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Assessment of groundwater quality using chemical indices and GIS mapping in Jada area, Northeastern Nigeria

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Abstract

Analytical results of groundwater quality in Jada and environs indicated that the order of abundance of cation concentration were Ca^{2+}>Mg^{2+}>K^{+}>Na^{+} while those of the anions were HCO_3^{-}>Cl^{-}>SO_4^{2-}>NO_3^{-}. The groundwater quality is good for human consumption based on Revelle and Contamination indices but poses health risk due to bacteriological contamination. The Revelle and Contamination indices ranged from 0.1 to 0.5 and -10.5 to -8.2 with mean values of 0.2 and -9.7 and coliform number counts ranged from 1 to 12 with mean of 4, respectively. EC, TDS and TH values indicated good quality water for irrigation practice. The chemical Index such as SAR, RSC, and KI, % Na, PI and MR were calculated. The results indicated that PI and MR values revealed groundwater quality that is unsuitable for irrigation practice. PI values ranged from 24.1 to 254.3% with mean of 93%, MR ranged from 34.3 to 82.5% with mean of 60.8%. Chloro-Alkaline

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Indices 1, 2 calculations show positive values which indicated exchange of Na and K from water with Mg and Ca of the rocks. The geographical information system using Inverse Distance Weighted (IDW) delineated areas of different groundwater quality status based on selected parameters.

Keywords: Indices, Groundwater, Contamination, Irrigation, Jada

1 Introduction

The assessment of groundwater quality status is important for socio-economic growth and development (Ishaku, 2011). Evaluation of water quality for human consumption, agricultural and industrial activities have not been given attention especially in developing countries like Nigeria. The chemical composition of water is an important factor to be considered before it is used for domestic or irrigation purpose (Suresh et al., 1991). Chemical composition of water may be rendered unfit for human consumption, and thus may lead to health problems. The importance of groundwater quality in human health has recently attracted a great deal of interest (Vasanthavisar et al., 2010). In the developing World, 80% of all diseases are directly related to poor drinking water and unsanitary conditions (UNESCO, 2006). On the other hand, water composition may concentrate salts in soils or water to such an extent that crop yield is affected (Bernstein, 1975). The quality status of an aquifer can be assessed with the use/calculation of environmental factors and indices, which include a wide spectrum of parameters (Tziritis et al., 2008). The authors further stressed that such factors may become a valuable tool for the assessment of environmental conditions of an area.

2 Description of the study area

The study area is Jada and environs; it is located between latitudes 8°43'N to 8°47'N and longitudes 12°06'E to 12°12'E (Figure 1), and covers an area of about 92Km^2. The area is characterized by dry and rainy seasons. The rainy season commences in April and ends late October. The average rainfall is about 1750 mm, and mean annual evapotranspiration of about 1200mm (Ogunbajo, 1978), and mean minimum and maximum temperatures of 15.2°C and 39.7°C (Adamawa State Diary, 2007). The major occupation of the people is agriculture and the area is characterized by rural setting. Sources of water supply are from hand-dug wells, shallow boreholes and streams. These sources of water supply are unreliable as the quality of the water is poor coupled with poor sanitary conditions. The type of waste disposal practice in the area is the open dump waste disposal system for household solid waste, and most residents use pit latrines. The main objective of the present study is to evaluate water quality status of the study area for drinking and irrigational purposes through the calculation of some indices and represent

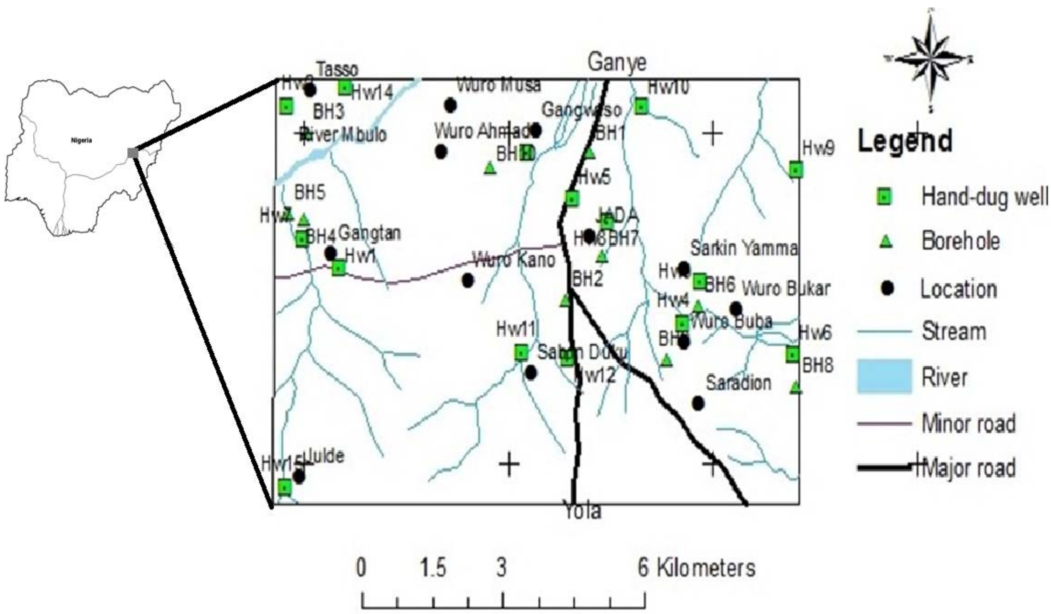

Figure 1: Map of the study area showing access routes and sampling points

them thematically using Geographic Information System (GIS). GIS can be used as a powerful tool for developing solutions for water resources problems for assessing water quality, determining water availability, preventing flooding, understanding the natural environment, and managing water resources on a local or regional scale (Ferry et al., 2003; Burrough and Mcdonnell, 1998).

