Assessment of Surface Water Quality: The Perspective of the Weija Dam in Ghana

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Abstract

Investigations into the water quality from the Weija Dam have been carried out. The inhabitants around the dam use the water for drinking and irrigation mainly, apart from fishing activities. Twenty five samples were collected and standard methods were used for the measurement of physical and chemical parameters. The ionic dominance pattern for cation and anion was $Na^+ > K^+ > Ca^{2+} > Mg^{2+}$ and $HCO_3^- > Cl^- > SO_4^{2-}$ respectively. The ionic dominance pattern of the study area was in contrast with the ionic dominance pattern of $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ and $HCO_3^- > SO_4^{2-} > Cl^-$ for fresh water and $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ and $Cl^- > SO_4^{2-} > HCO_3^-$ for sea water. Generally, anthropogenic activities along the Densu river basin and rock weathering, as opposed to evaporation-crystallisation and precipitation, could be the source of major ions in the dam. The hydrochemistry gives an indication that the water is soft and suitable for domestic use. The water was also found to be useful for irrigation without prior dilution with low salinity waters.

Keywords: Anthropogenic, Dominance, Irrigation, Hydrochemistry, Precipitation

1. Introduction

The definition of water quality depends on the desired use of water. Therefore, different uses require different criteria of water quality as well as standard methods for reporting and comparing results of water analysis [Babiker I.S, 2007, p699-715]. Rivers are the most important freshwater resource for man. Social, economic and political development has been largely related to the availability and distribution of freshwaters contained in riverine systems. Water quality problems have intensified through the ages in response to the increased growth and concentration of populations and industrial centres. Polluted water is an important vehicle for the spread of diseases. In developing countries 1.8 million people, mostly children, die every year as a result of water-related diseases [WHO, 2004].

Ghana's water resources have been under increasing threat of pollution in recent years due to rapid demographic changes, which have coincided with the establishment of human settlements lacking appropriate sanitary infrastructure. This applies especially to peri-urban areas, which surround the larger metropolitan towns in the country. Many such settlements have developed with no proper water supply and sanitation services. People living in these areas, as well as downstream users, often utilize the contaminated surface water for drinking, recreation and irrigation, which creates a situation that poses a serious health risk to the people [Verma B.L, 1990, p169-176]. A number of factors influence water chemistry-Gibbs (1970) proposed that rock weathering, atmospheric precipitation, evaporation and crystallization control the chemistry of surface water. The influence of geology on chemical water quality is widely recognized [Gibbs R.J, 1970, p1088-1090; Langmuir D., 1997; Lester J.N, 1999].

The influence of soils on water quality is very complex and can be ascribed to the processes controlling the exchange of chemicals between the soil and water [Hesterberg D, 1998, p121-133]. Apart from natural factors influencing water quality, human activities such as domestic and agricultural practices impact negatively on river water quality. It is, therefore, important to carry out water quality assessments for sustainable management of water bodies.

High sodium ions in water affect the permeability of soil and causes infiltration problems. This is because sodium when present in the soil in exchangeable form replaces calcium and magnesium adsorbed on the soil clays and causes dispersion of soil particles (i.e. if calcium and magnesium are the predominant cations adsorbed on the soil exchange complex, the soil tends to be easily cultivated and has a permeable & granular structure). This dispersion results in breakdown of soil aggregates. The soil becomes hard and compact when dry and reduces infiltration rates of water and air into the soil affecting its structure. This problem is also related with several factors such as the salinity rate and type of soil. For example sandy soils may not get damaged as easily as other heavier soils when it is irrigated with a high sodium absorption ratio (SAR) water. It means excess Sodium in irrigation water, relative to calcium and magnesium or to total salt content, can affect soil structure, soil aeration, flow rate, permeability, infiltration, etc. In the past, the sodium hazard has been expressed as per cent sodium of total cations. A better measure of the sodium hazard for irrigation is the sodium absorption ratio (SAR) which is used to express suitability of water for irrigation purposes [Rajendra P.D.S, 2009, p211-218]. This paper evaluates the hydrochemistry of Densu River, with respect to the Weija Dam, and assesses its quality for irrigation using Sodium Absorption Ratio (SAR) and Salinity Diagram.

