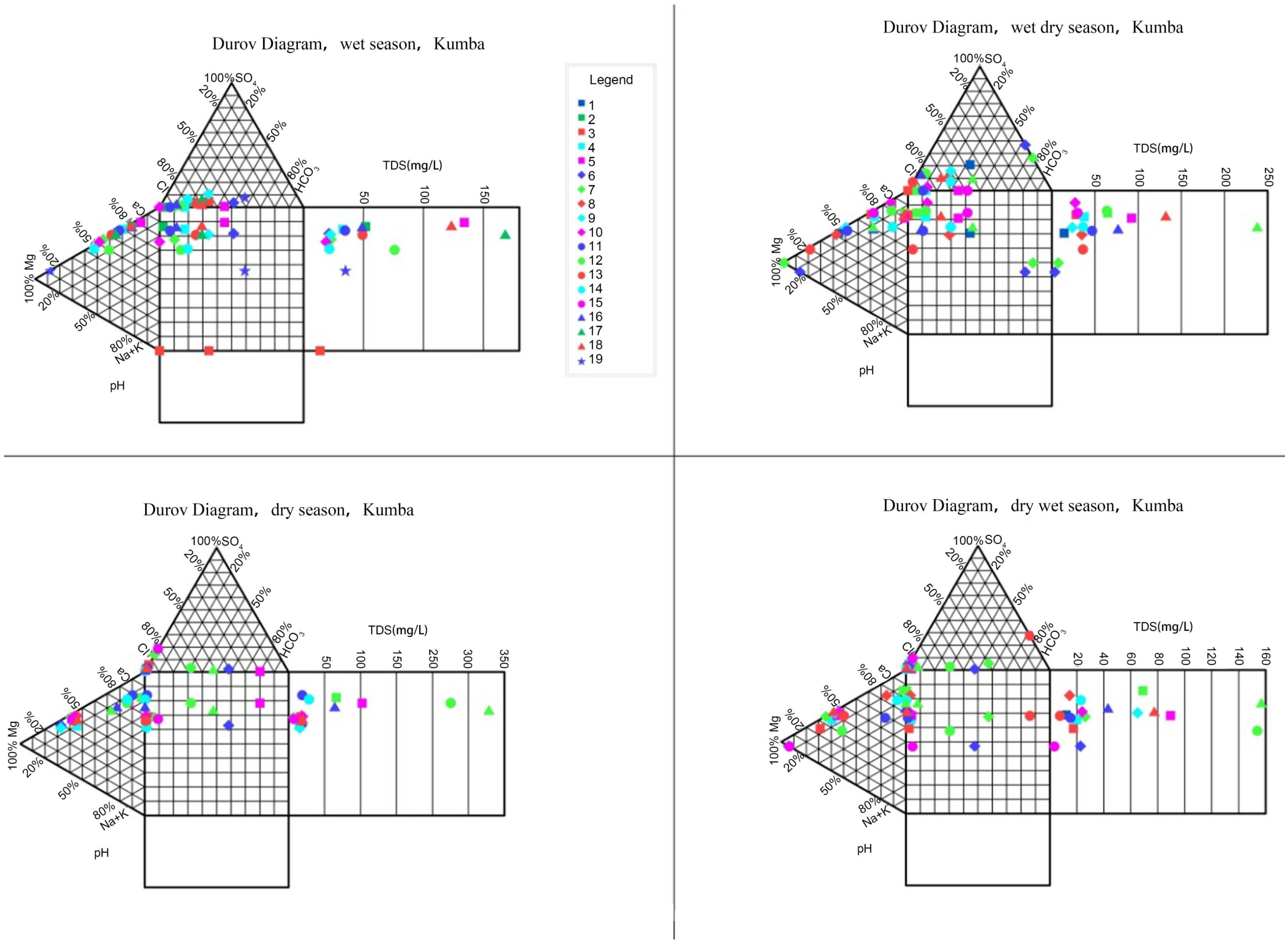

Figure 12. Durov plots of Kumba groundwater for the processes in groundwater evolution: for Wet season; Class-1: 14 samples, 66.67%; Class-2; 3 samples, 16.67% and Class-8: 1 sample, 5.56%. Wetdry; Class-1: 10 samples, 55.56%; Class-2; 4 samples, 22.22%; Class-4: 2 samples 11.11% and Class-6: 2 samples 11.11%. Dry season; Class-1: 4 samples, 22.22%; Class-2; 2 samples, 11.11%; Class-3:1 samples, 5.56%, Class-4:10 samples 55.56% and Class-5, 1 samples 5.56% and Drywet season; Class-1: 9 samples, 50%; Class-4: 5 samples 27.78% and Class-5: 3 samples 16.67% and Class-6: 1 samples 5.56%.

Table 8. Classification of Water based on Durov diagram four seasons in Kumba (Lloyd & Heathcoat, 1985).

Class	Hydrogeochemical processes	Wet		Wetdry		Dry		Drywet	
		No	%	No	%	No	%	No	%
1	HCO_3 and Ca dominant; indicates recharging waters groundwater	14	66.67	10	55.56	4	22.22	9	50
2	This water type is dominated by Ca and HCO_3 ions. Na is significant, ion exchange is presumed	3	16.67	4	22.22	2	11.11	0	0
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	0	0	0	0	1	5.56	0	0
4	SO_4 dominates, or anion discriminate and Ca dominant; mixed water or water exhibiting simple dissolution may be indicated.	0	0	2	11.11	10	55.56	5	27.78
5	No dominant anion or cation, indicates water exhibiting simple dissolution or mixing	0	0	0	0	1	5.56	3	16.67

Continued

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.	0	0	2	11.11	0	0	1	5.56
8	Cl dominant anion and Na dominant cation, related to reverse ion exchange of Na-Cl waters	1	5.56	0	0	0	0	0	0