The area is underlain by the Precambrian Basement Complex rocks, and consists of the older granites, gneiss and mylonites (Figure 2). The older granites cover extensive parts of the study area such as Julde, SabonDuku, WuroBuka and Wuro Musa areas. The gneissic rocks occur in the northwestern part, and underlie Gangton and Neso areas. The mylonite covers a small section of the area and covers the central portion of the study area. Analysis of borehole lithologic section revealed two aquifer system; these are the weathered overburden aquifer with thickness ranging from 6 m to 15 m with an average of 9 m and fractured

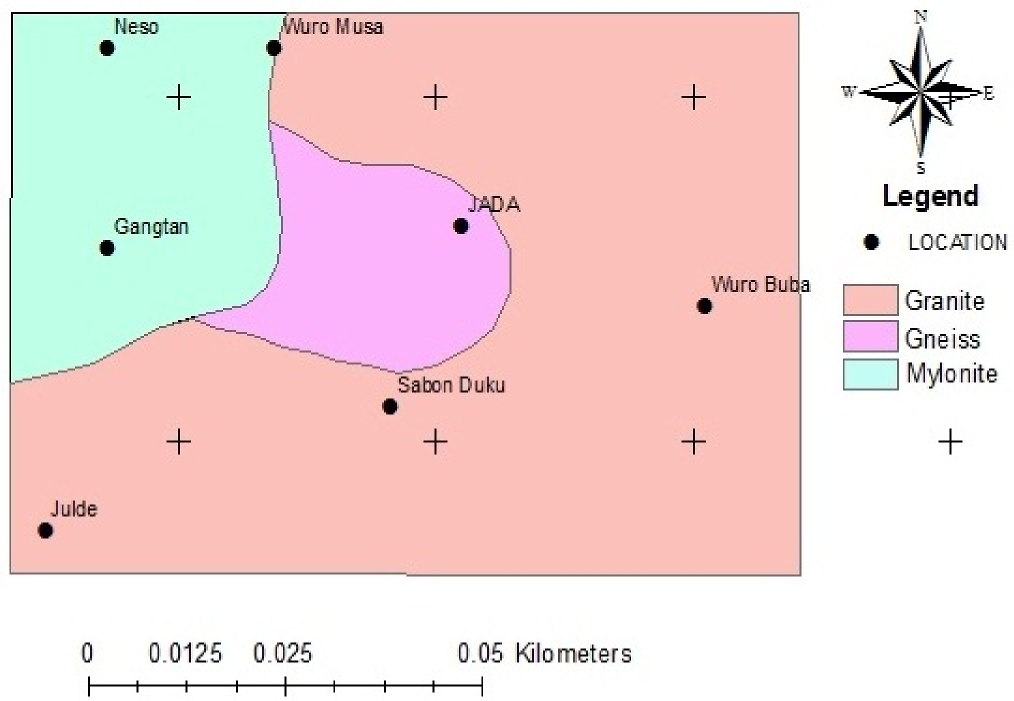

Figure 2: Geologic map of the study area.

basement aquifer having thickness ranging from 3 m to 18 m with an average of 12 m (Abubakar, 2010). Figure 3 indicates pockets of flow zones occur in the study area. Groundwater flow takes place towards the northern part of the study area, and towards the northwestern and southern parts, respectively. Other flow zones take place from the recharge zones located around Saradion and extend towards the northern part of Wuro Buba. From the recharge zones groundwater flows towards Wuro Bukar and Sarkin Yamma, and flows toward Wuro Kano areas, respectively. The discharge areas include Wuro Musa and Tasso areas in the northwestern part and Wuro Kano in the central part of the study area.

3 Materials and methods

25 water samples were collected from the different water sources, ten (10) samples from boreholes and fifteen (15) from hand-dug wells during rainy season period. The positions of the different water sources were determined using GPS. Before the collection of the samples, field parameters such as pH, EC and TDS were determined in the field using digital conductivity meter (HACH KIT) (Model 44600) for EC and TDS while pH was determined using HANNA pH meter (Model HI 28129). Bicarbonate was also determined in the field by titration using Sexana (1990) method. For the bacteriological analysis, sterile containers were used for the collection of the water samples. The samples were analyzed chemically using HACH spectrophotometer (Model DR/2400, USA). Bacteriological analysis was carried out using membrane filtration method employing the use of membrane assemblage (vacuum pump, Asbestos pad, Bukner flask and membrane funnel) and Leica Quebec Dark field colony counter. The bacteriological analysis was carried out according to WHO (1985).

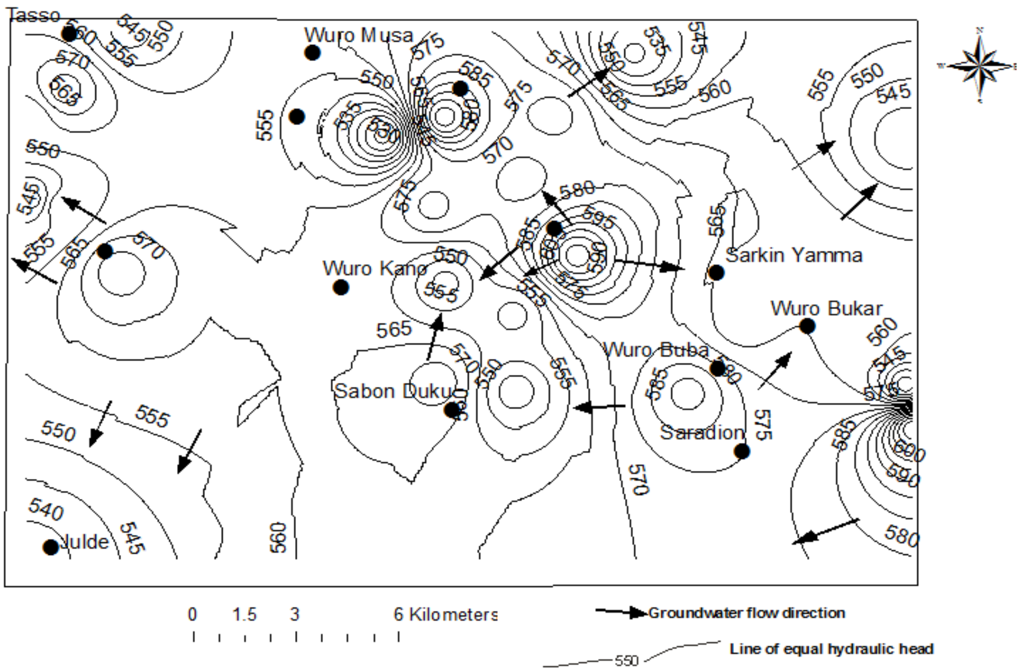

Figure 3: Hydraulic head distribution in unconfined aquifer in the study area

The samples for chemical analysis were carried out within 48 hours of collection while the bacteriological analysis was carried out within 24 hours of sample collection.

