

Hydrochemical characterization of groundwater in around Tirupati Area, Chittoor District, Andhra Pradesh, South India

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Abstract In the management of water resources, quality of water is just as important as its quantity. The main aim of this study has been to assess the variability of groundwater parameters to develop water quality of Tirupati area and its suitability for domestic and irrigation purpose. Further, the samples were analyzed for pH, EC, TDS, carbonates, bicarbonates, alkalinity, chlorides, sulfates, hardness, fluoride, calcium, magnesium, sodium, and potassium. Based on the analytical results, chemical indices like percent sodium, sodium absorption ratio (SAR), adjusted SAR, percent sodium (Na %), residual sodium carbonate (RSC) and permeability index (PI) have been calculated. Chadha rectangular diagram for geochemical classification and hydrochemical processes of groundwater indicated that most of waters are Ca–Mg–HCO₃ and Ca–Mg–Cl types. Assessment of water samples from various methods indicated that majority of the water samples are suitable for domestic and irrigation purpose.

Keywords Groundwater quality · Irrigation · Base-exchange indices · Gibbs ratio · Tirupati · South India

Introduction

Water, is going to be polluted day by day with increasing urbanization (Alshikh 2011). About 70 % of the earth's surface is covered with water. Ninety-seven percent of the water on the earth is salt water. Two percent of the water on earth is glacier ice at the North and South Poles. Less than 1 % of all the water on earth is fresh water that we can actually use (Gleick 1993). We use this small amount of water for drinking, transportation, heating and cooling, industry, and irrigation and many other purposes. On the other hand, rivers play a major role in assimilation or transporting municipal and industrial wastewater and runoff from agricultural land (Shrestha and Kazama 2007). Although surface water resources are used to meet the growing municipal demands due to over contamination, more stringent treatments would be required to make the surface water potable (Hall and Ellis 1985; Kankal et al. 2012). The major hazard in drinking water supplies is due to contamination from agricultural runoff and improper storage and handling of water (WHO 2006; Saha et al. 2006; Nagaraju et al. 2006). Groundwater is a valuable resource and being depleted day by day (Alley et al. 1999). The gradual depletion of groundwater resources is making communities switch to surface water and/or conjunctive use (Stephen et al. 2013). Due to rapid urban-industrialization, extension of irrigation, domestic needs, groundwater demand has tremendously increased in the Tirupati area. Earlier researchers have studied about groundwater quality of nearby areas of Tirupati (Dilli Rani et al. 2011; Janardhana raju and Krishna Reddy 2006; Nagaraju et al. 2014). Groundwater is the important source for domestic purpose for more than 70 % of the population in this area (Human Development Report of Andhra Pradesh 2007). The bore wells are major groundwater based

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structures used for the exploration of groundwater (Jasmin and Mallikarjuna 2013).

Chemistry of groundwater plays an important role in the study of groundwater quality (Hem 1985). Variations in the major ion chemistry of groundwater lead to identification of geochemical processes that control the groundwater quality (Sadashivaiah et al. 2008; Ravikumar et al. 2011; Srinivas et al. 2013). Ion exchange involves the replacement of ions adsorbed on the surface of fine grained materials in aquifers by ions in solution. Groundwater quality depends on the nature of rock formation, topography, soils, atmospheric precipitation, environment, quality of recharged water, and on subsurface geochemical processes. In view of the complexity of factors determining water quality, and the large choice of variables used to describe the status of water bodies in quantitative terms, it is difficult to provide a simple definition of water quality. Furthermore, our understanding of water quality has evolved over the past century with the expansion of water use requirements and the ability to measure and interpret water characteristics. To the best of our knowledge no hydrogeochemical investigation has been performed to delve into groundwater quality in and around Tirupati area. Hence, this work aims to confine about the hydrogeochemical investigation mainly focusing to identify groundwater geochemistry and its suitability for drinking and irrigation purposes. The main objective is to develop an understanding of regional groundwater quality as an aid to better knowledge of the groundwater regime for optimal management of groundwater resources.

Study area

Tirupati lies between 13°37' and 13°40' North latitude and 79°21' and 79°26' East longitude (Fig. 1). This is situated in Chittoor district of Andhra Pradesh, South India. Occurrence, movement and storage of groundwater are influenced by lithology, thickness and structure of rock formations. The chemical composition of groundwater results from the geochemical processes occurring as water reacts with the geologic materials which it flows (Appelo and Postma 1996). Main hydrologic formations in Tirupati area consist of weathered and fractured granites and quartzites. Ground water in the study area occurs under water table conditions in the weathered and fractured granites. Monsoon remains moderate and summer experiences temperatures ranging from 35 to 44 °C. In winter the minimum temperature is between 18 and 20 °C Celsius (Janardhana raju and Krishna Reddy 2006). In general summer spans from March to June, followed by the monsoon in July, followed by winter lasting through February.