22.22%; Class-4: Mixed water or water exhibiting simple dissolution, 2 samples 11.11% and Class-6 Mixing and uncommon dissolution influences, 2 samples 11.11%. Five classes occur in Dry season; Class-1: Recharging groundwater; 4 samples, 22.22%; Class-2; Ion exchange; 2 samples, 11.11%; Class-3 ion exchanged water, 1 samples, 5.56%, Class-4: Mixed water or water exhibiting simple dissolution; 10 samples 55.56% and Class-5 Simple dissolution or mixing, 1 samples 5.56%. Four classes occur in Drywet season; Class-1: Recharging groundwater; 9 samples, 50%; Class-4: Recharge, 5 samples 27.78% and Class-5 Simple dissolution or mixing, 3 samples 16.67% and Class-6 Mixing and uncommon dissolution influences, 1 samples 5.56%. There are no Classes; 3, 4, 5, 6, 7 and 9 in the Wet season; 3, 5, 7, 8 and 9 Wetdry; 6, 7, 8, and 9 Dry and no Classes; 2,3,7,8 and 9 in the Drywet season in Kumba.

In the Wet season, fresh recently recharging water from precipitation, exchanges ions with the weathered matrix of the aquiferous formations, while simple dissolution or mixing also goes on between the recently recharging groundwater and the existing groundwater in the aquiferous formations. In the Wetdry season, recharging groundwater having spent more time in the aquifer continues to exchange ions to a lesser extent with the matrix of the formation. While in the Dry season precipitation is absent, increasingly simple dissolution and mixing goes on between the remnants of the recently recharging groundwater and the pre-existing groundwater in the formation. In the Drywet season, new recharging water from precipitation emerges, exchanges ions with the weathered matrix of the aquiferous formations, while increasingly, simple dissolution or mixing also goes on between the recently recharging groundwater and the existing groundwater in the aquiferous formations.

The presence of Class-8 samples showing Na^+/Cl^- as dominant cation/anion, absence of Classes; 3, 4, 5, 6, 7 and 9 in the Wet season; Classes; 6, 7, 8, 9 in the Dry season indicates that, the groundwater in Kumba has an input related to reverse or inverse ion exchange of Na-Cl in the Wet seasonprobably of precipitation from the Atlantic Ocean nearby.

3.2. Water Quality

3.2.1. Domestic Water Quality

From WHO guideline values (WHO, 2017) of ions present in the groundwater have been used to calculate Water Quality IndexWQI for domestic use for four seasons in Kumba (Pradhan et al., 1998; Asadi et al., 2007). The weighted arithmetic water quality index was calculated and recorded on **Table 9**. WQI values ranged from −190.8 - 10.5, Wet season, Wetdry 6.37 - 120.29, Dry 1.59 - 130.67 and Drywet −11.95 - 17.26. Groundwater in Kumba is mostly 100% excellent in Wet and Drywet seasons; 94.44% excellent-good in the Wetdry season with 5.56% unsuitable at Cow-Fence; 83.34% excellent-good in the Dry season with 5.56% poor at New-Layout; Mbongo Str. and 11.11% unsuitable at Maduku Str. and Cameroon Str. Figure 13. These are the seasons when water is most scarce since many wells dry up.

3.2.2. Total Hardness H_T

Classifications of the groundwater hardness in the study Kumba in Kumba (Sawyer & McCarthy, 1967); H_T values were recorded as 0 - 235.59 mg/L in the Wet season, Wetdry 5.41 - 270.19 mg/L, Dry 18.26 - 264.21 mg/L and Drywet 6.19 - 235.55 mg/L. Groundwater in Kumba is soft in most areas in all the seasons 66.67% - 77.77% Table 10. In the Wet season, 11.11% is and 3 Corners; Moderately hard 22.22% around Mbongo Str., Cameroon Str. and 3 Corners hard around Maduku Str. and 3 Corners; Moderately hard 16.67% around Mbongo Str., Cameroon Str., Paradise and Alaska. In Wetdry season, 11.11% is hard around Maduku Str. Figure 14.

