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Effects of Seasonal Variations on Groundwater Facies Classification in Otte, Southwestern Nigeria

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Abstract

Groundwater assumes different composition from place to place due to continuous interactions with earth materials and change in climatic condition. These factors place water bodies into different class of suitability for human consumption. This study evaluated effects of seasonal variation on chemical budget of groundwater samples from Otte, Southwestern Nigeria. This was with a view to determining the dominant ions and sources of pollutants. A total of 37 samples were collected for physicochemical analysis. Physical evaluation revealed that turbidity, color, electrical conductivity and $_pH$ are higher in order of degree pollution at the wet season than dry season. Hydrochemical analyses revealed ionic dominance in the order of $Ca^{+2}>Mg^{+2}>Na^+$ and $Cl^->HCO^-_3>SO_4^{-2}$ for both seasons which is an indication of no change in seasonal effect. Also, $CaHCO^-_3$ is the major water facie while weathering of rock forming minerals is the predominant source of pollutants for both seasons. Thus, the study concluded that no significant variation in the chemical budget and mobilization of ions as a result of seasonal change. However physical parameters like color and turbidity show increase in the wet season while conductivity remain constant.

Keywords: Groundwater, Seasonal, Nigeria, Classification, Otte

1.   Introduction

The sources of water for any specific purpose are not as important as the suitability of the water for the desired purpose. With increasing human population, industrialization, urbanization and the consequent increase in demand for water for both domestic and industrial uses, the attendant increase in the implication of polluted water on man and the environment have been severally

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studied (Asiwaju-Bello and Akande, 2004; Ige *et al*., 2008*)*. Quality of groundwater drops when foreign materials that are dangerous to human health enter a water body through run-off, weathering or when concentration of natural elements fall short of required standard (Anudu *et al.,* 2011). Groundwater chemistry is largely a function of the mineral composition of the aquifer through which it flows (Lakshmanan *et al.,* 2003) and the interactions with the earth material in the saturated zone (Freeze and Cherry, 1979). Frequent failures and uneven distribution of rainfall, lack of surface water management technologies and change in climatic conditions are other major factors responsible for ionic budget in a groundwater body (Ordookhani *et al.,* 2012 and Nwakwoala, 2013).

This study attempts an evaluation of the effects of seasonal variation on ionic budget in hand dug wells of a typical basement complex area of Nigeria. This is also hope to help the determination of the water facie(s), source(s) of pollutants and suitability of the water for drinking, domestic and irrigation purposes.

Study Area

Location and Physical Setting

The study area is Otte, southwestern Nigeria. Its geographical co-ordinates lies between latitudes $08^0 15$'N and $08^0 20$'N and between longitudes $4^0 21$'E and $4^0 26$'E (Fig. 1). The area is drained by river Alalubosa and its tributaries which define a dendritic pattern of drainage, concordant to the general trend of the foliation surfaces on the surrounding inselbergs of crystalline rocks. The area is characterized by two climatic seasons: a wet season during which the groundwater is usually recharged by precipitation and a dry season. The wet season extends from April to October while the dry season lasts from November to March. The annual temperature is $26\text{-}27^0$C (Ige and Alao, 2010). The town is known for production of vegetables which is a major component of people's delicacies.

Geology and Hydrogeology of the Area

The study area is underlain by the crystalline Precambrian Migmatite-gneiss complex of the Nigerian basement complex (Jones and Hockey, 1964). The main rock units are the migmatitic and granitic gneisses (Fig.1) which are covered by superficial overburden materials believed to

have been derived from the process of weathering of the basement rocks. The outcrops are generally low-lying within the town and are covered by hard lateritic material which shows evidence of complete weathering and laterization processes.

The rock types have been described to have low primary porosity and permeability (Oluyide and Udeh, 1966). The overlying weathered rocks contain the perched aquifer units in the area (Oladeji *et al.,* 2012). The shallow aquifer, which is tapped through hand dug well, is the major source of water supply. This is often complemented by surface and rain water during the wet season. The hand-dug wells and surface water sources are particularly susceptible to anthropogenic activities such as waste from pit latrines and indiscriminate dumping of house hold solid waste into run-off water bodies. Thus, there is a high risk of pollution of underground water in the study area.

