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Quality assessment of groundwater for drinking and irrigation use in semi-urban area of Tripura, India

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ABSTRACT

The ground water quality of urban and rural area of Agartala (Tripura State, India) was studied to examine the suitability or otherwise of their use for drinking and irrigation purposes. Twenty one ground water samples were randomly collected during post monsoon season and analysed with reference to the World Health Organization (WHO) standards and Bureau of Indian Standards (BIS). The analysed data was validated using the best-fitted models. Interpretation of analytical data shows that Na-K-HCO_3 and Ca-Mg-HCO_3 are the dominant hydrochemical facies in the study area. The percent sodium level of samples indicated that 90 per cent samples are in permissible category of the sodium hazards for agricultural applications. The US salinity diagram illustrates that most of the groundwater samples fall in the field of C1S1, indicating low salinity and low sodium water, which can be used for irrigation on almost all type of soil. Other best-fitted model, like Permeability Index (PI), Kelly's Index (KI), Wilcox classification, SAR and RSC values also indicate that ground water is moderate to good for irrigation purposes. However, the presence of certain degree of cations, anions, iron and heavy metals indicates that the ground water in the study area is facing stress which could change the quality of the water in the near future.

Key words : Hydrochemistry, Groundwater, Drinking and irrigation Water quality, Graphical plots, *Tripura (India)*

Introduction

Ground water quality depletion by anthropogenic activities, such as urbanization and agricultural activities is a major problem in Agartala, the capital of north-eastern states of Tripura (India). Over the few decades, competition for economic development, associated with rapid growth in population and urbanization, has brought in significant changes in land use, resulting in more demand of water for agriculture and domestic activities. Due to inadequate availability of surface water, to meet the requirement of human activities, ground water remains the only option to supplement the ever-increasing demand of water. Ground water is the primary source of water for domestic, agricultural and industrial uses in many countries, and its contamination has been recognized as one of the most serious problems in north eastern states of India (Singh *et al.*, 2008). Each ground water system in an area is known to have a unique chemistry, which depends on several factors such as soil-water interaction, dissolution of mineral species, duration of solid-water interaction and anthropogenic sources (Stallard and Edmond, 1983; Faure, 1988; Subba Rao, 2002). Importance of hydrochemistry of ground water has led to a number of detailed studies on geochemical evolution of ground waters (Garrels, 1967; Paces, 1973; Sarin *et al.*, 1989).

Graphical and statistical approaches to assess the

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quality of ground water help to recognize the various hydro-chemical types in a ground water system. It further helps in evaluation of the suitability of ground water for drinking and irrigation purposes. The main objective of the present research work was to study the distribution of physico-chemical parameters in ground water of both urban and rural areas of Agratala and provide reliable water quality data to design economically effective methods for treatment of ground water and to make them potable with standard permissible limit of pollutants.

Materials and Methods

The study area

The study area (Agartala, Tripura, India) lies between north latitude $23^0 49'15''$ & $23^0 53'30''$ and east longitude $91^0 14'30''$ & $91^0 19'15''$. As per reports of Census of India, population of Agartala in the year 2011 was 399,688. The Climate is characterized by humid to sub-tropical climate i.e., moderate temperature and high humidity. The highest mean maximum temperature recorded is 35^0C (April) and lowest mean minimum temperature recorded is 10.4^0C (January). The average annual rainfall is around 2200 mm and the average number of rainy days is 100. The area receives rainfall mainly from SW monsoon, which commences in the month of May and lasts till September. The rainfall pattern during the last 40 years indicates falling long term trend at the rate of 19.4 mm per year (CGWB 2011).

The study area shows undulating plains with low lying flat topped mounds and narrows to wide valleys. Central portion is more or less flat and main urban part is at a lower level than its peripheral parts (rural area) which gives saucer shaped appearance. The average topographic elevation of Agartala is 12 m above msl. The central portion of the Agartala is bounded by the rivers Haora in the south and Katakhal in the north and remains flooded during the time of monsoon. A few streamlets are distributed all around the study area. The drainage system of the area is controlled by topography, local and regional structures. Broadly two types of soils are present i.e. Alluvial soils and Red sandy lateritic soils. The alluvial soil is found in the entire municipal area and along the river courses. The Red sandy Lateritic soil is found in the northern and southern parts. The study area is underlain by a succession of argillaceous and arenaceous sedimentary rocks, ranging in age from Mid-Tertiary to Recent. Alluvium of recent age made up of faint yellow, fine grained sand, light yellow silt and grey to dark grey clay in the valleys and river courses. Dupitila formation composed mainly of clay and silt, with some thin layers of coarse grained to gritty ferruginous sandstone. This sandstone forms the near surface aquifer, within 10-30 m bgl (below ground level), and are generally tapped by dug wells. Due to predominance of clay, the permeability and the storage capacity of the formation are very low. Ground water in this formation occurs in unconfined condition. The depth to water levels in the phreatic aquifers ranges from 1 m bgl to 5 m bgl. The pieziometric heads in the deeper zones varied from 3.73 to 23.45 m bgl during March (2010), and from 2.06 to 22.10 m bgl during November (2010). In general ground water movement is in west - north westerly direction (CGWB, 2011).

Study method

The present research work is based on 21 ground water samples collected during post monsoon season (November) from the study area (Fig. 1). These water samples were collected as per procedure outlined by CPHEEO (1998). The water samples were analyzed for various physico-chemical parameters using standards methods recommended by American Public Health Association (APHA, 1995). The physical parameters like pH, dissolved oxygen (D.O.) and total dissolved solids (TDS) were tested in the field at the time of sample collection using portable pH meter (Eutech Instrument) and water testing kit (MS Electronics, India). Analysis of cadmium, copper, iron, lead, nickel, zinc, calcium and magnesium was done using Atomic Absorption Spectrophotometer (Perkin Elmer AA200). Sulphate content was determined by the extent of turbidity created by precipitated colloidal barium sulphate suspension. Graphical representations of the concentrations of different ions in a water sample is developed using Piper diagram (1944), Durov Plot (1948), Stiff Pattern diagram (1951), Collin's Bar diagram (1923), Gibb's diagram (1970) and Back's classification (1961). The assessment of water quality suitability for irrigation was carried with the help of Magnesium Ratio, Water Hardness, Sodium Percentage, Residual Sodium Carbonate (RSC), Sodium Adsorption Ratio (SAR), Soluble Doneen's Permeability Index and Kelley's Index.