3.1 Calculation of indices

Revelle index, contamination index, SAR, RSC, Kelly ratio, Magnesium ratio, Percentage sodium and Permeability index were the indices employed in this study.

3.2 GIS Geo-data base

The map showing sampling points was scanned and imported into Arc GIS version 9.2 and was georeferenced and digitized. The different locations of the sampling points were imported into GIS software through point layer. Each sample point was assigned a unique code and stored in the attribute table. Data for selected parameters were linked to the sampling locations using the geodata base creation function of Arc GIS 9.2 software. The geo-database was used to generate the spatial distribution maps of the chemical indices. The present study used the Inverse Distance Weighted (IDW) method for spatial interpolation of the chemical indices. Inverse Distance Weighted (IDW) is an interpolation technique in which interpolated estimates are made based on values at nearby locations weighted only by distance from the interpolation location (Naoum and Tsanis, 2004). IDW method is based on the assumption that the value of an attribute z at some unvisited point is a distance weighted average of data points occurring within a neighbourhood or window surrounding the unvisited point (Karydas et al., 2009). The unknown value is estimated by the equation;

$$\hat{Y}(S_o) = \sum_{i=1}^{n} \lambda 1 Z(S_i) \quad (1)$$

where, $\hat{Y}(S_o)$ is the estimated value for an un-visited sampled location (S_o), n is the number of measured sample points surrounding the prediction location, $\lambda 1$ is

the weight for each measured point, and Z (S_i) is the observed value at location S_i. The weight λ1 is calculated as follows:

$$\lambda 1 = \frac{d_{io}^{-p}}{\sum_{i=o}^{n} d_{io}^{-p}} \quad (2)$$

Where, $\sum_{i=1}^{n} \lambda 1 = 1 \quad (3)$

The weight is reduced by a factor ρ, as the distance increases, and d_{io} is the distance between the predictions S_o and each of the measured location S_i. Weighting of the sampled locations highly depends on the power parameter ρ, meaning that when distance increases the weight decreases exponentially. IDW belongs to the category of local deterministic methods of interpolation (Burrough and Mcdonnell, 1988). The disadvantage of IDW is that the quality of interpolation result can decrease, if the distribution of each sample data points is uneven, and also maximum and minimum values in the interpolated surface can occur at sample data points.

4 Results and Discussion

4.1 Hydrogeochemical parameters of groundwater

The physicochemical parameters of the groundwater quality data were statistically analyzed and the results are presented in form of minimum, maximum, mean and standard deviation (Table 1). The order of abundance of the cations concentration is Ca^{2+}>Mg^{2+}>K^+>Na^+ while those of the anions are HCO_3^->Cl^->SO_4^{2-}>NO_3^-. The concentrations of Ca^{2+}, Mg^{2+}, K^+ and Na^+ ranged from 4.0 to 63.7, 5.8 to 52.3, 1.1 to 6.9 and 0.01 to 1.9 mg/l with mean values of 20.8, 19.2, 2.9 and 0.6 mg/l, respectively. The concentrations of the anions indicate that HCO_3^-, Cl^-, SO_4^{2-} and NO_3^- ranged from 121 to 273, 5 to 57.4, 1.2 to 27.6 and 1.4 to 20.7 mg/l with mean values of 205.2, 20.9, 14.9 and 9.2 mg/l, respectively. The pH ranges from 5.4 to 6.7 with an average of 6.2 which indicates the acidic condition of groundwater.

Table1: Summary of groundwater quality data in the study area

	Minimum	Maximum	Mean	Std. Deviation
pH	5.40	6.70	6.1600	.26458
EC	25.00	425.00	141.3040	114.02293
TDS	21.00	283.00	95.8600	75.01908
TH	10.00	97.00	40.1480	23.12684
Calcium	4.00	63.70	20.8320	14.76939
Magnesium	5.80	52.30	19.1800	11.35114
Sodium	.01	1.90	.6141	.55608
Potassium	1.10	6.90	2.9400	1.40564
Bicarbonate	121.00	273.00	205.2000	31.90089
Sulphate	1.20	27.60	14.8800	5.66627
Chloride	5.00	57.40	20.8920	15.25292
Nitrate	1.40	20.70	9.2280	4.84686
Coliform	1.00	12.00	4.1200	3.16649
Conindex	-10.48	-8.19	-9.6685	.59044
Revelle	.10	.50	.2000	.14142

4.2 Assessment of contamination

The contamination on the groundwater quality of the study area was determined with the use of Revelle and contamination index. According to Bacham et al. (1997), contamination index may be considered as such, if we take into account the measured concentration of the parameters and the upper permissible levels of a contaminant. Rapant et al. (1995) defined contamination index as;

$$Cd= \sum_{i=0}^{n} Cfi \quad (1) \text{ where } Cfi = \frac{CAi}{CNi} - 1 \qquad (4)$$

Where, C_d= contamination index

C_{fi}= contamination factor of i-th component

C_{Ai}= analytical value of the i-th component

C_{Ni}= upper permissible concentration of the i-th component

Contamination index (Cd) is calculated individually for each water sample, as a sum of the contamination factor of a single component that exceeds the maximum contaminant levels. Contamination index therefore summarizes the combinational effects of several quality parameters that may have harmful consequences to human environment (Tziritis et al., 2008). Rapant et al. (1995) classified contamination index into Cd <1 (low contamination), 1-3 (medium contamination) and Cd >3 (high contamination). From Appendix 1, the contamination index for the study area ranges from -10.5 to -8.2 with an average of -9.7 indicating low contamination.