Materials and methods

The sampling bottles were pre-conditioned with 5 % nitric acid and later rinsed thoroughly with distilled de-ionized water. Sample bottles were also rinsed with actual water samples at each bore well before collecting samples. A total of fifty groundwater samples from bore wells have been collected during post-monsoon season of 2012. pH and electrical conductivity of the water samples were measured in situ using portable water analysis kit (P-30 Series Hand-held Water Quality Meters for pH and conductivity—Analyticon Instruments Corporation, USA). The cations and anions were analyzed using standard methods (Trivedy and Geol 1986; APHA 2005; Mishra et al. 2012; Tripathi et al. 2012).

The following diagrams were constructed to find out the different facies present in groundwater of this study.

Hydrochemical facies for groundwater

These diagrams are also useful for visually describing the differences in major ion chemistry in groundwater flow systems. New diagram has been proposed for geochemical data presentations (Chadha 1999). The proposed diagram is a modification of Piper diagram (Piper 1953) with a view to extend its applicability in representing water analysis in the possible simplest way. In the present study, the groundwater of the study area has been classified as per Chadha's diagram (Chadha 1999) and to identify the hydrochemical processes. The diagram is a somewhat modified version of Piper trilinear diagram (Piper 1944) and the expanded Durov diagram (Durov 1948).

In this diagram the difference in mill equivalent percentage between alkaline earths (Ca + Mg) and alkali metals (Na + K), expressed as percentage reacting values, is plotted on the X axis and the difference in mill equivalent percentage between weak acidic anions (CO₃ + HCO₃) and strong acidic anions (Cl + SO₄) is plotted on the Y axis. The mill equivalent percentage differences between alkaline earth and alkali metals and between weak acidic anions and strong acidic anions would plot in one of the four possible sub-fields of the diagram. The square or rectangular field describes the overall character of the water. In order to define the primary character of water, the rectangular field is divided into eight sub-fields, each of which represents a water type: (1) alkaline earths exceed alkali metals; (2) alkali metals exceed alkaline earths; (3) weak acidic anions exceed strong acidic anions; (4) strong acidic anions exceed weak acidic anions; (5) alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions, respectively; such water has temporary hardness; (6) alkaline earths exceed alkali metals and

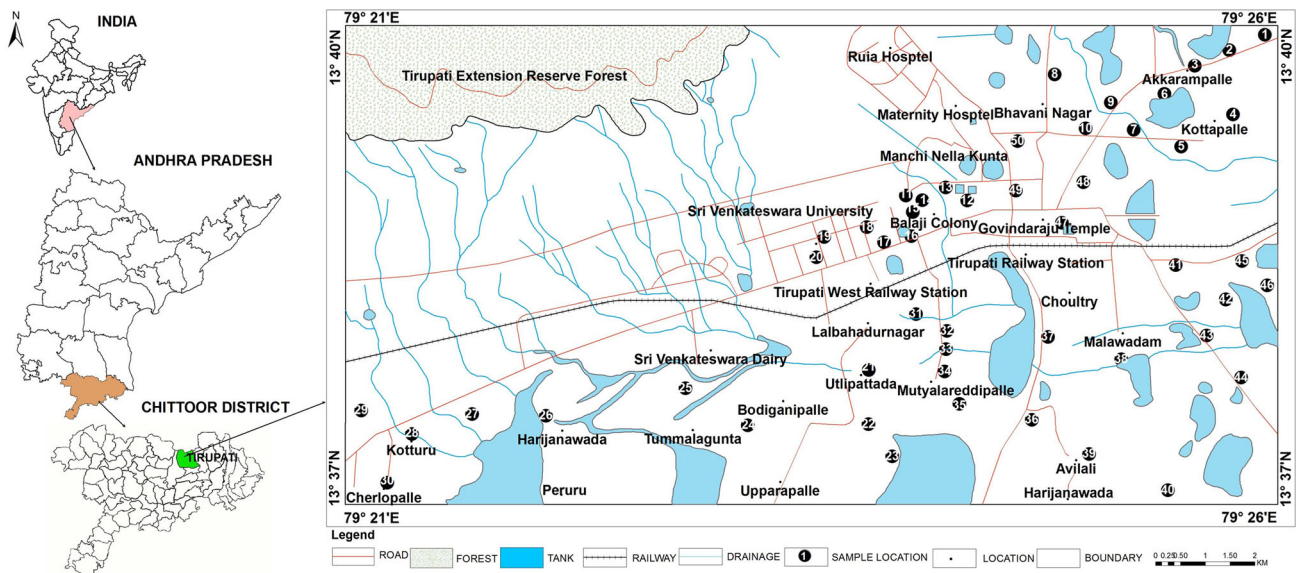


Fig. 1 Map of the study area with water sample locations

strong acidic anions exceed weak acidic anions; such water has permanent hardness; (7) alkali metals exceed alkaline earths and strong acidic anions exceed weak acidic anions; (8) alkali metals exceed alkaline earths and weak acidic anions exceed strong acidic anions.