2. Materials and Methods

2.1 The study area

The Weija dam is situated in Accra, the capital of the greater Accra region of Ghana. The Weija dam is 14 km long, 2.2 km wide and has total surface area of 38 km^2 with mean depth of 5 m [Vanden B.J.P, 1990, p240]. The dam, located between 0^o 20' W 0^o 25' W and 5^o 30' N 5^o 45' N was created in 1977 as a replacement for an earlier one which was washed away in 1968 by Ghana Water Company Limited through damming River Densu mainly to satisfy the demand for potable water supply [Asante K.A, 2005, p171-180]. Weija dam, located about 17 km west of Accra, is almost at the mouth of the 116 km long river Densu which lies between latitude 5^o 30^1N and 6^o 20^1N and between longitudes 0^o10^1 and 0^o35^1W. The Densu River takes its source from the Atewa range of hills in the Akim Abuakwa district of the eastern region of Ghana at altitude 0.64km above mean sea level [Akpabli C.K, 2001, p84-94]. From the source, the Densu river flows through the south-eastern direction till it reaches Mangoasi, then it changes its course and flows generally southwards till it enters the Gulf of Guinea through the Sakumo lagoon at Botiano, a fishing village which is 16 km west of Accra. The Weija dam currently provides drinking water to Western parts of Accra, as well as fisheries. Major crops grown in the catchment area include maize, cassava, sugarcane and vegetables.

2.2 Geology

About 95% the basin is underlain by granite and granodiorite of middle precambrian origin, except for the sources and toward the mouth [Akpabli C.K, 2001, p84-94] where they are underlain by the birimian and the Togo series respectively. The birimian is primarily made up of metamorphosed lava, phyllite, schists tuffs and grey wacke. From Weija to the mouth are characterized by quartz, shale and phyllite of the togo series.

2.3 Sampling

The sampling bottles were pre-conditioned with 5% nitric acid and later rinsed thoroughly with distilled de-ionized water. At each sampling site, the polyethylene sampling bottles were rinsed three times before sampling was done. The collection of the samples from the river was done with hand gloves and sampling done facing the direction of the flow of the river. The particles in the river disturbed by the feet were allowed to settle down before sampling. Pre-cleaned polyethylene sampling bottles were immersed about 10 cm below the water surface. 500cm^3 of the water samples were taken at each sampling point, about 10 m apart. Temperature, pH, electrical conductivity (EC), total dissolved solid (TDS), salinity and redox potential (eh) were measured in-situ. Two sets of water samples were collected at each of the twenty five sampling points. One was for the measurement of anions. The other, for analysis of cations and trace elements was acidified with 1% nitric acid to discourage the formation of precipitates and to keep the metal ions in the dissolved state. The samples were kept over ice in an ice chest and transported to the laboratory.

2.4 Sample preparation and analysis

Alkalinity was determined by strong acid titration method. Calcium (Ca) and magnesium (Mg) were analyzed by atomic spectrometry using the AA240FS Fast Sequential Atomic Absorption Spectrometer. Total hardness was by calculation. The water samples for anion analysis were filtered using a hand operated vacuum pump equipped with a 0.45µm cellulose acetate filter membrane. Chloride determination was undertaken using the argentometric titration. Nitrate (NO_3^-), sulphate (SO_4^{2-}) and phosphate (PO_4^{3-}) were determined by UV spectrophotometric method. Bicarbonate (HCO_3^-) determination was carried out using acid titration, with methyl orange as indicator.

3. Results and Discussion

3.1 Water Quality Assessment

The statistically summary of the results is presented in table 1. The results are compared to prescribed specification of World Health Organization (WHO, 2004) in assessment of the suitability for drinking and domestic consumption.

