Quality Characterization of Groundwater in Koilsagar Project Area, Mahabubnagar District, Andhra Pradesh, India

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ABSTRACT / Studies of groundwater chemistry in the Koilsagar project area of Andhra Pradesh indicate that the waters are sodium bicarbonate, sodium chloride, mixed cationic–mixed anionic, mixed cationic Na dominating bicarbonate, and mixed cationic Ca dominating bicarbonate types. Of them, sodium bicarbonate and mixed cationic Mg dominating bicarbonate types of waters are more prevalent.

Isocone mapping of specific conductance indicates that the ionic concentration increases from east to west in the area. Graphical treatment of chemical data reveals that, in general, the area has basic water, whereas the left flank canal area is dominated by secondary alkaline water, and Pallamarri and Pedda Rajmur villages have strongly acidic waters. Ion-exchange studies show that cation–anion exchanges exist all over the area except for two places, which have a base exchange hardened type of water.

Graphical representation further shows that most of the area has medium salinity–low sodium (C_2S_1) water useful for irrigation purposes. High salinity–low sodium (C_3S_1) and high salinity–medium sodium (C_3S_2) waters are present in some areas, which need adequate drainage to overcome the salinity problem.

Introduction

Koilsagar project area (latitude N16°30′40″–16°45″, longitude E77°43′47″–77°51′07″) is in Atmakur and Makthal taluks of the Mahabubnagar District of Andhra Pradesh, India (Fig. 1). It is a granitic terrain, forming a part of the peninsular shield and, for the purpose of hydrogeology, is a hard rock terrain. It is identified by the government of India as one of the drought-prone areas of the country. Evaluation of hydrogeological parameters in hard rock terrains is quite difficult, unlike in soft rock areas. Since quality is as important as quantity, the groundwater chemistry of the area was studied. The study includes determination of ionic concentrations, chemical classification, chemical relationship, ion-exchange processes, and irrigation suitability.

A number of techniques and methods have been developed to interpret the data. Zaporozec (1972) summarized the various modes of data representation and discussed about their possible use. In the present study, the method suggested by Hem (1975), the Piper trilinear diagram (Piper 1953), the Schoeller index (Schoeller 1959), and the U.S. Salinity Laboratory (1954) diagram are used for classifying groundwater.

Geologic Setting

The Koilsagar project area consists of granites with numerous basic and acidic enclaves and is traversed by basic dikes and veins of quartz, epidote, feldspar, and pegmatite. Granites are divided into pink and grey types, depending on the predominant color of K-feldspar. Pink granites are dominant and occupy a major part of the area under investigation. They are more susceptible to weathering than the grey varieties. Grey granites occupy limited areas and occur as pockets; at places they are interspersed with pink granites. They are compact, hard, and more resistant to weathering than pink granites. Gneissic granites are medium to coarse grained and occur at very few places in the area. In the area joints are more numerous with large intraspaces near the ground surface and diminish in width and intensity with depth. There are four major sets of joints present in the area and in the order of predominance they are in northeast–southwest, north–south, east–west, and northwest–southeast directions.

Sample Collection and Analysis

Water samples were collected from 24 representative wells in the area under investigation. Specific conductance and pH values were measured in the field. Laboratory analyses using standard methods of the American Public Health Association (APHA 1980) include the determination of the ionic concentrations of