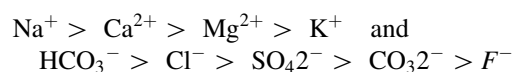
The minimum, maximum and average values of water quality parameters are given in Table 1.

Results and discussion

Groundwater chemistry

The minimum and maximum values of pH and electrical conductivity (EC) of groundwaters are ranging from 6.8 to 8.5 and 400 to 2550 $\mu\text{mhos/cm}$, respectively. Total dissolved solids (TDS) in the study area vary between 256.0 and 1632.0 mg/l. In the present study about 50 % of the studied wells, the TDS values have exceeded the the maximum permissible limit. The total hardness (as CaCO_3) from 116 to 752 mg/l.

In the study area, the Na and K concentrations in groundwater range from 24 to 150 and 2 to 14 mg/l, respectively. The concentrations of Ca and Mg ranges from 25 to 162 and 11 to 81 mg/l. The F content varies from 0.10 to 0.50 mg/l. The concentrations of CO_3 and HCO_3 ions found in the groundwater samples of study area are ranged from 2 to 9 and 32 to 535 mg/l, respectively. The concentration of Cl ranges from 43 to 461 mg/l. The alkalinity varies from 30.7 to 400.5 mg/l and the SO_4 varies from 7 to 94 mg/l. The abundance of the major ions in groundwaters of the study area is as follows:



The chemical data of the groundwater samples from Tirupati area are plotted in Gibbs diagram which shows that most of the samples of the study area fall in the category of precipitation dominance and the rock dominance, indicating that this process is also responsible for the groundwater chemistry. So the precipitation is the main processes which contribute ions to the groundwater of the study area.

The Chada's diagram can be used to study the various hydro chemical processes, such as base cation exchange, cement pollution, mixing of natural waters, sulphate reduction, saline water and other related hydro chemical problems (Chadha 1999). Results of analyses were plotted on the proposed diagram to test its applicability for geochemical classification of groundwater and to study hydrochemical processes (Fig. 2). It is evident from the results, that about 60 % samples fall in Ca–Mg–Cl Water Type and the remaining 40 % samples fall in Group Ca–Mg– HCO_3 water type.

Mechanism controlling groundwater chemistry

Gibbs diagrams (1970), representing the ratios of $(\text{Na}^+ + \text{K}^+) / (\text{Na}^+ + \text{K}^+ + \text{Ca}^{2+})$ and $\text{Cl}^- / (\text{Cl}^- + \text{HCO}_3^-)$ as a function of TDS, are widely employed to assess the functional sources of dissolved chemical constituents, such as precipitation dominance, rock dominance and evaporation dominance. Reactions between groundwater and the aquifer constituent minerals have a significant role on water

Table 1 Minimum, maximum, standard deviation and average values of different constituents of water samples

P. no.	Constituents	Min	Max	Average	St. dv.	St. error
1	Calcium (Ca) (mg)	25.0	162.0	84.0	31.8	4.5
2	Magnesium (Mg) (mg/l)	11.0	81.0	34.7	16.9	2.4
3	Sodium (Na) (mg/l)	24.0	150.0	93.4	35.6	5.0
4	Potassium (K) (mg/l)	2.0	14.0	3.7	2.8	0.4
5	Bicarbonate (HCO ₃) (mg/l)	32.0	535.0	282.2	144.6	20.4
6	Carbonate (CO ₃) (mg/l)	2.0	9.0	4.4	2.1	0.3
7	Sulphate (SO ₄) (mg/l)	7.0	94.0	52.4	25.8	3.6
8	Chloride (Cl) (mg/l)	43.0	461.0	189.6	97.6	13.8
9	Fluoride (F) (mg/l)	0.1	0.5	0.3	0.09	0.1
10	Total dissolved solids (mg/l)	256.0	1632.0	948.5	368.8	52.2
11	Hardness as CaCO ₃ (mg/l)	116.0	752.0	385.7	148.1	20.9
12	Alkalinity as CaCO ₃ (mg/l)	30.7	400.5	213.9	106.7	15.1
13	pH	6.8	8.5	7.8	0.35	0.1
14	Specific conductance (μmhos cm ⁻¹)	400.0	2550.0	1482.0	576.2	81.5
15	Non-carbonate hardness (NCH) as CaCO ₃ (mg/l)	-137.9	524.0	114.8	124.3	17.6
16	Sodium adsorption ratio (SAR)	0.7	3.5	2.2	0.7	0.1
17	adjusted SAR (adj. SAR)	1.4	7.9	4.9	1.90	0.3
18	Percent sodium (PS) (%)	16.8	49.4	36.8	8.2	1.2
19	Potential salinity (PS) (meq l ⁻¹)	1.3	13.9	5.9	2.9	0.4
20	Residual sodium carbonate (RSC) (meq l ⁻¹)	-10.5	2.8	-2.3	2.5	0.4
21	Permeability index (PI) (%)	32.6	75.4	56.7	9.9	1.4
22	Kelley's ratio	0.2	0.9	0.6	0.2	0.1
23	Magnesium ratio (%)	20.8	66.7	40.1	11.8	1.7
24	Calcium to magnesium molar ratio	0.5	0.70	1.7	0.8	0.1
25	Indices of base exchange (IBE) CAII	-1.65	0.5	0.09	0.42	0.06
26	Indices of base exchange (IBE) CAIII	-0.37	3.21	0.34	0.65	0.09
27	Gibbs ratio I	0.16	0.95	0.53	0.20	0.03
28	Gibbs ratio II	0.29	0.68	0.49	0.09	0.01

