Available online at www.elixirpublishers.com (Elixir International Journal)

Pollution

Elixir Pollution 63 (2013) 18127-18133

ISSN: 2229-712X

Groundwater quality assessment: A case study of Sanayapalem area, Andhra Pradesh, India

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ARTICLE INFO

Article history:
Received: 25 August 2013;
Received in revised form:
29 September 2013;
Accepted: 1 October 2013;

Keywords
Hydrogeochemistry,
Groundwater quality,
Sanayapalem.

ABSTRACT

The main aim of this study has been to assess the variability of groundwater parameters to develop water quality of Sanayapalem area. The ground water is a major source for irrigation in many arid and semi arid regions of India. A total of 30 groundwater samples were collected and analyzed for major cations and anions. The parameters like sodium absorption ratio (SAR), percent sodium, potential salinity, residual sodium carbonate, non carbonate hardness, Kelly's ratio, permeability index, indices of base exchange and Gibbs ratio were also calculated. Major ionic relationships indicate that weathering reactions have significant role in the hydrochemical processes of the groundwater system. Hydrogeochemical processes controlling the water chemistry are rock- water interaction. Various determinants such as Sodium Absorption Ratio (SAR), Percent Sodium (Na %), Residual Sodium Carbonate (RSC), and Kelley's Ratio revealed that most of the samples are suitable for irrigation.

Introduction

Land and water are critical natural resources that sustain human life and the lives of all other creatures on our planet. The careful husbandry of these natural resources is essential to world food security and environmental protection. When used in sustainable ways, land and water produce the food, fiber, and energy products that we all depend upon, and they will do so indefinitely. Sustainable use of land and water also is essential to maintenance of socially, economically, and ecologically viable communities. It is imperative, therefore, that we invest adequately in research, technology and development, and the effective transfer of new technologies. These are the roots of sound science on which the sustainable use of land water resources is based. Out of the total amount of global water, only 2.4% is distributed on the main land, of which only a small portion can be utilized as fresh water. The available fresh water to man is hardly 0.3-0.5% of the total water available on the earth and therefore, its judicious use is imperative (Ganesh and Kale, 1995). The fresh water is a finite and limited resource (Bouwer, 2000). The utilization of water from ages has led to its over exploitation coupled with the growing population along with improved standard of living as a consequence of technological innovations (Todd and Mays, 2005)

Groundwater is one of the primary sources of water for human consumption, agriculture and industrial uses in Andhra Pradesh. In recent years, an increasing threat to ground water quality due to human activities has become of great importance. The adverse effects on ground water quality are the results of man's activity at ground surface, unintentionally by agriculture, domestic and industrial effluents, unexpectedly by sub-surface or surface disposal of sewage and industrial wastes. Determination of physical and chemical quality of water is essential for assessing its suitability for various purposes like drinking, domestic, agricultural and industrial uses. A knowledge on hydrogeochemical processes that control its chemical composition leads to improved understanding of hydrochemical systems and this can contribute to effective management and utilization of the groundwater resource by clarifying relations among many hydrogeological parameters. The differences in the concentrations of dissolved ions in groundwater are generally governed by lithology, groundwater flow, geochemical reactions, the solubility of salts, and human activities (Bhatt et al 1996; Karanth, 1997; Ramkumar et al 2010). The quality of groundwater is dictated by its quantitative and qualitative composition of suspended solids and dissolved minerals or organic compounds (Jain et al 2005).

In the present study, the physico-chemical quality of groundwater from Sanayapalem area has been assessed with reference to their suitability for drinking and agricultural purposes.

Study Area

The study area is about 50 sq km in the Rapur Taluk of Nellore District, Andhra Pradesh. It forms part of the Survey of India toposheet No.57 N/11 and lies between 14°15' forms and 14° 19' N latitude and 79°38' and 79°41' east longitude (Figure 1). The area is accessible by the Nellore Rapur road which passes through north – western portion of the area. The topography of the region is uneven landscape with intermingling of hills and valleys. The general level of cultivated land is about 200 feet from which rise the hillocks of the area namely Guttikonda (689 feet), Varavadikonda and other isolated hillocks (340 feet). One ridge runs north – south and other runs approximately east – west from the southern end of the former describing as an 'L' shaped topographic feature. Along these ridges, the rocks crop above to form isolated small peaks here and there. In spite of the variations in alignment of these two

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ridges, the rocks that constitute these ridges, maintain uniformity in their strike and dip directions.

