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Seasonal Variations in the Hydrogeochemistry and the Domestic-Agro-Industrial Water Quality of the Granite-Gneiss Fractured Rock Aquiferous formations in Wum, North West Region, Cameroon

Akoachere RA[1]*, Mbei KK[2], Eyong TA[1], Egbe SE[1], Wotany ER[1] and Eduvie MO[3]

[1]Department of Geology, University of Buea, Buea, Cameroon

[2]Department of environmental Science, University of Buea, Buea, Cameroon

[3]National Water Resources Institute, Kaduna, Nigeria

Abstract

Wum the capital of Men chum Division is an important agricultural area in the Northwest Region in Cameroon vital for the food security of the country. The study objective was to determine and evaluate the seasonal variations during four hydrogeological seasons; dry (March), drywet (June), wet (September) and wetdry (December) in the groundwater chemistry, groundwater rock interactions and domestic-agro-industrial groundwater quality using hydrogeochemical tools; physicochemical parameters, ionic ratios, gibbs diagrams, piper diagrams, durov diagrams, Total Hardness HT, 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 index. From field physicochemical parameters; dry season, temperature, 21.5-25.3°C; EC0.01-0.51mS/cm; TDS, 0.01-0.34mg/L; drywet, pH, 2.6-6.9; Temperature, 21.7-23.1°C; EC, 0.01-6.30mS/cm, TDS, 0.01-4.22mg/L; wet pH, 3.3-7.1; Temperature, 20.8-26.6°C; EC, 0.17-3.90mS/cm, TDS, 0.11-2.61mg/L and wetdry, pH, 5.2-7.5; Temperature, 21.8-24.1°C; EC, 0.01-3.29mS/cm, TDS, 0.01-2.20mg/L. The sequence of abundance of major ions varied with seasons; dry season, Ca^{2+}>Mg^{2+}>NH^{4+}>K+>Na^{+}; HCO^{3-}>Cl^{-}>SO_4^{2-}>NO^{3-}>HPO_4^{2-}, drywet season Ca^{2+}>Mg^{2+}>K+>NH^{4+}>Na^{+}; HCO^{3-}>NO^{3-}>SO_4^{2-}>Cl^{-}>HPO_4^{2-},Wet season Mg^{2+}>Ca^{2+}>K^{+}>NH^{4+}>Na^{+}; HCO^{3-}>NO^{3-}>SO_4^{2-}>Cl^{-}>HPO_4^{2-} and wetdry season Ca^{2+}>Mg^{2+}>K^{+}>NH^{4+}>Na+; HCO^{3-}> SO_4^{2-}>NO^{3-}>Cl^{-}>HPO_4^{2-} for cations and anions respectively. Rock-groundwater Interaction has the weathering of the aquifer matrix as the primary dominant process in the acquisition of ions while atmospheric precipitation and evaporation-crystallization are the secondary contributing sources to the hydrogeochemistry through the processes of simple dissolution, mixing and ion exchange. Groundwater has two water types; $CaHCO^{3}$ the dominant water type in all seasons and $CaSO_4$ the minor water type that occurs only in the dry, drywet and wet dry seasons. Two hydrogeochemical facies occur: $CaMgHCO_3$ hydrogeochemical facies occurring in all seasons, characteristic of freshly recharged groundwater from precipitation and Ca-Mg-Cl-SO_4 hydrogeochemical facies occurring only in the dry season, characteristic of groundwater that has travelled some distance along its flow path. The groundwater character in Wum is as a result of ion exchanges between the weathered formations, simple dissolution and mixing within the two groundwater types along its flow path in the flow field. The groundwater in Wum is hard in wetdry season and soft to moderately hard in all seasons. The Water Quality Index (WQI) for groundwater in Wum is excellent-good 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 Solid (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. These hydrogeochemical facies, parameters and indices will serve as an important part of the toolkit for soil and water parameter evaluation for future development of agro-industries in the area of Wum.

Keywords: Domestic-Agro-Industrial-Water-Quality; Fractured-Rock-Aquifer; Hydrogeochemistry; Seasonal-Variation; Wum-Cameroon

***Corresponding author:** Akoachere RA, Department of Geology, University of Buea, Buea, Cameroon, Tel: +237 690153887, Email: r.akoachere@ubuea.cm

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Introduction

This study of Wum is situated between latitude 6.370 to 6.660N and longitude 10.065 to 10.340E in the Menchum Division of the North West Region of Cameroon shown in Figure 1. Wum subdivision has a population of over 130000 inhabitants and is 83 km from Bamenda, the North West regional capital. It is bordered to the West by Menchum valley, South by Bafut, East by Fundong and North by Fungom subdivisions. The main economic activity is agriculture; Pastoral farming and cattle grazing WCDP/PNDP (2011) [1].

Climate

Wum Municipality falls within the tropical humid climatic zone with some modifications due to the high and lowland areas found in this region. There is a distinct rainy season from mid-March to mid-November and dry seasons from mid-November to mid-March. The annual rainfall ranges between 2512.5mm and 3829.6mm.The total annual rainy days ranges from 173 to 196. August and February are the coldest and hottest months respectively.

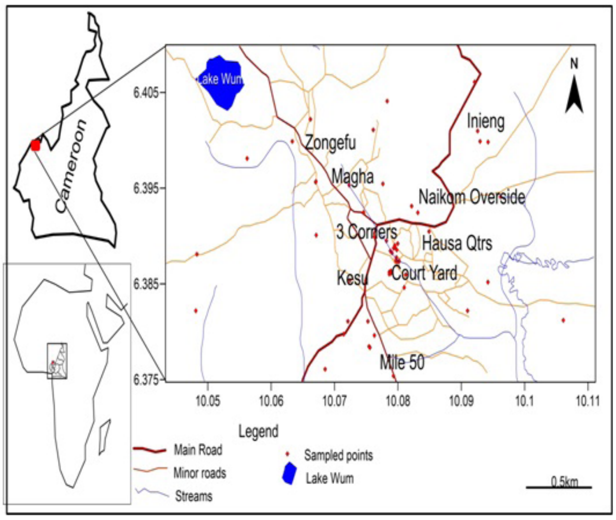

Figure 1: Location of the study area showing field tested and sampling points.

Vegetation

Lying in the savannah part of Cameroon, Wum has two common vegetation types, forests and grasslands. The forest in this region is the tropical transitional forests. Vegetation is of the Guinea Savanna type constituting mostly eucalyptus trees and raffia palms found mostly in valleys where the water table is considerably low [2] .

Relief and drainage

Wum is part of the Bamenda highlands, a chain of Precambrian hills with rocky cliffs. Most of the hills are conical and flat topped. The relief is monotonous with continuous chains of hills and valleys. Major hilly areas include Kesu to Mile 40 with spot height of 1130m. Slopes in Wum are steep 35-40°.

The drainage in Wum subdivision is dendritic with swift running Nweih, Nzala, Muoh and Menchum perennial rivers whose discharges increase significantly in the rainy season; Four lakes abound; Ilum, Oshien and Atwe. The river Menchum falls over one of the highest cliffs in West Africa. The larger rivers and lakes are far off from Wum town. Cameroon is gifted with large volumes of water resources with the second largest volume of available freshwater in Africa (After the Democratic Republic of Congo) estimated at 322 billion m^3. Groundwater constitutes 21.5 percent (57 billion m^3) of this resource and plays a vital role in the socio economic life of the country. Most rural communities in Cameroon rely on ground water to meet their water needs. Ironically, most of this enormous quantity of groundwater is of dubious quality and inaccessible due to lack of appropriate skilled professionals, equipment or financial resources allocated for this purpose. This is not different in Wum where there is an acute shortage of water with the present increase in population especially during the dry season due to the fact that there are only small surface streams in the town that together with wells dry up.

Geology and hydrogeology

Wum is located on the oku volcanic field on the Cameroon Volcanic Line CVL. The CVL is a N30E oriented tectonic structure made up of volcanic islands, continental volcanoes, plutonic and volcanic complexes ranging in age from 82 Ma to present. The CVL bears the active Mt Cameroon with latest eruptions in 1999 and 2000, with over 100 cinder cones and 40 maars presumed to be not older than 1 Ma Gaudru and Tchouankoue [3]. The Nyos maar is located in the southern continental part of the CVL and belongs to the monogenetic Oku volcanic field that culminates at Mt Oku (3011m). Volcanic activity in the Oku volcanic field ranges from effusive to explosive, and a wide range of compositions have been erupted including basanite, basalt, hawaiite, mugearite, trachyte, and rhyolite. Basement rocks are gneisses and granitoids, which formed during the Pan-African orogeny (~600 Ma) PinteÂ et al., [4]. The basement of Wum and its vicinity is mostly formed of granitic rocks of dominant micropegmatitic texture. Basaltic rocks appear as small flows directly overlapping the granitic basement. Pyroclastic surge deposits are found near the Lake Nyos crater and cap the basalt flows to the west of the volcano. The pyroclastic rocks contain broken pieces of basement granites and peridotite xenoliths Schmidt *et al.,* 2017 [5]. The aquiferous formations of Wum are mainly the regolith and the fractured crystalline rocks; granites gneisses and basaltspresented in figure 2.

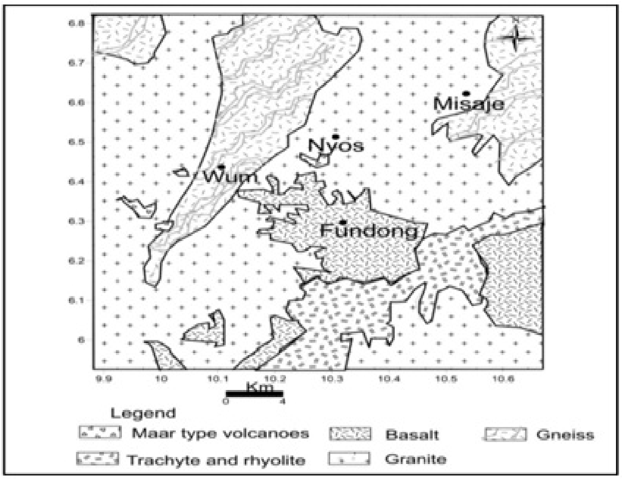

Figure 2: Geology of Wum: Area mainly made up of Gneiss, granite and patches of basalts and Maar type volcanoes [5].