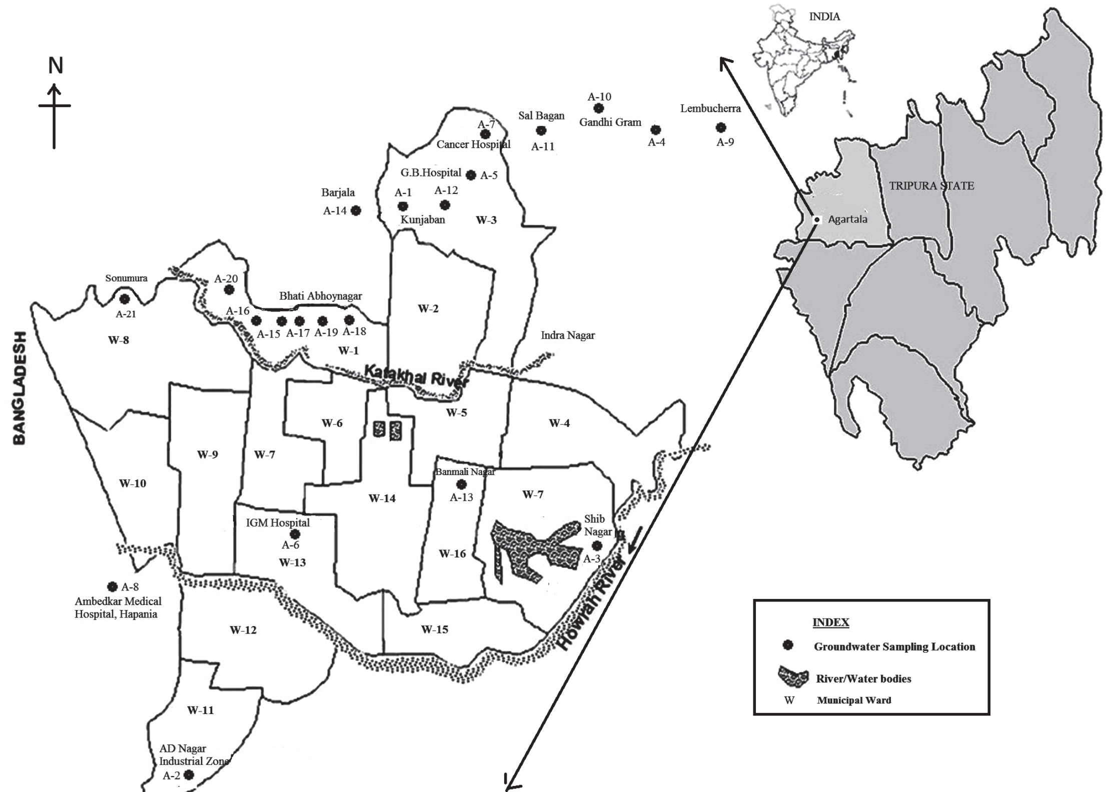

Fig. 1. Study area and location of water sampling in Agartala, Tripura (India).

Results and Discussion

Hydrochemistry of groundwater

Analysis of water samples of the study area revealed that ground water is acidic to alkaline with pH ranging from 4.30 to 8.25. The pH with average value of 6.06 is skewed towards acidic in nature (Fig. 2). Electrical conductivity (EC) ranges from 70 to 400 mg/L. Calcium (Ca) is the most abundant cation with concentrations ranging from 31 to 84 mg/L, Sodium (Na) concentration is varying from 5 to 18 mg/L, and Magnesium (Mg) concentration varying from 0.8 to 9.38 mg/L. Among anions Bicarbonate is the most abundant and its concentration ranges from 20 to 150 mg/L. Concentration of Chloride (Cl) ranges from 10 to 25 mg/L. The concentration of heavy metals like Mn (0.01-1.19 mg/L), Cd (0.001-0.09 mg/L), Pb (0.003-0.69 mg/L) and Zn (0.02-5.71 mg/L) was found above the permissible limit of both World Health Organization (WHO) standards and Bureau of Indian Standards (BIS) for drinking water. The concentration of Mn in 80% samples, Cd in 60% samples, Pb in 40% samples and Zn in 20% samples was found above the permissible limit. The concentrations of dissolved major cations and anions in the ground water vary both spatially and temporally. Abundance of these ions are in the

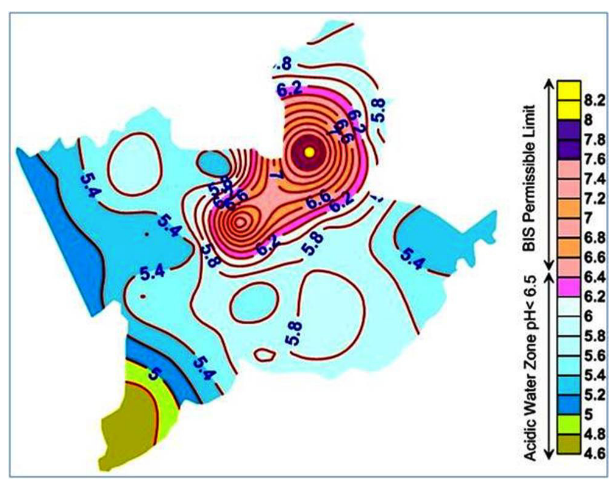

Fig. 2. Variation of pH in ground water of Agartala, Tripura (India).

following order: $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+} = HCO_3^{-} > Cl^{-} > SO_4^{2-} > NO_3^{-}$.

As per BIS (Bureau of Indian Standard) guidelines, the concentration of iron is beyond permissible limit (0.3 mg/L) in major part of the area. The Iron concentration in ground water ranges from 0.01 to 19.28 mg/L (Fig. 3). Ground water is potable only after treating for iron. Higher concentration of iron (more than 5 mg/L) is observed in the northern and southern parts. Whereas, the concentration of iron was below 5 mg/L in the central part of the study area. The iron concentration along the Haora River was less than 3 mg/L. The concentration of iron in shallow aquifer is lesser than that of deeper aquifers.

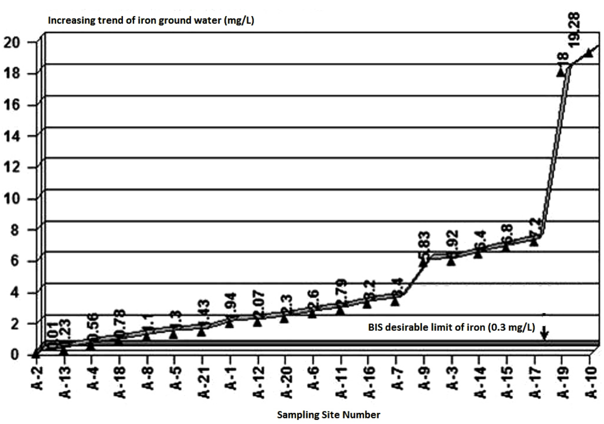

Fig. 3. Status of Iron in ground water of Agartala, Tripura (India).

Classification of groundwater types

Diagrams and contour maps are generally used to model hydrochemical data to identify the quality of ground water. In the present study, different accepted and widely used graphical methods such as Piper diagram (1944), Durov Plot (Durov, 1948), Stiff Pattern diagram (1951), Collin's Bar diagram (1923), Gibb's diagram (1970) and Back's classification (1961) were adopted for the classification and to gain better insight into the hydrochemical processes operating in the ground water flow system that resulted in the observed spatial and temporal variation in the ground water quality. The concept of hydrogeochemical facies has been used (Back, 1966; Morgan and Winner, 1962) to denote the diagnostic chemical character of water solutions in hydrologic systems. The facies reflect the effect of chemical processes occurring between the minerals of the lithologic framework and ground water (Edet, 1993; Edet and Okereke, 2002). The subsequent flow patterns modify the facies and control their distribution. The different classification for evaluation of ground water quality of study area is presented in Table 1.