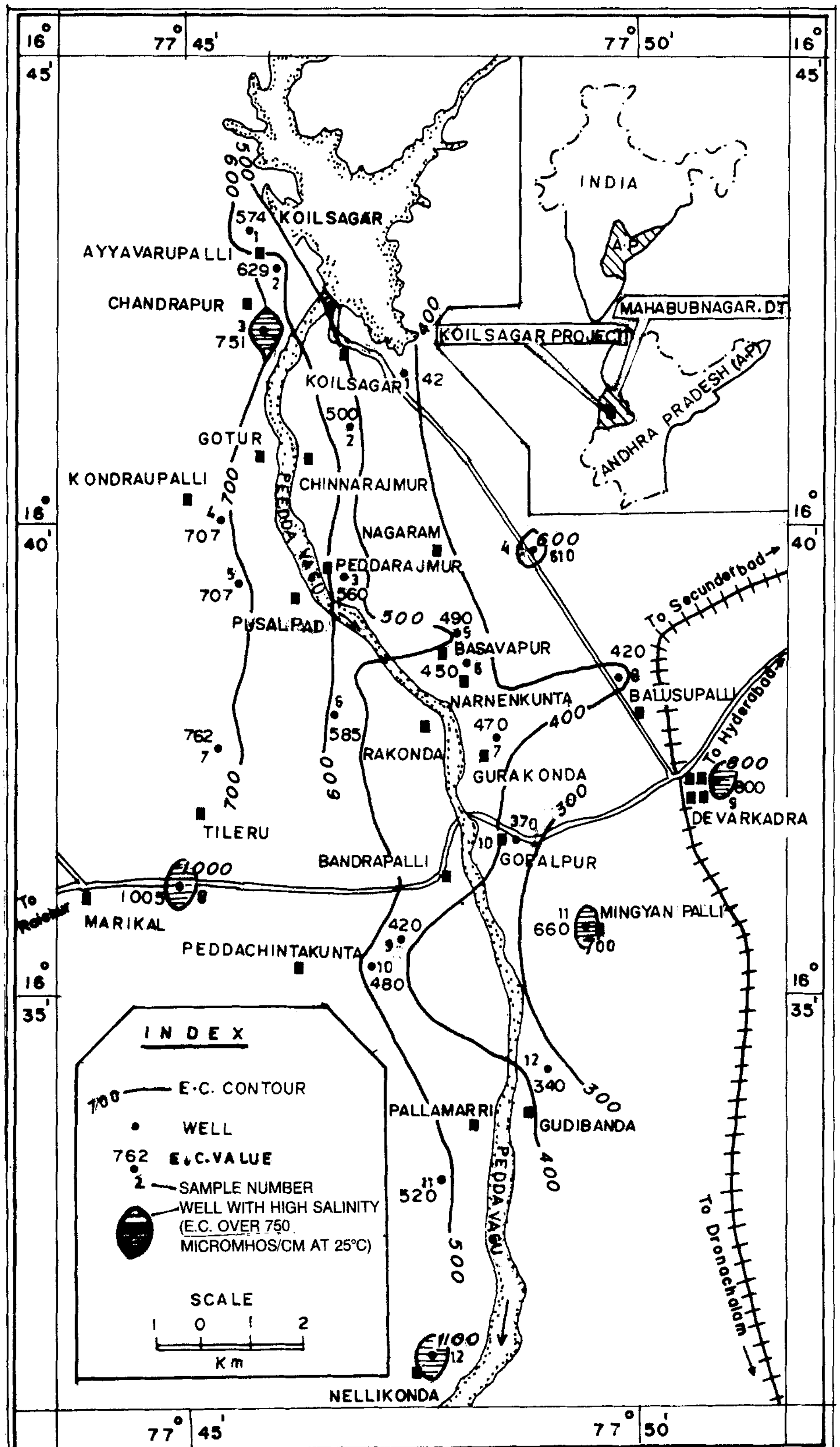

Figure 1. Isocone map of EC of Koilsagar project area, A.P. showing salinity variation.

Table 1. Analytical data of water samples of Koilsagar project area[a]