Geology

The Sanayapalem area presents complex suite of igneous and metamorphic formations of archeans and lower Proterozoic eras, which include metasediments like amphibolites and quartzites, muscovite and biotite schists and chlotite schists, igneous rocks like pegmatites, and metamorphic rocks like granite gneisses.

Climate and Rainfall

The area is characterised by hot and sub-humid climate and is in the tropical region. The maximum temperature is 42°C and a minimum temperature is 18°C. They receive rainfall during the months of July, August, September, and October with maximum precipitation in October. The heavy rainfall is limited to few days in a year due to depressions in Bay of Bengal which leads to flash floods of high discharge. The average rainfall is a little over 1000 mm with spatial and temporal variations.

Sampling and Analytical method

The samples were collected in polythene containers of 2 liters capacity for physicochemical analysis after pumping out sufficient quantity of water from the source such that, the sample collected served as a representative sample. Thirty representative water samples were collected covering the entire study area is shown in Figure 1. The groundwater quality was assessed by the analysis of physicochemical parameters such as pH, specific conductance (EC), total dissolved solids (TDS), hardness, alkalinity, calcium, magnesium, sodium, potassium, silica, bicarbonate, carbonate, chloride and sulphate were analysed by adopting the standard methods (Brown et al 1974; Hem, 1985; BIS, 1991; APHA, 1998). The results of the study area have been listed in Table 1 and Table 2.

Results and Discussion

The samples of the study area are showing pH values from 7.90 to 8.60. These values are within the limit prescribed by WHO (2006). Most of the water samples are slightly alkaline due to presences of carbonates and bicarbonates. Conductivity values area varied between 230 - 1190 µmhos/cm. Total Dissolved Solids (TDS) is important parameter in drinking water quality standard. It develops particular taste to the water and at higher concentration reduces its potability water. The TDS values are ranging between 147- 762 mg/l and the alkalinity has been found in between 44-230 mg/l. Hardness of water depends upon the amount of calcium and magnesium salts. Hardness value in the studied area varied from 71 to 446 mg/l.

Sodium adsorption Ratio (SAR)

Sodium content in the irrigation water affects particles dispersion, soil structure and crop production. If irrigation water with high sodium is applied to a soil for years, the sodium in the water can displace the calcium and magnesium in the soil. This will cause a decrease in the ability of the soil to form stable aggregates and a loss of soil structure. This will also lead to a decrease in infiltration and permeability of the soil to water leading to problems with crop production. The most common method to assess the effects of sodium is the applying sodium adsorption ratio (SAR). This is a measure of the suitability of water for use in agricultural irrigation, as determined by the concentrations of solids dissolved in the water. The Sodium Adsorption Ratio (SAR) has been calculated by the following equation given by Richards (1954).

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

According to Richard's classification, all the samples of the study area have been classified as excellent for irrigation because none of the samples exceeded the value of 10 mg/l (Table 2). In the present study, SAR values are ranging from 0.33 to 4.93. In addition, a diagram widely used for evaluating water for irrigation on the basis of sodium hazard and salinity hazard published by the U.S. Salinity Laboratory (1954) is presented in Figure 2. In this diagram, the SAR is plotted against specific conductance. The diagram is divided into 16 areas to rate of particular water that may give rise to salinity problem and undesirable ion exchange effects. Depending on the conductivity value, the salinity hazard is divided into four groups as low (C_1), medium (C_2), high (C_3), and very high (C_4). Similarly, the sodium alkali hazard is also divided into low (S_1), medium (S_2), high (S_3), and very high (S_4). The water samples fall mostly under C_2S_1 and C_3S_1 areas and their distribution is shown in Figure 2. All these waters are being used for irrigation as they posses good soil drainage.