Piper Trilinear diagram

The geochemical evolution of ground water can be understood by plotting the concentrations of major cations and anions in the Piper trilinear diagram. It is a combination of anion and cation triangle that lies on a common base line. The position of an analysis that is plotted on a Piper diagram can be used to make a tentative conclusion as to the origin of the water represented by the analysis. Four basic conclusions can be derived from the multiple analyses plotted on Piper diagrams. These are water type, precipitation or solution, mixing and ion exchange. Piper diagram divides water into four basic types according to their placement near the four corners of the diamonds. Water that plots at the top of diamond is high in $Ca^{2+} + Mg^{2+}$ and $Cl^{-} + SO_4^{2-}$; which results in an area of permanent hardness. The water that plots near left corner is rich in $Ca^{2+} + Mg^{2+}$ and HCO_3^{-} and is the region of water of temporary hardness. Water plotted at the lower corner of the diamond is primarily composed of alkali carbonates ($Na^{+} + K^{+}$ and $HCO_3^{-} + CO_3^{-}$), water lying near the right hand side of the diamond may be considered saline ($Na^{+} + K^{+}$ and $Cl^{-} + SO_4^{2-}$).

The ground water quality data of the study area plotted on the Piper trilinear diagram is shown in Figure 4. The cations plotted in the diagram are

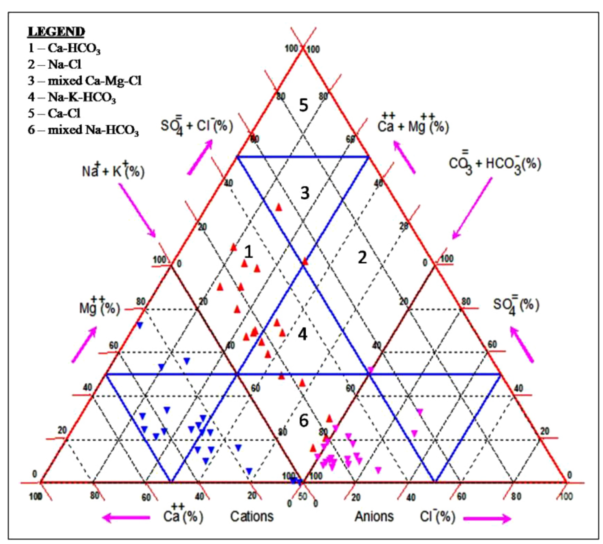

Fig. 4. Classification results of the groundwater using Piper diagram.

Table 1. Classification for groundwater quality evaluation of Agartala, Tripura (India)

Location	Site No.	Type of Classification						
		Piper	Durov		Stiff	Back		Gibb
			Cation Type	Anion Type				
Kunjaban	A-1	Mixed	Mg^{2+} Type	Intermediate	Mg^{2+}-HCO^-_3	Ca^{2+}-Mg^{2+}- Na^+	HCO^-_3-Cl^--SO^{2-}_4	RD*
A.D. Nagar	A-2	Ca^{2+} + Mg^{2+}- HCO^-_3	Mg^{2+} Type	HCO^-_3 Type	Mg^{2+}-HCO^-_3	Ca^{2+}-Mg^{2+}- Na^+	HCO^-_3-Cl^--SO^{2-}_4	RD
Shibnagar	A-3	Ca^{2+} + Mg^{2+}- HCO^-_3	Intermediate	HCO^-_3 Type	Ca^{2+}-HCO^-_3	Ca^{2+}-Mg^{2+}- Na^+	HCO^-_3-Cl^--SO^{2-}_4	RD
Gandhi Gram-1	A-4	Ca^{2+} + Mg^{2+}- HCO^-_3	Intermediate	HCO^-_3 Type	Ca^{2+}-HCO^-_3	Ca^{2+}-Mg^{2+}- Na^+	HCO^-_3-Cl^--SO^{2-}_4	RD
G.B. Hospital	A-5	Ca^{2+} + Mg^{2+}- HCO^-_3	Intermediate	HCO^-_3 Type	Na^+-HCO^-_3	Ca^{2+}-Mg^{2+}- Na^+	HCO^-_3-Cl^--SO^{2-}_4	RD
IGM Hospital	A-6	Ca^{2+} + Mg^{2+}- HCO^-_3	Intermediate	HCO^-_3 Type	Na^+-HCO^-_3	Ca^{2+}-Mg^{2+}- Na^+	HCO^-_3-Cl^--SO^{2-}_4	RD
RG Cancer Hospital	A-7	Mixed	Na^+ Type	HCO^-_3 Type	Na^+-HCO^-_3	Na^+-Ca^{2+}-Mg^{2+}	HCO^-_3-Cl^--SO^{2-}_4	RD
Ambedkar Hospital	A-8	Ca^{2+} + Mg^{2+}- HCO^-_3	Intermediate	HCO^-_3 Type	Na^+-HCO^-_3	Ca^{2+}-Mg^{2+}- Na^+	HCO^-_3-Cl^--SO^{2-}_4	RD
Lembucherra	A-9	Na^+ + K^+- HCO^-_3	Na^+ Type	HCO^-_3 Type	Na^+-HCO^-_3	Na^+ - K^+	HCO^-_3-Cl^--SO^{2-}_4	RD
Gandhi Gram-2	A-10	Na^+ + K^+- HCO^-_3	Na^+ Type	HCO^-_3 Type	Na^+-HCO^-_3	Na^+ - K^+	HCO^-_3-Cl^--SO^{2-}_4	RD
Salbagan	A-11	Na^+ + K^+- HCO^-_3	Na^+ Type	HCO^-_3 Type	Na^+-HCO^-_3	Na^+ - K^+	HCO^-_3-Cl^--SO^{2-}_4	RD
Kunjaban	A-12	Na^+ + K^+- HCO^-_3	Na^+ Type	HCO^-_3 Type	Na^+-HCO^-_3	Na^+-Ca^{2+}-Mg^{2+}	HCO^-_3-Cl^--SO^{2-}_4	RD
Banamalipur	A-13	Mixed	Intermediate	Intermediate	Na^+-SO^{-2}_4+PO^{2-}_4	Na^+-Ca^{2+}-Mg^{2+}	Cl^--SO^{2-}_4-HCO^-_3	RD
South Barjala	A-14	Ca^{2+} + Mg^{2+}- HCO^-_3	Intermediate	HCO^-_3 Type	Ca^{2+}-HCO^-_3	Ca^{2+}-Mg^{2+}- Na^+	HCO^-_3-Cl^--SO^{2-}_4	RD
Bhati Abhoynagar-1	A-15	Mixed	Na^+ Type	HCO^-_3 Type	Na^+-HCO^-_3	Na^+-Ca^{2+}-Mg^{2+}	HCO^-_3-Cl^--SO^{2-}_4	RD
Bhati Abhoynagar-2	A-16	Ca^{2+} + Mg^{2+}- HCO^-_3	Intermediate	HCO^-_3 Type	Mg^{2+}-HCO^-_3	Ca^{2+}-Mg^{2+}- Na^+	HCO^-_3-Cl^--SO^{2-}_4	RD
Bhati Abhoynagar-3	A-17	Mixed	Na^+ Type	HCO^-_3 Type	Na^+-HCO^-_3	Na^+-Ca^{2+}-Mg^{2+}-	HCO^-_3-Cl^--SO^{2-}_4	RD
Mailakhila	A-18	Ca^{2+} + Mg^{2+}- HCO^-_3	Intermediate	HCO^-_3 Type	Ca^{2+}-HCO^-_3	Ca^{2+}-Mg^{2+}- Na^+	HCO^-_3-Cl^--SO^{2-}_4	RD
Bhati Abhoynagar-4	A-19	Mixed	Na^+ Type	HCO^-_3 Type	Na^+-HCO^-_3	Ca^{2+}-Mg^{2+}- Na^+	HCO^-_3-Cl^--SO^{2-}_4	RD
Bitarban	A-20	Na^+ + K^+- HCO^-_3	Na^+ Type	HCO^-_3 Type	Na^+-HCO^-_3	Na^+-Ca^{2+}-Mg^{2+}	HCO^-_3-Cl^--SO^{2-}_4	RD
Sonumura	A-21	Ca^{2+} + Mg^{2+}- Cl^-	Mg^{2+}Type	Intermediate	Mg^{+2}-SO^{-2}_4+PO^{2-}_4	Ca^{2+}-Mg^{2+}	Cl^--SO^{2-}_4-HCO^-_3	RD