quality. Further, these studies are useful to understand the genesis of groundwater.

To understand the groundwater interaction, with precipitation, rock and evaporation, as mechanisms controlling the water chemistry (Gibbs 1970), the ratios $\text{Na}^+ + \text{K}^+$; $\text{Na}^+ + \text{K}^+ + \text{Ca}^{2+}$ and Cl^- : $\text{Cl}^- + \text{HCO}_3^-$ computed from the ionic concentration of groundwater of the Tirupati area are plotted against TDS (Fig. 3). Based on Gibbs diagram, there are three major mechanisms that regulate the chemistry of the groundwater: (1) evaporation dominance, (2) precipitation dominance and (3) rock dominance.

It is a plot of $(\text{Na}^+ + \text{K}^+)/(\text{Na}^+ + \text{K}^+ + \text{Ca}^{2+})$ versus $\log \text{TDS}$ and $\text{Cl}^-/(\text{Cl}^- + \text{HCO}_3^-)$ versus $\log \text{TDS}$. Figure 3 shows that, majority of them about 34 samples fall under precipitation dominance area (68 %) and remaining 16 samples (32 %) fall under rock dominance area.

This study reveals that both precipitation and rock weathering (e.g., granitic rocks) are responsible for the groundwater chemistry. Gibbs ratio I values in the present

study varies from 0.16 to 0.95 with a average value of 0.53 and Gibbs ratio II values varies from 0.29 to 0.68 with a average value of 0.49.

Sodium adsorption ratio (SAR)

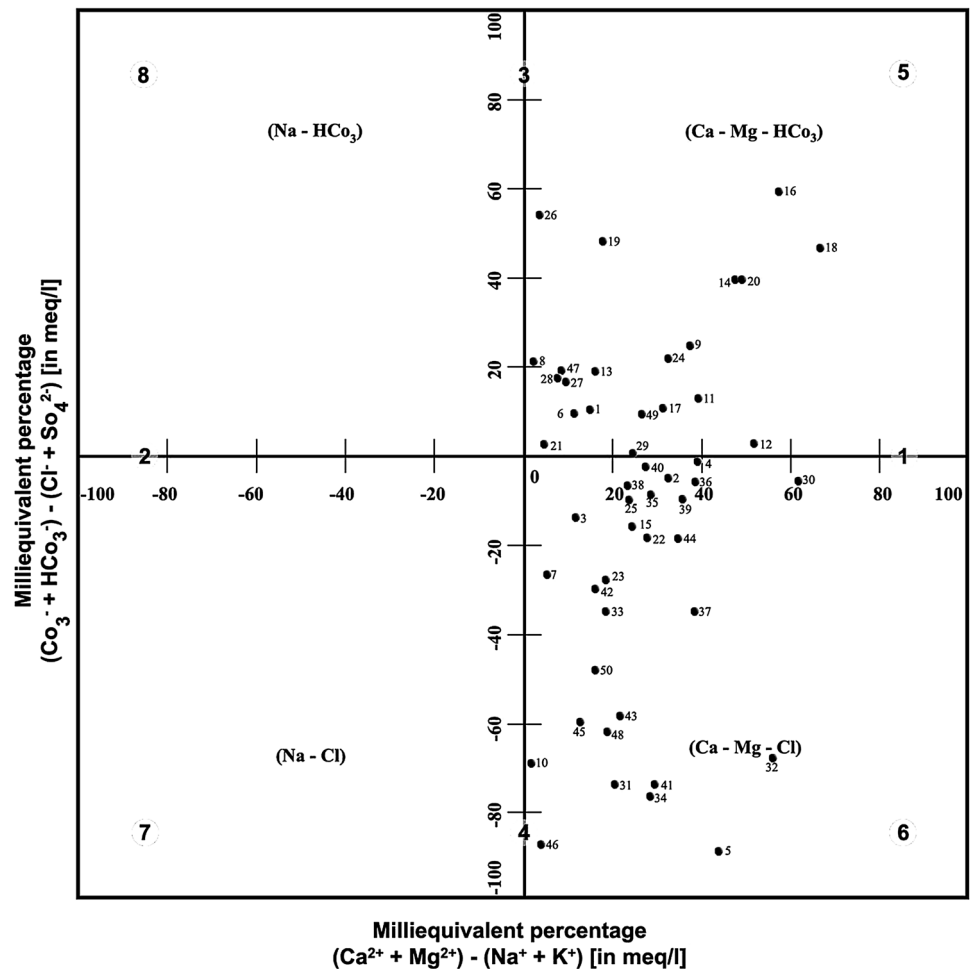
An important chemical parameter for judging the degree of suitability of water for irrigation is sodium content or alkali hazard, which is expressed as the sodium adsorption ratio (SAR) (Asadollahfardi et al. 2012).