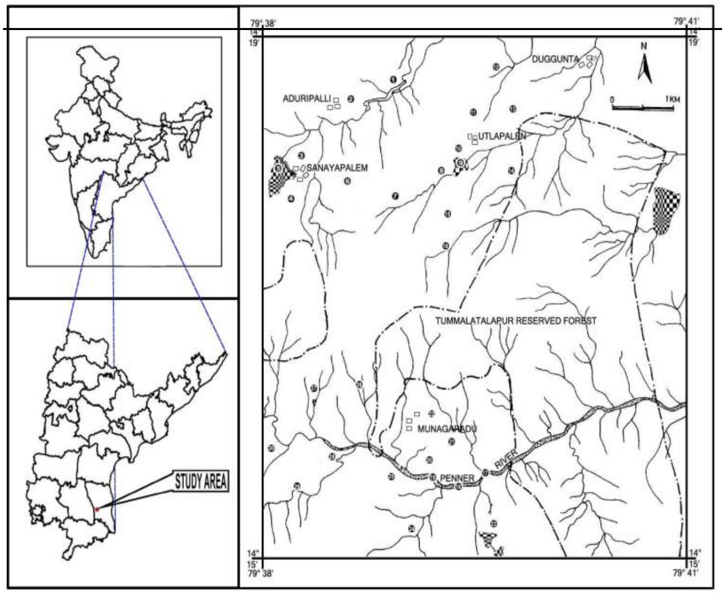

Figure 1 Locations of water samples in the study area

Percent sodium

Sodium concentration is important in classifying irrigation water because the sodium reacts with soil to reduce its permeability. Soils containing a large proportion of sodium with carbonate as the predominant anion are termed alkali soils; those with chloride or sulphate as the predominant anion are saline soils. The role of sodium in the classification of ground water for irrigation was emphasized because of the fact that sodium reacts with soil and as a result clogging of particles, there by reducing the permeability (Domenico and Schwartz, 1990; Todd and Mays, 2005). Percent sodium in water is computed to evaluate the suitability of water for irrigation (Wilcox, 1958).

Sodium content is usually expressed in terms of percent sodium

$$\%\,\mathrm{Na} = \frac{(\mathrm{Na} + \mathrm{K})}{(\mathrm{Ca} + \mathrm{Mg} + \mathrm{Na} + \mathrm{K})} \times 100$$

From the Table 2, it is observed that the percent sodium values of the study area samples vary from 10.29 to 68.96. Percent sodium is plotted against conductivity, which is designated as Wilcox diagram and is illustrated in Figure 3. It is clear that water samples fall into the categories of “Good to permissible” (40%), Excellent to good (46.70 %) and Permissible to doubtful (13.30%).

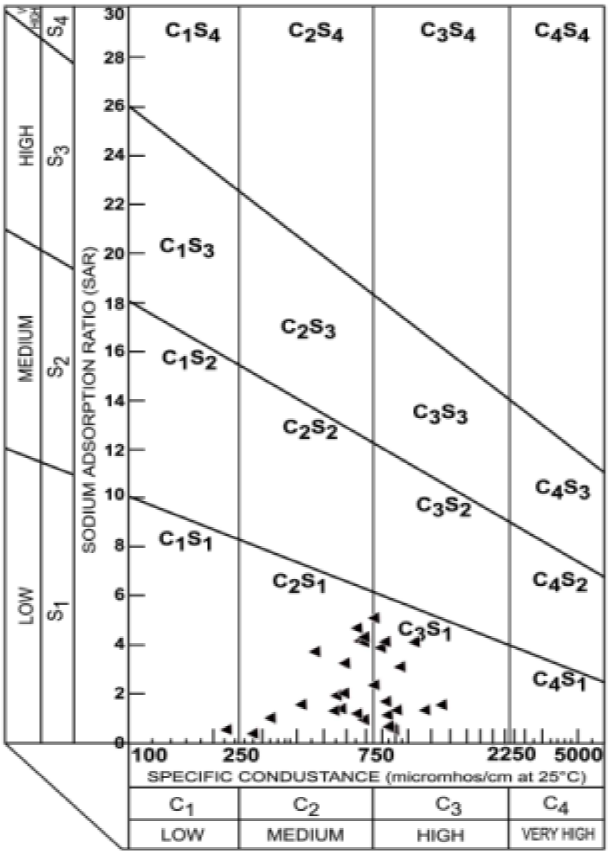

Figure 2 The quality of water in relation to salinity and sodium hazard (after U.S. Salinity Laboratory, 1854)

Kelly’s ratio

Kelly’s ratio is used to find whether groundwater is suitable for irrigation or not. Sodium measured against calcium and magnesium was considered by Kelly (1997) for calculating Kelly’s ratio. All concentration values are expressed in equivalents per million. Kelly’s ratio is calculated as follows:

Kelly’s ratio= Na/ (Ca+Mg)

Groundwater having Kelly’s ratio more than one is generally considered as unfit for irrigation. Kelly’s ratio for water samples varies from 0.10 to 2.19 (Table 2). According to Kelly’s ratio, 63% of the samples were found to be suitable for irrigation, whereas 37% were unsuitable.