Revelle Index (R) is also widely known as a criterion of groundwater quality assessment (Tziritis et al., 2008). The calculation of the index is based on the ionic ratio $Cl/(CO_3 + HCO_3)$ in meq/l (Revelle, 1946). Revelle index <1 indicates good water quality. All the values computed from the groundwater samples are <1 (Table 1), and thus is an indication of good quality water.

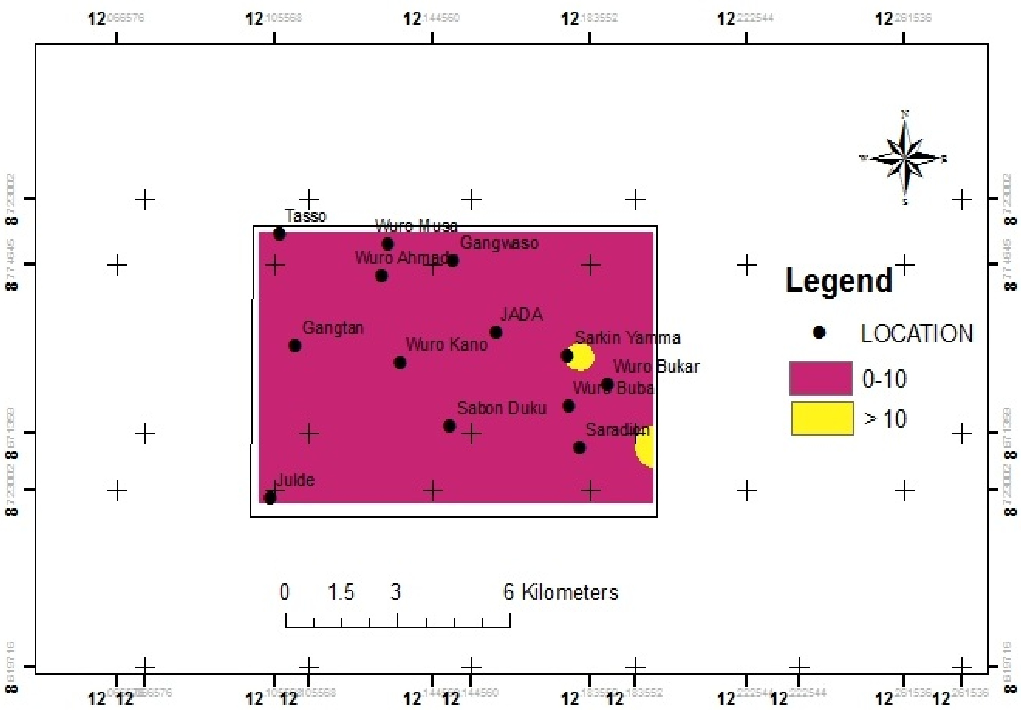

Figure 4: Spatial distribution of coliform in the study area

The coliform map (Figure 4) indicates higher coliform number counts above WHO limit of 10 in the south eastern part of the study area.

Bacteriologically contaminated groundwater is associated with water borne diseases such as viral hepatitis, schistosomiasis and cholera. The groundwater quality in some sections of the study area is bacteriologically contaminated and therefore unfit for human consumption.

4.3 Quality evaluation for agriculture

The water quality for irrigational practices is considered under the following as follows:

4.3.1 Sodium Adsorption Ratio (SAR)

If water used for irrigation is high in Na^+ and low in Ca^{2+} the ion-exchange complex may become saturated with Na^+ which destroys the soil structure, due to the dispersion of the clay particles (Todd, 1980) and reduces the plant growth. Excess salinity reduces the osmotic activity of plants (Subramani et al., 2005). The SAR is computed using the following equation

$$SAR = [Na^+] / \{([Ca^{2+}] + [Mg^{2+}]) / 2\}^{1/2} \quad (5)$$

Concentrations of ions are expressed in meq/l. There is a close relationship between SAR values in irrigation water and the extent to which Na^+ is absorbed (Subra Rao, 2006). Higher cumulative concentration of HCO_3^- and CO_3^{2-} than Ca^{2+} and Mg^{2+} concentration is an indication that residual carbonate will react with sodium, thereby resulting into sodium hazard (Wadie and Abduljalil, 2010). The computed SAR values in Appendix 1 range from 0.00 to 0.15 meq/l, all values are within the excellent class (Appendix 2).

4.3.2 Residual Sodium Carbonate (RSC)

RSC has been calculated to determine the hazardous effect of carbonate and bicarbonate on the quality of water for agricultural purpose (Aghazadeh and Mogaddam, 2010) and is determine from the following equation:

$$RSC= (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}) \qquad (6)$$

where all the ions are expressed in meq/l. Appendix 1 indicated that the computed RSC values range from -3.94 to 2.76 meq/l with of 0.74 meq/l. Appendix 1 revealed that 93% of the samples are within the safe water category as far as RSC is concerned.