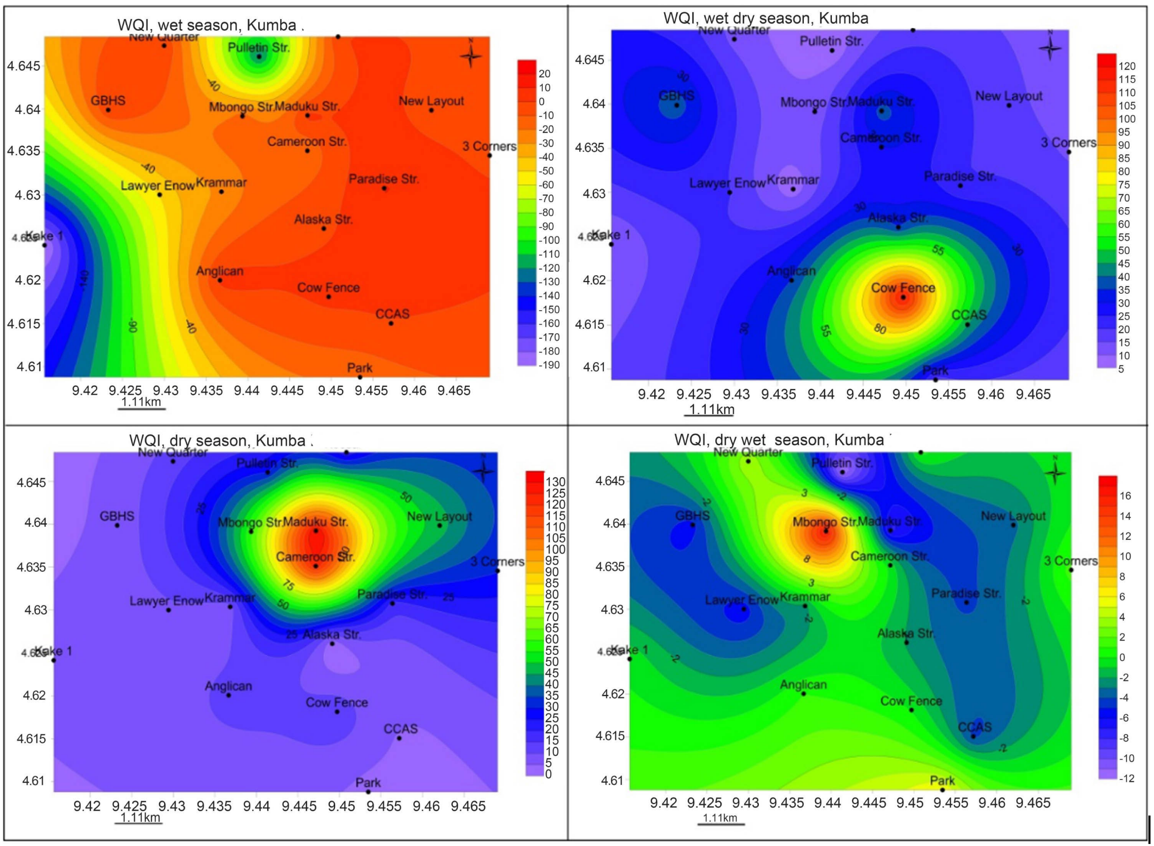

Figure 13. Seasonal variations of WQI during four hydrogeological seasons: Water is of overall good quality with greater values in the Wet season: Groundwater in Kumba is mostly good to excellent in the Wet, Wetdry and Drywet seasons. In the Wetdry season itis unsuitable at Cow-Fence and in the Dry season poor at New-Layout, Mbongo Str.; unsuitable at Maduku Str. and Cameroon Str.

Table 9. Seasonal variations of Water Quality Index Classification of groundwater samples for four seasons Kumba.

	Remarks	Wet		Wetdry		Dry		Drywet	
Index	Quality	No	%	No	%	No	%	No	%
0 - 25	Excellent	18	100	11	61.11	12	66.67	18	100
26 - 50	Good	0	0	6	33.33	3	16.67	0	0
51 - 75	Poor	0	0	0	0	1	5.56	0	0
76 - 100	Very poor	0	0	0	0	0	0	0	0
>100	Unsuitable	0	0	1	5.56	2	11.11	0	0

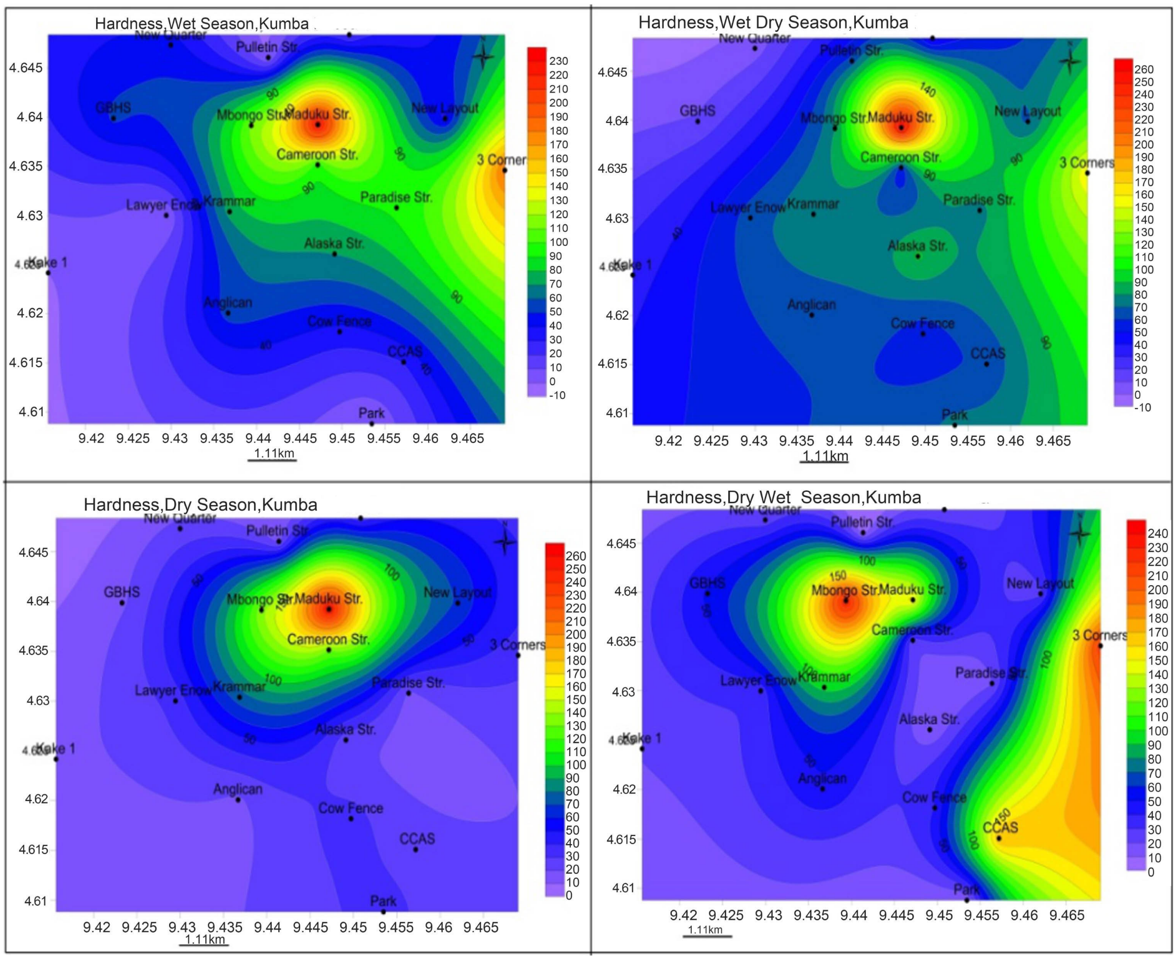

Figure 14. Spatial variation of hardness during four hydrogeological seasons: Groundwater in Kumba is soft in most areas in all the seasons. In the Wet season it is hard around Maduku Str. and 3 Corners; moderately hard around Mbongo Str., Cameroon Str., Paradise and Alaska. In Wetdry season, 11.11% is hard around Maduku Str. and 3 Corners; Moderately hard 22.22% around Mbongo Str., Cameroon Str. and 3 Corners. In the Dry season groundwater is hard around Maduku Str.; moderately hard around Mbongo Str., Cameroon Str., Paradise, Alaska. In the Drywet is hard around Maduku Str. and 3 Corners; moderately hard around Mbongo Str., Cameroon Str.