Residual Sodium Carbonate (RSC)

In addition to the total dissolved solids, the relative abundance of sodium with respect to alkaline earths and boron and the quantity of bicarbonate and carbonate in excess of alkaline earths also influence irrigation water quality. This excess is denoted by Residual Sodium Carbonate and determined as suggested by Richards (1954). The water with high RSC has high pH and land irrigated by such waters becomes infertile owing to deposition of sodium carbonate as indicated by the black colour of the soil (Eaton, 1950). In waters having high concentration of bicarbonate, there is tendency for calcium and magnesium to precipitate as the water in the soil becomes more concentrated. As a result, the relative proportion of sodium in the water is increased in the form of sodium carbonate.

According to U.S. Salinity Laboratory (1954), an RSC of less than 1.25 meq/l is safe for irrigation, values between 1.25 and 2.5 meq/l is of marginal quality, and a value of more than 2.5 meq/l is unsuitable for irrigation. In the present study, the waters are showing the RSC values of -5.36 to 1.06 which comes under the safe category for irrigation (Table 2).

Non-Carbonate Hardness (NCH)

Hardness of water relates to the reaction with soap, since Ca and Mg ions precipitate soap. Hardness is expressed as mg/l of $CaCO_3$. If the hardness as $CaCO_3$ exceeds the difference between the alkalinity as $CaCO_3$ and hardness as $CaCO_3$, it is termed as Non Carbonate Hardness. NCH is also called permanent hardness. From the Table 2 it can be delineated that the NCH values ranged from -52.73 to 267.89.

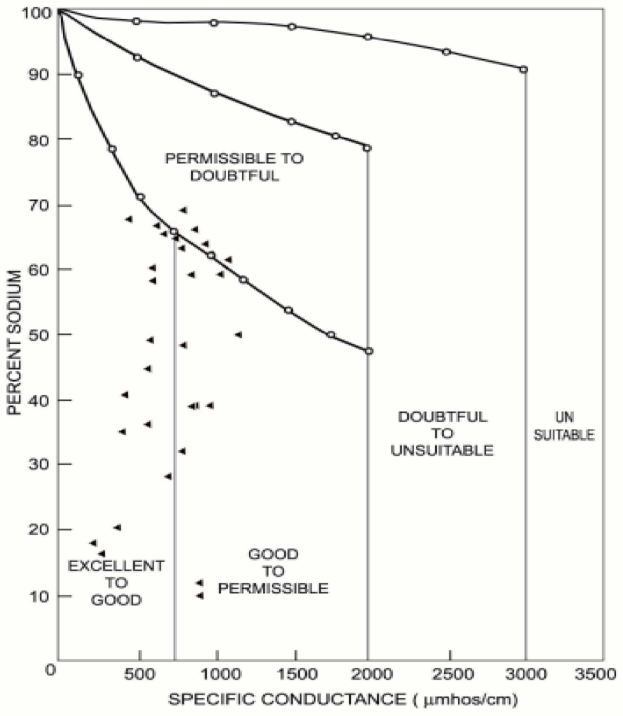

Figure 3 The quality of water in relation to electrical conductivity and percent sodium (Wilcox diagram)

Indices of Base Exchange (IBE)

Ion exchange is one of the important processes responsible for concentration of ions in the groundwater. The existence of abundant Na^+ may promote cation exchange. This can be confirmed by the two indices of base exchange (IBE) namely the chloro alkaline indices (CAI 1 and CAI 2) suggested by Schoeller (1977). When there is exchange between Na and /or K in groundwater with Mg and/or Ca in the aquifer material both indices are positive indicating reverse ion exchange. If the exchange takes place between Ca and/or Mg in groundwater with Na and/or K in the aquifer material, the indices will be negative, indicating ion exchange. The CAI 1 and CAI 2 values obtained were positive except for a few of the samples in Group 1 which had negative CAI 2 values. This suggests that reverse ion exchange is a dominant process in the groundwater.