Serial No.	Village	pH	EC (µmho/cm at 25°C)	Concentration (meq/l)								Water type	Schoeller index	Water type according to USDA (1954)
				Ca^{2+}	Mg^{2+}	Na^{2+}	K^{2+}	HCO_3^-	Cl^-	SO_4^{2-}	F^-			
Right flank canal area														
1.	Chandrapur	7.64	574	2.40	2.06	2.52	0.03	4.80	0.68	1.451	0.079	$Na\text{-}Ca\text{-}Mg\text{-}HCO_3$	−2.75	C_2S_1
2.	Ayyavarpalli	7.87	629	1.30	1.15	4.35	0.05	4.40	1.58	0.791	0.079	$Na\text{-}HCO_3$	−1.78	C_2S_1
3.	Gotur	7.56	757	2.40	3.04	3.00	0.03	5.60	1.58	1.237	0.053	$Mg\text{-}Na\text{-}Ca\text{-}HCO_3$	−0.91	C_3S_1
4.	Kondraupalli	7.76	707	1.45	1.15	4.35	0.03	4.80	1.13	0.997	0.053	$Na\text{-}HCO_3$	−2.81	C_2S_1
5.	Pusalpad	7.95	707	1.60	2.06	4.35	0.05	4.60	1.69	0.774	0.026	$Na\text{-}HCO_3$	−1.20	C_2S_1
6.	Rakonda	7.64	585	1.75	1.48	3.44	0.05	4.00	1.58	1.087	0.053	$Na\text{-}HCO_3$	−1.20	C_2S_1
7.	Tileru	7.60	762	1.60	3.54	2.91	0.03	5.60	1.35	1.077	0.053	$Mg\text{-}Na\text{-}HCO_3$	−1.71	C_2S_1
8.	Marikel	7.90	1005	1.60	1.15	7.70	0.05	6.40	1.02	3.027	0.053	$Na\text{-}HCO_3$	−6.59	C_3S_2
9.	Bandrapalli	7.15	420	1.60	1.89	1.57	0.08	3.60	1.13	0.357	0.053	$Mg\text{-}Ca\text{-}Na\text{-}HCO_3$	−0.46	C_2S_1
10.	Peddachintakunta	7.30	480	1.30	1.56	2.44	0.03	3.20	1.35	0.754	0.026	$Na\text{-}Mg\text{-}HCO_3$	−0.829	C_2S_1
11.	Pallamarri	8.00	520	2.10	0.82	3.22	0.03	2.00	3.61	0.481	0.079	Na-Cl	+0.099	C_2S_1
12.	Nellikonda	7.32	1076	1.90	3.70	4.48	0.10	8.00	0.79	1.337	0.053	$Na\text{-}Mg\text{-}HCO_3$	−4.68	C_3S_1
Left flank canal area														
1.	Koilsagar	7.00	420	2.55	1.32	1.65	0.03	4.00	0.68	0.79	0.079	$Ca\text{-}Na\text{-}HCO_3$	−1.47	C_2S_1
2.	Chinnarajmur	7.09	520	2.40	2.39	2.26	0.05	4.40	1.92	0.73	0.053	$Ca\text{-}Mg\text{-}Na\text{-}HCO_3$	−0.20	C_2S_1
3.	Peddarajmur	6.95	560	3.05	1.73	2.26	0.05	3.20	2.82	1.017	0.053	$Ca\text{-}Na\text{-}HCO_3\text{-}Cl$	+0.22	C_2S_1
4.	Nagaram	7.40	610	1.90	3.54	2.61	0.03	5.68	0.79	1.531	0.079	$Mg\text{-}Na\text{-}HCO_3$	−1.84	C_2S_1
5.	Basavapur	7.90	490	1.45	1.56	2.96	0.05	3.20	1.58	1.161	0.079	$Na\text{-}Mg\text{-}HCO_3$	−0.325	C_2S_1
6.	Narnenkunta	7.40	450	1.45	1.56	2.96	0.05	3.80	1.24	1.457	0.053	$Na\text{-}Mg\text{-}Ca\text{-}HCO_3$	−0.77	C_2S_1
7.	Gurakonda	7.30	470	1.75	2.39	1.96	0.03	4.00	1.13	0.947	0.053	$Mg\text{-}Na\text{-}Ca\text{-}HCO_3$	−0.76	C_2S_1
8.	Balusupalli	7.89	420	1.90	0.33	1.61	0.05	2.40	0.68	0.757	0.053	$Ca\text{-}Na\text{-}HCO_3$	−1.426	C_2S_1
9.	Deverkadra	7.15	800	1.00	1.89	4.78	0.13	4.80	2.93	0.92	0.053	$Na\text{-}HCO_3$	−0.675	C_3S_1
10.	Gopalpur	7.05	370	1.60	2.06	1.00	0.08	3.20	1.02	0.454	0.066	$Mg\text{-}Ca\text{-}HCO_3$	−0.058	C_2S_1
11.	Mingyanpalli	7.46	660	3.20	0.82	2.44	0.03	4.00	1.02	1.444	0.026	$Ca\text{-}Na\text{-}HCO_3$	−1.42	C_2S_1
12.	Gudibanda	7.55	340	1.75	1.56	0.87	0.03	2.80	0.56	0.06	0.079	$Ca\text{-}Mg\text{-}HCO_3$	−0.60	C_2S_1