In the Dry season 5.56% is hard around Maduku Str.; Moderately hard 16.67% around Mbongo Str., Cameroon Str., Paradise, Alaska. Dry-Wet 11.11% is hard around Maduku Str. and 3 Corners; Moderately hard 16.67% around Mbongo Str., Cameroon Str.

Table 10. Variations of groundwater hardness for four seasons Kumba.

	Remarks	Wet		Wetdry		Dry		Dry-Wet	
Hardness H_T	Classification	No	%	No	%	No	%	No	%
0 - 75	Soft	13	72.22	12	66.67	14	77.77	13	72.22
76 - 150	Moderately Hard	3	16.67	4	22.22	3	16.67	1	5.56
151 - 300	Hard	2	11.11	2	11.11	1	5.56	4	22.22

The variations of hardness has Agro-industrial implications since in Kumba there are presently food processing plants and related business being built that might develop scaling problems if the hardness variations of 18% - 28% with seasons are not taken into consideration at the planning stage.

3.2.3. Agro-Industrialwater Quality

Parameters that are generally considered for evaluation of the suitability of groundwater for irrigation were the percent sodium (% Na), magnesium hazard (MH), residual sodium carbonate (RSC), Kelley's ratio (KR), sodium adsorption ratio (SAR), electrical conductivity (EC), total dissolved solid (TDS) and USSL and Wilcox diagram.

a) Sodium Percentage% Na

Percentage of sodium values ranged from 0 - 100 Wet season; Wetdry, 0.71 - 19.18; Dry, 2.15 - 16.50 and Drywet, 0.41 - 27.30. Based on Wilcox classification (Wilcox, 1955); all 18 samples fall in the excellent to good category for all seasons Figure 15. This signifies groundwater in Kumba is good for irrigation at all times during the year.

b) Kelly's Ratio KR

Kelley's ratio was used as one of the basis of rating groundwater for irrigation purposes (Kelley, 1953). Values ranged from 0 to 0.07 in Wet season, 0.01 - 0.07 Wetdry season 0 - 0.026 Dry season and 0.0 - 0.07 Drywet season. All samples had KR value less than 1.00 in all four seasons thus fell under Class suitable; which is acceptable range for irrigation purposes all four seasons, Figure 16.

c) Residual Sodium Carbonate RSC

RSC values of groundwater samples in Kumba Figure 17. The RSC values of the groundwater varied from; Wet season, −4.22 - 0.10, Wetdry season −4.43 - −0.09, Dry season −3.79 - −0.36 and Drywet season −4.75 - 0.50. Novalues exceeded the 1.25 m.eq/L in all four seasons indicating the groundwater in Kumba is good for irrigation all year round.

d) Magnesium Adsorption Ratio MAR

MAR values of all the samples varied from −2 - 54.31 Wet season, Wetdry 0.005 - 100, Dry 1.02 - 75.22 and Drywet 1% - 100. 94.44% in the Wetdry and 61.11% Wet seasons of groundwater was suitable for irrigation while 61.11% in the Dry and 66.67% in the Drywet seasons respectively were unsuitable Figure 18, Table 11.

e) Sodium Adsorption Ratio SAR

The sodium adsorption ratio (SAR) indicates the sodium concentration in groundwater as USSL classification of the salinity hazard (USSL, 1954). Salinity

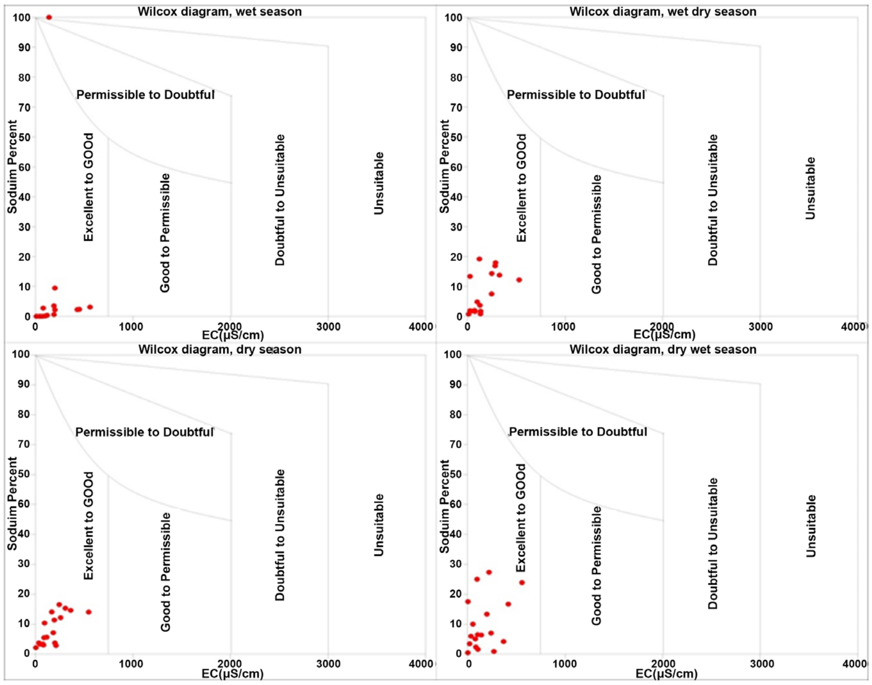

Figure 15. Wilcox diagram showing the suitability for irrigation; All 18 samples 100% fall into the excellent to good category for all four hydrogeological seasons. This signifies that groundwater in Kumba is good for irrigation at all times during the year.