There is uniform temperature distribution ranging from 25.30 mg/l-26.80 mg/l and a median and standard deviation of 26.20mg/l and 0.37mg/l respectively. The sample was taken during the dry season and the temperature seams suitable for aquatic life. Factors such as colour, depth, shade, amount of sunlight, volume of water, temperature of effluent dumped into the water could all contribute to the temperature. The surface water pH is in the range of 7.49 and 8.11 with mean and median values of 7.76 and 7.70 respectively. The pH values fall within the natural water pH range of 4.5 to 9.0. The mean and median values of the electrical conductivity (EC) are 324.24µs/cm and 330.00µs/cm respectively. The EC ranged from 214.00µs/cm to 369.00µs/cm. The standard deviation with respect to the mean is 27.68µs/cm. The small differences in physical parameters, as depicted in the line graphs in figure 1 and 2 may reflect the non variation in activities and processes prevailing in the surface and subsurface of the water.

The concentrations of the major cations in the river were generally in the order of $Na^+ > K^+ > Ca^{2+} > Mg^{2+}$ (fig 3). The major anion concentrations followed the order $HCO_3^- > Cl^- > SO_4^{2-}$ as depicted in a bar chart in figure 3. The ionic dominance pattern of the study area was in contrast with the ionic dominance pattern of $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ and $HCO_3^- > SO_4^{2-} > Cl^-$ for fresh water and $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ and $Cl^- > SO_4^{2-} > HCO_3^-$ for sea water (Burton & Liss, 1976).

The dominance of chloride over sulphate could probably be due to domestic activities resulting from household effluents, agrochemical use and anthropogenic point sources. The recommended limit for sodium concentration in drinking water is 200 mg l^{-1}. A higher sodium intake may cause hypertension, congenial heart diseases and kidney problems [Singh A.K., 2008, p745-758]. Concentrations of sodium are far below the prescribed limit of 200 mg l^{-1} in the analyzed water samples. Water hardness has no known adverse effects. However, hard water is unsuitable for domestic use. Depending on factors such as pH and alkalinity, a hardness of more than about 200 mg l^{-1} will lead to scale deposits in the piping system [Vander N.G.F.M, 2003, p554-563]. The total hardness ranged from 2.32 to 7.77, with a mean value of 5.89. This is a clear indication that the water is very soft and suitable for domestic use.

3.1.1 Cluster Analysis

The Cluster analysis organized the metals and physiochemical parameters into groups such that within-group similarity is maximized and among-group similarity is minimized. Dendogram for Q-mode cluster was plotted for samples collected in Weija dam (figure 4). The first cluster (Ca^{2+}, Mg^{2+}, K^+, SO_4^{2-}, Cl^-) analysis might be due anthropogenic activities and weathering of rocks. The samples were taken near the mouth of the Densu River, which is underlain by quartz, shale and phyllite. The weathering of shale and phyllite could be the source of calcium and magnesium (figure 5 shows a Gibbs plot which gives an indication that rock dissolution is a functional source of dissolved ions). The levels of magnesium and calcium were, however, low as compared to the WHO limits, with mean values of 1.42mg/l and 0.57mg/l respectively. Calcium ion is readily dissolved from rocks rich in calcium minerals, particularly carbonates and sulphates. Industrial, as well as, wastewater treatment processes can also contribute calcium to surface water. Acid rain can also encourage leaching from soil. Contribution of this source, through surface runoff could be attributed to the higher calcium levels compared to magnesium. The second cluster involving Na^+, HCO_3^- and TDS shows clearly the effect of Na^+ and HCO_3^- on TDS as can be observed in figure 4.