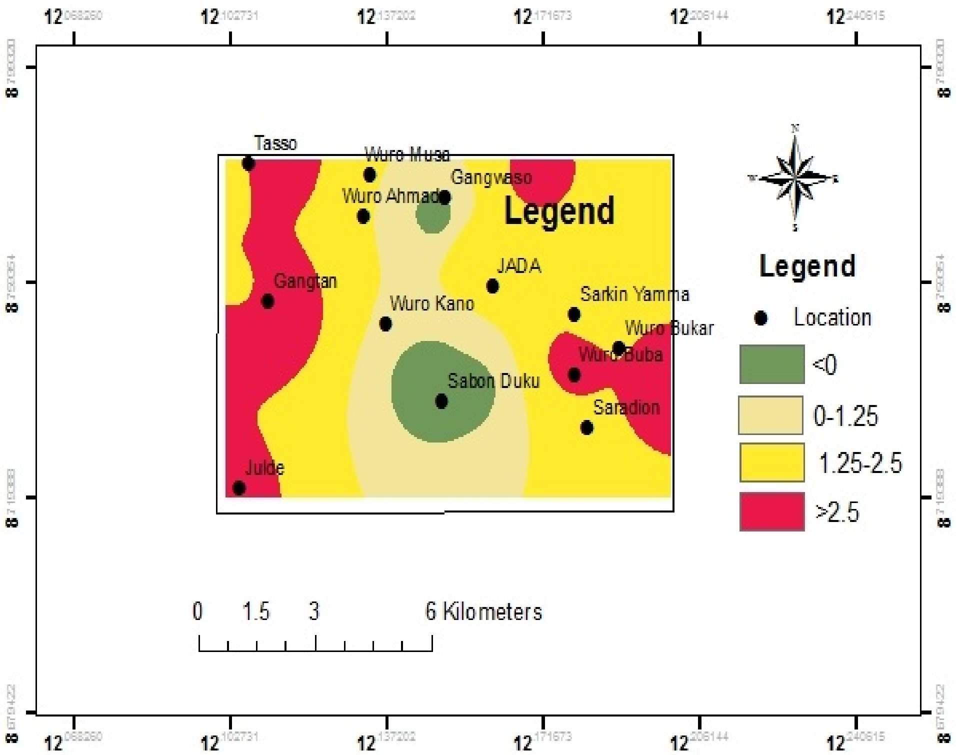

Figure 5: Spatial distribution of residual sodium carbonate in the study area RSC

Figure 5 illustrates water of safe quality occur around Sabon Duku and Gangwaso areas in the north southern part of the study area. The areas characterized by water of unsafe quality occur in northwestern, southwestern and southeastern parts of the study area. Hence continued use of water in those areas with high RSC waters will affect crop growing conditions.

4.3.3 Percentage Sodium (%Na)

The sodium in irrigation water is usually expressed in %Na (Tank and Chandel, 2010). When concentration of sodium ion is high in irrigated water, it tends to be absorbed by clay particles, dispersing magnesium and calcium ions. This exchange process of sodium in water for Ca^{2+} and Mg^{2+} in soil reduces the permeability and eventually results in soil with poor internal draining (Tiri and Boudoukha, 2010). Sodium is an important ion used for the classification of irrigation water due to its reaction with soil, reduces its permeability (Vasanthavigar et al., 2010). The %Na is computed with respect to relative proportion of cations present in water as:

$$Na\% = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + K^{+} + Na^{+}} \times 100 \quad (7)$$

Where, all ionic concentrations are expressed in meq/l. The computed Na% for the study area ranged from 1.50 to 9.90% with an average of 4.3%. Appendix 2 indicates that all values are within the excellent class.

4.3.4 Total Hardness (TH)

Hardness of water limits its use for domestic, industrial and agricultural activities. Water hardness can cause scaling of pots, boilers and irrigation pipes; it may also cause health problems to humans such as kidney failure (WHO, 2008). The values of total hardness ranged from 10 to 97 mg/l with an average of 40.2 mg/l. Appendix 2 indicates that the water ranged from soft to moderately hard. Figure 6 indicates that majority of parts of the study area are characterized by soft water while areas such as Sabon Duku in the south and areas close to Jada in the east and Gangwaso in the north are characterized by moderately hard water.

4.3.5 Kelly Index (KI)

Kelly index is used for the classification of water for irrigation purposes. Sodium measured against calcium and magnesium was considered by Kelly (1951) for calculating Kelly index. KI is calculated by using the formula:

$$KI= \frac{Na^{+}}{Ca^{2+} + Mg^{2+}} \quad (8)$$

Where, all the ions are expressed in meq/l. The KI values computed for the study area ranged from 0.00 to 0.07 meq/l with mean of 0.01 meq/l. All the values are below one (1), hence water is suitable for irrigational practice (Appendix 2).

4.3.6 Electrical Conductivity (EC)

EC is a good measure of salinity hazard to crops. Excess salinity reduces the osmotic activity of plants and thus interferes with the absorption of water and nutrients from the soil (Saleh et al., 1999). Appendix1 indicated that EC values. Appendix1 indicated that EC values ranged from 25 to 425 µS/cm with mean value of 141.3 µS/cm. The EC values are within the range of excellent to good quality water for irrigational practice (Appendix 2). Figure 7 illustrates the spatial distribution of EC over area of study. Majority of the area is characterized by excellent water quality while areas such as Sabon Duku in the south, Jada in the east and Gangwaso in the north revealed good quality water for irrigational practice.