The suitability of water for irrigation depends on the effects of the mineral constituents of water on both the plant and the soil [6]. Excessive amounts of dissolved ions in irrigation water affect plants and agricultural soil physically and chemically, thus reducing the productivity, thus parameters such as Electrical Conductivity EC, sodium percentage (Na%), Sodium Adsorption Ratio (SAR), Magnesium Adsorption Ratio (MAR), Residual sodium carbonate and Permeability Index (PI) were used to assess the suitability of ground water for irrigation purposes [7].

Assessment of water for agro-industrial suitability is important inorder to determine whether the water will have an adverse effect on the soil properties if used as irrigation water [8].This is vital for the development of an agricultural zone like Wum where farming is the major occupation of the citizens and there are currently studies going on to create large scale cash crop plantations.

Materials and Methods

Materials

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

Equipment/ Softwares	Specifications	Functions
Bike	Commercial bikes (Bensikin)	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 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 to 200oC)	To measure temperature of water
Total Dissolved Solid meter	Hanna HI 96301 with ATC	To measure Total dissolved solids in water
Water sampler	Gallenkampf 1000ml	To collect well water sample from well
Sample bottles	Polystyrene 500ml	To hold sample for onward transmission to laboratory
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

Table 1: Field Equipment, specifications and functions.

Methods

Prior to field tests, measurements and sampling, a reconnaissance field survey was carried out to identify and select representative wells and springs ISO 5667-1 [9].

Field measurements, tests and sampling were carried out in four hydrogeological seasons: dry (March), drywet (June), wet (September) and wetdry seasons (December). The study area was divided into 5 sections representing the main quarters. 31 representative wells and 7 springs were tested. 10 samples two samples per section were analyzed per season, except in the dry season where one sample was collected per section as many wells got dry. Seasonal measurements were carried out 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. groundwater samples were collected in a High Density Polyethylene (HDPE) 500 ml bottles, sealed and sent to the laboratory using standardprotocols ISO 5667-3 [10], ISO 5667-11 [11] and methods APHA [12] to analyze for:

Major cations in mg/L: Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} and NH_4^{+}.
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 Hounslow [13]. These were used in this study.

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 [14]. 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 Piper [15]. The diamond field is a matrix transformation of the graph of the anions $[SO_4^{2-}+ Cl^-]/\Sigma$ anions and cations $[Na+K]/\Sigma$ cations. This plot is a useful hydrogeochemical tool to compare water samples, determine water type and hydrogeochemical facies Langguth [16].This has been used here for these purposes. Durov diagram is a composite plot consisting of two ternary diagrams where the mill equivalent 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 [17]. The central rectangle is divided into nine classes which give the hydrogeochemical processes determining the character of the water types in the aquiferous formation Langguth [16], Lloyd and Heathcote [18].

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^+) and the WHO guidelines [19] in order to assess the degree of groundwater contamination and suitability table 2 Sisodia and Moundiotiya [20].

	Formula	Reference
Percentage Sodium	$\%Na = \frac{Na^+ + K^+}{Na^+ + K^+ + Ca^{2+} + Mg^{2+}} \times 100$	Wilcox (1955) [21]
Kelly's Ratio	$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}}$	Kelly (1940) [22]
Magnesium Adsorption Ratio	$MAR = \left(\frac{Mg^{2+}}{Mg^{2+} + Ca^{2+}}\right) \times 100$	Palliwal (1972) [23]
Total Hardness	TH ($CaCO_3$) mg/L = 2.5 Ca^{2+} + 4.1Mg^{2+}	Todd (1980) [24]
Residual Sodium Carbonate	$RSC = (CO_3 + HCO_3 - (Ca + Mg))$	Eaton (1950) [25]
Sodium Adsorption Ratio	$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$	Richard (1954) [26]
Permeability Index	$PI = \frac{((Na + K) + \sqrt{HCO_3}) * 100}{Ca + Mg + Na + K}$	Doneen (1962) [27]
Water Quality Index	$WQI = \sum_{i=1}^{n} W_i q_i \left[\sum_{i=1}^{n} W_i\right]^{-1}$	Sisodia and Moundiotiya (2006) [20]

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

For the determination of agro-industrial suitability of groundwater in Wum, the following parameters and indices; sodium adsorption ratio SAR, permeability index PI, Magnesium adsorption ratio, percent sodium, Kelly's ratio, Residual sodium carbonate and Wilcox diagram

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presented in Table2, together with the following softwares platforms; Surfer 12, Global mapper 11 and AqQA 1.5 AGIS 10.3 were used for data presentation, interpretation and analysis.

Results and Discussion

Physicochemical parameters

The physicochemical parameters of groundwater in Wum: Temperature, pH, EC and TDS for 10 wells and springs were evaluated and presented in table 3. All physicochemical parameters vary with seasons indicating seasonal influence on the phreatic aquifer.

Water level fluctuations: Groundwater levels vary in conformity with changes in precipitations in all four seasons typical of phreatic aquiferous formationsas shown in figure 3.

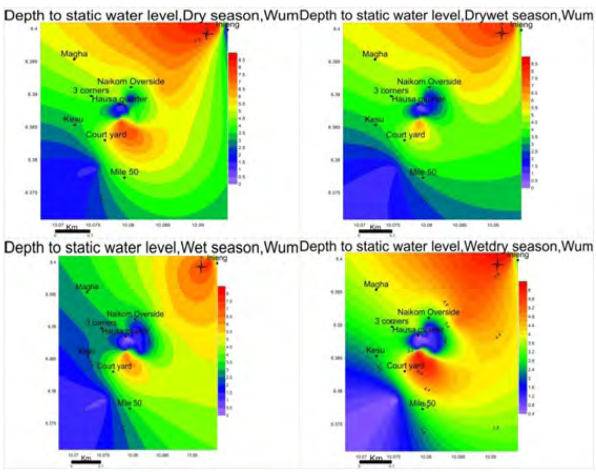

Figure 3: Depth to static water levels in four seasons. High values are at inieng and courtyard for all seasons.

Groundwater flow direction: Water level contours are similar to surface elevation contours. This indicates groundwater table mimics topography typical of phreatic aquifers. Flow is towards the northeastern parts of the study area for all seasons figure 4.

The levels of groundwater in a basement environment like Wum is controlled by the presence and extent of the weathered overburden/regolith as well as fissures, joints and fractures system in the underlying bedrock (Tijani *et al.,*2010) [28].

Temperature: The temperature of the groundwater in Wum is relatively low, ranged between 21.5-25.3 dry, 21.7-23.1 drywet, 20.8-26.6 wet and 21.8-24.1 wetdry seasons respectively figure 5. The temperature variation was similar in the different areas, suggesting a single aquifer since groundwater in the same aquifers have similar parameter values and temperature is one of them.

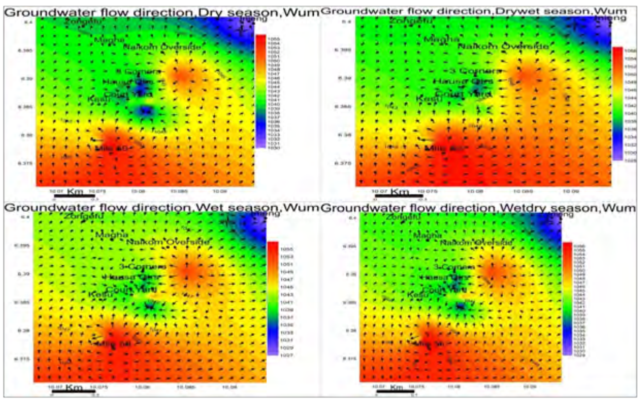

Figure 4: Groundwater flow direction in Wum indicating that water flows towards the northeastern parts of the study area all four seasons.

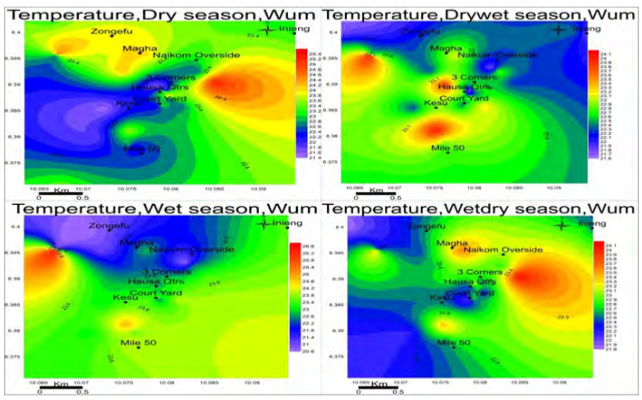

Figure 5: Temperature variations in Wum: Temperatures are highest in the wet season. High temperatures of groundwater can be found in zongefu, inieng, naikom quarters and mile 50.

pH: The pH of groundwater samples in the study area range from; 2.6-6.9 drywet, 3.3-7.1 wet and 5.2-7.5 wetdry season figure 6. This indicates that groundwater is acidic to per alkaline in all seasons.

Electrical conductivity: The observed conductance in the study area was low in all seasons, ranging from 0.01-0.51mS/cm in the dry season, 0.01-6.30mS/cm in the drywet season, 0.17-3.90mS/cm in the wet season and 0.01-3.29mS/cm wet-dry season as shown in figure 7. These low values of EC and TDS are a reflection of low salt content in groundwater. EC is highest in Magha and 3-corners for the dry season; Mile-50 in the drywet: Hausa quarter and naikom for wet and Courtyard for the wetdry season.