From the Table 2 it can be put forth that the CAI 1 values range from -1.45 to 0.82 and CAI 2 values vary from -0.49 to 1.29. From these values it can be interpreted that some of the samples in the study area fall into negative zones and some fall into positive zones. Viswanathaiah et al (1978) states that the Indices of Base Exchange (IBE) of groundwater of Vardha basin, Karnataka state, has pointed out that these ratios are positive in recharge areas and negative in discharge area.

Potential salinity

Potential salinity is defined as the chloride concentration plus half of the sulphate concentration. Doneen (1954) explained that the suitability of water for irrigation is not dependent on soluble salts. Doneen (1962) is of the opinion that the low solubility salts precipitate in the soil and accumulate with each successive irrigation, whereas the concentration of highly soluble salts increase the soil salinity. The potential salinity of the water samples range from 1.26 to 8.94.

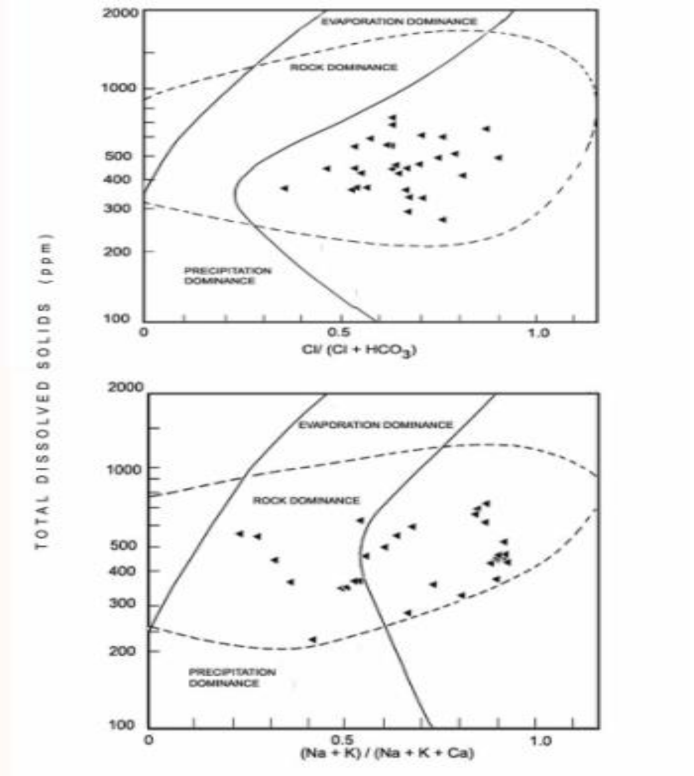

Figure 4 Mechanism controlling the quality of groundwater (after Gibb's 1970)

Permeability index (PI)

The soil permeability is affected by the long term use of irrigation water. Sodium, calcium, magnesium and bicarbonate content of the soil influence it. Doneen (1964) evolved a criterion for assessing the suitability of water for irrigation based on permeability index. (P.I.) where

$$P.I. = \frac{Na + \sqrt{HCO_3}}{(Ca + Mg + Na)} \times 100$$

Accordingly, waters can be classified as Class I, Class II and Class III orders. Class I and Class II waters are categorized as good for irrigation with 75 % or more of maximum permeability. Class III waters are unsuitable with 25% of maximum permeability. From the Table 2, it can be demarcated that the PI values vary from 27.48 to 91.09. Nearly 33 % water samples fall into the Class I Category of Donnen's chart and are categorized as good for irrigation.

Gibbs' diagram

The source of the dissolved ions in groundwaters can be understood by Gibbs diagram (Gibbs, 1970). The Gibbs ratios are calculated with the formulae given below:

Gibbs Ratio I (for Anion) = Cl / (Cl + HCO_3)
Gibbs Ratio II (for Cation) = (Na + K) / (Na + K + Ca)

Ramesam and Barua (1973) have also carried out similar research work in the northwestern regions of India. In the present study, Gibbs ratio values, in the present study varies from 0.37 to 0.91 for Gibbs ration I and from 0.22 to 0.93 for Gibbs ration II. Figure 4 shows that, almost all the samples fall in the rock weathering dominance area. The Gibbs' diagrams suggest that, chemical weathering of the rock forming minerals is the main process which contributes the ions concentration in the water. Evaluation of the water types using Gibbs' plot suggests that there is a clear indication of the contribution from the weathering of pyroxenes and amphibole in the hard rocks (Chapman, 1996).