The SAR parameter is obtained from the following equation

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

It measures the potential dangers posed by excessive sodium in irrigation water (Alagbe 2006). The sodium hazard or SAR is expressed in terms of classification of irrigation water as low (S1: <10), medium (S2: 10–18), high (S3: 18–26) and very high (S4: >26). A high SAR

Fig. 2 Chadha’s diagram (modified Piper diagram)



value implies a hazard of sodium (alkali) replacing Ca^{2+} and Mg^{2+} in the soil through a cation exchange process that damages soil structure, mainly permeability, and which ultimately affects the fertility status of the soil and reduces crop yield (Gupta 2005).

The level of salinity and SAR, adsorption of Na^+ by soils and clay minerals is greater at higher $\text{Mg}:\text{Ca}$ ratios. This is because the bonding energy of Mg^{2+} is less than that of Ca^{2+} , allowing more Na^+ adsorption and it happens when the ratio exceed 4.0 (Michael 1992). It is reported that soil containing high levels of exchangeable Mg^{2+} causes an infiltration problem (Ayers and Westcot 1985). The SAR values of the ground water samples in the study area varied from 0.7 to 3.5. The SAR values of the water samples of the study area are less than 10, and are classified as excellent for irrigation.

Adjusted SAR

The high concentration of sodium in irrigation water may negatively affect the soil structure and decrease the soil

hydraulic conductivity in fine-textured soil. The degree to which sodium will be absorbed by a soil is a function of the amount of sodium to divalent cations (Ca and Mg) and is regularly stated by the sodium adsorption ratio (SAR) (Bouwer and Idelovitch 1987). The SAR is a general water quality index that indicates the percentage of sodium in the water and function of the ratio of sodium to divalent cations such as Ca and Mg.

$$\text{adjSAR} = \text{SAR} [9.4 - p(k_2 - kc) + p(\text{Ca}^{2+} + \text{Mg}^{2+}) + p(\text{Alk})]$$

where pk_2 = negative logarithm of the second dissociation constant for carbonic acid; pkc = solubility constant for calcite; and p = negative logarithm of ion concentration (meq/l). The amount of $p(k_2 - kc)$, $p(\text{Ca}^{2+} + \text{Mg}^{2+})$ and $p(\text{Alk})$ related to $\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+$, $\text{Ca}^{2+} + \text{Mg}^{2+}$ and $\text{CO}_3^{2-} + \text{HCO}_3^-$ respectively, can be found in Bouwer (1993).

The adjusted SARadj value typically is computed, which take into account the effects of rainfall. Sodium also has adverse effects on the crops such as leaf burn in almond, avocado, and stone fruits (Bouwer and Idelovitch