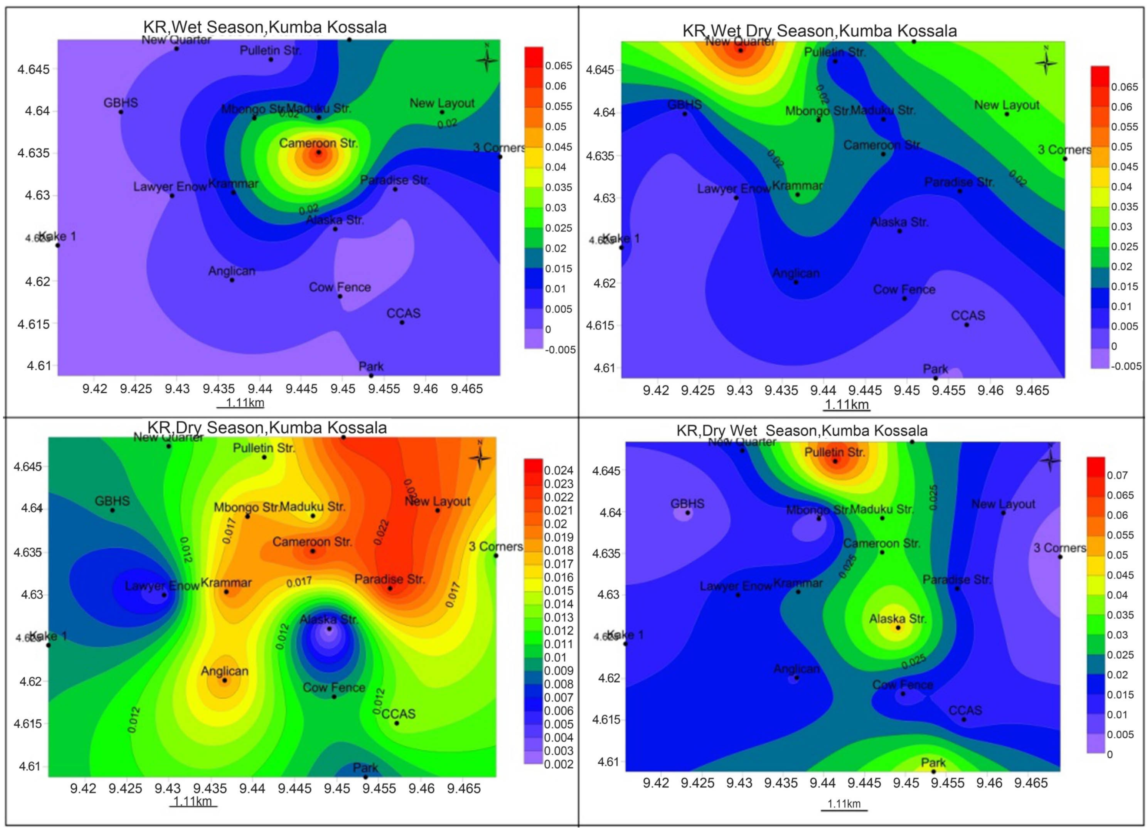

Figure 16. Spatial variation for Kelly Ratio during four hydrogeological seasons: KR values < 1 in all seasons, signify suitability of all groundwater for irrigation during all seasons.

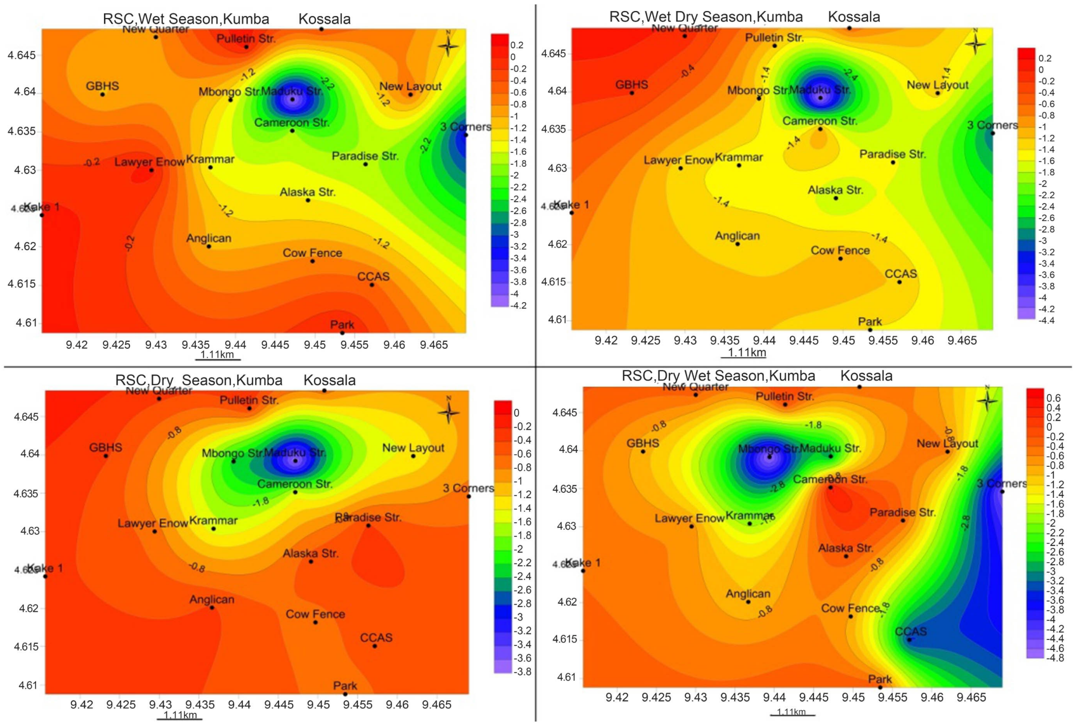

Figure 17. Spatial variation for Residual Sodium Carbonate during four hydrogeological seasons; Values are highest in the Drywetseason. No values exceeded 1.25 meq/L in all four seasons indicating the groundwater in Kumba is good for irrigation all year round.