2.   Materials and Methods

A total of Thirty seven (37) groundwater samples (20 in wet, 17 in dry season were collected from different hand-dug wells between 19th and 21st September, 2012 while dry season sampling was carried out between 14th and 16th February, 2013. A clean 1.0 litre plastic container was filled with water sample from each sampling location after rinsing it with the same water sample 2-3 times in each case. The filled plastic bottles were immediately capped tight to prevent trapping of atmospheric oxygen. The samples were adequately labeled and refrigerated to prevent cationic adsorption on the wall of the container during storage before being moved to the laboratory for chemical analysis.

Cationic analysis was done using Atomic Adsorption Spectrometry (AAS) to determine the concentration of Ca^{2+}, Mg^{2+}, Na^+ and K^+ in each water sample. Digital titration method was used to determine the concentration of anions: Cl^-, NO_3^-, HCO_3^-, CO_3^{2-} and SO_4^{2-} in the water samples. In order to check for seasonal variations in the ionic budget of water in the study area, the above procedure was repeated for water samples collected at the same locations during the dry season. The samples were taken at the peak of seasons to assume negative and positive peaks of ionic concentration. Correlation of results was done after data processing and interpretation using the Hydrochem software.
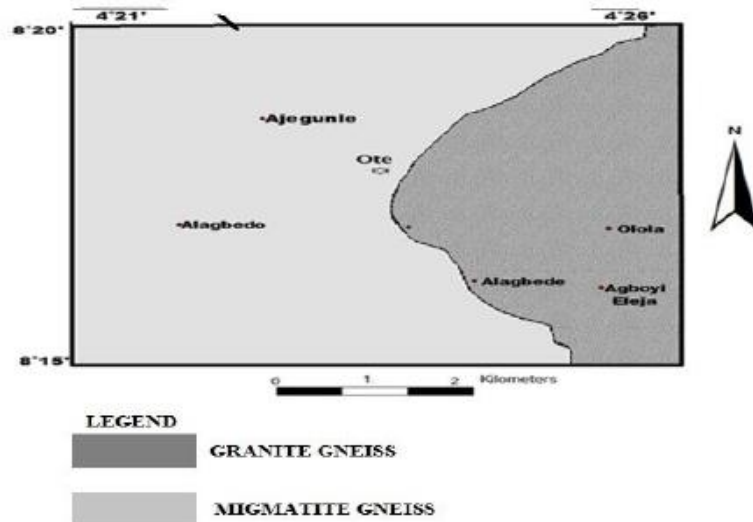
Figure 1: Geological Map of Otte and Environ (Adegbola and Adewoye, 2012)

3.   Results and Discussion

Physical Characteristics of Water Samples

Table 1 and 2 contain the location and some physical characteristics of water samples. Results showed seasonal variation in depth to water level (DWL), pH and temperature. DWL ranges from 1.30 – 7.35m and 3.00 - 8. 59m at the dry and wet seasons respectively.

Table 1: Sample location and water characteristics (dry season)