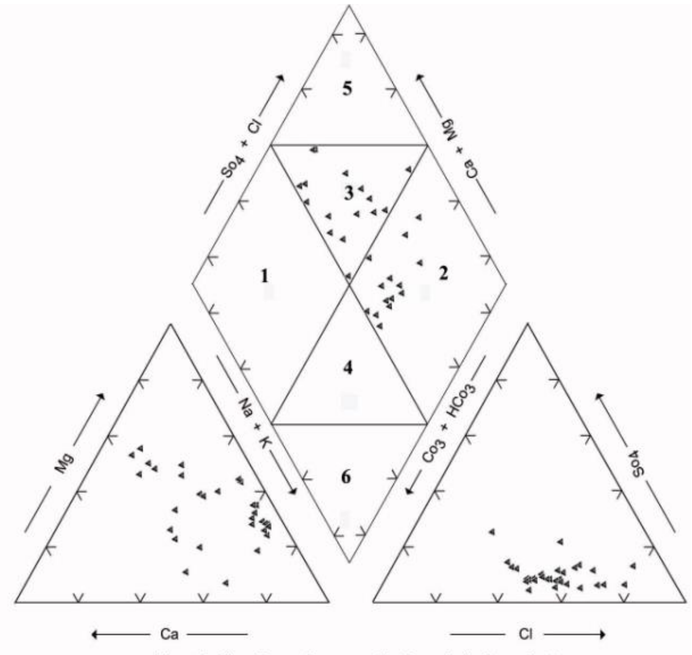

Figure 5 Piper diagram for representing the analysis of groundwater

Piper Diagram

Earlier workers (Hill, 1940; Piper, 1944; Durov, 1948; Back, 1966) have suggested a third plotting field that represents a projection of the triangles into a common area, where the analysis can be represented by one single point. The position of this single point depends upon the concentration of different cations relative to each other and that of the anions with respect to one another. Whereas Hill (1940) and Piper (1944) used a diamond-shaped field area for projection, Durov (1948) used a rectangular field.

Piper (1944) based on the concentration of dominant cations and anions have proposed a trilinear diagram to show the percentages at mill equivalents per liter of cations and anions in water samples. The Piper diagram was modified by Davis and Dewiest (1967). This is useful to understand the total chemical character of water samples in terms of cation-anion pairs. The Piper diagram reveals similarities and differences among groundwater samples because those with similar qualities will tend to plot together as groups (Todd, 2001). This diagram is very useful in bringing out chemical relationships among groundwater in more definite terms (Walton, 1970). The Piper diagram (Figure 5) consisting of two triangular and one interventing diamond-shaped field. All the three sides of the two triangular fields and the four sides of the diamond shaped field are divided into 100 parts. The percentage reacting values at the three cation groups – Ca, Mg and (Na + K) are plotted as a single point in the left triangular field and the three anion groups – (HCO_3 + CO_3), SO_4 and Cl similarly on the right triangular field.