3.2 Suitability for irrigation

The suitability of water for irrigation purposes is measured by many indices. In this study, the sodium adsorption ratio (SAR), which measures the proportion of sodium relative to the combined concentrations of calcium and magnesium, and the salinity as measured by the electrical conductivity (EC) were used to construct the United States Salinity Laboratory's diagram [USSL, 1954, p147] for surface water from Weija. Soils with high sodium content are known for having a poor soil structure [Appelo C.A.J, 2005, p649]. Problems with soil structure arise when Na^+ forms about 15% of the exchangeable cations and the ionic strength is less than 0.015 [Appelo C.A.J, 2005, p649]. The Exchangeable Sodium Ratio, ESR, is function of the activity of sodium divided by the square root of the sum of Ca^{2+} and Mg^{2+} activities [Appelo C.A.J, 2005, p649]. The ESR is related to the SAR by the following equation:

$$ESR = 0.0158 \times SAR$$

$$SAR = \frac{Na^+}{\sqrt{Ca^{2+} + Mg^{2+}}}$$

When waters of high sodium relative to the concentrations of magnesium and calcium are used for irrigation, they tend to impart this property to the soils, thus affecting their agricultural properties. The USSL (1954) diagram relates the SAR with the EC of water and places the samples into irrigation water categories based on the combination of the two parameters. Fig. 6 is the salinity diagram of the water samples studied from Weija dam based on USSL (1954) diagram. It is found from the table of classification of water samples based on salinity hazard (Table 2); table of classification of water samples based on USSL sodium hazard for irrigation (Table 3), as well as US Salinity diagram of Weija Dam samples indicate that the water is very suitable for irrigation.

4. Conclusion

The physical parameters were within the required values for drinking water. The pH values indicate that the water is neutral to slightly alkaline. According to the WHO, the range of desirable pH values of water prescribed for drinking purposes is 6.5 – 9.2. The EC and TDS values are less than the maximum permissible limits of 1500µs/cm and 1000 mg l^{-1}, respectively. The concentrations of the major cations in the river were generally in the order of $Na^+ > K^+ > Ca^{2+} > Mg^{2+}$. The major anion concentrations followed the order $HCO_3^- > Cl^- > SO_4^{2-}$. The ionic dominance pattern of the study area was in contrast with the ionic dominance pattern of $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ and $HCO_3^- > SO_4^{2-} > Cl^-$ for fresh water and $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ and $Cl^- > SO_4^{2-} > HCO_3^-$ for sea water. Generally, anthropogenic activities along the Densu river basin and weathering could be the source of major ions in the basin. The water is soft because the total calcium, magnesium and for that matter total hardness is far below the recommended threshold proposed by WHO. Sodium adsorption ratio (SAR), and the United States Salinity Laboratory's diagram revealed that the surface water samples are suitable for irrigation purposes under normal Temperature and pH condition.

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Table 1. Summary of Measured Parameters

Parameter(units)	**Minimum**	**maximum**	**mean**	**median**	**STDEV.**	**WHO/2004**
K^+(mg/L)	13.00	16.00	13.98	13.90	0.69	200
Na^+(mg/L)	66.20	79.10	71.19	71.60	2.82	200
Mg^{2+}(mg/L)	0.22	0.77	0.57	0.56	0.09	150
Ca^{2+}(mg/L)	0.56	1.85	1.42	1.39	0.23	200
SO_4^{2-}(mg/L)	9.39	16.03	11.61	11.51	1.37	250
Cl^-(mg/L)	33.99	39.99	36.99	36.99	1.58	250
HCO_3^-(mg/L)	96.00	102	98.96	100.00	1.43	240
pH	7.49	8.11	7.76	7.70	0.16	6.5-9.2
Eh	4.00	6.00	4.92	4.90	0.60	1500
TDS	135.40	163.70	143.94	143.00	4.78	1000
EC	214.00	369.00	324.24	330.00	27.68	-
Temp.	25.30	26.80	26.12	26.20	0.37	-
TH	2.32	7.77	5.89	5.76	0.95	500

Table 2. Classification of water samples based on salinity hazard

Salinity hazard class	EC (μs/cm)	Water class	Number of samples
C1	100-250	Excellent	1
C2	250-750	Good	24
C3	750-2250	Doubtful	0
C4	>2250	Unsuitable	0

Table 3. Classification of water samples based on USSL sodium hazard for irrigation

Sodium hazard class	SAR in equivalent per mole	Water class	Number of Samples
S1	<10	Excellent	0
S2	10-18	Good	24
S3	18-26	Doubtful	1
S4	>26	Unsuitable	0

