Assessment of Ground Water Quality of Udayagiri area, Nellore District, Andhra Pradesh, South India

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Abstract

This study was carried out to analyse groundwater quality in certain parts of Udayagiri area of Andhra Pradesh, where groundwater is the main source of drinking water and irrigation purpose. Thirty water samples were collected and analyzed for major cations: Na^+, Ca^{2+}, K^+, Mg^{2+} and anions: Cl^-, $CO3^{2--}$, $HCO3^-$, $SO4^{2-}$. The important constituents that influence the water quality for irrigation such as Electrical Conductivity (EC), Total Dissolved Solids (TDS), sodium absorption ratio (SAR), adjusted SAR, percent sodium (Na %), residual sodium carbonate (RSC), permeability index (PI), chloroalkaline indices, Kelly's ratio, magnesium ratio and Gibbs ratios were assessed. Assessment of Sodium adsorption ratio (SAR), percent sodium (% Na) and the Wilcox diagram reveal that the waters are suitable for irrigation purposes. Chada's graphical method was used to identify geochemical facies of groundwater samples and geochemical processes occurring in study area. The type of water that predominates in the study area is Ca-Mg-HCO_3 type. The study could help to understand the hydrogeochemical characteristics of the aquifer system for taking effective management measures to mitigate the inferior groundwater quality for sustainable development.

Keywords: Hydro-geochemistry, Groundwater Quality Assessment, Udayagiri

Introduction

Water is a solvent and dissolves minerals from the rocks with which it comes in contact. Water is a natural resource and a basic need for drinking, domestic, agricultural, industrial, environmental activities, etc. (Prasanth et al. 2012). The global importance of groundwater as a major source of freshwater for agricultural and domestic uses cannot be over-emphasized. Approximately 97% of the earth's useable fresh water is stored as groundwater (Delleur, 1999). Also, groundwater constitutes an important component of the water cycle, and it is partly used to maintain soil moisture, stream flow and wetlands, as well as being the sources of drinking water, agricultural and industrial supplies in many parts of the world. It is estimated that groundwater respectively constitutes approximately 40 % and 70 % of the total global water resources being used for irrigation and domestic purposes Qiu (2010). India is facing a serious problem of natural resource scarcity, especially that of water in view of population growth and economic development. Water is a prime natural resource, a basic human need and a precious national asset and hence its use needs

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appropriate planning, development and management. Geochemistry and quality evaluation of water depends upon various physicochemical factors, mobility of elements, and climate (Bashir et al. 2013).

Groundwater is a vital resource, especially in arid and semiarid areas. Sufficient groundwater with high quality is required to meet increasing domestic, agricultural, and industrial needs. Groundwater withdrawals exceeding naturally renewable storage bring about environmental problems, such as forming a cone of depression and extracting nonrenewable groundwater (Jamshidzadeh and Mirbagheri, 2011; Chen et al. 2014). Groundwater, being a dynamic resource, undergoes modifications both quantitatively and qualitatively. The groundwater chemically evolves by the interaction with aquifer minerals or by the inter mixing among the different groundwater reservoirs along flow path in the subsurface (Wallick and Toth 1976; Nagaraju et al 2011). Ground water may contain dissolved minerals and gases that give it the taste enjoyed by many people. Evaluation of the groundwater chemistry and delineation of various hydrogeochemical processes that are involved in the evolution of groundwater quality by adopting various graphical methods and interpreting different indices were attempted by many workers in the recent past (Nagaraju et al 2014; Raju 2007).

The Important parameters of water like pH, Ca, Mg, Na, K, Cl, SO4, HCO3, CO3, TH, and TDS were assessed for drinking water quality with reference to WHO standards. Significant irrigational parameters such as SAR, Adjusted SAR, Na%, PS, RSC, MAR, KR, and PI are also planned to evaluate to accomplish the practical guidelines for combating drinking and agriculture problems faced by the inhabitants of area. In Udayagiri area, a detailed geochemical study was carried out in order to identify groundwater quality. Hence, it is vital to study and understand the different hydrogeochemical characteristics of aquifers in geological terrains. The aims of this study were to understand the groundwater hydrochemistry, detect its control mechanisms, and evaluate the groundwater comprehensively. Further, to identify groundwater quality and its suitability for domestic use by comparing the concentrations of selected water quality parameters.