Test	Dry				Dry Wet				Wet				Wet Dry			
	Min	Max	Mean	Std	Min	Max	Mean	Std	Min	Max	Mean	Std	Min	Max	Mean	Std
T(oC)	21.5	25.3	23.0	23.0	0.1	23.1	26.7	26.1	20.8	26.6	23.0	22.9	21.8	24.1	22.7	22.7
PH	-	-	-	-	2.6	16.9	6.51	6.40	3.3	7.1	5.44	5.37	5.2	7.5	6.25	6.21
EC(mS/cm)	0.01	0.51	0.11	0.12	0.01	6.30	0.26	1.01	0.17	3.90	1.13	0.95	0.01	3.29	1.05	0.83
TDS(mg/L)	0.01	0.34	0.07	0.08	0.01	4.22	0.17	0.68	0.11	2.61	0.76	0.64	0.01	2.20	0.70	0.55

Table 3: Field Equipment, specifications and functions.

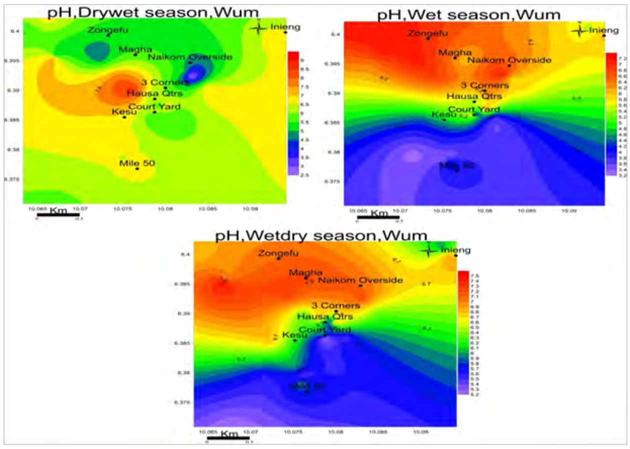

Figure 6: Spatial variation of pH in wum for three seasons; Note decrease in pH values wet and wetdry seasons around mile 50 and court yard while in the drywet season the pH values increase around 3 corners.

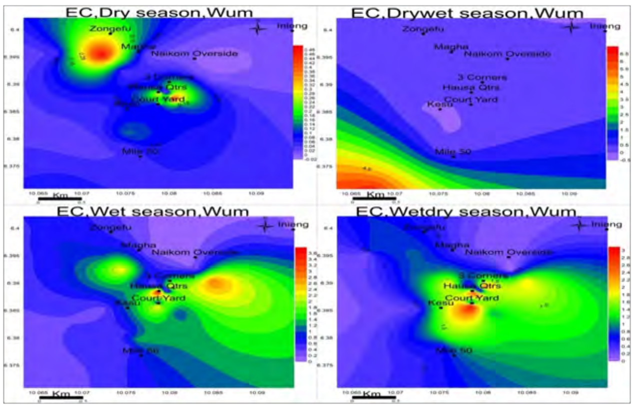

Figure 7: Spatial variation of electrical conductivities (mS/cm) in wum for four seasons; EC is at maximum in the drywet season and minimum in the dry season.

Total dissolved solids: The values of TDS range from 0.01-0.34mg/L in the dry season, 0.01-4.22mg/L drywet season, 0.11-2.61mg/L wet season and 0.01-2.20mg/L wetdry season with the highest value observed in the wet season as in figure 8. TDS is highest at Magha and 3-corners for dry season: Mile-50 in the drywet season: Hausa quarter and Naikom in the wet season and Courtyard for Wetdry season. TDS is highest in drywet season due to the absence of rain in the formations, at this point the ionic concentration is higher but moving towards the heart of rainy season and groundwater becomes more dilute and keeps decreasing each season until the next drywet season.

Groundwater ionic content in Wum

The ionic content varied with seasons as presented in tables 4, 5, 6 and 7. During the dry season the ionic trend was Ca^{2+}>Mg^{2+}>NH4+>K+>Na+, for cations and HCO_3^->Cl^->SO_4^{2-}>NO_3^->HPO_4^{2-} for anions. This same pattern was observed in most of the areas with exceptions in Hilltop, where K^+ was greater than NH_4^+. A different trend was observed in the anions where HPO_4^{2-} was greater than NO_3^- in Zongefu and Manyi. However, Cl^- was absent in most samples but whenever it was present, it usually had a higher value than SO_4^{2-} giving it a higher total concentration.

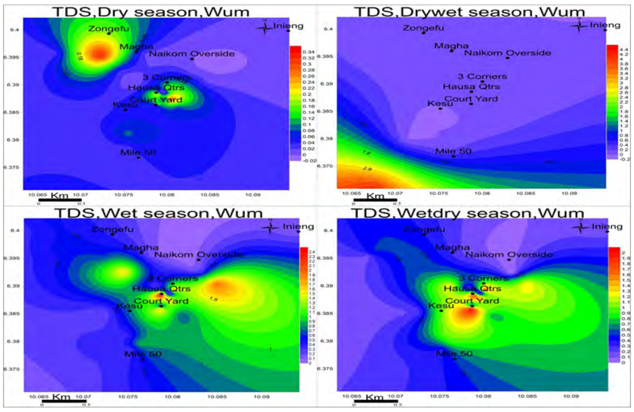

Figure 8: Spatial variation of total dissolved solids mg/L in Wum for four seasons. TDS is highest in the drywet season and lowest in the dry season.

In the drywet season the trend was Ca^{2+}>Mg^{2+}>K^+>NH_4^+>Na^+ for cations and HCO_3^->NO_3^->SO_4^{2-}>Cl^->HPO_4^{2-} for anions though at Canteen, Ndangasen, Jopacc and Twins Cl^->SO_4^{2-}.

Wet season: The trend was Mg^{2+}>Ca^{2+}>K^+>NH_4^+>Na^+ and HCO_3^->NO_3^->SO_4^{2-}>Cl^->HPO_4^{2-}. In Zongefu, Twins and Ndangasen for cations as Na+>$NH_4^+$and for the anions in Twins and Ndangasen Cl^-> SO_4^{2-}.

Wetdry season: The trend was Ca^{2+}>Mg^{2+}>K^+>NH_4^+>Na^+ for cations though Na+>NH_4^+ in Kesu and Zongefu. For Anions, it was in the order; HCO_3^-> SO_4^{2-}>NO_3^->Cl^->HPO_4^{2-} even though Cl^->NO_3^- in Canteen.

Ionic ratios of groundwater

Ionic ratios of groundwater in Wum have been determined as presented in table 8,9,10 and 11 and used to infer the sources and formation contribution to groundwater ionic contentin table 12.

Rock-groundwater interaction in wum

From Gibbs diagram, the sources of ionic content in groundwater are; 30% comes from evaporation and crystallization in the wet and wetdry seasons 50-70% comes from rock-weathering dominance for all seasons: 60% dry and drywet, 50% wet and 70% wetdry. 40% dry and drywet seasons together with 20% in wet season comes from atmospheric precipitation determined from figure 9 and presented in table 13. This indicates the weathering of the aquifer matrix is the primary dominant process in the acquisition of ions while atmospheric precipitation and evaporation-crystallization are the secondary contributing processes to the hydrogeochemistry in Wum.

Groundwater types

The diamond field of Piper's diagram has seven classes A-G classifying water types and designated with alphabets from A to G as in figure 10. Water from Wum falls into three; A, B, D categories as in table 14 and there are no category C, E, F and G in all seasons. Category A has 60-100% of samples for all four seasons. This indicates bicarbonate as prevailing ion of groundwater in Wum.

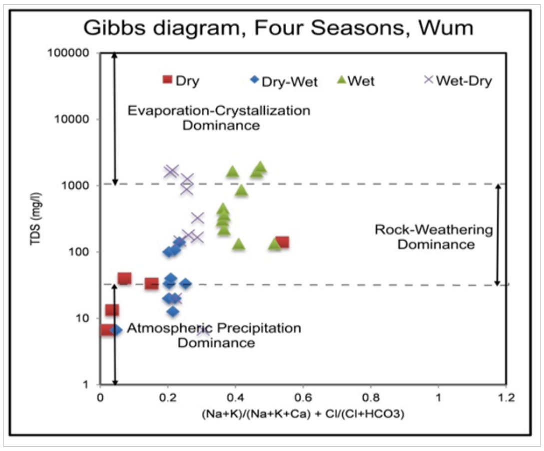

Figure 9: Gibbs diagram for sources of ionic content in Wum: 50-70% of the samples plot in the rock -weathering dominance field for all the seasons, while 40% in the dry, drywet and 20 % in the wet season fall in Atmospheric precipitation dominance.30% in the wet and wetdry seasons fall in the Evaporation-Crystallization dominance field.

In the dry season there exist: Category A; 4 samples, 80% characterized by normal earth alkaline water with prevailing bicarbonate and Category B, 1 sample, 20% characterized by normal earth alkaline water with prevailing bicarbonate. In the drywet season: Category A 9 samples, 90% is characterized by normal earth alkaline water with prevailing bicarbonate and Category B; 1 sample, 10% are characterized by normal earth alkaline water with prevailing bicarbonate. In the wet season: Category A; 10 samples, 100%; characterized by normal earth alkaline water with prevailing bicarbonate. In the wetdry season: Category A is composed of 6 samples, 60% characterized by normal earth alkaline water with prevailing bicarbonate. Category B; 2 samples, 20% are characterized by normal earth alkaline water with prevailing bicarbonate or chloride and Category D; 2 samples, 20%; are characterized by earth alkaline water with prevailing HCO_3^-.

Groundwater in Wum is made up of 2 water types; $CaHCO_3$ is the dominant water type 80-100% in all seasons and $CaSO_4$ the minor water type 20% in the dry season presented in table 14.

Dry Season (mg/L)										
Location	**Na^+**	**K^+**	**Mg^{2+}**	**Ca^{2+}**	**NH_4^+**	**HCO_3**	**NO_3^-**	**SO_4^{2-}**	**Cl^-**	**HPO_4**
Zongefusp	0.13	0.54	5.00	5.00	4.95	6.1	0	1.29	0	0.12
Twins wl	0.45	5.02	19.9	19.9	3.91	23.18	1.23	1.94	16	0.03
Hilltop sp	0.03	0.16	5.00	5.00	5.73	8.54	0	2.07	0	0
Manyiwl	0.1	0.54	9.85	9.85	5.01	8.54	0	1.75	0	0.11
Jopaccst	0.19	2.15	9.8	9.8	6.15	51.2	1.86	4.08	2	0
Min	0.03	0.16	5	5	3.91	6.1	0	1.29	0	0
Max	0.45	5.02	19.9	19.9	6.15	51.2	1.86	4.08	16	0.12
Mean	0.18	1.68	9.91	9.91	5.15	19.51	0.62	2.23	3.60	0.05
Std.	0.16	2.02	6.08	6.08	0.85	18.00	0.88	1.08	6.99	0.06

Table 4: Basic statistics of results from chemical Analysis of groundwater for dry season, Wum.