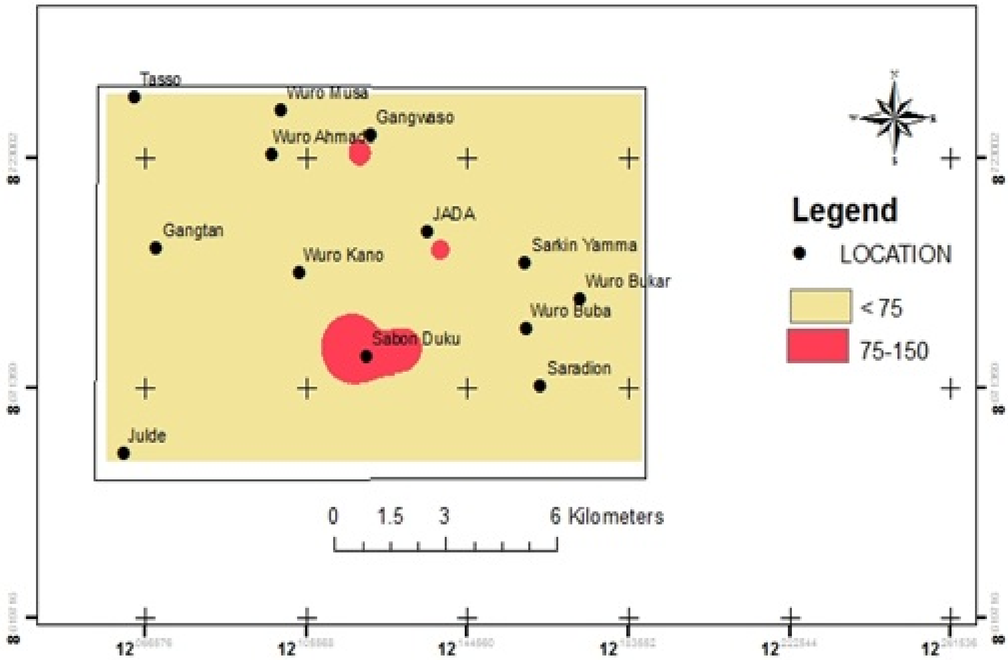

Figure 6: Spatial distribution of total hardness in the study area

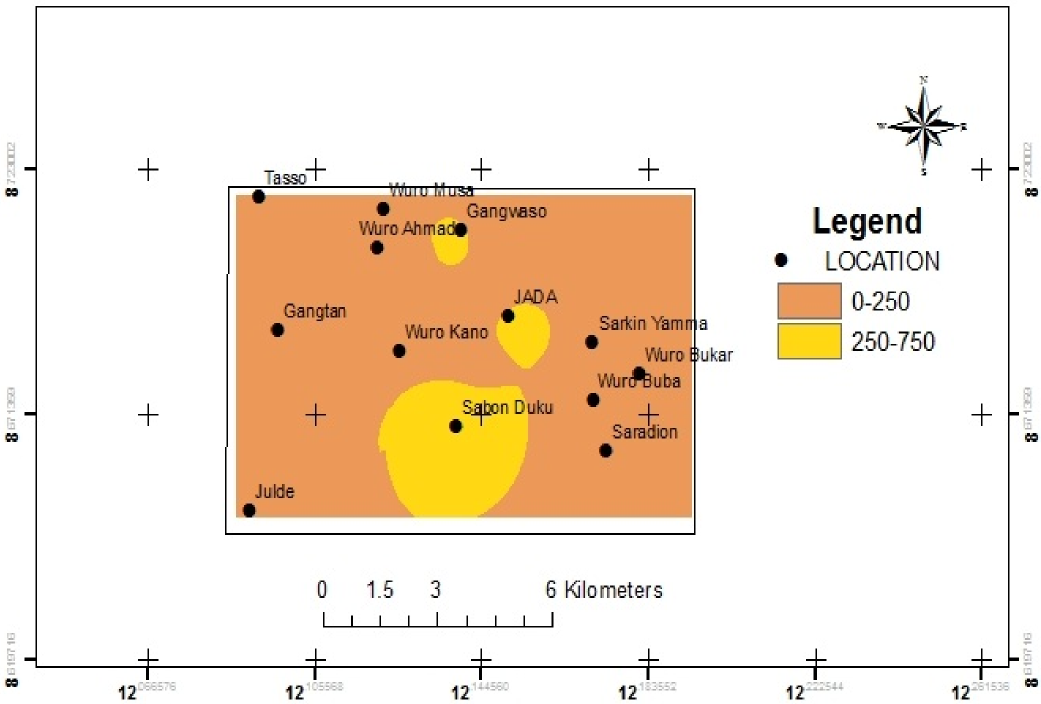

Figure 7: Spatial distribution of electrical conductivity in the study area

4.3.7 Total Dissolved Solids (TDS)

Salts of calcium, magnesium, sodium and potassium present in irrigation water may pose to be injurious to plants (Obiefuna and Sheriff, 2011). The authors went further to stress that salts from the major ions when present in excess quantities can affect the osmotic activities of the plants and may prevent adequate aeration. The values of TDS from the water samples ranged from 21 to 283 mg/l with mean of 95.9 mg/l. All the values are less than 150 mg/l, and hence are within the non saline class.

4.3.8 Permeability Index (PI)

The permeability of soil is affected by long-term use of irrigation water and is influenced by sodium, calcium, and magnesium and bicarbonate contents in the soil (Vasanthavigar et al., 2010). Doneen (1964) evolved a criterion for evaluating the suitability of water for irrigation based on PI. PI is calculated using the following equation:

$$PI=[(Na^{+}+HCO3^{-})/(Ca^{2+}+Mg^{2+}+Na^{+})]\ 100 \quad (9)$$

where, all ions are expressed in meq/l. The PI values computed for the area ranged from 24.1 to 254.3% with mean of 93%. Appendix 1 indicated that 44% of the samples fall under class II while 56% fall under class III of the Doneen chart. According to Nagaraju et al (2006), waters can be classified into class I, II and III based on PI values, and class I and II waters are categorized as good for irrigation with 75% or more maximum permeability. Class III waters are unsuitable with 25% of maximum permeability. Figure 8 illustrates the spatial distribution of PI over the area, and indicates the distributions of class II and III water types. The areas having class II water type include areas covering Wuro Ahmadu in the north towards Sabon Duku in the south and extend to the extreme part of the south. Other areas are covered by pockets of class II water type which include Jada, areas occurring between SarkinYamma and Wuro Bukar in the east, and areas between

Wuro Buba and Saradion. Other areas occur in the extreme north and south east.