*RD- Rock Dominance

showing the dominance of Na^+ or K^+ type in maximum number of samples. In anion plot it is clearly seen that HCO_3^- + CO_3^- is dominant. Majority of ground water samples (43%) fall in mixed Ca^{2+}-Mg^{2+}-HCO_3^-. About 24% of the samples represented Na^+-K^+-HCO_3^- and rest of them was fall in the mixed type, Na-HCO_3 and Ca-Mg-Cl type (Table 1). Ca-HCO_3 type of water is likely caused by rainfall recharge processes, associated with low EC values. Calcium ion present in the ground water of the study area might have come from dissolution of precipitates of $CaCO_3$ and Ca Mg $(CO_3)_2$ during recharge. This means that ground water in the area is mainly made up of mixtures of earth alkaline metals and has temporary hardness. Most of the water samples are coming in unpolluted to slightly polluted category.

Durov's Double Triangular diagram

Some of the shortcomings of Piper trilinear plots are removed in the double triangular diagram proposed by Durov (1948). In this diagram, the major ions as percentage of milliequivalents per liter (meq/L) in two base triangles and total cations (top triangle, Na^++K^+, Ca^{2+}, Mg^{2+}) and total anions (left triangle, Cl^-, HCO_3^-, SO_4^{2-}) are set equal to 100 per cent. The data points in the two base triangles are projected into square (combined field of Na^++K^+ and HCO_3^-) of the main field which lies perpendicular to the third axis in each triangle. It shows clustering of water quality data points and finally displays some possible geochemical processes that could affect the water genesis (Srivastava and Ramanathan, 2008).

Durov diagram was used to shed light on the hydro-geochemical processes in ground water aquifers in the study area, and shown on Fig. 5. The cations triangle shows scattering in the distribution of the samples. About 42 per cent of ground water samples occupies the corner of the Na + K type concentration and same percentage of samples are clustering in the intermediate type which indicates the impact of the mixing with the deep ground water (Table 1). On the anions triangle, it is clear that most samples are clustering around HCO_3 type indicates that the ground water falls in the region of carbonate weathering. In general, calcite dissolution and reverse ion exchange process controls the water chemistry in the study area.

Collin's Bar diagram

The Collin's (1923) bar diagram give a visual impact

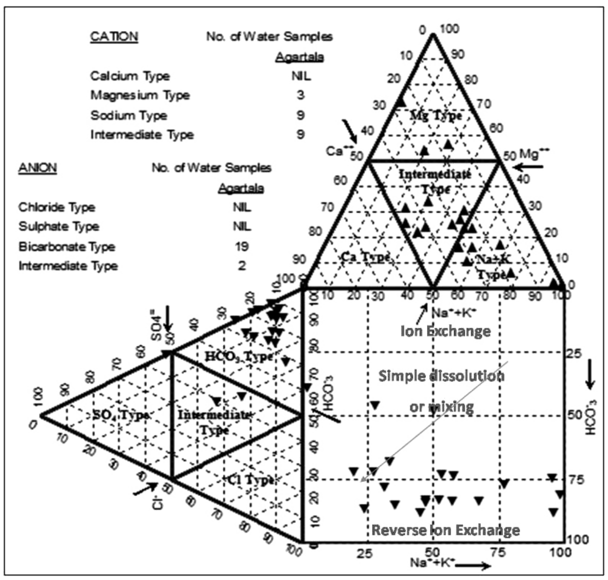

Fig. 5. Clusters of groundwater types and their plots on Durov's Diagram.

of the water type so that water samples that have similar shapes can be visually identified as having the same chemistry. It plots major anions on one side (right side) and major cations on the other side (left side) with projected points depending on the abundance of the ion in meq/L. Collin's Bar Diagram (Fig. 6) illustrate the relative concentrations of cations and anions from the ground waters in the study area. It is evident that the ground water system has the variable water chemistry for each sampled hydrologic regime. In addition, these charts suggest that the dominant cations are sodium and calcium and the dominant anion is bicarbonate.

Stiff Pattern diagram

Pattern diagrams, first suggested by Stiff (1951) for representing chemical analyses by four parallel horizontal and one vertical axes. Concentrations (meq/L) of four major cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) are plotted to the left of a vertical zero axis and four major anions (Cl^-, SO_4^{2-}, HCO_3^-, $NO_3^- + PO_4^{2-}$) to the right. The resulting points, when connected, form an irregular polygonal pattern; waters of a similar quality define a distinctive shape.

From the Stiff diagram data (Figure 7, Table 1) of the study area, the anion abundance relates and agrees well with the Piper diagram and Collin's bar diagram by that the dominant anion is bicarbonates while the dominant cation is sodium followed by magnesium and calcium. This water has the same source and is from the same aquifer system.

Back's classification

The facies mapping approach as suggested by Back

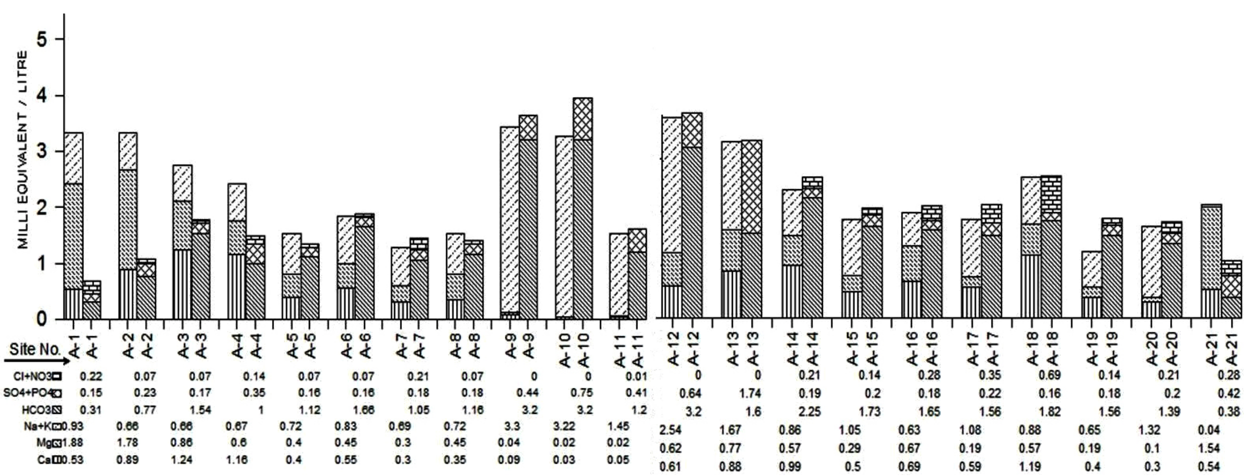

Fig. 6. Relative composition of cations and anions in ground water on Collin's Bar Diagram.