Dry Season (mg/L)										
Location	**Na^+**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**NH_4^+**	**HCO_3^-**	**NO_3^-**	**SO_4^{2-}**	**Cl^-**	**HPO_4^-**
Zongefu	0.18	3.99	9.11	1.23	0.19	45.01	2.34	0.84	0.42	0.00
Kesu	0.14	3.24	7.38	1.45	0.15	40.26	1.05	0.96	0.32	0.00
Checksense	0.40	4.34	13.21	9.21	0.89	20.03	12.90	2.12	0.84	0.00
Twins	0.60	5.97	22.16	3.69	0.00	45.14	4.28	1.69	3.68	0.00
Hilltop	0.16	3.00	6.22	1.35	0.13	39.91	1.01	0.91	0.31	0.00
Ndangasen	0.70	6.90	25.01	5.33	0.50	48.99	7.99	3.19	4.95	0.00
Canteen	0.00	0.00	2.46	0.92	1.61	17.08	3.03	8.71	0.84	0.00
Manyi	0.41	5.53	14.22	9.65	0.75	21.45	11.67	3.65	0.84	0.00
Jopacc	0.05	1.44	2.46	2.11	0.10	56.12	0.07	1.82	0.63	0.00
Jean	0.30	4.41	12.32	8.63	0.69	18.30	10.33	1.19	0.74	0.00
Min	0.00	0.00	2.46	0.92	0.00	17.08	0.07	0.84	0.31	0.00
Max	0.70	6.90	25.01	9.65	1.61	56.12	12.90	8.71	4.95	0.00
Mean	0.29	3.88	11.46	4.36	0.50	35.23	5.47	2.51	1.36	0.00
Std.	0.23	2.08	7.61	3.58	0.50	14.54	4.82	2.38	1.60	0.00

Table 5: Basic statistics of results from chemical Analysis of groundwater for drywet season, Wum.

Dry Season (mg/L)										
Location	**Na^+**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**NH_4^+**	**HCO_3^-**	**NO_3^-**	**SO_4^{2-}**	**Cl^-**	**HPO_4^-**
Zongefu	0.15	4.11	4.11	8.91	0.12	48.27	2.26	0.74	0.51	0.00
Kesu	0.21	5.01	5.01	12.11	0.25	54.05	3.42	0.62	0.63	0.00
Checksense	0.44	5.21	5.21	12.11	0.91	40.05	14.10	1.95	0.89	0.10
Twins	0.90	5.90	5.90	23.31	0.04	65.25	9.30	1.05	4.89	0.20
Hilltop	0.13	4.11	4.11	5.35	0.21	49.17	3.05	0.75	0.52	0.00
Ndangasen	0.90	7.01	7.01	24.05	0.80	51.25	8.95	2.81	4.99	0.00
Canteen	0.10	0.21	0.21	3.11	1.95	27.09	6.08	7.11	0.94	0.00
Manyi	0.45	6.22	6.22	15.51	0.81	20.95	11.95	2.44	0.96	0.00
Jopacc	0.08	2.41	2.41	3.51	0.25	58.11	1.18	1.02	0.85	0.00
Jean	0.50	5.01	5.01	15.21	0.85	20.95	11.45	0.99	0.93	0.10
Min	0.08	0.21	0.21	3.11	0.04	20.95	1.18	0.62	0.51	0.00
Max	0.90	7.01	7.01	24.05	1.95	65.25	14.10	7.11	4.99	0.20
Mean	0.39	4.52	4.52	12.32	0.62	43.51	7.17	1.95	1.61	0.04
Std.	0.31	1.98	1.98	7.45	0.58	15.67	4.58	1.97	1.76	0.07

Table 6: Basic statistics of results from chemical Analysis of groundwater for wet season, Wum.

Dry Season (mg/L)										
Location	**Na^+**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**NH_4^+**	**HCO_3^-**	**NO_3^-**	**SO_4^{2-}**	**Cl^-**	**HPO_4^-**
Zongefu	0.18	6.10	10.03	1.03	0.12	50.71	2.84	2.84	0.73	0.20
Kesu	0.56	5.51	15.91	15.84	0.99	26.13	13.03	13.03	1.39	0.10
Checksense	0.46	5.65	13.51	12.51	0.95	55.25	15.95	15.95	0.99	0.10
Twins	0.95	5.89	25.93	17.03	0.82	73.99	11.47	11.47	6.22	0.30
Hilltop	0.11	4.52	5.74	8.03	0.51	69.07	5.94	5.94	0.59	0.00
Ndangasen	0.85	7.44	23.94	23.71	0.85	53.97	9.54	9.54	5.85	0.10
Canteen	0.15	0.19	3.85	5.84	1.99	35.03	8.94	8.94	10.51	0.20
Manyi	0.55	6.35	15.11	15.95	0.94	25.11	11.99	11.99	0.97	0.00
Jopacc	0.15	2.59	4.05	4.05	0.31	61.01	1.21	1.21	1.43	0.00
Jean	0.35	8.08	13.84	1.51	0.34	74.32	5.96	5.96	0.94	0.00
Min	0.11	0.19	3.85	1.03	0.12	25.11	1.21	1.21	0.59	0.00
Max	0.95	8.08	25.93	23.71	1.99	74.32	15.95	15.95	10.51	0.30
Mean	0.43	5.23	13.19	10.55	0.78	52.46	8.69	8.69	2.96	0.10
Std.	0.30	2.32	7.64	7.60	0.53	18.40	4.67	4.67	3.39	0.11

Table 7: Basic statistics of results from chemical Analysis of groundwater for wetdry season, Wum.

No	**SO_4/ Cl**	**Na/ Cl**	**Mg/Cl**	**Na/ HCO_3**	**Ca/ HCO_3**	**Ca/ SO_4**	**Ca/ Mg**	**Ca+Mg/ Na+K**	**HCO_3 /∑An**	**NO_3/ ∑An**	**SO_4/ ∑An**	**Cl/ ∑An**	**Na^+K^+Cl /Na^+ K^-Cl^+Ca**	**Na /Na^+Cl**	**Mg /Ca^+Mg**	**Ca /Ca^+SO_4**	**Ca^+Mg /SO^4**	**Mg/Ca**
1	0.00	0.00	0.00	0.02	0.82	3.88	1.00	14.93	0.81	0.00	0.17	0.00	0.12	1.00	0.50	0.79	7.75	1.00
2	0.12	0.03	1.24	0.02	0.86	10.26	1.00	7.28	0.55	0.03	0.05	0.38	2.29	0.03	0.50	0.91	20.52	1.00
3	0.00	0.00	0.00	0.00	0.59	2.42	1.00	52.63	0.80	0.00	0.20	0.00	0.04	1.00	0.50	0.71	4.83	1.00
4	0.00	0.00	0.00	0.01	1.15	5.63	1.00	30.78	0.82	0.00	0.17	0.00	0.06	1.00	0.50	0.85	11.26	1.00
5	2.04	0.10	4.90	0.00	0.19	2.40	1.00	8.38	0.87	0.03	0.07	0.03	0.43	0.09	0.50	0.71	4.80	1.00
Min	0.00	0.00	0.00	0.00	0.19	2.40	1.00	7.28	0.55	0.00	0.05	0.00	0.04	0.03	0.50	0.71	4.80	1.00
Max	2.04	0.10	4.90	0.02	1.15	10.26	1.00	52.63	0.87	0.03	0.20	0.38	2.29	1.00	0.50	0.91	20.52	1.00
Mean	0.43	0.02	1.23	0.01	0.72	4.92	1.00	22.80	0.77	0.01	0.13	0.08	0.59	0.62	0.50	0.79	9.83	1.00
Std.	0.90	0.04	2.12	0.01	0.36	3.27	0.00	19.14	0.13	0.02	0.07	0.17	0.97	0.52	0.00	0.09	6.53	0.00

Table 8: Ionic ratios of groundwater ions: Summary statistics for dry season.

Citation: Akoachere RA, Mbei KK, Eyong TA, Eduvie MO, Engome RW, et al. (2019) Seasonal Variations in the Hydrogeochemistry and the Domestic-Agro-Industrial Water Quality of the Granite-Gneiss Fractured Rock Aquiferous formations in Wum, North West Region, Cameroon. J Environ Sci Curr Res: S1001.