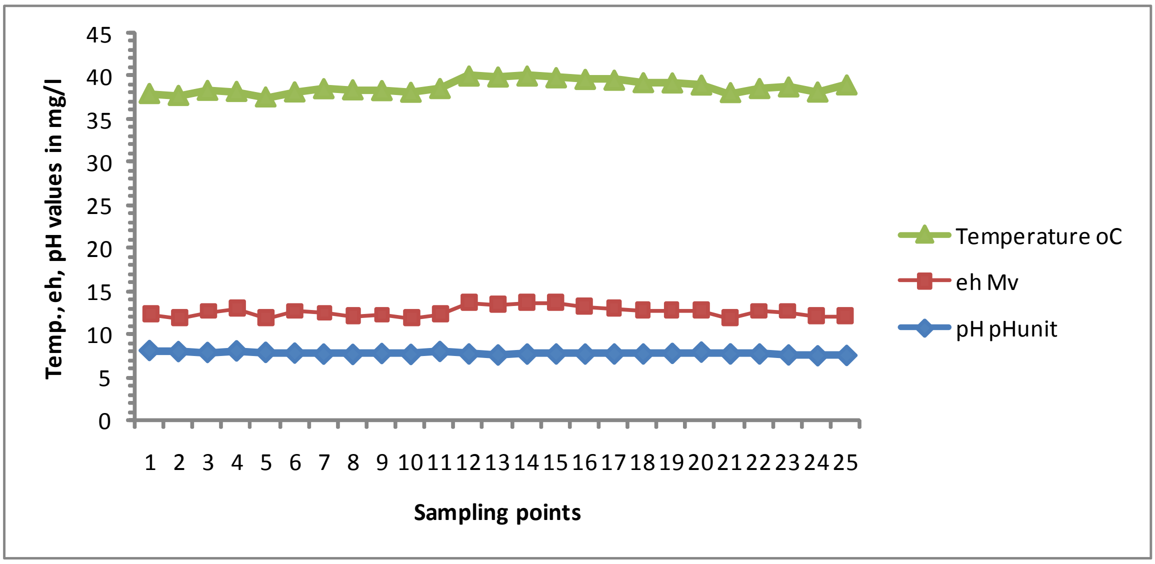

Figure 1. Variation in Temperature, Redox potential and pH

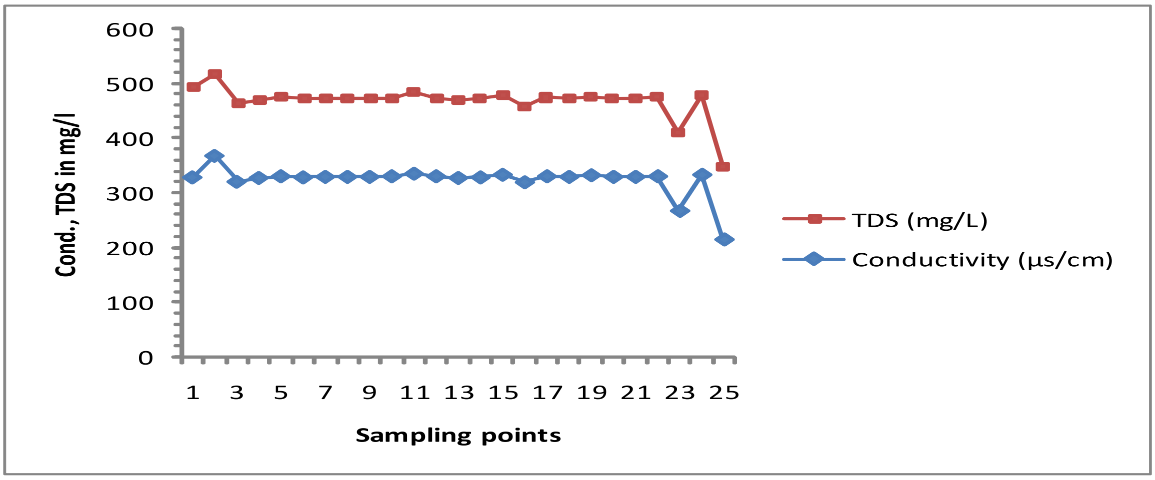

Figure 2. Variations in Conductivity and TDS