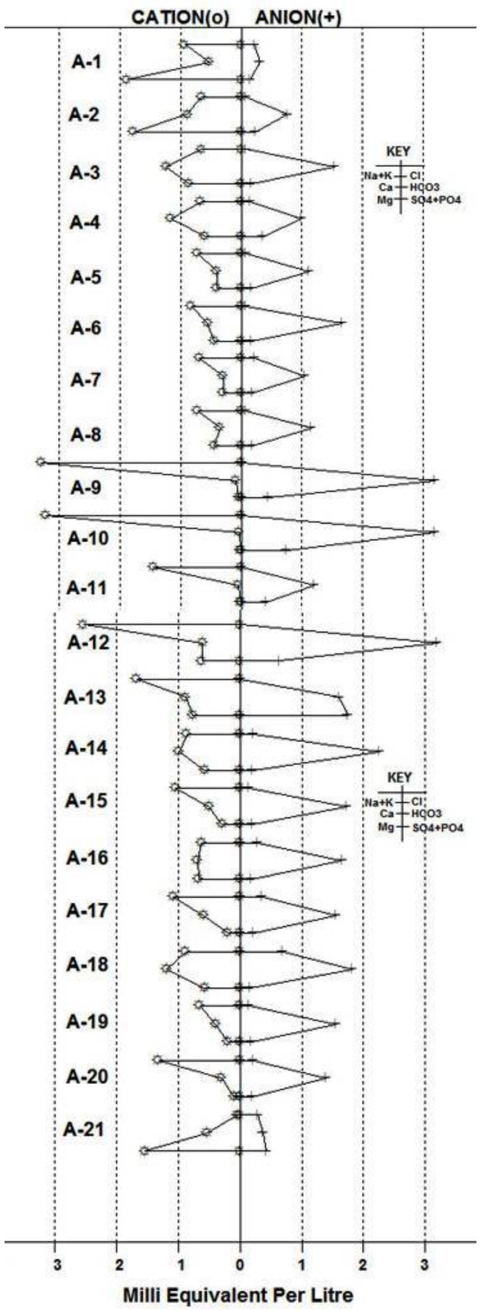

Fig. 7. Stiff Pattern Diagram of the study area.

(1961) is also one way of smoothening chemical data. In this classification, ground water samples of the study area are classified according to facies with two templates for the Piper diagram. The data plots for the study area (Fig. 8) revealed that water quality falls on the cation facies, such as Ca-Mg-Na =55%, Na-Ca-Mg=30%, whereas in anion facies, 85

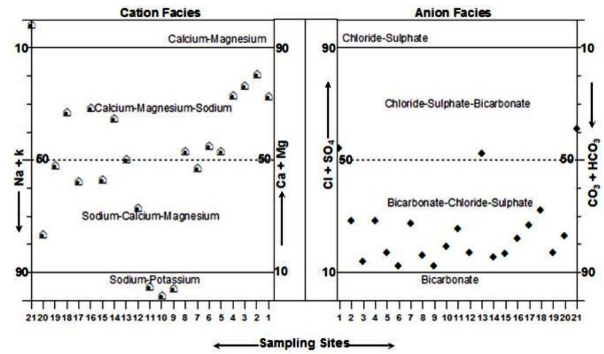

Fig. 8. Back's Classification of ground water of study area.

percent of ground water samples fall on HCO_3-Cl-SO_4 facies.

Gibbs' diagram

The Gibbs diagram is widely used to establish the relationship of water composition and aquifer lithological characteristics (Gibbs, 1970). Three distinct fields such as precipitation dominance, evaporation dominance and rock–water interaction dominance areas are shown in the Gibbs diagram (Fig. 9). The study area data plots on Gibbs diagram indicate that rock dominance mechanisms is controlling ground water chemistry. The rock–water interaction dominance field indicates the interaction between rock chemistry and the chemistry of the percolation waters under the subsurface.

Suitability of groundwater for irrigation

The assessment of ground water quality suitability for irrigation was carried out from 12 locations (Figure 1) of agriculture fields with the help of different criteria like Magnesium Ratio, Water Hardness, Sodium Percentage, Residual Sodium Carbonate (RSC), Sodium Adsorption Ratio (SAR), Soluble Doneen's Permeability Index, and Kelley's Index, presented in Table 2.

Magnesium ratio

Generally Ca^{2+} and Mg^{2+} maintain a state of equilibrium in most ground water (Hem, 1985). During equilibrium more Mg^{2+} in ground water will adversely affect the soil quality rendering it alkaline resulting in decrease of crop yield (Kumar *et al.*, 2007). Paliwal (1972) developed an index for calculating the magnesium hazard (magnesium ratio). MR is calculated using the formula:

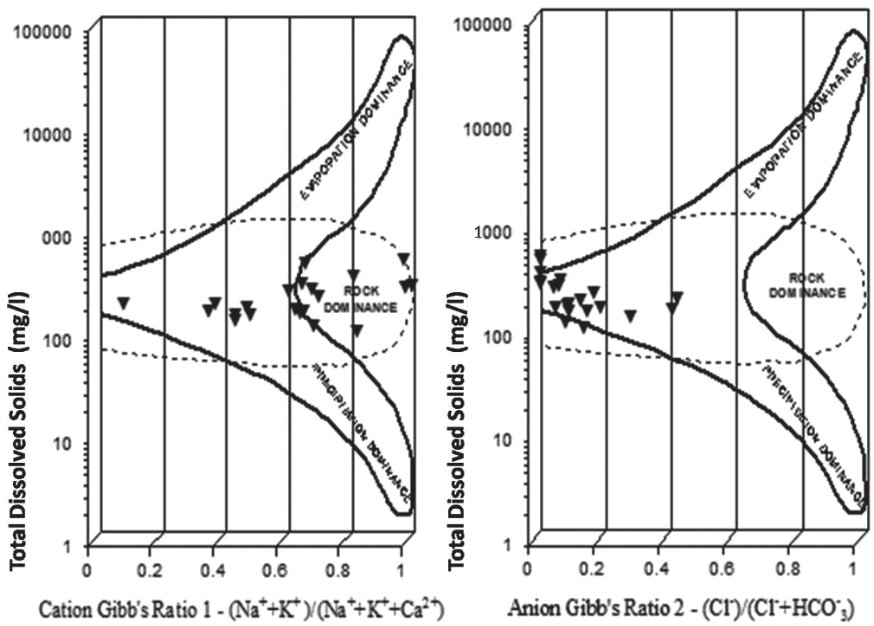

Fig. 9. Gibb's Diagram of the study area.

$$MR = (Mg^{2+} \times 100) / (Ca^{2+} + Mg^{2+})$$

Mg^{2+} hazard is likely to be developed in the soil when this ratio exceeds 50 per cent. The degree of hazardous effects would increase with the increase of Mg^{2+}/Ca^{2+} ratio. However the harmful effect of Mg^{2+} of irrigation water on soil is likely to be reduced by the release of Ca^{2+} on dissolution of $CaCO_3$ if present in the soil. The MR values ranges from 32.51 to 66.67 mg/L (Table 2) and about 40 per cent of the ground water samples of the study area exceeded the permissible limit of 50 mg/L indicating the unfavourable effect on crop yield and increase in soil alkalinity. Those samples may adversely affect the crop yield by making it more alkaline (Paliwal, 1972).