No	SO_4/ Cl	Na/ Cl	Mg/Cl	Na/ HCO_3	Ca/ HCO_3	Ca/ SO_4	Ca/ Mg	Ca+Mg/ Na+K	HCO_3 /∑An	NO_3/ ∑An	SO_4/ ∑An	Cl/ ∑An	Na+K+Cl /Na+ K-Cl+Ca	Na /Na+Cl	Mg /Ca+Mg	Ca /Ca+SO_4	Ca+Mg /SO^4	Mg/Ca
1	2.00	0.43	2.93	0.00	0.20	10.85	7.41	2.48	0.93	0.05	0.02	0.01	0.36	0.30	0.12	0.92	12.31	0.14
2	3.00	0.44	4.53	0.00	0.18	7.69	5.09	2.61	0.95	0.02	0.02	0.01	0.35	0.30	0.16	0.88	9.20	0.20
3	2.52	0.48	10.96	0.02	0.66	6.23	1.43	4.73	0.56	0.36	0.06	0.02	0.33	0.32	0.41	0.86	10.58	0.70
4	0.46	0.16	1.00	0.01	0.49	13.11	6.01	3.93	0.82	0.08	0.03	0.07	0.41	0.14	0.14	0.93	15.30	0.17
5	2.94	0.52	4.35	0.00	0.16	6.84	4.61	2.40	0.95	0.02	0.02	0.01	0.38	0.34	0.18	0.87	8.32	0.22
6	0.64	0.14	1.08	0.01	0.51	7.84	4.69	3.99	0.75	0.12	0.05	0.08	0.45	0.12	0.18	0.89	9.51	0.21
7	10.37	0.00	1.10	0.00	0.14	0.28	2.67	0.00	0.58	0.10	0.29	0.03	0.52	0.00	0.27	0.22	0.39	0.37
8	4.35	0.49	11.49	0.02	0.66	3.90	1.47	4.02	0.57	0.31	0.10	0.02	0.35	0.33	0.40	0.80	6.54	0.68
9	2.89	0.08	3.35	0.00	0.04	1.35	1.17	3.07	0.96	0.00	0.03	0.01	0.64	0.07	0.46	0.57	2.51	0.86
10	1.61	0.41	11.66	0.02	0.67	10.35	1.43	4.45	0.60	0.34	0.04	0.02	0.33	0.29	0.41	0.91	17.61	0.70
Min	0.46	0.00	1.00	0.00	0.04	0.28	1.17	0.00	0.56	0.00	0.02	0.01	0.33	0.00	0.12	0.22	0.39	0.14
Max	10.37	0.52	11.66	0.02	0.67	13.11	7.41	4.73	0.96	0.36	0.29	0.08	0.64	0.34	0.46	0.93	17.61	0.86
Mean	3.08	0.31	5.25	0.01	0.37	6.84	3.60	3.17	0.77	0.14	0.07	0.03	0.41	0.22	0.27	0.79	9.23	0.42
Std.	2.81	0.19	4.42	0.01	0.25	4.10	2.25	1.39	0.18	0.14	0.08	0.02	0.10	0.12	0.13	0.22	5.27	0.28

Table 9: Ionic ratios of groundwater ions: Summary statistics for dry-wet season Wum.

No	SO_4/ Cl	Na/ Cl	Mg/Cl	Na/ HCO_3	Ca/ HCO_3	Ca/ SO_4	Ca/ Mg	Ca+Mg/ Na+K	HCO_3 /∑An	NO_3/ ∑An	SO_4/ ∑An	Cl/ ∑An	Na+K+Cl /Na+ K-Cl+Ca	Na /Na+Cl	Mg /Ca+Mg	Ca /Ca+SO_4	Ca+Mg /SO^4	Mg/Ca
1	1.45	0.29	17.47	0.00	0.09	5.55	0.46	3.06	0.93	0.04	0.01	0.01	0.61	0.23	0.68	0.85	17.59	2.17
2	0.98	0.33	19.22	0.00	0.09	8.08	0.41	3.28	0.92	0.06	0.01	0.01	0.61	0.25	0.71	0.89	27.61	2.42
3	2.19	0.49	13.61	0.01	0.13	2.67	0.43	3.07	0.70	0.25	0.03	0.02	0.66	0.33	0.70	0.73	8.88	2.32
4	0.21	0.18	4.77	0.01	0.09	5.62	0.25	4.30	0.81	0.12	0.01	0.06	1.50	0.16	0.80	0.85	27.82	3.95
5	1.44	0.25	10.29	0.00	0.08	5.48	0.77	2.23	0.92	0.06	0.01	0.01	0.61	0.20	0.57	0.85	12.61	1.30
6	0.56	0.18	4.82	0.02	0.14	2.49	0.29	3.93	0.75	0.13	0.04	0.07	1.30	0.15	0.77	0.71	11.05	3.43
7	7.56	0.11	3.31	0.00	0.01	0.03	0.07	0.00	0.66	0.15	0.17	0.02	-2.98	0.10	0.94	0.03	0.47	14.81
8	2.54	0.47	16.16	0.02	0.30	2.55	0.40	3.26	0.58	0.33	0.07	0.03	0.64	0.32	0.71	0.72	8.91	2.49
9	1.20	0.09	4.13	0.00	0.04	2.36	0.69	2.38	0.95	0.02	0.02	0.01	0.82	0.09	0.59	0.70	5.80	1.46
10	1.06	0.54	16.35	0.02	0.24	5.06	0.33	3.67	0.61	0.33	0.03	0.03	0.67	0.35	0.75	0.84	20.42	3.04
Min	0.21	0.09	3.31	0.00	0.01	0.03	0.07	0.00	0.58	0.02	0.01	0.01	-2.98	0.09	0.57	0.03	0.47	1.30
Max	7.56	0.54	19.22	0.02	0.30	8.08	0.77	4.30	0.95	0.33	0.17	0.07	1.50	0.35	0.94	0.89	27.82	14.81
Mean	1.92	0.29	11.01	0.01	0.12	3.99	0.41	2.92	0.78	0.15	0.04	0.03	0.44	0.22	0.72	0.72	14.12	3.74
Std.	2.10	0.16	6.28	0.01	0.09	2.35	0.20	1.20	0.14	0.12	0.05	0.02	1.24	0.10	0.10	0.25	9.09	3.97

Table 10: Ionic ratios of groundwater ions: Summary statistics for Wet season.

No	SO_4/ Cl	Na/ Cl	Mg/Cl	Na/ HCO_3	Ca/ HCO_3	Ca/ SO_4	Ca/ Mg	Ca+Mg/ Na+K	HCO_3 /∑An	NO_3/ ∑An	SO_4/ ∑An	Cl/ ∑An	Na+K+Cl /Na+ K-Cl+Ca	Na /Na+Cl	Mg /Ca+Mg	Ca /Ca+SO_4	Ca+Mg /SO^4	Mg/Ca
1	3.89	0.25	1.41	0.00	0.20	3.53	9.74	1.76	0.88	0.05	0.05	0.01	0.45	0.20	0.09	0.78	3.89	0.10
2	9.37	0.40	11.40	0.02	0.61	1.22	1.00	5.23	0.49	0.24	0.24	0.03	0.36	0.29	0.50	0.55	2.44	1.00
3	16.11	0.46	12.64	0.01	0.24	0.85	1.08	4.26	0.63	0.18	0.18	0.01	0.38	0.32	0.48	0.46	1.63	0.93
4	1.84	0.15	2.74	0.01	0.35	2.26	1.52	6.28	0.72	0.11	0.11	0.06	0.49	0.13	0.40	0.69	3.75	0.66
5	10.07	0.19	13.61	0.00	0.08	0.97	0.71	2.97	0.85	0.07	0.07	0.01	0.53	0.16	0.58	0.49	2.32	1.40
6	1.63	0.15	4.05	0.02	0.44	2.51	1.01	5.75	0.68	0.12	0.12	0.07	0.54	0.13	0.50	0.72	4.99	0.99
7	0.85	0.01	0.56	0.00	0.11	0.43	0.66	0.00	0.55	0.14	0.14	0.17	-1.72	0.01	0.60	0.30	1.08	1.52
8	12.36	0.57	16.44	0.02	0.60	1.26	0.95	4.50	0.50	0.24	0.24	0.02	0.37	0.36	0.51	0.56	2.59	1.06
9	0.85	0.10	2.83	0.00	0.07	3.35	1.00	2.96	0.94	0.02	0.02	0.02	0.78	0.09	0.50	0.77	6.69	1.00
10	6.34	0.37	1.61	0.00	0.19	2.32	9.17	1.82	0.85	0.07	0.07	0.01	0.44	0.27	0.10	0.70	2.58	0.11
Min	0.85	0.01	0.56	0.00	0.07	0.43	0.66	0.00	0.49	0.02	0.02	0.01	-1.72	0.01	0.09	0.30	1.08	0.10
Max	16.11	0.57	16.44	0.02	0.61	3.53	9.74	6.28	0.94	0.24	0.24	0.17	0.78	0.36	0.60	0.78	6.69	1.52
Mean	6.33	0.27	6.73	0.01	0.29	1.87	2.68	3.55	0.71	0.12	0.12	0.04	0.26	0.20	0.43	0.60	3.20	0.88
Std.	5.41	0.18	6.05	0.01	0.20	1.08	3.58	2.00	0.17	0.08	0.08	0.05	0.71	0.11	0.18	0.16	1.68	0.47

Table 11: Ionic ratios of groundwater ions: Summary statistics for Wet-dry season.

Ionic Ratio	Dry	Drywet	Wet	Wetdry	Interpretation
SO/CL	0.00-0.12	0.46-10.37	0.21-7.56	0.85-16.11	Sulphate reduction and suggests additional sources of Sulphate
Na/Cl	0.00-2.04	0.00-0.52	0.09-0.54	0.01-0.57	No Na-adsorption during freshening and absence of marine water.
Mg/Cl	0.00-0.10	1.00-11.66	3.31-19.22	0.56-16.44	Depict a cation-exchange and silicate weathering environment
Na/HCO	0.00-4.90	0.00-0.02	0.00-0.02	0.00-0.02	Low weathering of Na-feldspar or other Na-silicates.
Ca/HCO	0.00-0.02	0.04-0.67	0.01-0.30	0.07-0.61	Ca-silicate weathering from rocks
Ca/SO	0.19-1.15	0.28-13.11	0.03-8.08	0.43-3.53	There is no gypsum dissolution in volcanic regions
Ca/Mg	2.40-10.26	1.17-7.41	0.07-0.77	0.66-9.74	Typical of coastal regions due to cation-exchange
Mg/Ca	4.80-20.52	0.14-0.86	1.30-14.81	0.10-1.52	Silicate weathering
(Ca+Mg)/(Na+K)	1.00-1.00	0.00-4.73	0.00-4.30	0.00-6.28	Occurrence of silicate weathering over carbonate weathering.
$HCO_3^-/\sum$Anions	7.28-52.63	0.56-0.96	0.58-0.95	0.49-0.94	Rainwater
$NO_3/\sum$Anions	0.55-0.87	0.00-0.36	0.02-0.33	0.02-0.24	No anthropogenic activities.
$SO_4/\sum$Anions	0.00-0.03	0.02-0.29	0.01-0.17	0.02-0.24	No oxidation of sulphides.
$Cl^-/\sum$Anions	0.05-0.20	0.01-0.08	0.01-0.07	0.01-0.17	Rock weathering and rainwater
$\frac{Na^+ + K^+ - Cl^-}{Na^+ + K^+ - Cl^- + Ca^{2+}}$	0.00-0.38	0.33-0.64	-2.98-1.50	-1.72-0.78	Some plagioclase weathering in all seasons except wet season
$\frac{Na^+}{Na^+ + Cl^-}$	0.04-2.29	0.00-0.34	0.09-0.35	0.01-0.36	Halite Solution; Sodium source other than halite-albite, ion exchange and rainwater
$\frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}}$	0.03-1.00	0.12-0.46	0.57-0.94	0.09-0.60	Silicate weathering. Ferromagnesian minerals but no evidence of granitic weathering
$\frac{Ca^{2+}}{Ca^{2+} + SO_4^{2-}}$	0.50-0.50	0.22-0.93	0.03-0.89	0.30-0.78	Ion exchange/Calcium removal and Calcium source from silicates
$\frac{Ca^{2+} + Mg^{2+}}{SO_4^{2-}}$	0.71-0.91	0.39-17.61	0.47-27.82	1.08-6.69	No dolomite at all, Dedolomitization

Table 12: Ionic Ratios for dry, dry-wet, wet and wet-dry seasons with inferred formation input.