Table 1 Chemical analyses of ground water samples in the study area

Sl. No	Sample No.	EC (µ mhos/ cm	pH	Si (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Na+K (mg/l)	HCO_3 (mg/l)	CO_3 (mg/l)	Cl (mg/l)	SO_4 (mg/l)	TDS (mg/l)	Hardness as $CaCO_3$ (mg/l)	Alkalinity as $CaCO_3$ (mg/l)
1	L1	330	8.20	5	19	12	22	4	26	71	9	50	10	211	98	74
2	L2	470	8.20	4	13	11	76	2	78	77	13	99	14	301	71	88
3	L3	890	8.60	5	35	39	37	64	101	196	14	139	33	570	252	163
4	L4	950	8.40	9	48	7	38	146	184	163	38	136	32	608	147	189
5	L5	1100	7.90	3	19	34	42	168	210	188	17	199	41	704	198	102
6	L6	1070	7.90	4	21	41	138	26	168	79	16	306	30	685	220	96
7	L7	1190	8.20	10	14	60	58	128	189	208	33	225	27	762	269	230
8	L8	600	8.50	6	49	8	69	2	71	87	64	72	21	384	139	178
9	L9	790	8.40	7	11	24	127	3	130	99	10	190	44	506	138	99
10	L10	790	8.40	7	52	20	75	31	106	39	5	230	52	506	215	44
11	L11	340	8.30	6	19	18	10	8	18	85	7	40	14	218	119	86
12	L12	230	8.30	7	21	20	11	5	16	76	6	52	12	147	125	60
13	L13	440	8.00	7	20	23	43	6	49	51	15	102	29	282	147	68
14	L14	720	8.40	9	34	39	36	26	62	175	9	123	26	461	234	160
15	L15	840	8.60	10	9	37	118	4	122	112	16	262	31	538	169	122
16	L16	580	8.40	8	17	28	57	5	65	83	10	101	57	371	167	87
17	L17	610	8.00	8	7	24	74	4	78	139	27	48	40	390	127	166
18	L18	730	8.50	11	8	25	110	3	113	112	29	136	28	467	125	143
19	L19	700	8.60	7	7	22	100	3	103	146	25	114	14	448	116	161
20	L20	560	8.40	4	39	17	43	3	46	74	10	110	31	358	156	88
21	L21	290	8.60	5	20	15	8	4	12	75	2	39	15	186	114	64
22	L22	690	8.50	8	11	25	122	5	127	52	72	141	37	442	130	137
23	L23	920	8.40	8	72	64	21	4	25	192	11	198	35	589	446	179
24	L24	980	8.50	7	12	53	111	3	114	124	13	242	28	627	291	130
25	L25	690	8.00	6	32	43	44	6	50	110	13	162	19	642	252	117
26	L26	610	8.00	12	9	24	81	8	89	128	24	132	26	460	125	142
27	L27	720	8.50	10	9	24	102	4	106	118	32	128	32	476	120	142
28	L28	910	8.30	8	52	54	20	5	25	185	13	182	33	576	428	160
29	L29	870	8.40	5	42	16	49	4	53	82	15	102	28	352	156	82
30	L30	880	8.30	11	7	22	98	3	101	95	20	130	32	485	225	132

Table 2. Hydrogeochemical data of the ground water samples

S.No	Sample No.	Sodium Adsorption Ratio (SAR)	Residual Sodium Carbonate	Non Carbonate Hardness	Permeability Index	Kelly's Ratio	Indices of Base Exchange		Gibbs Ratio I	Gibbs Ratio II	Percent sodium (meq/l)	Potential salinity (meq/l)
							Chloroalkaline Indices 1	Chloroalkaline Indices 2				
1	L1	0.98	-0.48	23.88	70.45	0.50	0.25	0.21	0.55	0.53	35.38	1.51
2	L2	3.76	0.14	-6.76	91.09	2.13	-0.20	-0.29	0.69	0.84	68.37	2.94
3	L3	1.03	-1.29	64.57	51.81	0.33	0.17	0.16	0.55	0.65	39.56	4.26
4	L4	1.36	0.95	-47.59	71.01	0.56	-0.40	-0.34	0.59	0.69	64.41	4.17
5	L5	1.33	-0.11	5.62	64.22	0.49	-0.09	-0.11	0.65	0.87	62.02	6.04
6	L6	4.03	-2.60	129.88	68.45	1.36	0.23	0.80	0.87	0.86	60.14	8.94
7	L7	1.50	-1.14	57.07	53.51	0.45	0.09	0.11	0.65	0.89	50.69	6.63
8	L8	2.40	0.45	-22.33	68.67	0.97	-0.50	-0.26	0.59	0.56	49.59	2.25
9	L9	4.93	-0.58	28.75	84.44	2.19	-0.05	-0.09	0.77	0.91	68.96	5.82
10	L10	2.24	-3.44	171.83	54.16	0.77	0.38	1.29	0.91	0.61	48.88	7.03
11	L11	0.40	-0.81	40.46	56.42	0.18	0.43	0.26	0.45	0.40	20.84	1.27
12	L12	0.41	-1.25	62.67	50.10	0.18	0.59	0.51	0.54	0.37	18.38	1.59
13	L13	1.56	-1.56	77.89	58.43	0.65	0.30	0.44	0.78	0.67	41.19	3.18
14	L14	1.00	-1.75	87.51	50.34	0.32	0.36	0.34	0.55	0.57	31.26	3.74
15	L15	3.89	-1.13	56.61	75.18	1.47	0.29	0.72	0.80	0.92	60.00	7.71
16	L16	1.98	-1.46	73.20	64.65	0.79	0.09	0.08	0.68	0.75	45.29	3.44
17	L17	2.98	0.84	-42.14	85.34	1.39	-1.45	-0.49	0.37	0.91	58.85	1.77
18	L18	4.31	0.34	-16.86	84.75	1.95	-0.27	-0.30	0.68	0.92	66.45	4.13
19	L19	4.18	1.06	-52.73	90.51	2.02	-0.38	-0.35	0.58	0.93	67.23	3.36
20	L20	1.45	-1.80	90.22	56.97	0.56	0.37	0.53	0.72	0.50	36.80	3.42
21	L21	0.33	-0.94	47.10	56.53	0.16	0.59	0.41	0.47	0.31	16.79	1.26
22	L22	4.66	0.64	-32.07	78.71	2.04	-0.37	-0.36	0.82	0.91	67.61	4.36
23	L23	0.44	-5.36	267.89	27.48	0.10	0.82	1.08	0.64	0.22	10.29	5.95
24	L24	3.08	-2.50	125.07	63.87	0.97	0.28	0.63	0.77	0.89	49.74	7.12
25	L25	1.20	-2.91	145.28	46.19	0.37	0.55	0.95	0.72	0.56	28.72	4.77
26	L26	3.20	0.46	-23.19	83.49	1.46	0.00	0.00	0.64	0.89	60.62	3.99
27	L27	4.03	0.57	-28.36	84.96	1.83	-0.26	-0.25	0.65	0.91	65.21	3.94
28	L28	0.46	-3.59	179.26	33.02	0.12	0.81	1.00	0.63	0.28	12.42	5.48
29	L29	1.63	-1.58	78.75	59.39	0.63	0.22	0.27	0.68	0.52	39.57	3.17
30	L30	4.10	0.06	-2.84	85.71	1.98	-0.18	-0.23	0.70	0.93	66.79	4.00