S/N	LOCATION	TYPE	COORDINATES	DWL(m)	TOTAL DEPTH	pH	TEMP.(^{O}C)
1	ILEPANU COMPOUND	HW	N08^{0}18.729′ E004^{0}23.041′	5.90	7.30	6.32	25.6
2	ILE OLOHUNYO	HW	N08^{0}18.764′ E004^{0}23.032′	7.35	8.95	6.63	25.3
3	ABU YARIN	BH	N08^{0}18.775′ E004^{0}23.042′	ND	ND	6.61	25.9
4	ILE BAALE (ALANGUA)	HW	N08^{0}18.833′ E004^{0}23.041′	5.60	9.40	-	-
5	MARKET	HW	N08^{0}18.729′ E004^{0}23.040′	3.05	8.15	6.83	25.4
6	ALALUBOSA (CLOSE TO STREAM)	HW	N08^{0}18.861′ E004^{0}23.155′	1.30	5.25	6.94	26.9
7	STAGNANT STREAM	-	N08^{0}19.979′ E004^{0}23.105′	ND	ND	7.10	25.9
8	ILE AYETORO	HW	N08^{0}18.946′ E004^{0}23.008′	2.50	4.65	6.93	25.5
9	ILE IGBO	HW	N08^{0}19.006′ E004^{0}22.913′	5.60	6.93	7.06	26.8
10	ILE PANU (BY GOVT. RESERVOIR)	HW	N08^{0}18.907′ E004^{0}22.842′	7.09	8.34	6.70	26.6
11	SCHOOL(OTE LGA)	BH	N08^{0}18.761′ E004^{0}22.948′	ND	ND	6.84	25.5
12	ILE ABO	HW	N08^{0}18.897′ E004^{0}23.302′	2.00	4.35	7.03	27.3
13	ISALE OLOKAA	HW	N08^{0}18.993′ E004^{0}23.257′	1.80	3.55	6.78	29.6

14	ISALE HOSPITAL	HW	N08^{0}18.895′ E004^{0}23.213′	2.50	3.60	7.06	27.1
15	ALHAJA ELELUBO	HW	N08^{0}18.915′ E004^{0}23.224′	2.60	3.73	6.88	30.4
16	ILE AJINIKIRUN	HW	N08^{0}18.925′ E004^{0}23.204′	2.90	6.10	6.97	25.2
17	ILE FAJE	HW	N08^{0}18.837′ E004^{0}23.231′	4.00	5.10	6.74	25.8
18	CHIEF IMAM'S COMPOUND	HW	N08^{0}18.776′ E004^{0}23.174′	6.90	7.7	6.48	26.1
19	CENTRAL MOSQUE	HW	N08^{0}18.732′ E004^{0}23.088′	6.30	6.6	6.64	25.7
20	BEHIND RESERVOIR	WH	N08^{0}18.900′ E004^{0}22.835′	ND	ND	6.69	28.4
21	DAM	-	N08^{0}21.607′ E004^{0}22.433′	ND	ND	7.28	25.1

Table 2: Sample location and water characteristics (wet season)

S/N	LOCATION	TYPE	COORDINATES	DWL(m)	TOTAL DEPTH (m)	pH	TEMP.(^{O}C)
1	ILEPANU COMPOUND	HW	N08^{0}18.729′ E004^{0}23.041′	6.42	7.92	6.83	25.9
2	ILE OLOHUNYO	HW	N08^{0}18.764′ E004^{0}23.032′	8.59	8.86	6.85	26.7
3	ABU YARIN	BH	N08^{0}18.775′ E004^{0}23.042′	ND	ND	6.56	27.0
4	ILE BAALE(ALANGUA)	HW	N08^{0}18.833′ E004^{0}23.041′	5.39	9.38	6.67	27.1
5	MARKET	HW	N08^{0}18.729′ E004^{0}23.040′	3.73	8.10	7.25	25.5
6	ALALUBOSA(CLOSE TO STREAM)	HW	N08^{0}18.861′ E004^{0}23.155′	3.06	5.24	7.05	25.9
7	STAGNANT STREAM	-	N08^{0}19.979′ E004^{0}23.105′	ND	ND	ND	ND
8	ILE AYETORO	HW	N08^{0}18.946′ E004^{0}23.008′	3.00	5.80	7.09	26.3
9	ILE IGBO	HW	N08^{0}19.006′ E004^{0}22.913′	5.59	6.90	7.20	26.2
10	ILE PANU (BY GOVT. RESERVOIR)	HW	N08^{0}18.907′ E004^{0}22.842′	7.42	8.41	6.46	27.4
11	SCHOOL(OTE LGA)	BH	N08^{0}18.761′ E004^{0}22.948′	ND	ND	ND	ND
12	ILE ABO	HW	N08^{0}18.897′ E004^{0}23.302′	1.73	3.71	7.18	26.8
13	ISALE OLOKAA	HW	N08^{0}18.993′ E004^{0}23.257′	1.70	2.92	7.19	26.0
14	ISALE HOSPITAL	HW	N08^{0}18.895′ E004^{0}23.213′	3.00	3.70	7.20	25.2
15	ALHAJA ELELUBO	HW	N08^{0}18.915′ E004^{0}23.224′	2.63	3.52	7.12	25.0
16	ILE AJINIKIRUN	HW	N08^{0}18.925′ E004^{0}23.204′	5.29	5.39	7.49	26.9
17	ILE FAJE	HW	N08^{0}18.837′ E004^{0}23.231′	3.89	4.65	9.97	26.1
18	CHIEF IMAM'S COMPOUND	HW	N08^{0}18.776′ E004^{0}23.174′	6.72	6.92	6.53	26.0
19	CENTRAL MOSQUE	HW	N08^{0}18.732′ E004^{0}23.088′	5.95	6.09	7.17	28.0
20	BEHIND RESERVOIR	BH	N08^{0}18.900′ E004^{0}22.835′	ND	ND	ND	ND