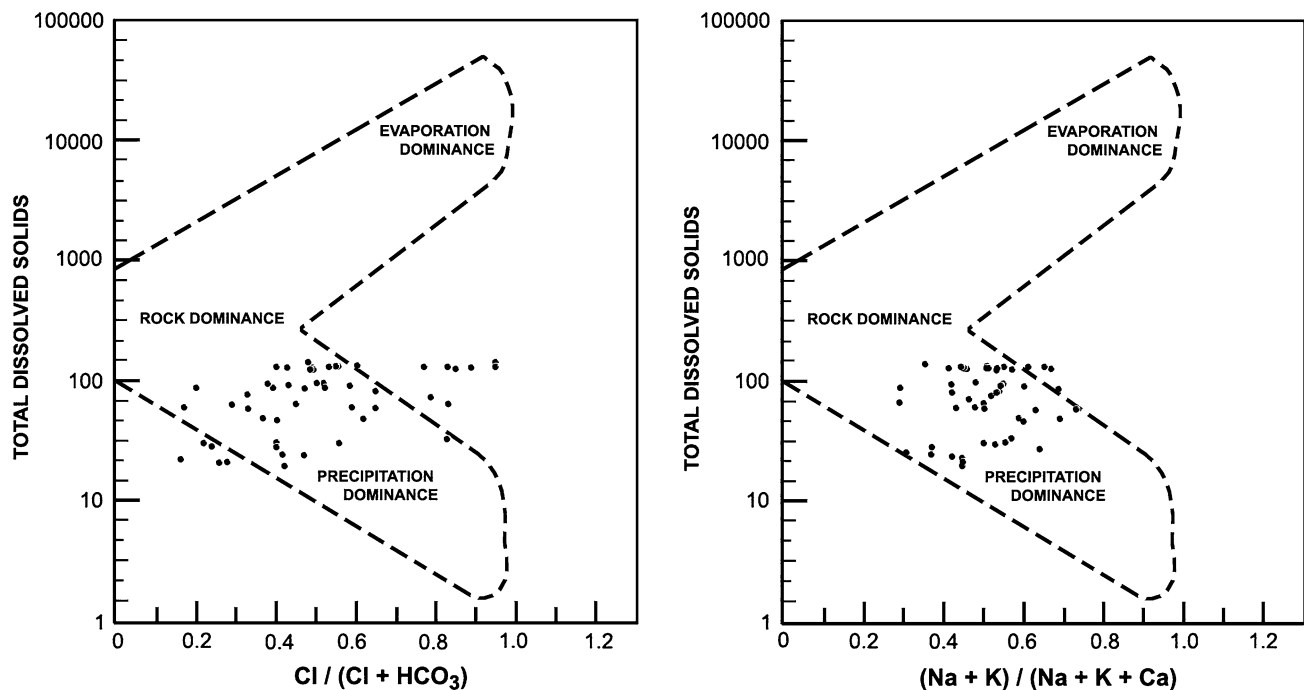


Fig. 3 Mechanism controlling the chemistry of groundwater (after Gibbs 1970)

1987). It is reported that if the SAR_{adj} is below 3, it is good for irrigation and shows increasing problems if the SAR is between 3 and 9. Further, if the SAR is above 9, there are severe problems (Ayers and Tanji 1981). In the present study adjusted SAR values are ranging from 1.4 to 7.9 with a mean value of 4.9.

USSL classification

The US Salinity Laboratory's diagram is used widely for rating irrigation water where SAR is plotted against EC (Richards 1954). Here, SAR is an index of sodium hazard and EC is an index of salinity hazard (Parimala Renganayaki and Elango 2013). The SAR and EC values of the water samples in the study area were plotted in the graphical diagram (Fig. 4). Majority of the water samples (about 72 %) in the study area falling in C3S1 (EC < 2250 $\mu\text{mhos/cm}$) high salinity with low sodium). About 22 % of the samples are falling in C2S1 (EC < 750 $\mu\text{mhos/cm}$ medium salinity with low sodium) and 3 samples are falling in C4S1 (EC > 2250 $\mu\text{mhos/cm}$ very high salinity with low sodium). (10, 3 and, 46).

Wilcox's diagram (1948) is especially implemented to classify groundwater quality for irrigation. Figure 5 can provide the apparent situation to understand the suitability of water for irrigation. 60 % of all samples were good to permissible; and 22 % were excellent to good categories. Remaining 18 % of samples are falling under Doubtful to unsuitable category.

Non-carbonate hardness (NCH)

Hardness of water relates to the reaction with soap as 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. It is also called permanent hardness. From the Table 1, it can be delineated that the NCH values ranged from -137.9 to 524.0 with an average of 114.8.

Permeability index

It occurs when normal infiltration rate of soil is appreciably reduced and hinders moisture supply to crops which is responsible for two most water quality factors as salinity of water and its sodium content relative to Ca and Mg. Highly saline water increases the infiltration rate.

Doneen (1964) defined permeability index (PI) as:

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{(Ca^{2+} + Mg^{2+} + Na^+)} \times 100$$

In the study area, the PI values varied from 32.6 to 75.4.

Kelly's ratio

Kelley's ratio was used to classify the irrigation water quality (Kelly 1940), which is the level of Na^+ measured