Rock-water Interaction	TDS mg/L	Dry		Drywet		Wet		Wetdry	
		No	%	No	%	No	%	No	%
Evaporation-Crystallization Dominance	1000-100000	0	0	0	0	3	30	3	30
Rock - Weathering Dominance	50-1000	3	60	6	60	5	50	7	70
Atmospheric Precipitation Dominance	1-50	2	40	4	40	2	20	0	0

Table 13: Four seasonal variations for cations plus anions in rock/groundwater interaction in Wum.

Class	Piper-Langguth Classification Wum Characteristic-Water type	Dry		Drywet		Wet		Wetdry	
		No	%	No	%	No	%	No	%
Diamond Field									
A	**Normal earth alkaline water ; prevailing HCO_3^-**	4	80	9	90	10	100	6	60
B	**Normal earth alkaline water ; prevailing HCO_3^- or Cl^-**	1	20	1	10	0	00	2	20
D	**Earth alkaline water ; increased portions of alkalis; prevailing HCO_3^-**	0	0	0	0	0	0	2	20
Cation Field									
1	**Ca^- rich waters**	0	0	6	60	0	0	2	20
2	**Mg^- rich waters**	5	100	4	40	10	100	8	70
Anion Field									
4	**HCO_3^- waters**	4	80	10	100	10	100	10	100
6	**Cl^- waters**	1	20	0	0	0	0	0	0

Table 14: Categories of Wum groundwater Wum.

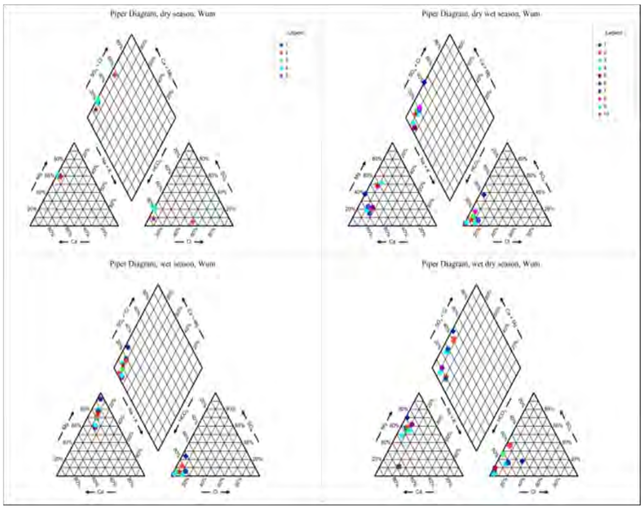

Figure 10: Piper's diagram [15] for 3 water types and 2 groundwater hydrogeochemical facies in Wum; Field (I): Ca- Mg-Cl-SO_4 hydrogeochemical facies, 1 sample 20% in the dry season. None exists in the other seasons. This facies is characteristic of stagnant groundwater zones. Field (IV), Ca_Mg_HCO_3 hydrogeochemical facies has 4 samples, 80% dry season and 10 samples, 100% drywet, wet and wetdry seasons. $CaHCO_3$ is the dominant water type 80-100% in all seasons and of $CaSO_4$, 20% in the dry season.

Piper's hydrogeochemical facies: From the Piper's diagram shown in figure 10, groundwater in Wum is characterized by two hydro chemical facies. Field (I): Ca-Mg-Cl-SO_4 hydrogeochemical facies, 1 sample 20% in the dry season. None exists in the other seasons. This facies is characteristic of groundwater some distance along its flow paths. Field (IV) Ca-Mg-HCO_3 hydrogeochemical facies has 4 samples, 80% during the dry season, while 10 samples, 100% drywet, wet and Wetdry seasons. These facies are characteristic of freshly recharged groundwater that has equilibrated with CO^2 and soluble carbonate minerals under an open system conditions in the vadose zone typical of shallow groundwater flow systems in crystalline phreatic aquifers. No samples plotted on field II and III in all 4 seasons season. The high contribution of alkaline earth elements in all seasons is due to direct ion-exchange processes which enrich groundwater with alkaline earth elements (Table 15).

Hydrogeochemical character of Wum groundwater

Based on Durov diagrams of groundwater in Wum shown in figure 11; Lloyd and Heathcoat classification seen in table 16, groundwater in Wum belongs to 3 classes: classes 3, 5 and 6. Two classes occur in dry season: Class 5 simple dissolution or mixing 1 sample (20%) and Class 6 probable mixing or uncommon dissolution influences: 4 samples (80%) respectively. Two classes occur during the drywet season; Class 3 ions exchange water 1 sample (10%) and Class 6 probable mixing or uncommon dissolution influences: 9 samples (90%) respectively. One class occurs in the wet season: Class 6 probable mixing or uncommon dissolution influences 10 samples (100%). Three classes of occur in the wetdry season: Class 3 ion exchange water: 2 samples (20%); Class 5 simple dissolution or mixing: 1 sample (10%) and Class 6 probable mixing or uncommon dissolution influences: 7 samples (70%) respectively. There are no Classes 1,2,4,7 and 9 in the wet season; 3,5,7,8 and 9 Wetdry; 6, 7, 8, and 9 dry seasons and no Classes 2,3,7,8 and 9 in the drywet season in Wum. In the wet season, fresh recently recharging water exchanges ions with the matrix of the formation, while simple dissolution or mixing also goes on between the recently recharging precipitation and the existing groundwater in the formation. In the dry season, recharging groundwater having spent more time in the formation continues to exchange ions to a lesser extent with the matrix of the formation while increasingly; simple dissolution or mixing also goes on between the recently recharging groundwater and the pre-existing groundwater in the formation, piston flow. The absence of samples in classes 1, 2, 4, 5, 7, 8, and 9 in all seasons indicates that the groundwater character in Wum is as a result of ion exchanges between the weathered formations, simple dissolution and mixing within the various groundwater types within the flow field.

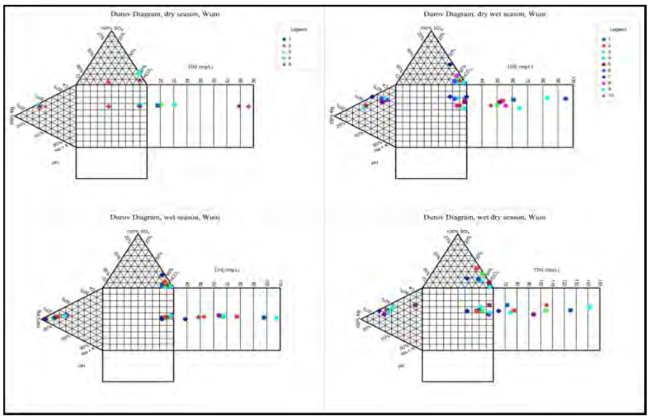

Figure 11: Durov diagrams of groundwater in Wum: For dry season; Class 5, simple dissolution or mixing; wet season; Class 6 probable mixing or uncommon dissolution influences: 10 samples (100%). wetdry season: Class 3 ion exchange water: 2 samples (20%); Class 5 simple dissolution or mixing: 1 samples (10%) and Class 6 probable mixing or uncommon dissolution influences: 7 samples (70%) respectively.

Rock-groundwater interaction: Based on the Durov diagrams of groundwater during various seasons in Wum shown in figure 11; Lloyd and Heathcoat classification seen in table 16, Wum groundwater samples plotted in:i) class 6; 80% Wet, 90% drywet, 100% wet and 70% wetdry seasons indicating water types resulting from mixing or uncommon dissolution influences. ii) class 5, 20% dry season and 10%, wetdry season indicating water exhibiting simple dissolution or mixing.iii) class 3, 10% drywet and 20% Wetdry indicating ion exchanged groundwater. The Durov diagram thus indicates that, simple dissolution, mixing and ion exchange are the dominant processes governing rock-groundwater interaction in Wum.

Water quality

Water Quality Index (WQI) for domestic use: Using the WHO guideline values of ions present in the groundwater WQI values were determined. Pradhan et al., [29]; Asadiet al., [30].WQI values ranged from 3.86-42.91 in the dry season, -0.330-30.449 in drywet, -78.713-12.268 wet and -0.079-42.715 wetdry season. Groundwater in Wum is excellent-good for domestic use base on WQI is presented in table 17 and figure 12.

Fields	Hydrogeochemical facies	Dry		Drywet		Wet		Wetdry	
			%	No	%	No	%	No	%
Field I	Ca - Mg - Cl -SO_4	1	20	0	0	0	0	0	0
Field IV	Ca - Mg - HCO_3	4	80	10	100	10	100	10	100

Table 15: Classification of hydrogeochemical facies based for four seasons Wum.

Class	Hydrogeochemical facies	Dry		Drywet		Wet		Wetdry	
		No	%	No	%	No	%	No	%
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	10	0	0	2	20
5	No dominant anion or cation, indicates water exhibiting simple dissolution or mixing	1	20					1	10
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.	4	80	9	90	10	100	7	70

Table 16: Classification of Water based on Durov diagram four seasons Wum.