Area of Study

It is located between longitudes 79°17' 00" and 79°26' 30’’ E and latitudes 14°51' 00" and 15°00' 00" N (Figure 1). Udayagiri area the hydrogeological scenario is favouring for bore wells and its depth varies from 50 to 60 m depth. The annual rainfall is about 1033 mm. The farmers drilled bore wells upto 100 m depth along lineaments/favourable locations to tap fractured aquifers comprise mainly quartzites and shales with limited fractures, forming poor aquifers in Udayagiri area. The climate of the area enjoys a temperature ranging from the highest mean maximum of 42°C in April to lowest mean maximum of 32°C in January.

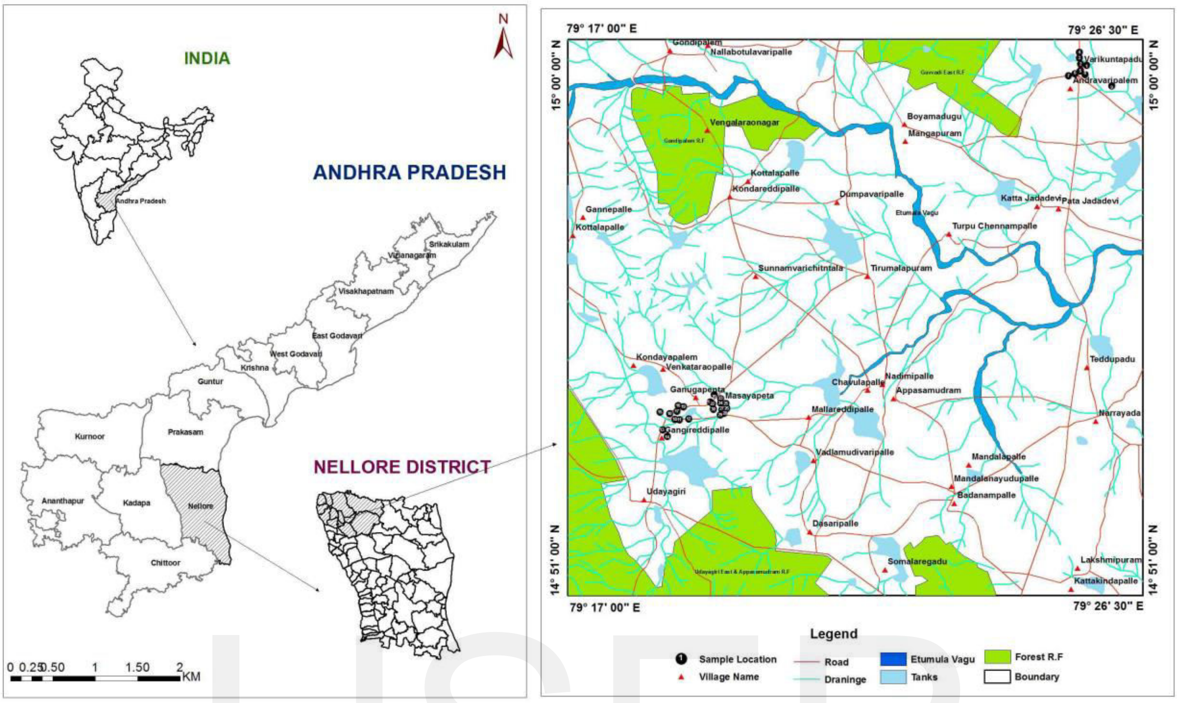

Figure 1 **Map of the study area with water sample locations**

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Materials and Methods

A total of 30 groundwater samples were collected from Udayagiri area during September 2014. The water samples were collected from bore wells/hand pumps after 10 minutes of pumping and transferred into precleaned polyethylene bottles. All the water samples were analyzed for the following parameters: pH, Electrical Conductivity (EC), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^{+}), Bicarbonate ($HCO3^{-}$), Carbonate ($CO3^{2-}$), Chloride (Cl^{-}), Sulphate ($SO42^{-}$) . Others include sodium absorption ratio (SAR), adjusted SAR, percent sodium (Na %), residual sodium carbonate (RSC), permeability index (PI), chloroalkaline indices, Kelly's ratio, magnesium ratio and Gibbs ratios were assessed. Assessment by use of Sodium Absorption Ratio (SAR), percent Sodium (% Na). Electrical conductivity and pH were measured in the field immediately after sampling, while determination of major cations (Na^{+}, K^{+}, Ca^{2+}, $Mg^{2+}$and anions (F^{-}, Cl^{-},SO_4^{2-} HCO_3^{-}, CO_3^{-}) were carried out in the laboratory using the standard analytical procedures recommended by APHA (2005). The geochemical analyses of ground water samples were presented in Table 1