The pH values range from 6.10 to 7.28 with an average value of 6.74 during wet season, but range from 6.46 to 7.49 with average value of 6.98 in the dry season. Concentration of TDS range from 65 to 902 mg/l with a mean of 483.35mg/l in wet season and 60 to 730mg/1 with a mean of 451.1 mg/l in dry season. This signified a slight increase in the concentration of ions during the wet season which may be due to contribution from surface run-off to the shallow wells. Water table is also expectedly higher and nearer to surface in the wet season thereby facilitating active leaching and subsequent infiltration that could change the chemical composition of groundwater.

All water samples fall within fresh water category since they have TDS values are less than 1000mg/l (Fetter, 1990) at both seasons. During dry season, the concentration of cations Ca^{2+}, Mg^{2+}, Na^+, K^+ ions hovers between 19.8 to 51.1; 1.30 to 12.50; 2.10 to 44.90; 0.40 to 45.4mg/l with a mean of 32.31, 6.37, 21.00 and 18.34mg/l respectively. The order of abundance is $Ca^{2+}>Mg^{2+}> (Na^++K^+)$. During wet season the concentration of cations: $Ca^{2+} >Mg^{2+}> Na^+> K^+$ ions range from 20.00 to 200.00; 2.86 to 67.21; 1.89 to 33.18 and 4.05 to 76.95mg/l with a mean of 77.49, 39.18, 15.97 and 35.63mg/l respectively. The order of ionic abundance is $Ca^{2+}> (K^++Na^+)>Mg^{2+}$. This shows that there is slight change in the abundance of major cations which is probably due to effect of dilution.

 Similarly, the concentration of anions in dry season is as follows: HCO_3^-, SO^{2-}_4, CI^-, CO^-_3 - 34.20 to 224.50, 10.00 to 40.00, 12.00 to 155.40 and 0.0 mg/l with a mean of 190.30, 21.76, 79.9 and 0.0mg/l respectively. The order of abundance is $CI^-> HCO^-_3 + CO_3 > SO^{2-}_4$ (Table 3). In wet season, HCO^-_3, SO^{2-}_4, CI, NO^-_3 ranged from 28.56 to 159.12, 1.00 to 57.00, 0.98 to 185.49 and 0.0 mg/l with mean values of 85.68, 19.30, 71.66 and 0mg/l respectively. The order of anionic abundance is $CI^- > HCO^-_3 +CO_3> SO^{2-}_4$. The order of ionic is the same but vary in concentration from element to element.

During wet season, nitrate values at four stations (5, 15, 16 and 17) are found to be high, above the WHO prescribed limit of 50ppm. Three of these stations are found to be linked closely to open dumpsite while the fourth (station 5) had "life duck resident" in the caved portion of the well.

Hydrochemical Classification and Source of Pollutant Determination

Piper's diagram

The evolution of hydrochemical parameters of groundwater can be illustrated by plotting the concentration of major cations and anions in the Piper's diagram as shown in Figure 2. It indicates that the groundwater samples analysed during the dry season and wet season fall in the field of $CaHCO_3$ and $CaMgSO_4$; and $CaHCO_3$ and $NaHCO_3$ water types respectively.