Total hardness

Hard water is unsuitable for both domestic and irrigation use and it is a measure of the Ca^{2+} and Mg^{2+} content expressed in equivalent of calcium carbonate. Hardness of water (temporary and permanent) in water is mainly due to the precipitation of Ca^{2+} and Mg^{2+} salts like carbonates, sulphates and chlorides. The total hardness (TH) in mg/L is determined by the following formula (Todd, 1980):

$$TH\ (mg/L) = 2.497\ Ca^{2+} + 4.115 Mg^{2+}$$

In the study area, TH ranges between 130 to 400 mg/L (Table 2), representing (70%) of the ground water samples below the permissible limit. The sources of 30 per cent of high TH in the study area is might be due to discharges of city effluents onto the barren land which gets infiltrated into the aquifers.

Residual Sodium Carbonate (RSC)

In water having high concentration of bicarbonate there is tendency for calcium and magnesium to precipitate as carbonates. As a result, the relative proportion of sodium in the water is increased in the form of sodium bicarbonate. Residual Sodium Percentage (RSC) is calculated to determine the hazardous effect of carbonate and bicarbonate on the quality of water used for agricultural activities (Raju, 2007) and it is calculated by using the formula; where all the ions are expressed in meq/L.

$$RSC = (CO^{2-}_3 + HCO_3)\ \ (Ca^{2+} + Mg^{2+})$$

According to Eaton (1950), on the basis of RSC the water is divided into three categories i.e., good (RCS <1.25 meq/L), medium (RSC: 1.25 to 2.50 meq/L) and bad (RSC >2.50 meq/L). Continues use of waters having RSC more than 2.5 meq/L leads to salt build up which may hinder the air and water movement by clogging the soil pores and lead to degradation of the physical condition of soil. According to this classification, 90 per cent samples are found in good category, while 10 per cent are ranged in medium category as specified in Table 2. From the observed values ground water samples are suitable for irrigation purposes.

Wilcox classification

Percentage of Na^+ is widely used for assessing the suitability of water for irrigation purposes (Wilcox, 1955). The sodium percentage is computed with respect to relative proportion of cations present in water; where all the ions are expressed in meq/L.

$$Na\ \% = [(Na^+ + K^+) / (Ca^{2+} + Mg^{2+} + Na^+ + K^+)] \times 100$$

Sodium percentage values reflected that the water was under the category of 'good' (20 - 40 Na %), 'permissible' (40 - 60 Na %) and 'doubtful' (60 - 80 Na %) class. The values of sodium per cent are varying from 2.05 to 67.53 (Table 2). According to this classification, 40 per cent samples are found in good category, while 50 per cent samples are ranged in permissible limit. Hence, 90 per cent of sampling points falling under between excellent to good category (Fig. 10). When the concentration of sodium ion is high in irrigation water, Na^+ tends to be absorbed by clay particles, displacing 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 drainage.

Sodium adsorption ratio (SAR)

Sodium concentration is very important in classifying irrigation waters. If water used in irrigation is high in Na^+ and low in Ca^{2+}, the cation exchange complex may become saturated with Na^+. Sodium is introduced into the aquifer in the area from rainwater and dissolution from rocks. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed as the Sodium Adsorption Ratio (SAR). SAR is calculated based on the formula (Richards, 1954) as given below:

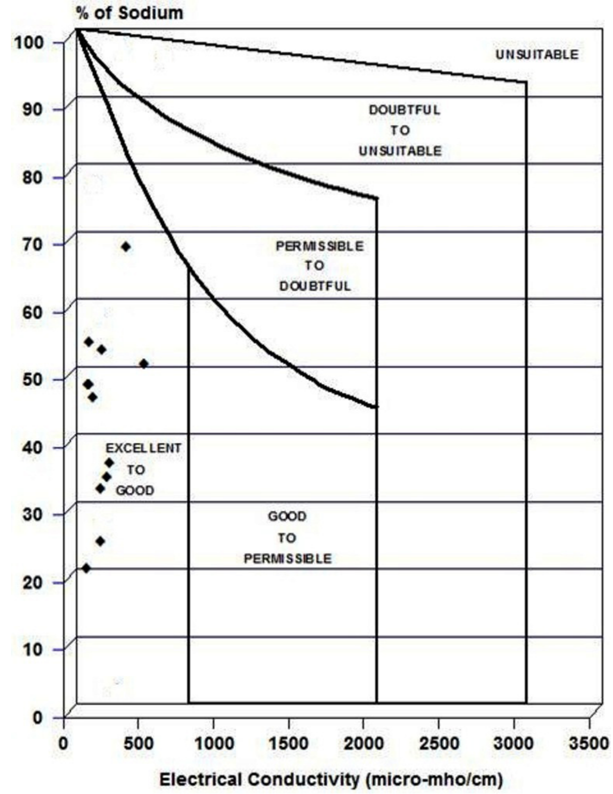

Fig. 10. Wilcox classification of ground water of the study area.

Table 2. Irrigation suitability data of groundwater from agriculture area around Agartala, Tripura (India)

Site No.	Mg^{2+} Ratio (mg/L)	TDS (mg/L)	RSC (meq/l)	Na (%)	SAR (mg/l)	Doneen's Classification PI (meq/l)	Doneen's Classification Class	Kelley's Index (meq/l)
A-2	44.98	218	0.66	45.31	1.17	115.70	Class-III	0.83
A-3	73.88	168	-1.70	2.05	0.04	31.19	Class-II	0.02
A-6	49.95	196	0.45	53.45	1.26	132.74	Class-III	1.15
A-8	36.58	100	0.95	57.40	1.68	129.26	Class-III	1.35
A-9	32.51	144	0.97	52.40	1.19	153.66	Class-III	1.10
A-10	77.92	134	-2.11	27.80	0.85	44.37	Class-II	0.38
A-11	40.78	142	-0.56	23.84	0.64	68.85	Class-II	0.31
A-13	66.67	130	-1.90	19.88	0.57	46.25	Class-II	0.25
A-14	50.32	300	1.98	67.53	3.25	115.05	Class-III	2.08
A-18	36.61	152	0.69	35.54	0.97	97.49	Class-III	0.55
A-19	46.60	400	-0.06	50.26	1.84	88.26	Class-II	1.01
A-21	56.51	232	0.36	47.15	1.13	118.19	Class-III	0.89

SAR = Na⁺ / SQRT [(Ca²⁺ + Mg²⁺) / 2]

Ca^{2+}, Na^{+} and Mg^{2+} have been used to calculate Sodium Adsorption Ratio (SAR) for the ground water samples. High SAR values (>10) could cause sodium to replace adsorbed calcium or magnesium, thereby damaging the soil structure. When the concentration of sodium is high in irrigation water, sodium ions tend to be absorbed by clay particles, displacing magnesium and calcium ions. The exchange process of sodium in water for magnesium and calcium in soil reduces permeability and eventually results in soil with poor drainage. Hence, air and water circulation is restricted during wet conditions and such soils are usually hard when dry (Collins and Jenkins, 1996; Saleh *et al.*, 1999).