S. No.	Constituents	Min	Max	Average	S.D	SE
1	Calcium (Ca) (mg/l)	14	114	53	33	6.02
2	Magnesium (Mg) (mg/l)	33	122	80	25	4.56
3	Sodium (Na) (mg/l)	31	312	96	67	12.23
4	Potassium (K) (mg/l)	2	56	11	11	2.01
5	Bicarbonate (HCO_3) (mg/l)	168	827	419	169	30.86
6	Carbonate (CO_3) (mg/l)	39	181	80	39	7.12
7	Sulphate (SO_4) (mg/l)	11	120	51	31	5.66
8	Chloride (Cl) (mg/l)	28	228	110	65	11.87
9	Fluoride (F) (mg/l)	0.09	1.05	0.53	0.25	0.05
10	Total dissolved solids (mg/l)	65	177	121	30	5.48
11	Hardness as $CaCO_3$ (mg/l)	148	540	354	113	20.63
12	Alkalinity as $CaCO_3$ (mg/l)	567	1771	1152	355	64.81
13	pH	6.98	7.70	7.41	0.16	0.03
14	Specific conductance (µmhos/cm)	100	272	186	46	8.40
15	Non-carbonate hardness	-499	246	-14	179	32.68
16	Sodium adsorption ratio (SAR)	0.65	7.03	2.15	1.79	0.33
17	Adjusted SAR (Adj. SAR)	1.78	17.00	5.56	4.33	0.79
18	Percent sodium	14.17	70.23	32.07	16.95	3.09
19	Residual sodium carbonate	-4.92	9.99	0.28	3.57	0.65
20	Permeability Index	30.01	91.93	50.86	17.23	3.15
21	Chloroalkaline indices 1	-5.65	0.49	-0.91	1.47	0.27
22	Chloroalkaline indices 2	-0.67	0.27	-0.12	0.27	0.05
23	Kelley's Ratio	0.16	2.29	0.58	0.58	0.11
24	Magnesium Ratio	59.89	88.34	73.40	8.13	1.48
25	Gibbs Ratio I	0.11	0.48	0.30	0.12	0.02
26	Gibbs Ratio II	0.34	0.94	0.60	0.20	0.04

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

Results and Discussion

In the present study, the pH is in range of 6.98 to 7.70 indicates its suitability for irrigation. Crops are very sensitive to pH of the irrigating water. The best range of pH for irrigation is between 6.5 and 8.4 (Bauder et al. 2010) indicating all studied samples are suitable for irrigation purpose. The EC is ranging from 100 to 272 µmhos/cm. alkalinity hazard is the leading water quality character which affects the production of crops, measured in terms of EC. In case of high EC, low amount of water is available to plants (Bauder et al. 2013). Ca is varying from 14 to 144 mg/l and Mg is ranging from 33 to 122 mg/l; Na is between 31 to 312 mg/l and K is varying from 2 to 56 mg/l. The fluoride concentration is ranging from 0.09 mg/l to 1.05 mg/l. The total dissolved solids lie between 65 mg/l to 177 mg/l, in which most of the samples within desirable limit. The concentration of sulphate varies between 11 mg/l to 120 mg/l. The HCO_3 and CO_3 concentrations in ground water ranges from 168 to 827 mg/l and 39 to 181 mg/l respectively. The chloride content varies from 28 to 228 mg/l/. The alkalinity varies from 567 to 1771 mg/l and the hardness varies from 148 to 540 mg/l. The abundance of the major ions in groundwater is in following order:

Na>Mg>Ca>K> and Cl> HCO_3^-> CO_3^{2-}> SO_4^{2-}

Drinking water quality assessment

Total hardness (TH) and total dissolved solids (TDS) and are two important parameters in assessing drinking water quality. Total dissolved solids represent the total weight of dissolved solids in a solution and express the degree of salinity of a medium (Mitra et al. 2007). The concentration level of TDS in groundwater can be classified as fresh groundwater (TDS<1000 mg/L), brackish water (1000<TDS<10000 mg/L) and saline water (TDS>10000 mg/L) (Wanda et al. 2011). Total hardness is a measure of dissolved Ca^{2+} and Mg^{2+} in water and is expressed as $CaCO_3$.The total hardness (as $CaCO_3$) in groundwater can be classified as soft water (TH<150 mg/L), moderately hard water (150<TH<300 mg/L), hard water (300<TH<450 mg/L) and very hard water (TH>450 mg/L) (Li et al. 2014).

The plot of TDS versus TH suggests that the groundwater samples lie in the zones Z1, Z2, and Z3 indicating different quality levels among these samples (Figure 2). Samples those belonging to zones of Z1 and Z2 are suitable for human consumption because they are fresh water with acceptable degrees of hardness. Further, the samples that belong to zones of Z3 hard in nature.

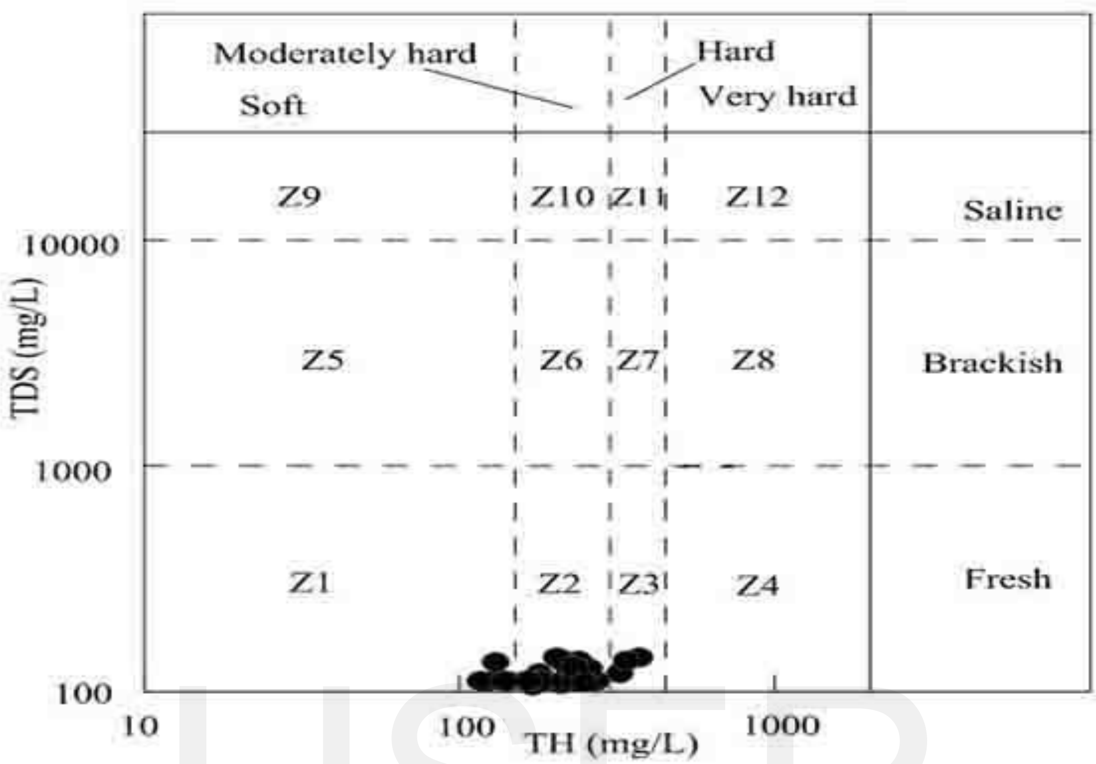

Figure 2 Plot of TDS versus TH expressed in mg/L as $CaCO_3$.

Evaluation of groundwater quality for irrigation

Total salt concentration as measured by EC, sodium percentage (Na %), sodium absorption ratio (SAR) , Adjusted SAR (Adj. SAR), residual sodium carbonate (RSC) and permeability index (PI) are the general parameters for assessing the suitability of groundwater for agricultural uses (Hounslow, 1995; Aghazadeh 2010; Chidambaram, 2010).