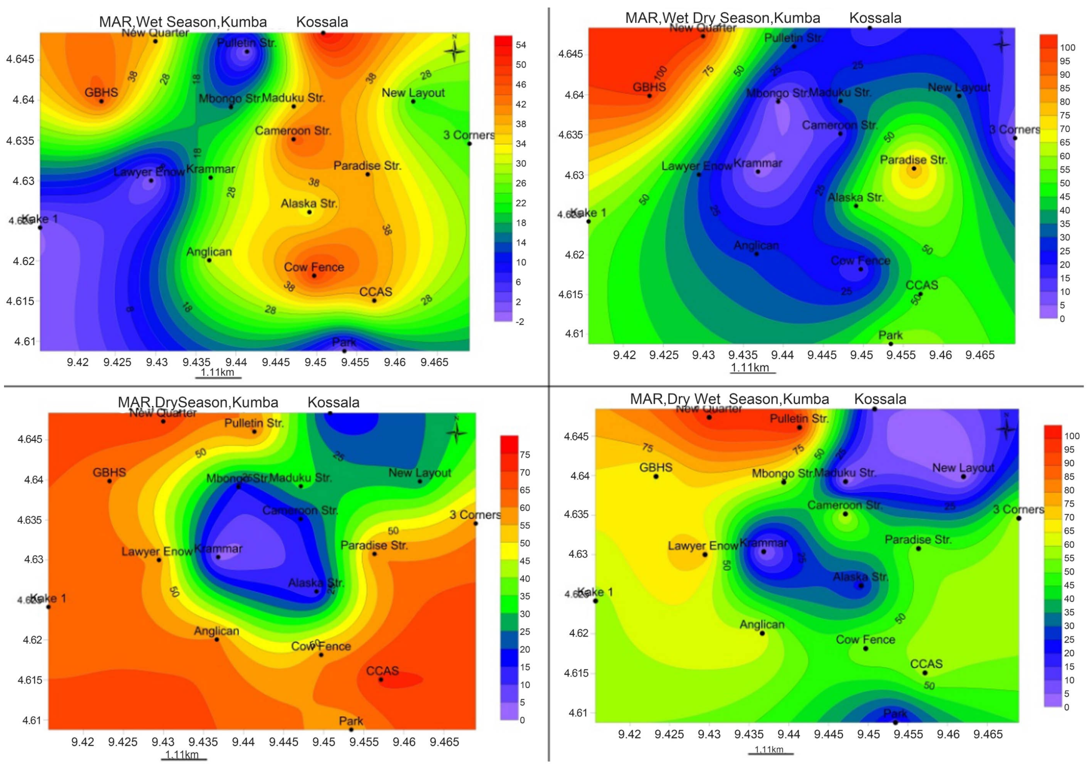

Figure 18. Spatial variation for Magnesium Adsorption Ratio during four hydrogeological seasons: 94.44% in the Wetdry and 61.11% Wet seasons of groundwater was suitable while 61.11% and 66.67% are unsuitable in the Dry and Drywet seasons respectively.

Table 11. Magnesium Adsorption Ratio of groundwater for four seasons, Kumba.

MAR	Class	Wet		Wet-Dry		Dry		Dry-Wet	
		No	%	No	%	No	%	No	%
<50	Suitable	17	94.44	11	61.11	7	38.89	6	33.33
>50	Unsuitable	1	5.56	7	38.89	11	61.11	12	66.67

hazard to crop irrigation is measured on the basis of specific conductance.

The EC values indicate majority of the samples are in the Excellent class S_1C_0; 50% in Wet, 38.89% in Wetdry, 38.89% in Dry, and 44.44% in Drywet. Very good S_1C_1 class had 33.33% in Wet, 38.89% Wetdry, 33.33% Dry and 22.22% inDrywet seasons. The Good class S_1C_2 had 16.67% in the Wet, 22.22% Wetdry, 27.78% Dry and 33.33% Drywet. All in the groundwater fell in the S_1 salinity hazard class Excellent which is suitable for irrigation in all seasons in Figure 19 and Table 12. From Figure 20, peak SAR values occur at Cameroon Str. for Wet seasons; 3 Corners for Drywet; Mbongo, Maduka Str. and Cameroon Str. for Dry and Maduka Str. for Drywet season.

From the USSL classification most of the ground water samples fell in S_1-C_0; S_1-C_1; S_1-C_2 classes characterized by low alkalinity-very low salinity hazard, low alkalinity-low salinity hazard and low alkalinity-medium salinity hazard respectively and hence all groundwater are suitable for irrigation during all four seasons Table 13.

f) Permeability Index PI

The PI of groundwater samples in the study Kumba in m.eq/L Figure 21. 94% of groundwater samples fell in the Class II in the Wet, Dry and Drywet seasons which are good for irrigation. One sample in Wetand two samples in the Wetdry fell in Class III unsuitable for irrigation. In the Dry season, one sample is in Class I; excellent for irrigation Figure 21, Table 14.

4. Conclusion

Depth to water varies with the seasons and the water table is the lowest during the Dry season. Most wells with depths less than eight meters dry up with just a few centimeters of water at during this period. During the Wet season, the water table is at the surface in the lowest lying areas with an exceedingly high pollution potential as run off fills the wells with all kinds of runoff loads since many wells are poorly constructed.

Ionic ratios indicate groundwater in Kumba is affected to a great extent by silicate weathering mostly Ca-silicates and Mg-silicates from the minerals found in basalts with little weathering of Na-feldspar and Na-silicates, no Na-absorption, some Sulphate from external sources, no oxidation of sulphides and no anthropogenic contribution.