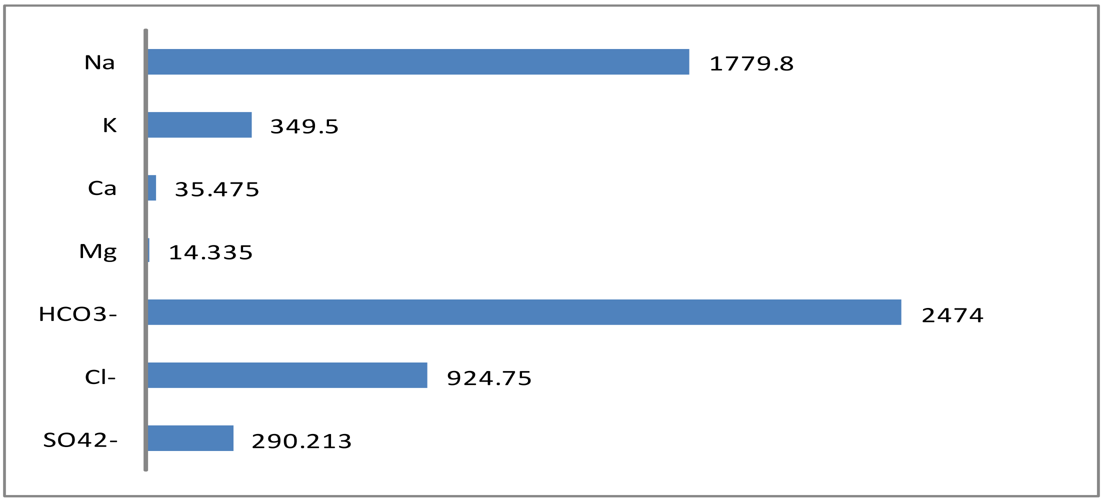

Figure 3. Bar graph of total major ion concentration

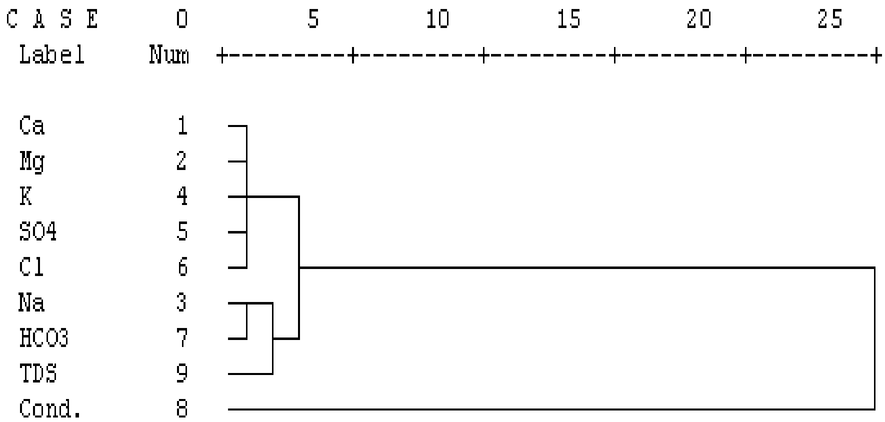

Figure 4. Dendogram for Q-mode cluster analysis for samples collected in Weija