Sodium adsorption ratio (SAR)

Sodium hazard in relation to calcium and magnesium concentration is expressed in terms of sodium adsorption ratio. High sodium concentration (SAR) leads to development of an alkaline soil (Khodapanah et al. 2009; Essington, 2015), which becomes hard and compact when dry and impervious to water penetration. Therefore, it causes damage to the soil physical structure and undesirable to plant growth. High concentration of cations is mainly responsible for sodium or alkali hazard in irrigation water (Ogunfowokan et al. 2013; Gholami and Srikantaswamy 2009). Low SAR values are always desirable (Raihan and Alam

2008) because it influence infiltration rate of water. It can be determined from the following expression:

$$\text{S.A.R.} = \frac{Na^{+}}{\sqrt{\frac{1}{2}(Ca^{2+} + Mg^{2+})}}$$

Where all ionic concentrations are represented in meq/L

The SAR values varied from 0.65 to 7.03 meq/L with an average value of 2.15 meq/L and have been classified as suitable for irrigation (Table 1).

Integrated effect of EC and SAR

The best measure of a water likely effect on soil permeability is the waters SAR considered together with its EC. In this study, the US salinity diagram (Figure 3) which is based on the integrated effect of EC (salinity hazard) and SAR (alkalinity hazard), has been used to assess the water suitability for irrigation (US Salinity Laboratory, 1954). When the analytical data of EC and SAR plotted on the US salinity diagram, it is illustrated that most of the water samples fall in the class of C1-S1 indicating low salinity with low sodium water, which can be used for irrigation on almost all types of soil, with only a minimum risk of exchangeable sodium while two samples are falling in C1-S2 (low sodium-medium salinity) (Figure 3). This type of water can be suitable for plants having good salt tolerance but restricts its suitability for irrigation, especially in soils with restricted drainage (US Salinity Laboratory, 1954; Karanth, 1989; Todd, 1995; Todd and Mays, 2005).

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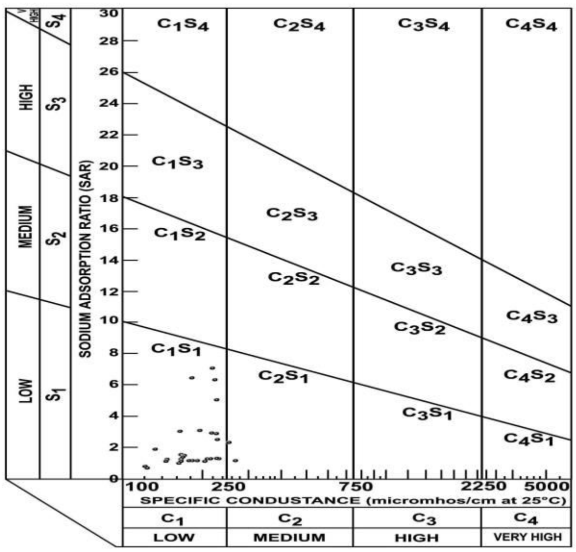

Figure 3 The quality of water samples in relation to salinity and sodium hazard (after U.S. Salinity Laboratory1954)

Adjusted SAR (Adj. SAR)

For waters containing significant amounts of bicarbonate, it is proposed a modification in the old SAR procedure to include changes in soil water composition that are expected to result due to dissolution/precipitation of lime in the soil upon irrigation (Bower and Maasland, 1963). Therefore, the adjusted sodium adsorption ratio (adj SAR) is sometimes used (Ayers and Westcot, 1985), and it is an SAR value corrected to account for the removal of Ca^{2+} and Mg^{2+} by their precipitation with CO_3^{2-} and HCO_3^- ions in the water added. It can be calculated by using the following formula:

$$pHc = (pK_2 + pK_c) + p(Ca^{2+} + Mg^{2+}) + pAlk$$

where p refers to the negative logarithm, K_2 is the second dissociation equilibrium constant of carbonic acid, K_c is solubility equilibrium constant for calcite. Concentrations of Ca^{2+}, Mg^{2+}, CO_3^{2-} and HCO_3^- in meq/L.