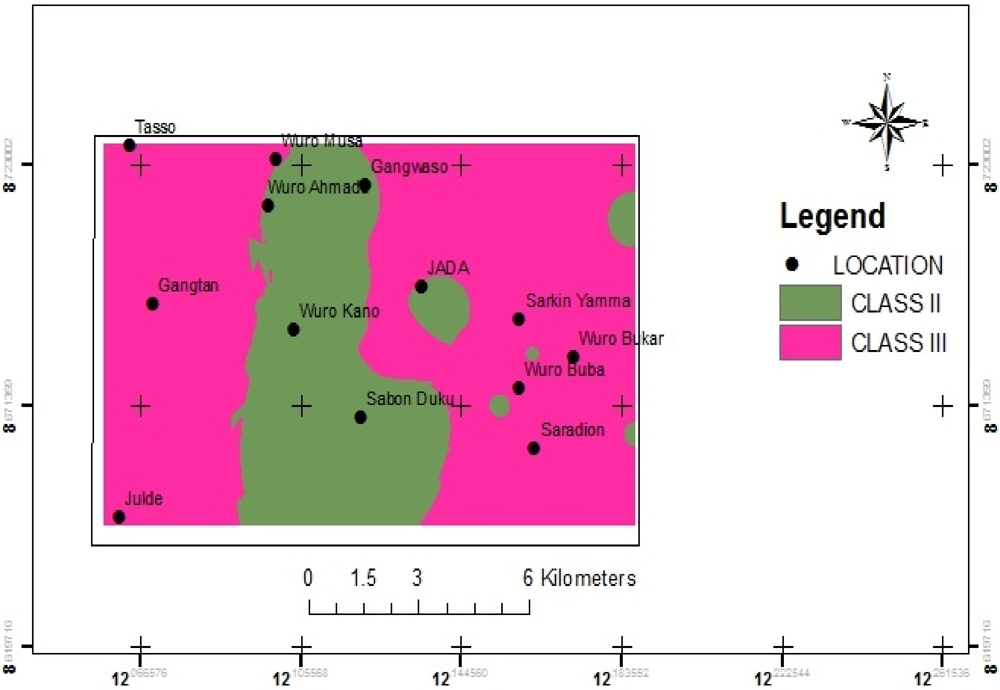

Figure 8: Spatial distribution of permeability index in the study area

4.3.9 Magnesium Ratio (MR)

Generally, calcium and magnesium maintain equilibrium in most waters (Hem, 1985). In equilibrium Mg^{2+} in waters will adversely affect crop yield (Nagaraju et al., 2006). The measure of the effect of magnesium in irrigated water is expressed as magnesium ratio. Paliwal (1972) developed an index for calculating the magnesium hazard (MR). MR is calculated using the formula:

$$MR=[Mg^{2+}/(Ca^{2+}+Mg^{2+})]x100 \quad (10)$$

where, all ionic concentrations are expressed in meq/l. The computed MR values in the study area ranges from 34.3 to 82.5% with mean of 60.8% (Appendix 1). Less than 50% of MR is suitable for irrigation while more than 50% MR is unsuitable for irrigation practice (Appendix 2).

Based on this classification, Appendix 1 indicates that 76% of the samples are unsuitable for irrigational practice. Figure 9 illustrates MR distribution over the study area and indicates that majority of the areas are characterized by the distribution of high MR values. Continuous use of water with high magnesium content will adversely affect crop yield and therefore suggests quick intervention. Pockets of areas however, reveal water of low magnesium content especially Tasso area in the northwest and areas around Jada, Julde, Sabon Duku and Gangwaso in the southwest, south and northern part of the study area, respectively.

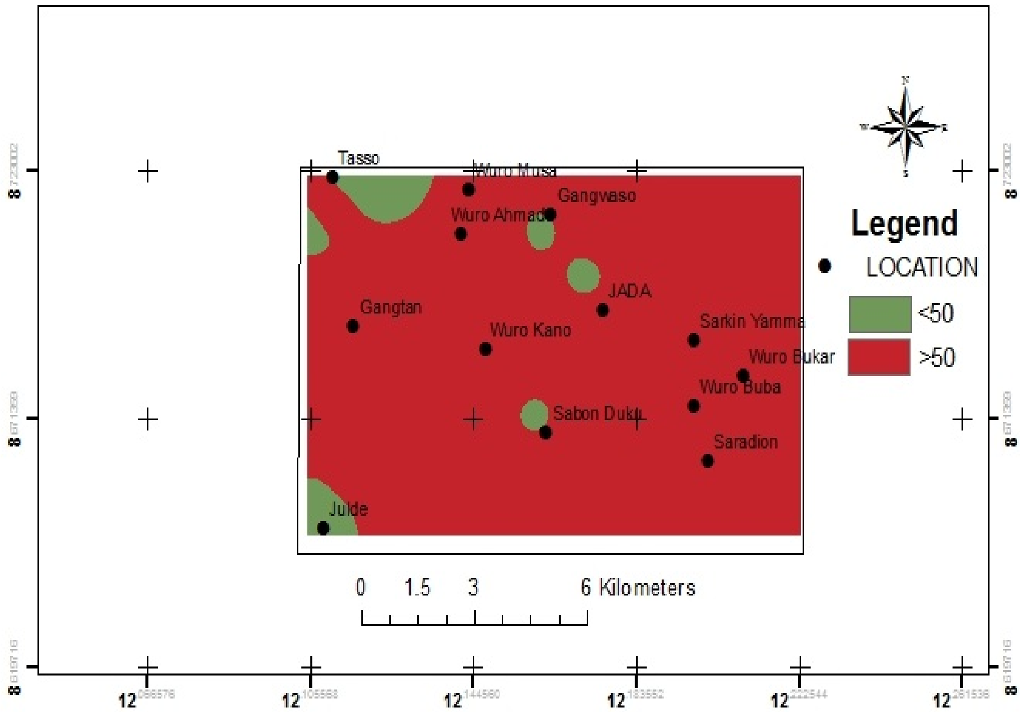

Figure 9: Spatial distribution of magnesium ratio in the study area

4.3.10 Indices of Base Exchange

Changes in chemical composition of groundwater along its flow path can be understood by studying the Chloro-Alkaline Indices (CAI). Schoeller (1965, 1977) suggested 2 Chloro-Alkaline Indices CAI 1, 2 for the interpretation of ion exchange between groundwater and host environment. The Chloro-Alkaline Indices are calculated from the following relations:

1) Chloro-Alkaline Indices

$$I= [Cl - (Na + K)]/Cl \quad (11)$$

2) Chloro-Alkaline Indices

$$I= [Cl - (Na + K)]/SO_4+HCO_3+CO_3+NO_3 \quad (12)$$

Positive Chloro-Alkaline Indices indicate exchange of Na and K from the water with Mg and Ca of the rocks and is negative when there is an exchange of Mg and Ca of the water with Na and K of the rocks (Nagaraju et al., 2006). In this present study, CAI_1 values range from 0.06 to 0.95 with mean of 0.70 while CAI_2 values range from 0.01 to 0.21 with mean value of 0.07 (Appendix 1). All the computed values of CAI are positive, thus indicating exchange of Na and K from water with Mg and Ca of the rocks.