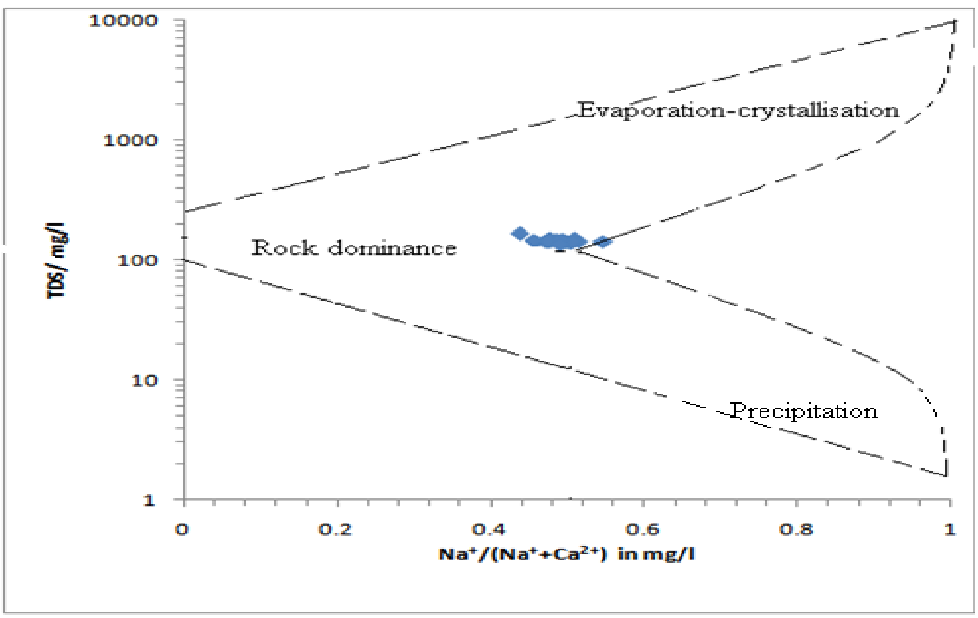

Figure 5. Plots of TDS vs. Na+/ (Na+ +Ca2+) (after Gibbs, 1970)

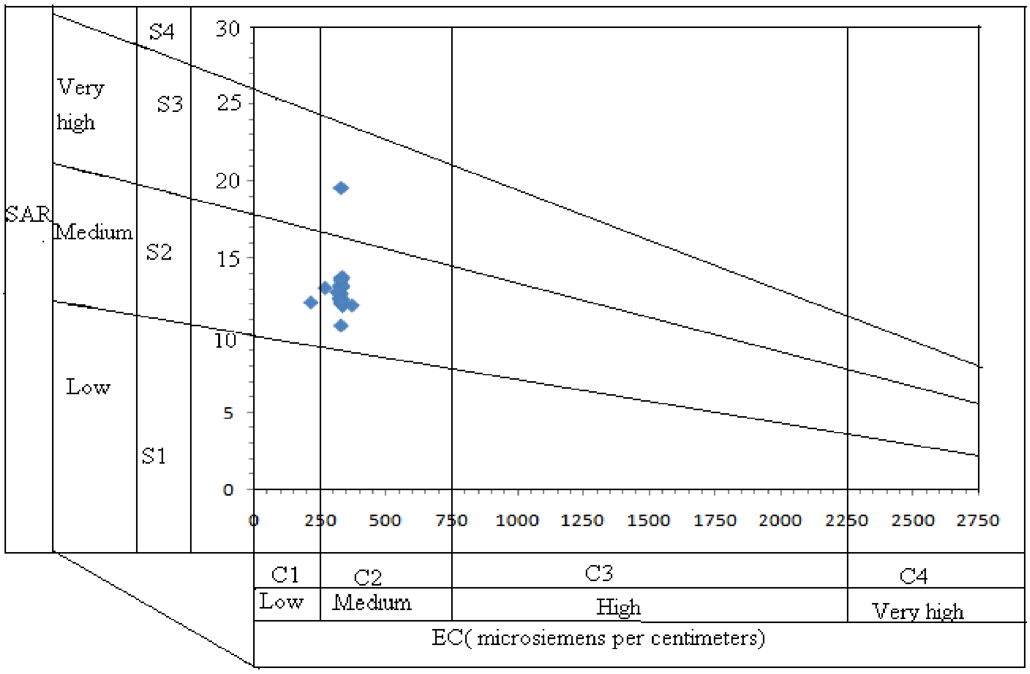

Figure 6. Salinity diagram of Weija Dam samples