Gibbs diagram

The source of the dissolved ions in the groundwater can be understood by Gibbs diagram (Gibbs, 1970). It is a plot of $(Na^+ + K^+)/ (Na^+ + K^+ + Ca^{2+})$ vs log TDS and $Cl^- /(Cl^- + HCO^-_3)$ vs log TDS and is as depicted in Figure 3. It shows that almost all the samples both season fall within the boundaries of rock dominance which suggests chemical weathering of the rock forming minerals as a major contributor of ions in the well water

Wilcox diagram

This is a plot of Na% to other cations (Wilcox, 1948) against electrical conductance when ionic concentration are expressed in equivalent per million (Fig. 4). The position of samples in the Wilcox plot shows that the groundwater samples are good for irrigation

4.   Conclusion

Seasonal chemical budget and determination of sources of ion in Otte, Nigeria revealed the following conclusion:

i.   Seasonal variation had no effect on the abundance of analyzed major cations and anions

ii.   That two (2) dominant hydrochemical facies are present at both seasons viz:
     $CaHCO_3 > Ca-MgHCO_3$ for dry season and $CaHCO_3 > CaSO_4$ in the wet season. Based on the low concentration of ions which are within general limit of SON and WHO, the water facies are drinkable.

iii. That the source of pollutants at the two seasons is predominantly though weathering of rock-forming minerals and indicated in the positions of samples on the Gibb's plot.

iv.   That the Total Dissolved Solid values in both seasons were found to be in the range of 60

– 902 which classifies the samples as fresh water.

v. That the positions of the samples in the Wilcox plot make them suitable for irrigation activities.

vi. Comparison of the data with WHO (2011) places the water samples within the acceptable threshold for drinking and irrigation purposes at wet and dry seasons.

vii. Though the suitability of water for irrigation is determined based on Wilcox diagram, it is only empirical conclusion since other factor factors (%Na, SAR, soil type etc) have roles to play in determining the suitability of water
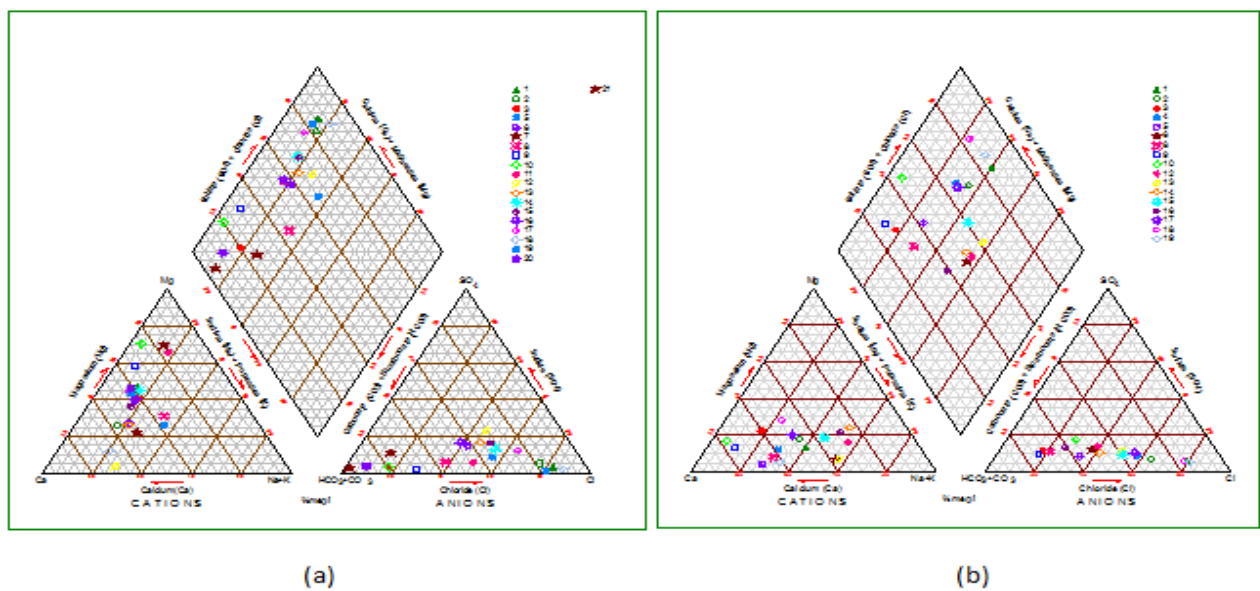