5 Conclusions

The groundwater quality in Jada and environs has been evaluated for their chemical composition and suitability for human consumption and agricultural uses. The order of abundance of cations concentration is $Ca^{2+}>Mg^{2+}>K^{+}>Na^{+}$ while those of the anions are $HCO_3^{-}>Cl^{-}>SO_4^{2-}>NO_3^{-}$. Revelle index, contamination index, SAR, RSC, Kelly ratio, Magnesium ratio, Percentage sodium and Permeability index were the indices employed in this study. The results indicate that groundwater quality status is good for human consumption based on Revelle and contamination indices while on the other hand, the groundwater pose health risk due to bacteriological contamination. The groundwater quality is unsuitable based on permeability index and magnesium ratio. Chloro-Alkaline Indices 1, 2 calculations show positive values. The positive values indicate exchange of Na and K from water with Mg and Ca of the rocks. The application of the geographical information system using Inverse Distance Weighted (IDW) method proved a useful tool in delineating areas of different groundwater quality status based on selected parameters. Inverse Distance Weighted (IDW) method is an interpolation technique in which interpolated estimates are made based on values at nearby locations weighted only by distance from the interpolation location. This study recommends that areas indicated by poor groundwater quality for human consumption due bacteriological contamination, periodic chlorination should be employed while areas of inferior groundwater quality for irrigation, appropriate soil amendments should be applied on agricultural farmlands.

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Appendix 1: Parameters used for the evaluation of groundwater quality for irrigational practice

Code	SAR	RSC	Na%	MR	TH (mg/l)	KI	EC	TDS	PI	Chloro-Alkaline Indices 1	Chloro-Alkaline Indices 2
BH1	0.09	2.22	7.8	70.9	17	0.04	63	42	155	0.85	0.08
BH2	0.15	2.41	9.9	71.2	24	0.07	104	69	156	0.82	0.08
BH3	0.05	1.76	4.1	64.3	38.6	0.02	89	60	81.7	0.69	0.03
BH4	0	1.37	1.9	60.9	40.4	0	108	72	77.4	0.79	0.03
BH5	0.04	1.24	5.1	76.5	29.7	0.01	50	33	88.9	0.79	0.07
BH6	0	0.64	4.8	64.1	40	0	89.6	59.8	69.9	0.58	0.03
BH7	0.04	-1.74	1.8	64	76.9	0.01	392	261	36.6	0.95	0.21
BH8	0.005	0.37	3.1	82.5	43.8	0.001	85.2	79.6	61.6	0.51	0.02
BH9	0.005	0.58	4.2	65.8	36.9	0.002	94.5	63	72.5	0.29	0.01
BH10	0.004	-0.17	1.8	55.1	52.3	0.001	176.9	121	52.6	0.06	0.01
Hw1	0.08	2.76	7.6	52.6	27	0.03	126	84	123	0.75	0.04
Hw2	0.06	1.40	3.3	34.3	36	0.02	219	147	90.2	0.95	0.18
Hw3	0.02	1.36	6.1	71.2	20	0.007	123	82	119.2	0.30	0.008
Hw4	0.001	2.41	7.3	71	10	0.006	32	21	254.3	0.81	0.04
Hw5	0.007	1.43	2.9	42.8	17	0.003	63	42	117	0.87	0.07
Hw6	0.001	2.13	3.3	66.4	22.6	0.0003	87	33	127.7	0.79	0.03
Hw7	0.005	1.02	2.2	64.9	41	0.001	25	57.8	69.1	0.89	0.07
Hw8	0.09	0.15	8.0	54.5	47.7	0.03	79	52.6	60.1	0.22	0.01
Hw9	0	0.46	2.7	78.8	38.4	0	110	73.1	64.1	0.52	0.01
Hw10	0.07	2.04	6.0	64.3	21.8	0.03	56.4	37.6	131.6	0.84	0.07
Hw11	0.02	-3.94	3.0	46.3	97	0.005	374	249	24.1	0.81	0.20
Hw12	0.02	-2.34	1.5	71.2	87	0.005	425	283	32.2	0.95	0.21
Hw13	0.03	-2.72	2.4	46.6	83.6	0.006	317	211	30.7	0.88	0.19
Hw14	0.007	1.90	3.1	34.5	24	0.003	103	69	130.4	0.87	0.06
Hw15	0.006	1.86	4.1	46.4	31	0.003	141	94	99.7	0.77	0.04
Min.	0.00	-3.94	1.50	34.30	10.00	0.00	25.00	21.00	24.10	0.06	0.01
Max.	0.15	2.76	9.90	82.50	97.00	0.07	425.00	283.00	254.30	0.95	0.21
Mean	0.03	0.74	4.32	60.84	40.15	0.01	141.30	95.86	93.02	0.70	0.07
STD	0.039	1.733	2.323	13.177	23.127	0.017	114.022	75.019	50.865	0.248	0.069

Appendix 2: Standards use for the classification of groundwater quality for irrigation purposes

Parameter	Range	Class	Samples
SAR (Mandel and Shiftan, 1980)	0-10 10-18 18-26 >26	Use for all soil types Preferably use on coarse textured soil May produce harmful effect, good soil management is required Unsatisfactory	All samples
RSC (California Fertilizer Committee, 1975)	<1.25 1.25-2.5 >2.5	Safe Marginally suitable Unsuitable	BH5, BH6,BH7,BH8,BH9
%Na (Wilcox, 1955)	<20 20-40 40-60 60-80 >80	Excellent Good Permissible Doubtful Unsuitable	All samples
MR (Ayers and Westcot, 1985)	<50 >50	Suitable Unsuitable	
TH (Vasanthavigar, 2010)	<75 75-150 150-300 >300	Soft Moderately Hard Very hard	
KI (Sundary, 2009)	<1 >1	Suitable Unsuitable	
EC (Vasanthanvigar, 2010)	<250 250-750 750-2000 2000-3000	Excellent Good Permissible Doubtful	
TDS (Robinove et al., 1958)	<1000 1000-3000 3000-10000 >10000	Non saline Slightly saline Moderately saline Very saline	