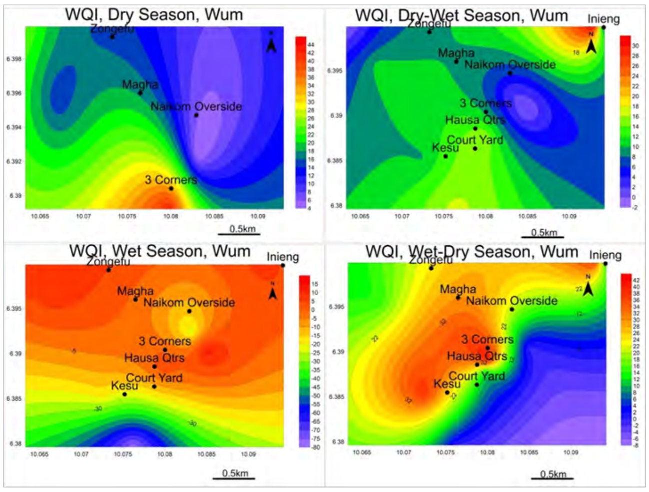

Figure 12: Spatial variation of WQI for four seasons: groundwater in Wum is Excellent-Good in all seasons.

WQI	Class	Dry		Drywet		Wet		Wetdry	
Value	Quality	No	%	No	%	No	%	No	%
0-25	Excellent	4	80	9	90	10	100	7	70
26-50	Good	1	20	1	10	0	0	3	30

Table 17: Water Quality Index Classification of groundwater samples for four seasons Wum.

Total Hardness (HT): Total hardness values range from: 33-131.34 in the dry season, 9.92-84 in the drywet, 13.28-116.13during the wet and 26.73-157.06 during the wetdry season as presented in figure 13. This implies that groundwater in Wum is hard in wetdry season and soft to moderately hard in all the other seasons as shown in table 18. Irrigation water quality for agro-industrial use

Parameters that are generally considered for evaluation of the suitability of ground water for irrigation are: 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.

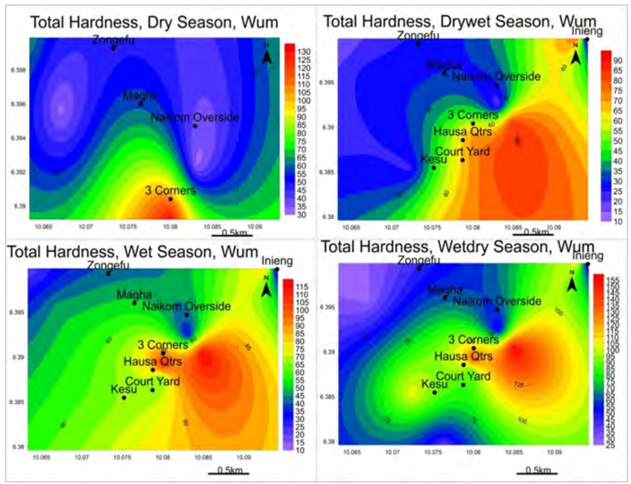

Figure 13: Spatial variation of total hardness for four seasons: There is a general increase from wet to dry season. Groundwater is harder Southeast of Wum, from Naikom, overside, Inieng and Mile 50.

WQI	Class	Dry		Drywet		Wet		Wetdry	
0-75	Soft	4	80	8	80	7	70	5	50
76-150	Moderately Hard	1	20	2	20	3	30	4	40
151-300	Hard							1	10

Table 18: Groundwater Hardness for four seasons in Wum.

Sodium percentage: Percentage of sodium values ranged from dry season, 0.81-5.33; 0-16.57 drywet, 3.52-14.65 wet and wetdry, 1.66-21.87. Based on Wilcox [31] classification. All samples fell in the excellent to good category for dry and drywet seasons. In the wet and wetdry seasons, 6 samples fell in the excellent to good category while 2 and 1 fell in the good to permissible respectively. 2-3 samples fell in the doubtful to unsuitable category in Figure 14.

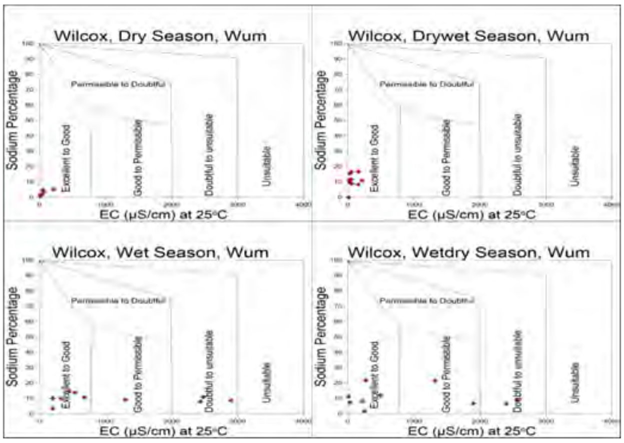

Figure 14: Wilcox diagram showing groundwater suitability for irrigation: All samples fall into the excellent category in the dry and drywet seasons 3(30%) and 2(20%) in the wet and Wetdry season are doubtful to unsuitable.

Groundwater in Wum has a high concentration of bicarbonate which is highest in the wet and wetdry seasons; which indicates a high probability for the precipitation of calcium and magnesium as water resides longer in the formations the concentration of Sodium in water increases in the form of sodium carbonate.

Kelly's ratio: Kelley's ratios range from 0.002 to 0.009 dryseason, 0 to 0.0185 drywet season, 0.007 to 0.0177 wet season and 0.005-0.0187 wetdry season. All samples had KR values less than 1.00 implying that the groundwater in Wum is suitable for irrigation purposes all four seasons seen in table 19 and figure 15.

		Dry		Drywet		Wet		Wetdry	
	Water Class	No of samples	%	No of samples	%	No of samples	%	No of samples	%
<1	Suitable	5	100	10	100	10	100	10	100

Table 19: Water classes based on kelly's ratio wum.

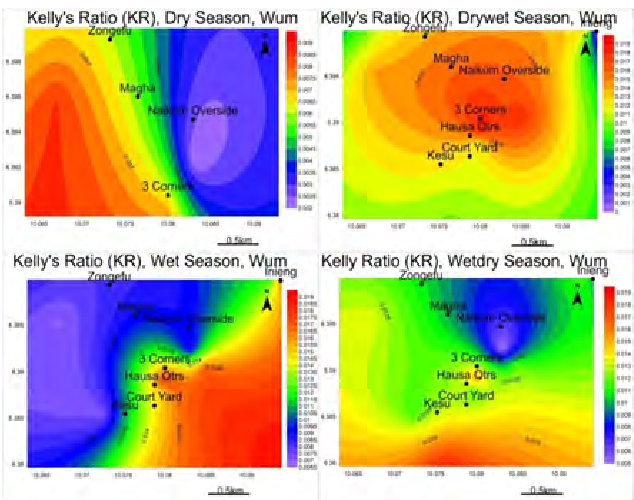

Figure 15: Spatial variation for Kelly Ratio for four seasons. Values are much higher in the Wetdry season.

Residual sodium carbonate: The RSC values of the groundwater in Wum varied from -2.25 to -0.46 during the dry season, -1.15 to -0.62 drywet season, -1.49 to 0.54 wet season and -2.26 to 0.46 drywet season. No sample exceeded 1.25 indicating that all samples are good for irrigation purposes based on RSC shown in figure 16 and table 20.

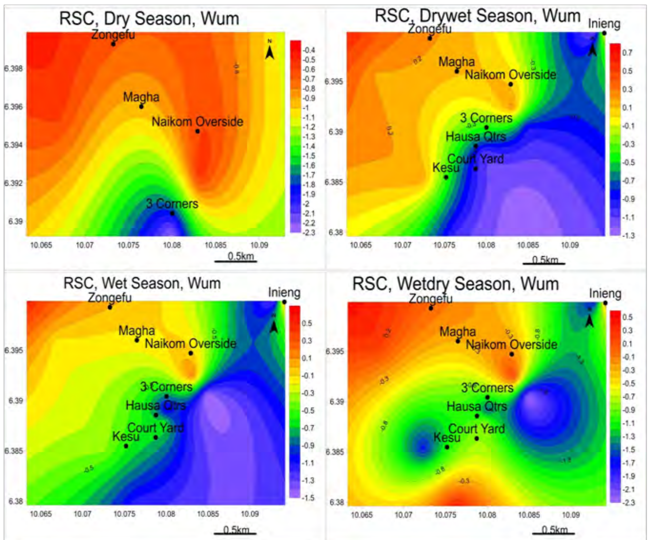

Figure 16: Spatial variation for Residual Sodium Carbonate for four seasons: Higher values are found in the drywet and wet seasons. Values peaks towards Zongefu in all seasons.

	Remarks	Dry		Drywet		Wet		Wetdry	
		No of samples	%	No of samples	%	No of samples	%	No of samples	%
<1.25	Good	5	100	10	100	10	100	10	100

Table 20: Groundwater quality based on residual sodium carbonate wum.

Magnesium adsorption ratio: MAR values of all the samples varied from 18.21-58.57% in the drywet season, 68.21-96.07% in the wet season and 14.48-71.43during the wetdry season shown in figure 17 indicating that the groundwater in Wum is not suitable for irrigation based on MAR. Some wells were dry in the dry season as such their samples could not be collected and analyzed.

Sodium adsorption ratio: The sodium adsorption ratio reflects sodium concentration in water which accumulates during irrigation in soils presents a hazard. The sodium adsorption ratio is presented in figure 18 and table 21. All samples fall in the excellent class for all seasons.

Based on SAR, all samples are good for irrigation. When the SAR values and specific conductance of water are known, combining them strongly explains the effect of alkali hazard and salinity hazard as in table 16. Most of the groundwater samples in Wum fell in C0-S0 type, C1-S1 types and are characterized by medium salinity-low alkali hazard and low salinity-low alkali hazard respectively and hence are suitable for irrigation.