Four groundwater types occur varying with seasons; $CaSO_4$ is the dominant water type in the Wet and Wetdry seasons; $MgHCO_3$ and Na + K-Cl Wet season; MgCl and $MgHCO_3$ in the Wetdry; $CaSO_4$ and $CaHCO_3$ in the Dry and Drywet

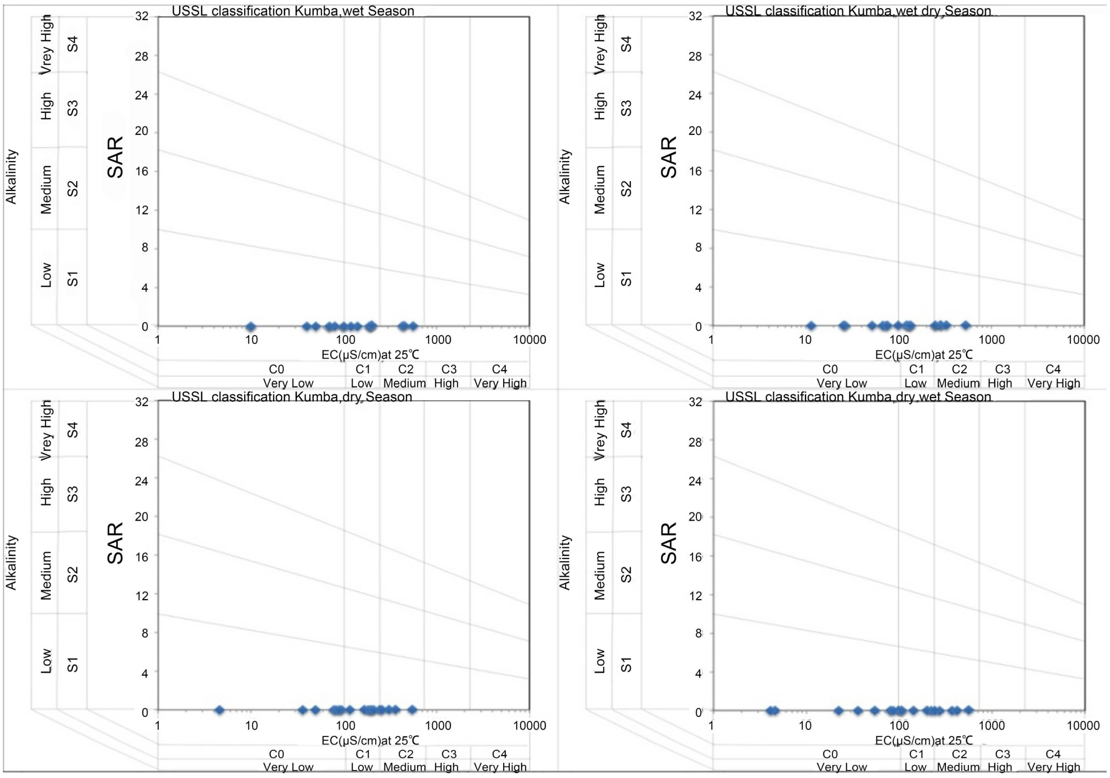

Figure 19. USSL Salinity hazard Class using EC during four hydrogeological seasons. Samples fall in Classes S_1C_0, S_1C_1 and S_1C_2 indicating excellent to good suitability for irrigation.

Table 12. USSL Salinity hazard Class for groundwater for four seasons in Kumba (Richard, 1954).

Alkalinity Hazard	EC Class	EC (μS/cm)	Quality Remark	Wet		Wetdry		Dry		Dry-Wet	
				No	%	No	%	No	%	No	%
S_1 Low	C_0 Very low	0 - 100	Excellent	9	50	7	38.89	7	38.89	8	44.44
S_1 Low	C_1 Low	101 - 250	Very Good	6	33.33	7	38.89	6	33.33	4	22.22
S_1 Low	C_2 Medium	251 - 750	Good	3	16.67	4	22.22	5	27.78	6	33.33

Table 13. Water quality based on SAR for four Seasons (Richard, 1954).

Salinity Hazard Class	SAR meq/mole	Remarks	Wet		Wetdry		Dry		Drywet	
			No	%	No	%	No	%	No	%
S_1	<10	Excellent	18	100	18	100	18	100	18	100

Table14. Permeability Index classification of groundwater four Seasons (Doneen, 1962).

Classes	PI	Remarks	Wet		Wetdry		Dry		Dry-Wet	
			No	%	No	%	No	%	No	%
Class I	>75	Excellent	0	0	1	5.56	1	5.56	0	0
Class II	50 - 75	Good	17	94.44	14	77.77	17	94.44	17	94.44
Class III	25	Unsuitable	1	5.56	2	11.11	0	0	1	5.56