The pHc can be calculated using the standard table given by reference(Ayers and Westcot, 1976) which related to the concentration values from water analysis. This concept has been found very useful for predicting the effect of sodium hazard of irrigation water on soil properties. Values of pHc above 8.4 indicate tendency to dissolve lime from soil through which the water moves; values below 8.4 indicate tendency to precipitate lime from waters applied (Ayers and Westcot, 1985). In the present study Adj. SAR values are ranging from from 1.78 to 17.00.

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Sodium percentage (Na %) and Wilcox diagram

The amount of sodium in irrigation water is referred as Na%. The Na content of water reacts with the soil and accumulates in the pore spaces thus reducing its permeability (Khan and Abbasi 2013). Sodium concentration is important in classifying irrigation water because sodium causes an increase in the hardness of the soil because it tends to be absorbed by clay particles, displacing magnesium and calcium ions, when high in irrigation water. This exchange process reduces the permeability and results in soil with poor internal drainage (Tijani, 1994). Na% was calculated by using the formula (Wilcox 1955) given below.

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

Where all ionic concentrations are represented in meq/L

The Na% values are ranging from 14.17% to 70.23% with an average value of 32.07% (Table 1). Plot of Electrical conductivity verses Na% is important to evaluate the irrigation water suitability. Wilcox diagram (1948) is also used to classify water for irrigation (Figure 4). The plot of the Wilcox diagram shows that all samples are falling in excellent to good category range.

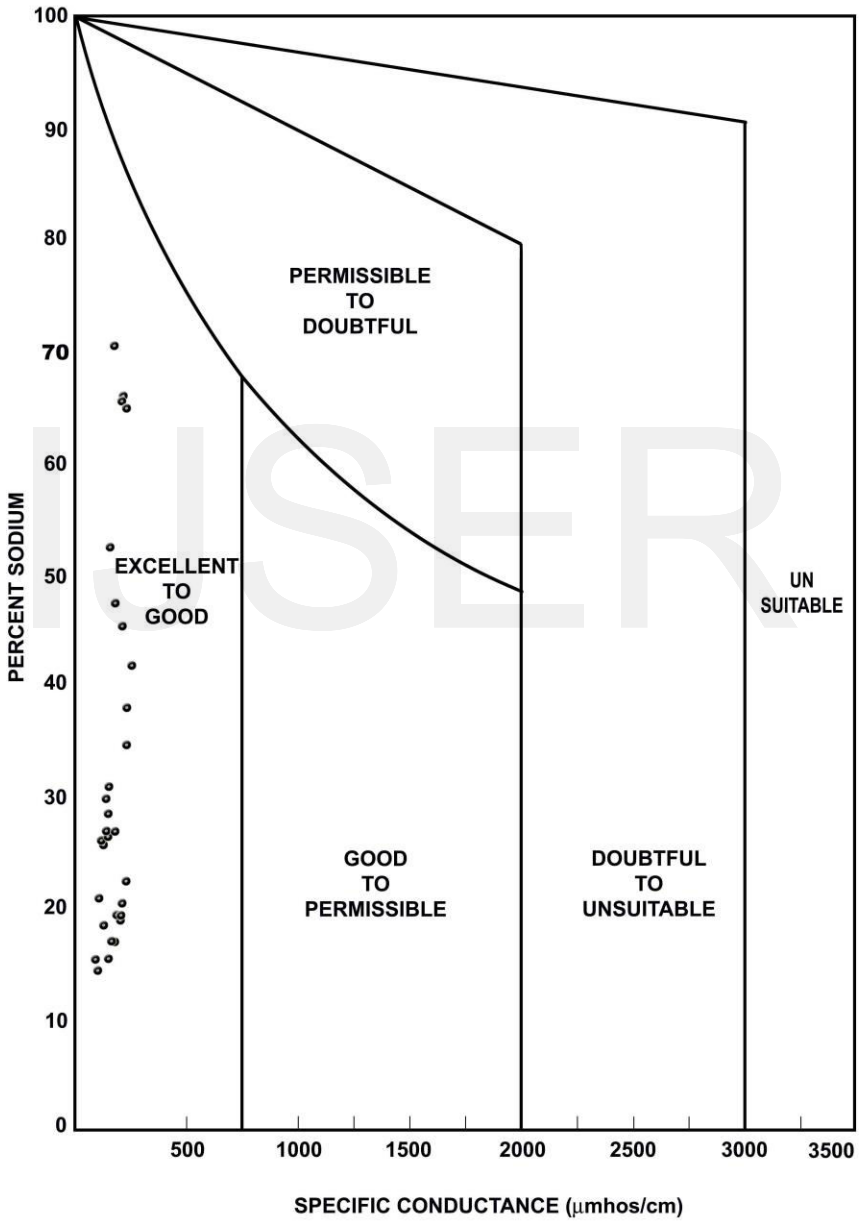

Figure 4 The quality of water in relation to electrical conductivity and percent sodium (Wilcox diagram)