[a]Nomenclature of water type: Na-Cl = sodium chloride, Na-HCO = sodium bicarbonate water, Mg-Na-Ca-HCO = mixed cationic magnesium dominating bicarbonate water, $Ca\text{-}Na\text{-}HCO_3\text{-}Cl$ = mixed cationic (Ca dominating) and mixed anionic (HCO_3 dominating) water, $Na\text{-}Mg\text{-}Ca\text{-}HCO_3$ = mixed cationic Na dominating bicarbonate water, $Ca\text{-}Na\text{-}HCO_3$ = mixed cationic Ca dominating bicarbonate water.

Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-, and F^-. Using the electrical neutrality method, SO_4^{2-} is determined. Data from field measurements and major ion analysis are presented in Table 1.

Ionic Concentrations

Sodium is the predominant cation, with a concentration range of 0.87–7.7 meq/l, and potassium occurs in minor concentrations (0.03–0.13 meq/l). Among alkaline earths, magnesium varies from 0.33 to 3.70 meq/l and calcium from 1.3 to 3.2 meq/l. Bicarbonate is the predominant anion, with concentration varying between 2 and 8 meq/l. Chloride is the principal anion among the strong acids and varies from 0.56 to 3.61 meq/l. Fluoride occurs in minor concentrations from 0.026 to 0.079 meq/l. Isocone mapping of specific conductance (Fig. 1) shows that the degree of ionic concentration increases from east to west in the area.

Chemical Classification

Classification schemes developed are based on the concentration of various predominant cations and anions or on the interrelationships of ions. Hem (1975) suggested that water in which no one cation or anion constitutes as much as 50 percent of the total should be recognized as "mixed type" and identified by the names of all the important cations and anions. In the area under investigation, 50 percent or more of individual cationic or anionic concentrations in their respective totals have been considered in formulating the water type. Inc cases where no one cation or anion constitutes as much as 50 percent of the total but is dominant, the water is classified as mixed dominating ion water type.

On the basis of the chemical characteristics, the waters in the area can be classified into six groups: sodium bicarbonate water, sodium chloride water, mixed cationic Na dominating bicarbonate water, mixed cationic Mg dominating bicarbonate water, mixed cationic Ca dominating bicarbonate water, mixed cationic (Ca dominating), and mixed anionic (HCO_3 dominating) water.

The types of waters present in the Koilsagar area and their percentage distribution in space are presented in Table 2. It is clear from the table that the area is dominated by sodium bicarbonate and mixed cationic Mg dominating bicarbonate types of waters. Sodium chloride, mixed cationic, and mixed anionic waters occupy the least percentage of the area.

Table 2. Distribution of type of water in Koilsagar project area

Serial No.	Water type	No. of samples	Percentage of area with water type
1.	Sodium bicarbonate water	6	25.00
2.	Sodium chloride water	1	4.20
3.	Mixed cationic Na dominating bicarbonate water	5	20.80
4.	Mixed cationic Mg dominating bicarbonate water	6	25.00
5.	Mixed cationic Ca dominating bicarbonate water	5	20.80
6.	Mixed cationic (Ca dominating) and mixed anionic (HCO_3 dominating) water	1	4.20

Chemical Relationships

The trilinear diagrams of Piper are very useful in bringing out chemical relationships among groundwaters in more definite terms than is possible with other plotting methods (Walton 1970). Chemical data of the area are subjected to graphical treatment by plotting them in a Piper (1953) trilinear diagram (Fig. 2). Distribution of the groundwater samples in different subdivisions of the diamond-shaped field of the Piper diagram (Fig. 2 and Table 3) reveal that (1) in general, the area under study has basic water, (2) more places in the left flank canal (LFC) area have secondary alkaline water, (3) Pallamarri (right flank canal area) and Pedda Rajmur (left flank canal area) villages have strongly acidic water, (4) primary salinity water occurs only in Pallamarri village, and (5) the entire area is devoid of primary alkalinity and secondary salinity waters.