The two points in each triangular field show the relative concentration of several dissolved constituents of water samples. Later a third point is plotted in the central diamond – shaped field after computing percentage reacting values for anion and cations separately. This field shows the complete chemical character of the water samples that gives the relative composition of ground water about cation-anion point. These three fields reflect the chemical character of ground water according to the relative concentration of its constituent but not according to the absolute concentrations. Later Piper (1953) classified the diamond shaped field of trilinear diagram into nine areas to know quickly the quality of water and they are given below.

In general, we have classified the sample points into 6 fields piper diagram. They are 1. Ca-HCO3 type; 2. Na-Cl type; 3. Ca-Mg-Cl type; 4.Ca-Na-HCO3 type; 5. Ca-Cl type; and 6. Na-HCO3 type. In the present study, it is noted that out of 30 samples confined to the two types. Majority of samples are plotted in the fields of Na-Cl type (14 samples) and Ca-Mg-Cl type (16samples).

Conclusion

The groundwaters of the study area are safe for irrigation, the water samples are classified for finding out its suitability for irrigation according to Wilcox diagram. This diagram illustrates that most of the groundwater samples fall in the categories of excellent to good and good to permissible levels. Based on the USSL diagram, the waters are classified with reference to SAR. In general, most of the samples are showing medium and high alkalinity hazard with low sodium hazard and are falling mostly under C_2S_1 and C_3S_1 areas. The suitability of water for irrigation is evaluated based on SAR, %Na, RSC and salinity hazards. Most of the samples in Sanayapalem area fall in the suitable range for irrigation purpose either from SAR, % Na or RSC values.

The chloroalkalinity index is used to evaluate the extent of base exchange during rock-water interaction. The trilinear diagram shows that most of the groundwater samples fall in the field of Na-Cl and Ca-Mg-Cl facies. The overall quality of waters in the study area rules out any pollution from extraneous sources. As such, the waters are very good for domestic and irrigation uses. The enrichment of constituent elements (sodium, potassium, calcium, magnesium and the anions) in waters is mainly due to minerals like feldspars, mica, and hornblende. These minerals are responsible for the release of above-mentioned elements predominantly in large amounts. These cations are solubilised and removed by leaching, leaving a residue deprived of its easily soluble bases.

Hence, the study has helped to improve understanding of hydrogeochemical characteristics of the area for effective management and proper utilization of groundwater resources for better living conditions of the people. A continuous monitoring program of the water quality will avoid further deterioration of the water quality in this region.

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