Permeability index (PI)

The soil permeability is influenced by long term use of irrigation water and sodium, calcium, magnesium, bicarbonate content of the soil. Doneen (1964) has evolved a formula, permeability index (PI) to measure the soil permeability for assessing the suitability of water for irrigation purposes.

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

Where, all ionic concentrations are expressed in terms of meq/L

In the present study, the PI values are varying from 30.01 to 91.93 (Table 1). WHO (1989) uses a criterion for assessing the suitability of water for irrigation based on permeability index. According to the permeability index values, 80% comes under class II (P.I. ranges from 25 to 75%) category.

Residual Sodium Carbonate (RSC)

Residual sodium carbonate is calculated to determine the hazardous effect of carbonate and bicarbonate on the quality of water for agricultural purpose, (Eaton 1950). RSC was determined by using the equation given below, where all concentrations are expressed in meq/L.

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

RSC is another alternative measure of the sodium content in relation with Mg and Ca. This value may appear in some water quality reports although it is not frequently used. In addition, RSC is considered not appropriate for irrigation if it is greater than 2.5 meq/L (Table 1). Residual sodium carbonate in ground water samples varied from -4.92 to 9.99 with an average value of 0.28 meq/L. The present study indicates that majority of ground water samples are appropriate for irrigation purpose (Table 1).

Non-carbonate hardness (NCH):

Non-carbonate hardness is the part of water total hardness that is not generated by carbonates, but mainly by anions of sulfate. It is also the measure of magnesium and calcium salts apart from bicarbonate and carbonate salts like magnesium chloride and calcium sulfate. Hardness of water relates to the reaction with soap, since Ca and Mg ions precipitate soap. Hardness is expressed as ppm 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. In the present study NCH values ranged from -499 to 246 with an average value of -14.

Chloroalkaline indices

The Chloroalkaline indices (CAI) indicate the ion-exchange between the groundwater and its host environment. The ion exchange between the groundwater and its environment during residence or travel has been studied by Schoeller (1967; 1977). In the study area most of the samples have negative values except one which shows a positive value. If CAI is negative, there will be an exchange between (Na+K) with calcium and magnesium (Ca + Mg) in rocks. If the ratio is positive, there is no base change in CAI. Most of the values in CAI I are negative and one value is positive. The positive value indicates the absence of base exchange. The negative value of the ratio indicates base exchange between sodium and potassium in water with calcium and magnesium in the rocks. In the present study, CAI varies from -5.65 to 0.49 and CAII Indices to ranges from-0.67 to 0.27 (Table 1).

Kelley's ratio (KR)

It has suggested that the sodium problem in irrigation water could be very conveniently worked on the basis of the values of Kelly's ratio (Kelly 1951). In general, groundwater with Kelly's ratio greater than one is unfit for irrigation. Kelly's ratio is calculated for our study area which ranges from 0.16 to 2.29 meq/L. The samples that have more than one of Kelly's ratio are unfit for irrigation. Kelley's index (rule of thumb approach) however had low discriminatory capacity for both English and Dutch sample. The investigators showed that the index was an efficient indicator of male pelvis but it proved little better than chance at correctly determining sex in the female pelvis.

Magnesium ratio (MR)

Excess of magnesium in the soil easily affects the crop yield. In both the seasons, magnesium value is greater than the permissible limit except few stations and ranges from 59.89 to 88.34 meq/L. The magnesium ratio >50 is considered harmful and unsuitable for irrigation purposes. High magnesium ratio may be due to the passage of surface water and subsurface water through limestone, Kankar and granite rock formation in the study area (Pandian and Sankar 2007).