Ion-Exchange Process

Robinson (1962) has presented a general survey of the literature on ion-exchange phenomena of particular interest in water chemistry, and Half Ferrish (1962) described in greater detail the ion-exchange process and mathematical means of evaluating it (Hem 1975). To determine the ion-exchange process in the groundwater of the area under study, the Schoeller index (Schoeller 1959) is used.

$$b = r\frac{Cl - (Na + K)}{Cl}$$

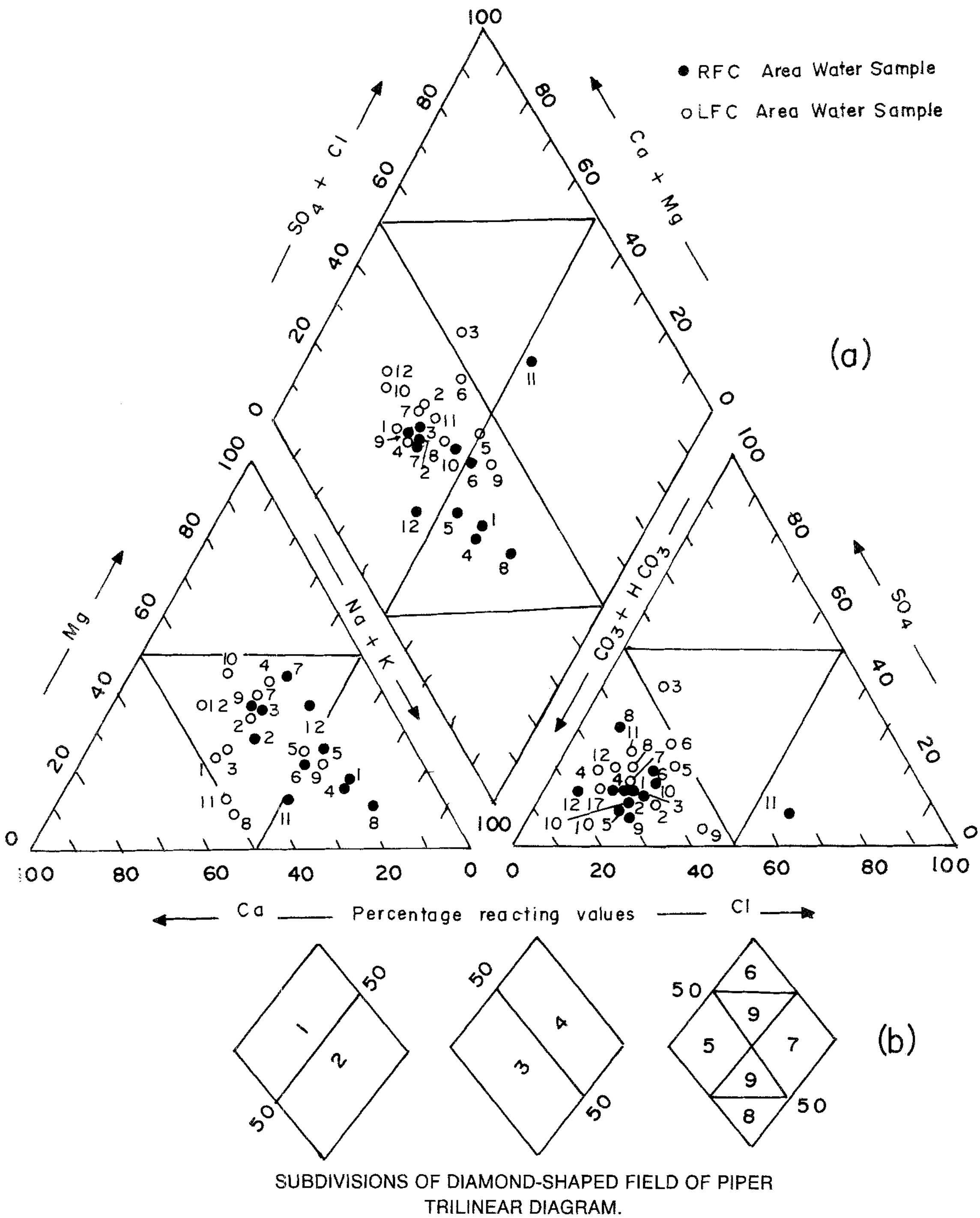

Figure 2. Chemical data of water from Koilsagar project area, A.P., plotted in Piper trilinear diagram.