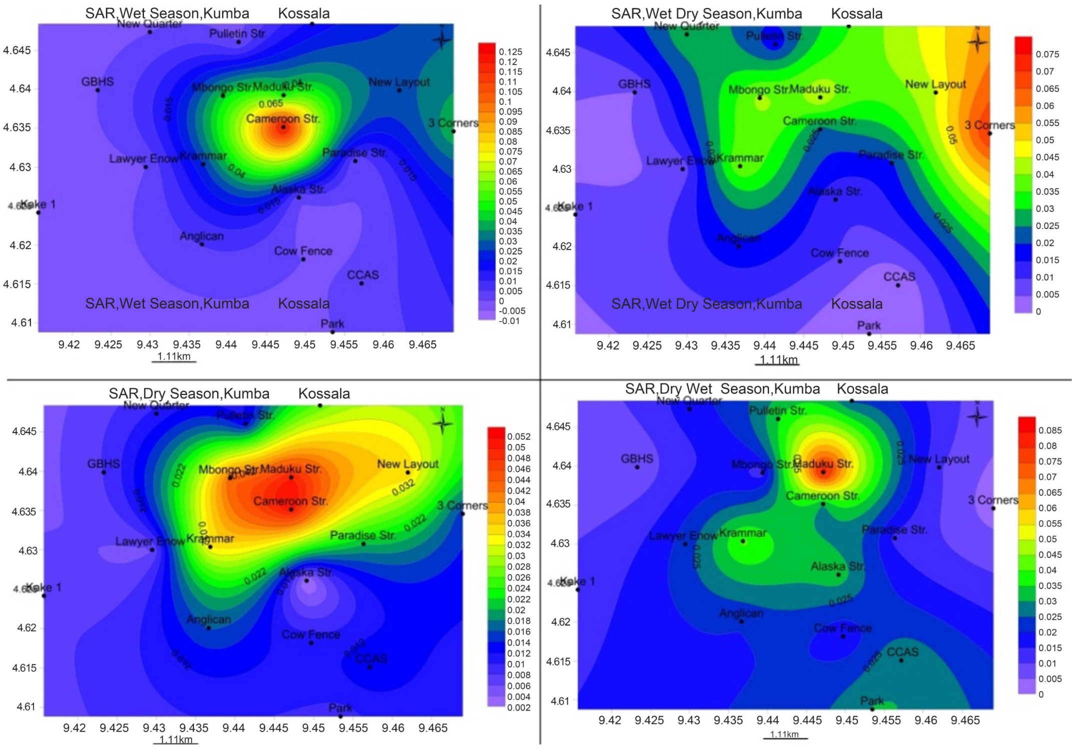

Figure 20. Spatial Variation of Sodium Adsorption Ratio during four hydrogeological seasons in Kumba. Peak values occur at Cameroon Str. for Wet seasons; 3 Corners for Drywet; Mbongo, Maduka Str. and Cameroon Str. for Dry and Maduka Str. for Drywet season. Groundwater is suitable for irrigation during all four seasons.

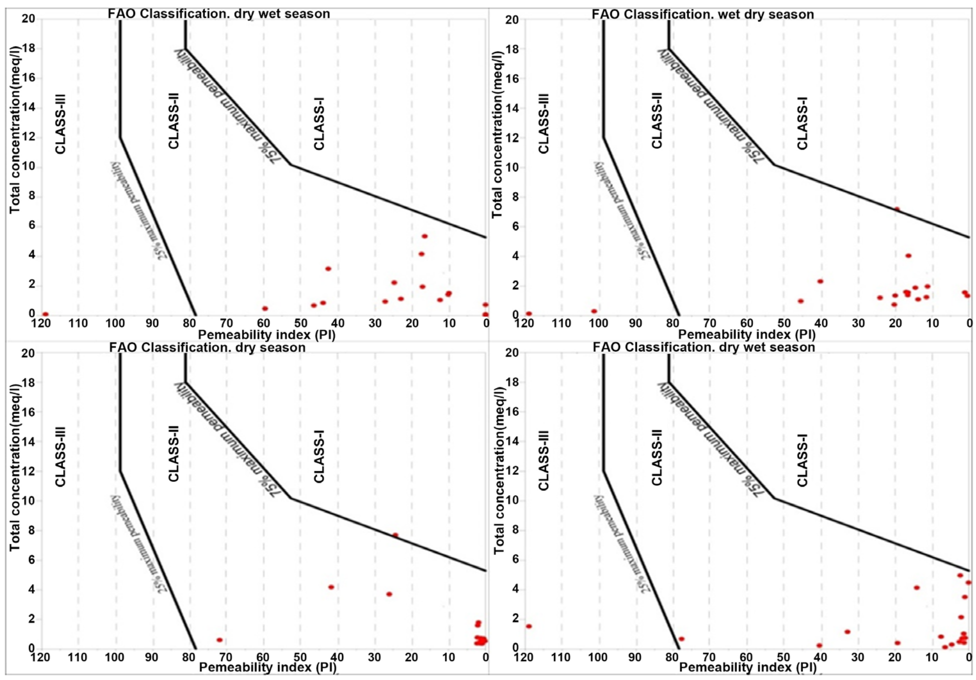

Figure 21. Groundwater FAO classification of groundwater using Permeability Indexduring: (a) Wet season (b) Dry seasons (c) Wet season and (d) Dry seasons. In the Dry season, one sample is in Class I; excellent for irrigation. Majority of groundwater samples fall in Class II in all four seasons. One sample in Wet and two samples in the Wetdry fell in Class III unsuitable for irrigation.

seasons. Three hydrogeochemical facies occur and vary with the seasons: Ca-Mg-Cl-SO_4 the most dominant occurs in the Wetdry, Dry and Drywet seasons; Ca-Mg-HCO_3 hydrogeochemical facies occurring in the Wetdry, Dry and Drywet season and Na-K-SO_4 occurring only in the wet season. The presence of Na + K-Cl groundwater type in Kumba has an input related to reverse or inverse ion exchange of Na-Cl in the Wet season probably of precipitation from the Atlantic Ocean nearby.

The Hydrogeochemical character of groundwater in Kumba indicates that weathering of the aquifer matrix is the primary process in the acquisition of ions while atmospheric precipitation is the secondary process controlling the groundwater aqueous geochemistry in Kumba for all seasons.

In the Wet, Wetdry, Dry and Drywet seasons; fresh recently recharging water from precipitation, exchanges ions with the weathered matrix of the aquiferous formations, while simple dissolution or mixing also goes on between the recently recharging groundwater and the existing groundwater in the aquiferous formations.

WQI Water of groundwater for domestic use is mostly excellent in all seasons.

Agro-industrial water quality evaluation of the suitability of groundwater for irrigation found indices for; % Na, RSC, KR, SAR, EC, PI, TD, USSL classification and Wilcox diagrams are within the suitable range for irrigation purposes during all four seasons. However, while Magnesium Absorption Ratio MAR for more than half of the samples were suitable during the Wet and Wetdry seasons, more than half were unsuitable in the, Dry and Drywet season. This is significant since it is during the drier seasons that irrigation water is needed.

Groundwater in Kumba is mostly soft with few moderately hard and lesser hard groundwaters in few areas in all the four seasons. These variations of hardness with seasons has Agro-industrial implications since in Kumba there are presently food processing plants and related business being built that might develop scaling problems if the hardness variations with seasons are not taken into consideration at the planning stage.

All hydrogeochemical parameters vary with seasons and these variations show the impact of annual seasonal changes on the aqueous geochemistry of groundwater in Kumba.

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Conflicts of Interest

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

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