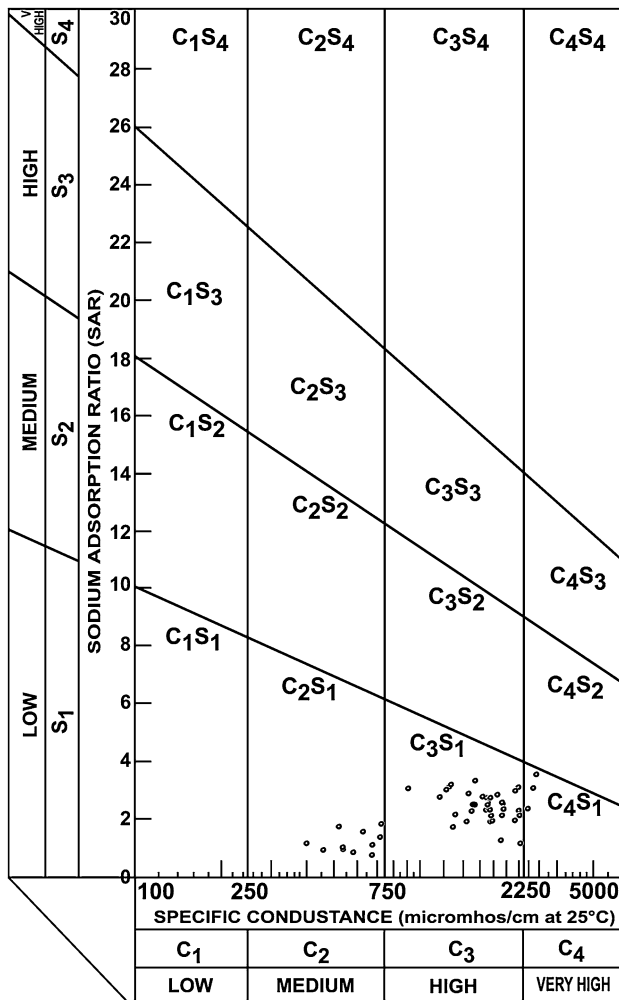


Fig. 4 The quality of water samples in relation to salinity and sodium hazard (after US salinity Laboratory 1954)

against Ca and Mg. The formula for calculating the Kelly’s ratio is as follows: Kelly’s ratio (KR) (Kelly 1963) described as:

$$KR = \frac{Na^+}{(Ca^{2+} + Mg^{2+})}$$

Kelly’s ratios for all the groundwater samples are calculated and it lies between 0.2 and 0.9 with a mean value of 0.6. Kelly’s ratio value less than one is suitable for irrigation. According to this classification, majority of the samples are suitable for irrigation.

Magnesium hazard

Generally, Ca²⁺ and Mg²⁺ maintain a state of equilibrium in most waters. More Mg²⁺ in waters adversely affects the crop yield. In this study magnesium hazard was evaluated by two following methods including “magnesium ratio” and “Ca to Mg molar ratio”. From the Table 1, it is seen

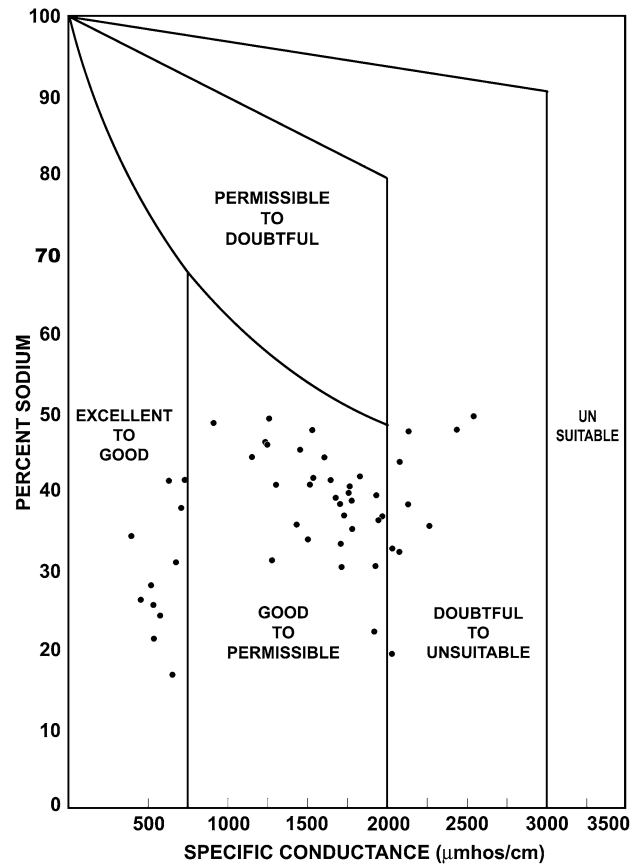


Fig. 5 The quality of water in relation to electrical conductivity and percent sodium (Wilcox diagram)

that the magnesium ratio {Mg ratio = [Mg/(Ca + Mg)] × 100} has varied from 20.8 to 66.7 with an average value of 40.1. In this study nearly 22 % of samples exceeding permissible limits, would adversely affect the crop yield as turn the soils more alkaline (Paliwal 1972).

Residual sodium carbonate

Residual sodium carbonate (RSC) index of irrigation/soil water is used to indicate the alkalinity hazard of soil. RSC index is used to find the suitability of water for irrigation in clay soils which has high cation exchange capacity. When dissolved sodium in comparison with dissolved Ca and Mg is high in water, clay soil swells or undergoes dispersion which drastically reduces its infiltration capacity. The RSC can be calculated as follows (Raghunath 1987).

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

all the concentrations are expressed in meq/l. The classification of irrigation water based on the RSC values shows minimum value of −10.5 and maximum value of 2.8.