Richards (1954) classified the concentration of soluble salt in irrigation water (salinity hazard) into four classes on the basis of electrical conductivity, EC and SAR (sodium hazard). The different classes of salinity hazard include low, C1 (EC < 250 μS/cm); medium, C2 (EC 250–750 μS/cm); high, C3 (EC 750 -2250 μS/cm); and very high, C4 (EC > 2250 μS/cm). The sodium hazard classes include: low, S1 (SAR < 10); medium, S2 (SAR 10 -18); high, S3 (SAR 18–26); and very high, S4 (SAR > 26). The calculated SAR for the ground waters ranges (Table 2) from 0.04 – 3.25 mg/L. As per U.S. Salinity Laboratory Staff (USSLS 1954) diagram, cent per cent (100%) samples fall in S1, indicating low salinity and low Na water for irrigation purposes for most soils and crops with no danger of development of exchange Na and salinity (Fig. 11). This shows that the water samples are good for irrigation (Johnson, 1975).

Doneen's permeability index (PI)

The permeability of soil is affected by long-term use of irrigation water and is influenced by sodium, calcium, magnesium and bicarbonate contents in soil. Doneen (1964) has evolved a criterion for assessing the suitability of water for irrigation based on Permeability Index (PI). It is calculated by using the formula; where all the ions are expressed in meq/L.

$$PI = [Na^{+} + SQRT\ (HCO_{3}^{-}) \times 100] / [(Ca^{2+} + Mg^{2+} + Na^{+})]$$

According to PI values, the ground water samples fall in Class II and Class III (Fig. 12) indicating water is moderate to good for irrigation purposes (Arumugam and Elangovan, 2009).

Kelley's index

Kelly's index (KI) is used for the classification of

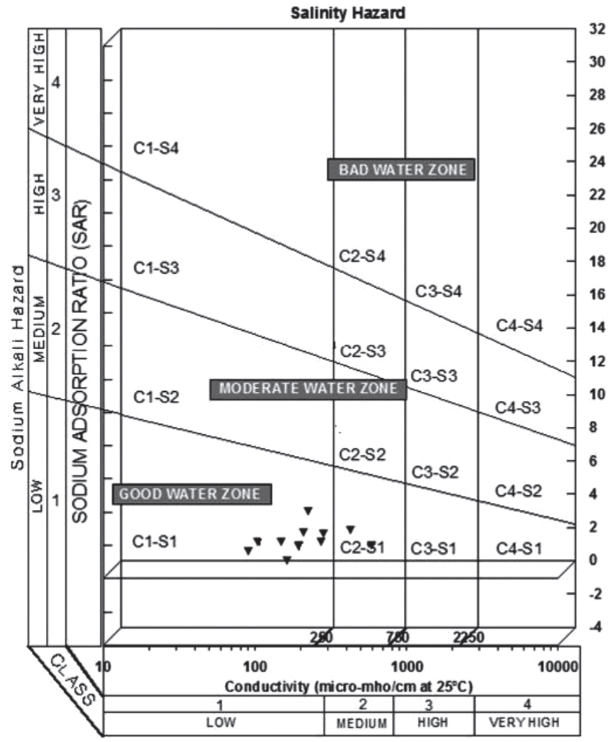

Fig. 11. USSLS classification of the ground water of the study area.

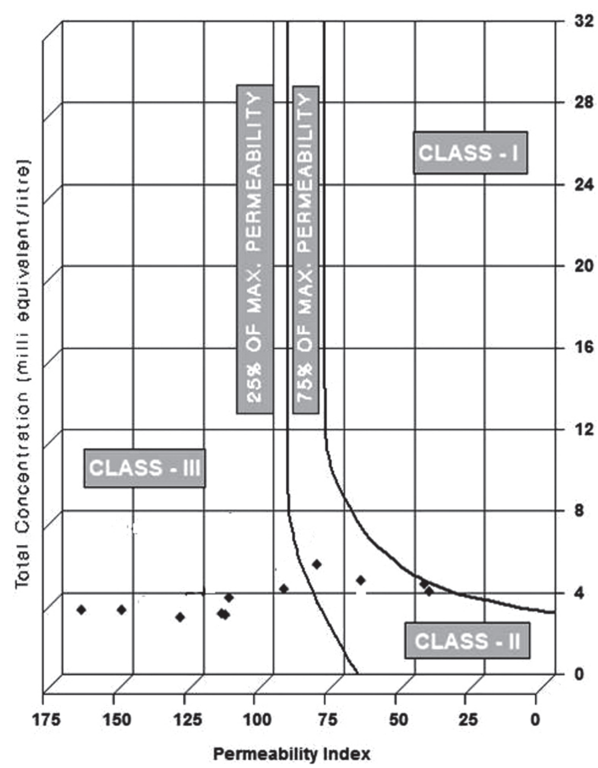

Fig. 12. Classification criteria as per Doneen's Permeability Index.

water for irrigation purposes. Sodium measured against calcium and magnesium is considered for calculate this parameter. A KI (>1) indicates an excess level of sodium in waters (Kelly 1940). Therefore, waters with a KI (<1) is suitable for irrigation, while those with greater ratio are unsuitable (SunIdaray *et al.*, 2009). KI is calculated by using the formula; where all the ions are expressed in meq/L.

$$KI = Na^+ / (Ca^{2+} + Mg^{2+})$$

KI in the present study varied between 0.02 and 2.08 (Table 2) which are within the permissible level of irrigation water quality standard.

Conclusion

Interpretation of hydro-chemical analysis of ground water in urban and rural area of Agartala (Tripura State, India) is generally alkaline, fresh with temporarily hard in nature. The water quality parameters such as Iron, Ca^{2+}, Mg^{2+} and HCO_3^{-} were found to above permissible limit for domestic purpose except at few locations. Concentration of heavy metals such as Mn, Zn, Pb and Cd was above the permissible limit (BIS & WHO) for drinking which may entail various health hazards and the use of such ground water should be done only after proper water treatment.

Two major hydro-chemical facies Na-K-HCO_3 and Ca-Mg-HCO_3 were identified using Piper diagram. The concentration of cation is in the order of $Na^+ > Ca^{2+} > Mg^{2+} > K^+$, while for the anions it is $HCO_3^{-} > Cl^{-} > SO_4^{2-} > CO_3^{2-}$. As per Back's classification, mixed Ca^{2+}-Mg^{2+}-Na^+ and HCO_3^--Cl^--SO_4^{2-} type of ground water are predominant in the study area. Gibbs' diagram of the study area indicates that rock dominance mechanisms is controlling ground water chemistry. The sodium percentage values as per Wilcox classification, ground water samples belong to good to excellent category for irrigation purposes. The per cent sodium level of samples indicated that only 10 per cent samples are doubtful whereas, 90 per cent samples are in permissible category of the sodium hazards for agricultural applications. The Durov diagram indicated that most of the ground water samples belong to HCO^-_3 type of anion facies, 42 per cent of samples $Na^+ + K^+$ type of cation facies and remaining samples are intermediate type. The US salinity diagram illustrates that most of the ground water samples fall in the field of C1S1, indicating low salinity and low sodium water, which can be used for irrigation on almost all type of soil. Permeability index and Kelly's index values also indicate that ground water is moderate to good for irrigation purposes. According to the overall assessment, ground water quality was found to be suitable for irrigation and drinking purposes except high iron concentration which need proper treatment before use.