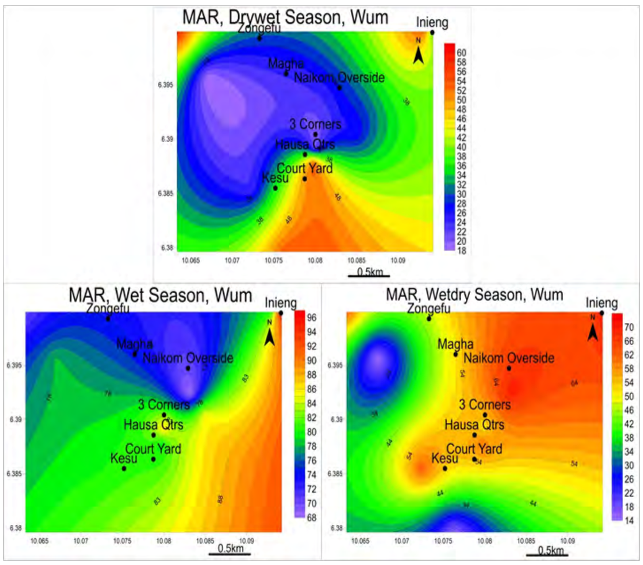

Figure 17: Spatial variation for Magnesium Adsorption Ratio for four seasons: There is greater magnesium absorption in the wet season. Higher values extend from Southeast towards Northeast from one season to the other.

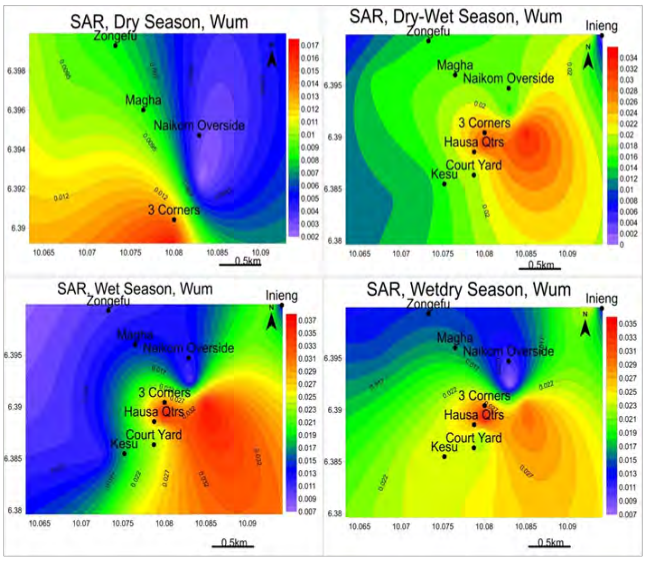

Figure 18: Spatial Variation of SAR of groundwater in Wum for four Seasons. Values are highest in the wet season. Values peak at Naikom, Overside.

USSL salinity hazard classification: The USSL Salinity Hazard Classification to crop irrigation is measured by the specific conductance [32]. In the dry season, 80% are excellent and 20% very good. For drywet; 70% are excellent and 30% very good. For wet season; 20% very good, 40% good, 10% doubtful and 30% unsuitable and wetdry season; 20% are excellent and 10% very good, 30% good, 20% doubtful and 20% unsuitable presented in table 22 and figure 19. Therefore groundwater increases in salinity hazard in the wet and wetdry seasons. None fell in Classes C2, C3 and C4, in dry and drywet seasons.

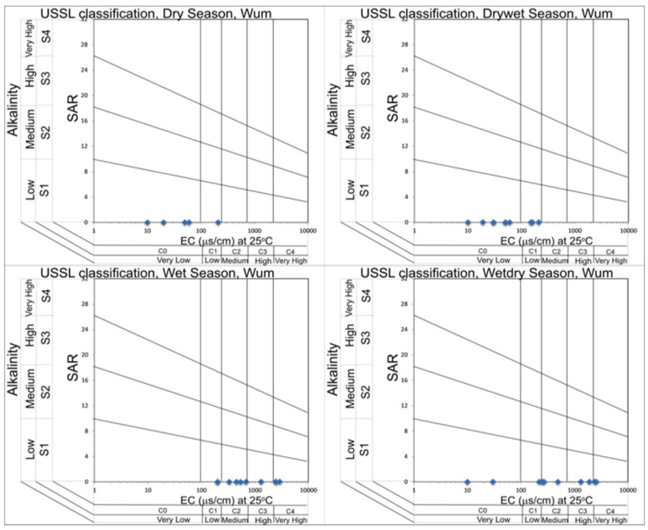

Figure 19: USSL salinity hazard class using electrical conductivity for four season: Groundwater in the study area falls in excellent to very good in dry, drywet and some wetdry season. Groundwater is mostly unsuitable in the wet and wetdry season.

Permeability index: The groundwater samples of the study area fell in class-I and II as presented in figure 20 and table 23: Class II, 100% in the dry season, 50% in the drywet season, 60% in the wet season and 40% in the wetdry season that indicated water is good for irrigation. Class III, 50% in the drywet season, 40% in the wet season and 60% in the wetdry season which indicates the water is unsuitable for irrigation.

Groundwater indices of: Sodium percent, residual sodium carbonate, Kelley's ratio, sodium adsorption ratio, electrical conductivity, total dissolved solid, USSL and Wilcox index were determined, evaluated and found to be suitable for agro-industrial uses in all seasons but for Permeability index and Magnesium adsorption ratio that were not suitable in some areas and in some seasons. The significance of low values of these indices is that the groundwater in the study area will have no adverse effect on the soil properties and is thus suitable for irrigational purposes whereas high magnesium adsorption ratio may be due to the passage of surface water and subsurface water through formation in the study area [33].

High permeability indices could be due to high concentration of sodium, calcium, magnesium and bicarbonate in the groundwater which could affect the soil structure and other soil properties.

Conclusion

Groundwater levels vary in rhythm with changes in precipitations in all four seasons, water level contours are similar to surface elevation contours and groundwater table mimics topography typical of phreatic aquifers with all physicochemical parameters varying with seasons indicating seasonal influence on the phreatic aquifer. An evaluation of the ionic ratios indicates ions in the groundwater in Wum are from rock weathering and rainwater; portrays a cation-exchange and silicate weathering environment.

Sodium Hazard Class	SAR meq/mole	Remarks	Dry	%	Drywet	%	Wet	%	Wetdry	%
S1	<10	Excellent	5	100	10	100	10	100	10	100

Table 21: SAR classification of groundwater for four seasons, Wum.

Salinity Hazard Class	EC (µS/cm)	Quality	Dry		Dry-Wet		Wet		Wet-Dry	
			No	%	No	%	No	%	No	%
C0	0-100	Excellent	4	80	7	70	0	0	2	20
C1	101-250	Very Good	1	20	3	30	2	20	1	10
C2	251-750	Good	0	0	0	0	4	40	3	30
C3	751-2250	Doubtful	0	0	0	0	1	10	2	20
C4	>2250	Unsuitable	0	0	0	0	3	30	2	20

Table 22: USSL salinity hazard classification for groundwater in wum.

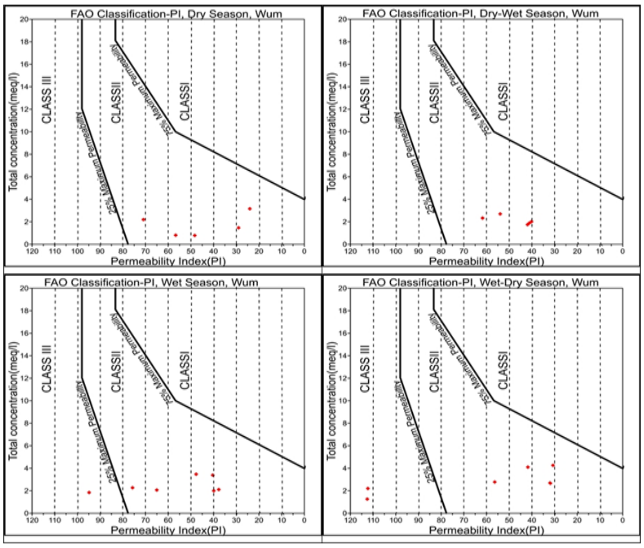

Figure 20: FAO classification of groundwater in Wum using permeability index for four seasons: 40-100% of samples fell in Class II (good) during all the four seasons and 40-60% of the samples fell in Class III (unsuitable) in the drywet, wet and wetdry seasons.

Rock-Groundwater Interaction in Wum has the weathering of the aquifer matrix as the primary dominant process in the acquisition of ions while atmospheric precipitation and Evaporation-Crystallization are the secondary contributing processes to the hydrogeochemistry in Wum.

Groundwater in Wum is made up of two water types; $CaHCO_3$ is the dominant water type in all seasons and $CaSO_4$ the minor water type occurs in the dry, drywet and wetdry seasons.

There are two hydrochemical 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 crystalline phreatic fractured rock aquifers.

Hydrogeochemical character of Wum groundwater varies with season: In the wet season, fresh recently recharging water exchanges ions with the matrix of the formation, while simple dissolution or mixing also goes on between the recently recharging precipitation and the existing groundwater in the formation. In the dry season, recharging groundwater having spent more time in the formation continues to exchange ions to a lesser extent with the matrix of the formation while increasingly; simple dissolution or mixing also goes on between the recently recharging groundwater and the pre-existing groundwater in the formation, piston flow.

The groundwater in Wum is hard in wetdry season and soft to moderately hard in all seasons. The Water Quality Index for groundwater in Wum is excellent-good for domestic use. The groundwater indices of; Sodium Percent, Residual Sodium Carbonate, Kelley's ratio, Sodium Adsorption Ratio, Electrical Conductivity, Total Dissolved Solid, USSL and Wilcox index were determined, evaluated and found to be suitable for agro-industrial uses in all seasons.

Permeability Index and Magnesium Adsorption Ratio are not suitable in some areas and in some seasons, Therefore, more attention should be paid on groundwater quality monitoring (PI and MAR) in Wum, for ensuring dependable, affordable groundwater and protecting the quantity available for future use during the planning stage of large scale farming in Wum.

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