Table 3. Characterization of groundwater in Koilsagar project area, on the basis of Piper trilinear diagram

Subdivision number of the diamond-shaped field	Characteristics of corresponding subdivision of the diamond-shaped field	Number of samples	
		RFC area	LFC area
1	Alkaline earths (Ca + Mg) exceed alkalies (Na + K)	6	10
2	Alkalies exceed alkaline earths	6	1
3	Weak acids (CO_3 + HCO_3) exceed strong acids (So_4 + Cl + F)	11	11
4	Strong acids exceed weak acids	1 (Pallamarri village)	1 (Pedda Rajmur village)
5	Carbonate hardness ("secondary alkalinity") exceeds 50%, that is, chemical properties of the groundwater are dominated by alkaline earths and weak acids	6	8
6	Noncarbonate hardness (secondary salinity) exceeds 50%, that is, chemical properties are dominated by alkaline earths and strong acids	Nil	Nil
7	Noncarbonate alkali (primary salinity) exceeds 50%, that is, chemical properties are dominated by alkalies and strong acids	1 (Pallamarri village)	Nil
8	Carbonate alkali (primary alkalinity) exceeds 50%, that is, chemical properties are dominated by alkalies and weak acids	Nil	Nil

where r is ionic concentration in meq/l. If Na and K in water are exchanged with Mg and Ca, the value of ratio (b) will be positive, indicative of a base-exchange reaction. The negative values of the ratio (b) indicate chloro–alkaline disequilibrium and the reaction as a cation–anion exchange reaction.

Schoeller index values of the groundwater samples of the area (Table 1) reveal that cation–anion exchange (chloro–alkaline disequilibrium) exists all over the area, except at two places (Pallamarri and Pedda Rajmur villages) where values are positive, indicating a base-exchange reaction (chloro–alkaline equilibrium).

Groundwater with a base-exchange reaction, in which the alkaline earths have been exchanged for sodium ions ($HCO_3 > Ca + Mg$) may be referred to as base-exchange softened water, and those in which the sodium ions have been exchanged for the alkaline earths ($Ca + Mg > HCO_3$) may be referred to as base-exchange hardened water (Handa 1969).

In Pallamarri and Pedda Rajmur villages, the values of the Schoeller index are positive and alkaline earths have higher concentrations than bicarbonate, indicative of exchange of sodium ions for alkaline earths and the water as base-exchange hardened water.

Irrigation Suitability

Groundwater quality for irrigation is generally expressed by class of relative suitability, taking sodium content and electrical conductivity into consideration. Eaton (1950) has recommended the concentration of residual sodium carbonate for determining irrigation suitability of water. According to the U.S. Salinity Laboratory of the Department of Agriculture (1954), electrical conductivity and sodium adsorption ratio should be considered in determining the suitability of water quality for irrigation.

The distribution of data from the Koilsagar area in the USDA diagram (Fig. 3) shows that most of the area has medium salinity–low sodium (C_2S_1) water (Table 1) and is useful for irrigation purposes. Devarkadra, Tileru, Gotur, and Nelli Konda villages have high salinity–low sodium (C_3S_1) waters, and Marikal has high salinity–medium sodium (C_3S_2) water, indicating a need for adequate drainage to overcome salinity for irrigational purposes.

Conclusions

The Koilsagar project area is a hard rock terrain consisting granites and forms a part of Peninsular Shield of India. The isocone map of specific conductance of the area shows that there is an increasing trend in ionic concentration in the area from east to west. A study of the chemical characteristics of the water shows that the area is dominated by sodium bicarbonate and mixed cationic Mg dominating bicarbonate types of waters.