(a)   (b)

Figure 4(a and b): Position of water samples in Piper's diagram in wet (a) and dry (b) season

Table 3: Seasonal variation of Ionic dominance in the study area

Sample	Dominant cation		Dominant anion	
	Wet season	Dry season	Wet Season	Dry season
1	Mg^{2+}	Ca^{2+}	Cl^-	Cl^-
2	Ca^{2+}	Ca^{2+}	Cl^-	Cl^-
3	Mg^{2+}	Ca^{2+}	$HCO_3^- + CO_3^-$	$HCO_3^- + CO_3^-$
4	Ca^{2+}	Ca^{2+}	Cl^-	Cl^-
5	Ca^{2+}	Ca^{2+}	Cl^-	$HCO_3^- + CO_3^-$
6	Ca^{2+}	Ca^{2+}	$HCO_3^- + CO_3^-$	$HCO_3^- + CO_3^-$
7	Ca^{2+}	ND	$HCO_3^- + CO_3^-$	ND
8	Ca^{2+}	Ca^{2+}	$HCO_3^- + CO_3^-$	$HCO_3^- + CO_3^-$
9	Mg^{2+}	Ca^{2+}	$HCO_3^- + CO_3^-$	$HCO_3^- + CO_3^-$
10	Mg^{2+}	Ca^{2+}	$HCO_3^- + CO_3^-$	$HCO_3^- + CO_3^-$

11	Mg^{2+}	ND	$HCO_3^- + CO_3^-$	ND
12	Ca^{2+}	$Na^+ + K^+$	Cl^-	$HCO_3^- + CO_3^-$
13	Ca^{2+}	$Na^+ + K^+$	Cl^-	Cl^-
14	Mg^{2+}	$Na^+ + K^+$	Cl^-	$HCO_3^- + CO_3^-$
15	Ca^{2+}	$Na^+ + K^+$	Cl^-	Cl^-
16	Ca^{2+}	$Na^+ + K^+$	$HCO_3^- + CO_3^-$	$HCO_3^- + CO_3^-$
17	Mg^{2+}	Ca^{2+}	Cl^-	Cl^-
18	Ca^{2+}	Ca^{2+}	Cl^-	Cl^-
19	Mg^{2+}	Ca^{2+}	Cl^-	Cl^-
20	Mg^{2+}	ND	$HCO_3^- + CO_3^-$	ND
21	Mg^{2+}	ND	$HCO_3^- + CO_3^-$	ND

ND- Not determined.