From this study, it is concluded that the ground water are generally suitable for drinking and irrigation purposes. However, due to increasing pressure of the population and intensive agricultural activities could lead to the declination of the water quality in the area. The presence of higher amount of certain cations, anions, iron and some heavy metals indicates little pollution in the ground water. However, these cations need to be monitored over the time in order to keep a sustainable water management in the area. On the other hand, it is necessary to mention that river system plays a major role in assimilation or transporting municipal and industrial wastewater and runoff from agricultural land and mixing with the ground water.

References

APHA., 1995. *Standard Methods for the Examination of Water and Waste Waters.* American Public Health Association, 16th Edition, New York.

Arumugam, K.and Elangovan, K. 2009. Hydrochemical characteristics and groundwater quality assessment in Tirupur Region, Coimbatore District, Tamil Nadu, India. *Environ. Geol.*, 58: 1509-20

Back, W. 1966. *Hydrochemical facies and groundwater flow pattern in northern part of Atlantic Coastal Plain*. US Geological Survey Professional Paper 498A.

Back, W. 1961. *Techniques for Mapping of Hydrochemical Facies*. US Geological Survey Professional Paper 424-D

CGWB., 2011. *Groundwater scenario in major cities of India*. Central Groundwater Board, Ministry of Water Resources, Govt. of India, Faridabad, India.

Collins, W.D. 1923. Graphical Representation of Water Analysis. *Ind. Eng. Chem.* 15 : 394

Collins, R. and Jenkins, A. 1996. The impact of agricultural land use on stream chemistry in the middle hills of the Himalayas, Nepal. *J. Hydrol.* 185 : 71-86.

CPHEEO., 1998. A *manual on water supply and treatment.* Central Public Health and Environmental Engineering Organization (CPHEEO), Akalank Publication, New Delhi.

Doneen, L.D. 1964. *Notes on Water Quality in Agriculture.* Water Science and Engineering Paper 4001, Dept. of Water, Science and Engineering, Univ. of California, Davis, USA.

Durov, S.A. 1948. Natural Waters and Graphic Representation of their Composition. *Dok l. Akad. Nank. SSSR,* 59 **:** 87-90.

Eaton, F.M. 1950. Significance of Carbonate in Irrigation Water. *Soil Sci.* 69 (2) : 123-33.

Edet, A.E. 1993. Groundwater quality assessment in parts of Eastern Niger Delta, Nigeria. *Environ. Geol.* 22 : 41-46.

Edet, A.E. and Okereke, C.S. 2002. Delineation of shallow groundwater aquifers in the coastal plain sands of Calabar area (Southern Nigeria) using surface resistivity and hydrogeological data. *J. Afr Earth Sci.* 35 : 433-43.

Gibbs, R.J. 1970. Mechanisms Controlling World's Water Chemistry. *Science.* 170 **:** 1088.

Faure, G. 1988. *Principles and applications of geochemistry*. 2nd ed. Prentice-Hall, Engle Wood Cliffs.

Garrels, R.M. 1967. Genesis of some ground waters from igneous rocks p. 405-20 In: P.H. Abelson edited. *Researches in geochemistry*. Wiley, New York.

Hem, J. D. 1985. Study and interpretation of the chemical characteristics of natural water, 3rd edn. *US Geol. Surv. Water Suppl.* 2254-263.

Johnson, E. E. 1975. *Groundwater and wells.* Johnson Division, UDP Inc. St Paul MN.

Kumar, M., Kumari, K., Ramanathan, A.L.and Saxena, R. 2007. A comparative evaluation of groundwater suitability for irrigation and drinking purposes in two intensively cultivated districts of Punjab, India. *Environ. Geol.* 53 : 553-74.

Kelly, W.P. (Eds). 1940. Permissible composition and concentration of irrigated waters. Proceeding of the ASCF 66.

Kelley, W.P., Brown, S.M. and Liebig, G.F. Jr. 1940. Chemical Effects of Saline Irrigation Water on Soil. *Soil Sci.* 49:95-107.

Morgan, C.O. and Winner, M.D. Jr. 1962. *Hydrogeochemical facies in the "400-foot" and "600 - foot" sands of the Baton Rouge area, Louisiana*. US Geological Survey Professional Paper 450-B.

Paces, T. 1973. Steady state kinetics and equilibrium between groundwater and granite rock. *Geochim Cosmochim. Acta.* 37 : 2641-63.

Paliwal, K.V. 1972. *Irrigation with Saline Water.* IARI, Monograph no. 2 (new series), New Delhi.

Piper, A.M. 1944. *A Graphical Procedure in the Geochemical Interpretation of Water Analysis*. U S Geological Survey Groundwater Note 12.

Raju, N.J. 2007. Hydrogeochemical parameters for assessment of groundwater quality in the upper Gunjanaeru River basin, Cuddapah District, Andhra Pradesh, South India. *Environ. Geol*. 52**:**1067-74.

Richard, L.A. 1954. Diagnosis *and improvement of saline and alkali soils*; Agric. handbook 60, Wash., USDA, DC, 160.

Saleh, A., Al-Ruwaih, F. and Shehata, M. 1999. Hydrogeochemical processes operating in the main aquifers of Kuwait. *J. Arid Environ.* 42**:**195-209

Srivastava, S.K. and Ramanathan, A.L. 2008. Geochemical assessment of ground water quality in vicinity of Bhalswa landfill, Delhi, India, using graphical and multivariate statistical methods. *Environ. Geol.* 53:1509-28

Stallard, R.F. and Edmond, J.N. 1983. Geochemistry of the Amazon-II. The influence and the geology and weathering environment on the dissolved load. *J. Geophys. Res.* 88**:**9671-88

Sundaray, S.K., Nayak, B.B. and Bhatta, D. 2009. Environmental studies on river water quality with reference to suitability for agricultural purposes: Mahanadi river estuarine system, India - a case study. *Environ. Monitor. Assess.* 155:227-43

Sarin, M.M., Krishnaswami, S., Killi, K., Somayajulu, B.L.K. and Moore, W.S. 1989. Major ion chemistry of the Ganga-Brahmaputra River basin system: weathering processes and fluxes to the Bay of Bengal. *Geochim. Cosmochim. Acta.* 53:997-1009.

Singh, A.K., Bhagowati, S., Das, T.K., Yubbe, D., Rahman, B., Nath, M., Obing, P., Singh, W.S.K., Renthlei, C. Z., Pachuau L. and Thakur, R. 2008. Assessment of arsenic, fluoride, iron, nitrate and heavy metals in drinking water of northeastern India. *ENVIS Bulletin: Himalayan Ecol.* 16: 5-12

Stallard, R. F. and Edmond, J. N. 1983. Geochemistry of the Amazon-II. The influence and the geology and weathering environment on the dissolved load. *J. Geophys. Res.* 88 : 9671-88.

Stiff, H.A. Jr. 1951. The Interpretation of Chemical Water Analysis by Means of Patterns. *J. Petrol Tech.* 3:15-16.

Subba Rao, N. 2002. Geochemistry of groundwater in parts of Guntur district, Andhra Pradesh, India. *Environ. Geol*. 41 : 552-62.

Todd, D.K. 1980. *Groundwater Hydrol.* Wiley, New York.

US Salinity Laboratory Staff 1954. *Diagnosis and Improvement of Saline and Alkaline Soils*; USDA Handbook no. 60.

WHO. 1971. *International Standards for Drinking Water.* WHO, Geneva.

Wilcox, L.V. 1955. *Classification and use of irrigation waters.* U.S. Dept. Agric. Circular 969, Wash., U.S. Dept. Agric., DC, 19.