Chloroalkaline indices

Chloroalkaline indices I and II are used to understand the chemical reactions in which ion exchange takes place (Swarna Latha and Nageswara Rao 2012). Ions in groundwater exchange with the ions of its aquifer environment during the periods of residence and movement. They are calculated as follows:

$$\text{CAI-I} = \frac{\text{Cl}^- (\text{Na}^+ + \text{K}^+)}{\text{Cl}^-},$$

$$\text{CAI-II} = \frac{\text{Cl}^- (\text{Na}^+ + \text{K}^+)}{(\text{SO}_4^{2-} + \text{HCO}_3^- + \text{CO}_3^{2-} + \text{NO}_3^-)}$$

where the concentration of ions are in meq/l.

Both the above indices are negative if there is an exchange between Ca or Mg in the groundwater with Na and K in the aquifer material, and both these indices will be positive if there is a reverse ion exchange (Schoeller 1977).

From the Table 1, it can be put forth that the CAI- I values range from -1.65 to 0.70 and CAI- II values vary from -0.37 to 3.21 . 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. They indicate the exchange of Na and K from the water with Mg and Ca of the rocks which are mainly of granitic origin (Nagaraju et al. 2015).

Sodium percentage (Na %)

Sodium concentration is an important factor in classifying the water for irrigation purposes because it can react with soil resulting in the clogging of particles, thereby, reducing the permeability of water and respiratory gases (Todd and Mays 2005; Sundaray et al. 2009). Sodium concentration in groundwater is a very important parameter in determining the irrigation quality. Todd (1980) defined soluble sodium percentage (SP) as:

$$\text{SP} = \frac{(\text{Na}^+ + \text{K}^+)}{\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+} \times 100$$

where all the ionic concentrations are in meq/l.

The determined values of sodium percentage lies between 16.8 and 49.4 (Table 1). In irrigation water if the sodium concentration became high, sodium ions tends to replace the Mg^{2+} and Ca^{2+} ions by absorbed clay particles. This exchange process in soil reduces the permeability and eventually decreases the internal drainage of the soil. Hence, water and air circulation is restricted during wet conditions, and such soils become hard in dry conditions (Collins and Jenkins 1996; Saleh et al. 1999; Subramani et al. 2005). Dissolution–precipitation of secondary carbonates, chemical weathering of rock forming minerals,

and ion exchange between water and clay minerals are some of the general reactions responsible for the geochemical constitution of the groundwater. Dissolution of both primary silicate and carbonate minerals may lead to the increase of Ca, Na, Mg, and HCO_3^- , which increase the value of pH (Rouabhia et al. 2011). The higher concentrations of Na and Cl in groundwater are probably controlled by rock water interaction most likely by feldspar weathering. The low sodium in some of the samples is due to the ion exchange with Ca and Mg in clays, which is common in saline groundwater (Cartwright et al. 2004).

Conclusion

Generally, the groundwater quality of the area is hard, fresh and slightly alkaline in nature. The dominant groundwater type was Ca-Mg- HCO_3^- type and mixed Ca-Mg-Cl type. The major ions in most of the locations were found to be within in WHO permissible limit for drinking water. The groundwater geochemistry reveals that the present status of groundwater samples collected in the study area is better for drinking and irrigation purposes except few samples, which are crossing the allowable limits of World Health Organization (WHO) standards.

Sodium is the most dominant ion, but the common trend was Na and Ca are the dominant cations with Cl and HCO_3^- as the dominant anions. Even though the majority of samples are within the permissible limits, few are crossing it and some are very close to the allowable limits which indicate there may be a deterioration of water quality in near future. This was because of the interaction of the ground water with sewage and intensive agricultural practices.

The Ca present in groundwaters is derived from Ca rich minerals like feldspars, pyroxenes and amphiboles from granitic rocks. The major source of Mg in the groundwater is due to ion exchange of minerals in rocks and soils by water. Considering the gross salinity, total hardness, pH, and other irrigation parameters, majority of the groundwater samples shows a fresh to highly saline, hard to very hard, slightly alkaline, and excellent to permissible nature, respectively. The calculated chemical parameters such as Na %, SAR, RSC, PI, MR, and KR indicate that the water in the study area can be used for irrigation with improved drainage facilities. High values of electrical conductivity and high concentration of the chemical constituents such as Na^+ , Cl^- , SO_4^{2-} and HCO_3^- present in the groundwater may be due to dissolution of mineral phases and may be under the influence of anthropogenic activities such as interaction with sewage from urban and industrial waste, massive usage of fertilizers, and intense agricultural practices. Gibbs plots confirm that the most of the samples of

the study area fall in the category of precipitation dominance and the rock dominance, indicating that this process is also responsible for the groundwater chemistry. So the precipitation is the main processes which contribute ions to the groundwater of the study area. Further, the rural to urban migration in Tirupati town increases urban expansion which in turn leads to several groundwater quality problems.

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