Table 4: Summary of physiochemical parameter and WHO (2011) Standard

| Measured parameter	Range		Annual Mean	Standard Deviation	WHO(2011) standard		Note
	Wet season	Dry season			Health-based Guideline value	Acceptability Threshold/optimum value	
pH	6.1- 7.28	6.46-7.49	6.86	0.33	-	6.5-8.5	SON (2007)
Conductivity (μS/cm)	100-1190	90-1100	677.03	343.81	-	1000	
Colour (Pt/Co Units)Raw	0-150	0-11	8.00	25.69	-	<15 TCU	
Turbidity (FTU)	0-20	0-3	1.24	3.53	-	<5 NTU	
Total Dissolved Solid (mg/L)	65-902	60-730	468.57	229.81	-	1000	
Total Hardness (mg/L $CaCO_3$)	148-575	112-230	248.41	133.63	-	100-300	
Total Alkalinity (mg/L $CaCO_3$)	28-156	28-184	89.73	45.50	-	At least 40	
Chloride	0.98-185.49	11.95-155.4	75.46	51.86	-	200-300	
Nitrate (mg/L)	1.74-16.24	4.32-13.65	9.21	3.09	50	-	Methaemo globinaemi a in infant
Bicarbonate (mg/L $CaCO_3$)	28.56-159.12	34.16-224.48	100.39	53.74	-	-	
Sulphate (mg/L)	1.0-57.0	10.0-40.0	20.43	16.26		250	
Calcium (mg/L)	20-200	19.76-51.09	56.72	39.55	-	100-300	
Magnesium (mg/L)	2.86-67.21	1.33-13.97	24.10	21.84	-	-	
Sodium (mg/L)	1.89-33.18	2.1-44.94	18.28	11.24	-	200	
Potassium (mg/L)	4.05-76.75	0.42-45.36	27.69	19.04	-	-	
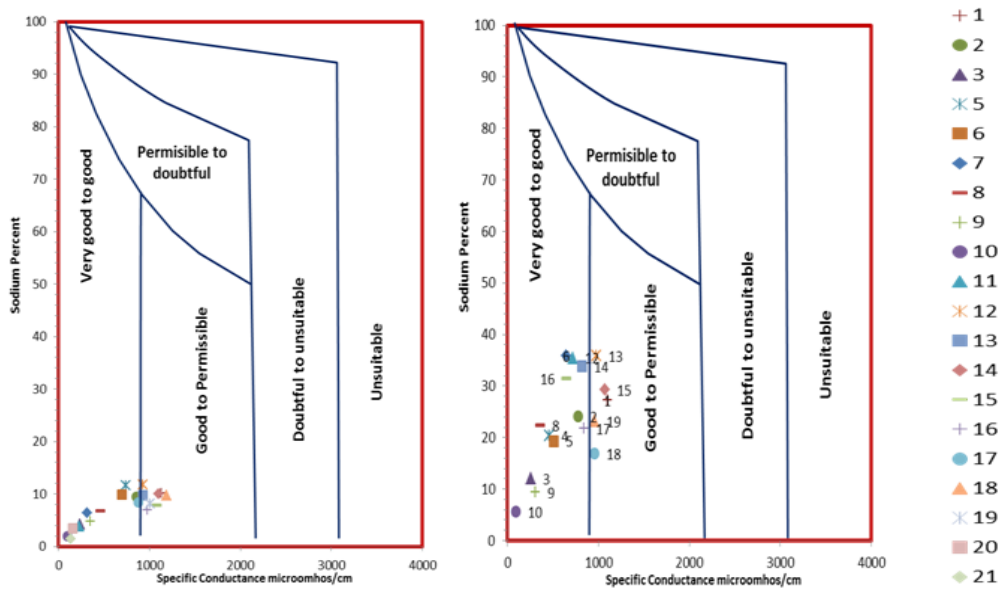
Figure 4: Plots of Sodium(%) against specific conductance in (a) wet season (b) dry season (after Wilcox, 1951)
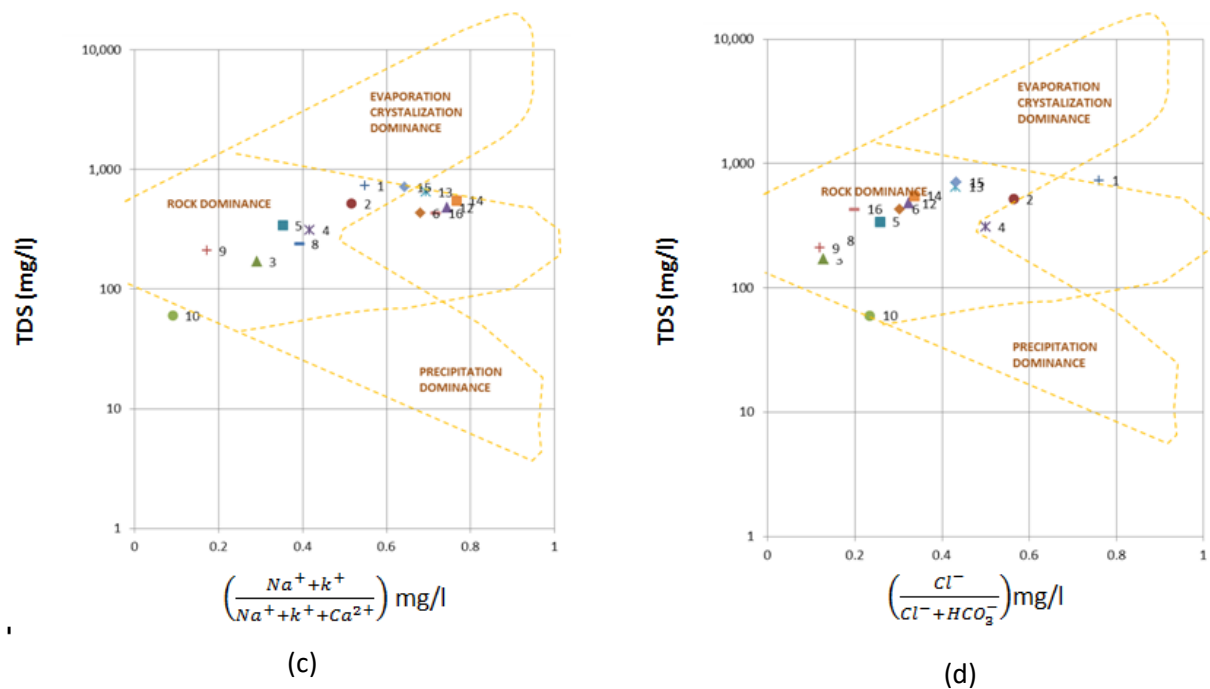
(c)