The Piper trilinear diagram shows that, in general, the area has basic water and two villages have strongly

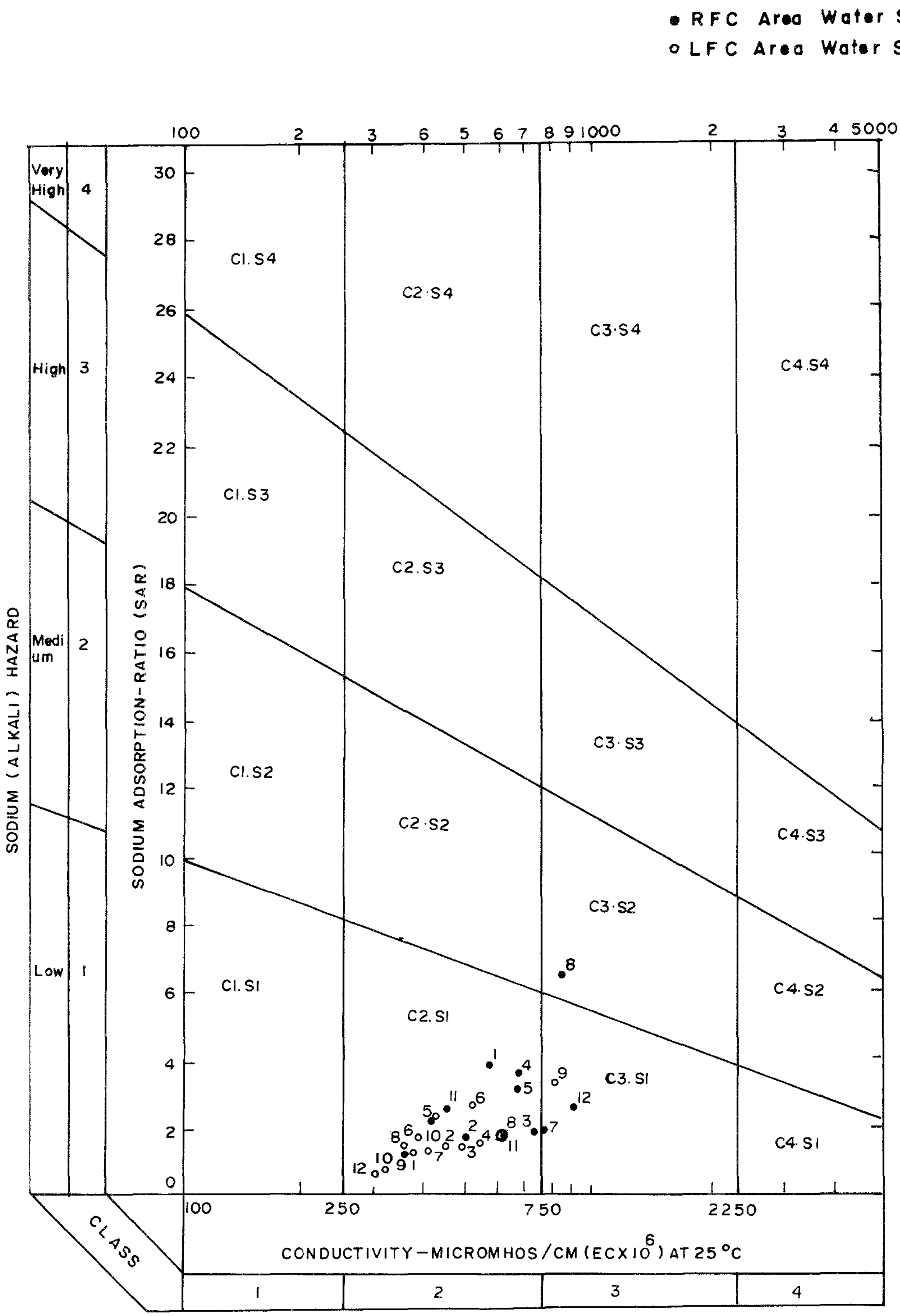

Figure 3. USDA diagram for irrigation water classification with data from Koilsagar project area, A.P.

acidic waters. The entire area is devoid of primary alkalinity and secondary salinity waters but primary salinity water occurs in Pallamarri village.

The Schoeller index values are negative for the whole area except for two villages showing cation–anion exchange (chloro–alkaline disequilibrium). While most of the area has water suitable for irrigation, some pockets have high salinity–medium sodium and high salinity–low sodium water and need better drainage to overcome salinity problems.

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