(d)
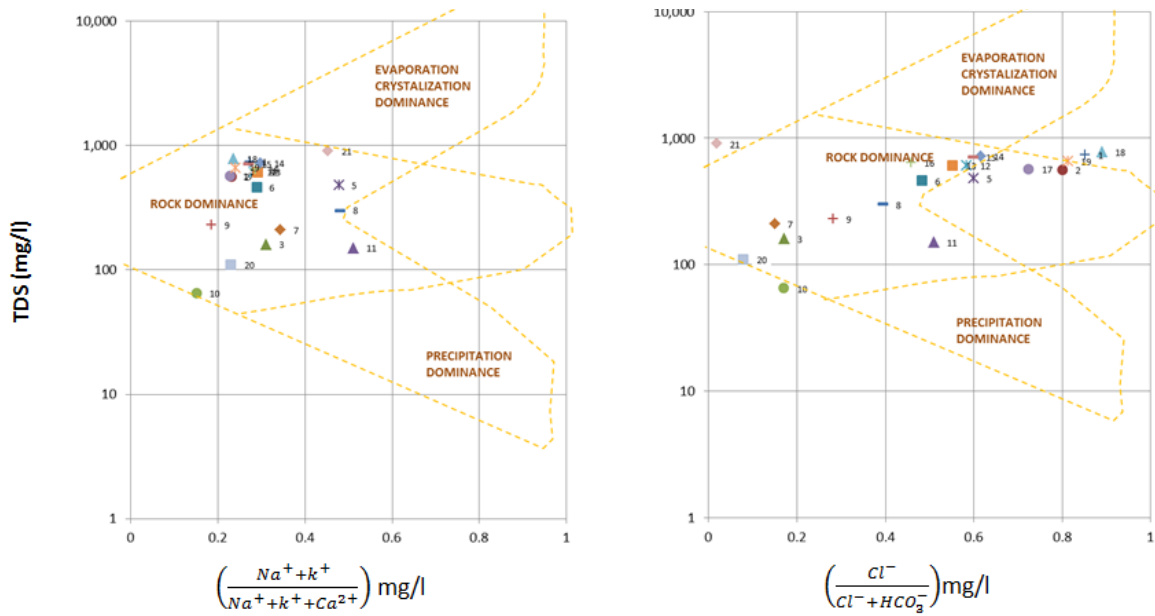
Figure 5(a, b, c and d): Gibb's diagrams for wet (a and b) and dry (c and d) seasons.

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