Hydrogeochemical facies

Hydrogeochemical assessment have been carried out to study the concentration of Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-,SO_4^{2-}, HCO_3^-, and other parameters like temperature, pH, electric conductivity (EC), total hardness(T.H) and total dissolved solid (TDS). Hydrogeochemical facies interpretation is a useful tool for determining the flow pattern and origin of chemical histories of groundwater, and it is used to express similarity and dissimilarity in the chemistry of groundwater samples based on the dominant cations and anions.

Mechanism controlling the groundwater geochemistry

The Gibbs diagram (1970) has been used to evaluate the hydrochemistry of groundwater in the study area. Mechanism controlling groundwater geochemistry a reaction between groundwater and aquifer minerals has a significant role in water quality which is useful to understand the genesis of water (Gibbs 1970; Subramani et al. 2009; Vasanthavigar et al. 2012). The chemical data of water samples of the area are plotted in Gibbs diagrams (Figure 5). Majority of the samples irrespective of the formation falls in the rock weathering region. The samples falling in rock weathering zone may be due to the chemical weathering with the dissolution with rock forming minerals. In the present study Gibbs ratio 1 values are varying from 0.11to 0.48 Gibbs ratio 2 ranging from 0.34 to 0.94 (Table 1).

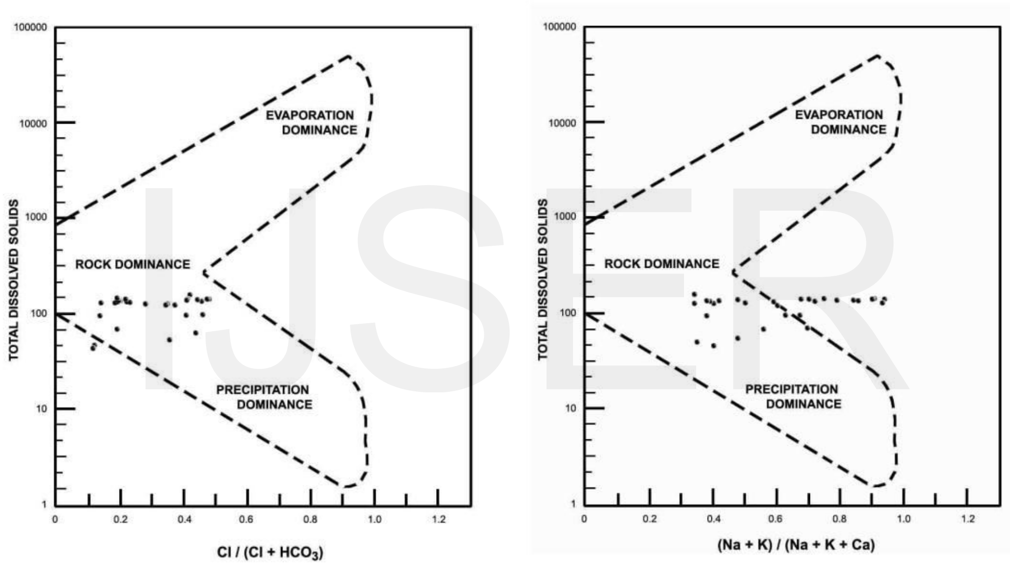

Figure 5 Mechanism controlling the chemistry of groundwater (after Gibbs 1970)

Chadas Diagram

In this diagram, the difference in milliequivalent percentage between alkaline earths (calcium plus magnesium) and alkali metals (sodium plus potassium), expressed as percentage reacting values, is plotted on the X axis and the difference in milliequivalent percentage between weak acidic anions (carbonate plus bicarbonate) and strong acidic anions (chloride plus sulphate) is plotted on the Y axis (Chadha 1999). The resulting field of study is a square or rectangle depending upon the size of the scales chosen for the X and Y coordinates. The milliequivalent percentage differences between alkaline earth and alkali metals and between weak 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. The diagram has all the advantages of the diamond shaped field of the Piper trilinear diagram and can be used to study various hydrochemical processes, such as base cation exchange, cement pollution, mixing of natural waters, sulphate reduction, saline water (end-product water) and other related hydrochemical problems. The chemical analysis data of all the samples collected from Udayagiri area has been plotted on Chadha's diagram (Figure 6). It is clearly evident from the results that majority (87%) of the samples of the study area fall in Group 5 (Ca–Mg–HCO_3 type) and remaining in Na- HCO3 type.

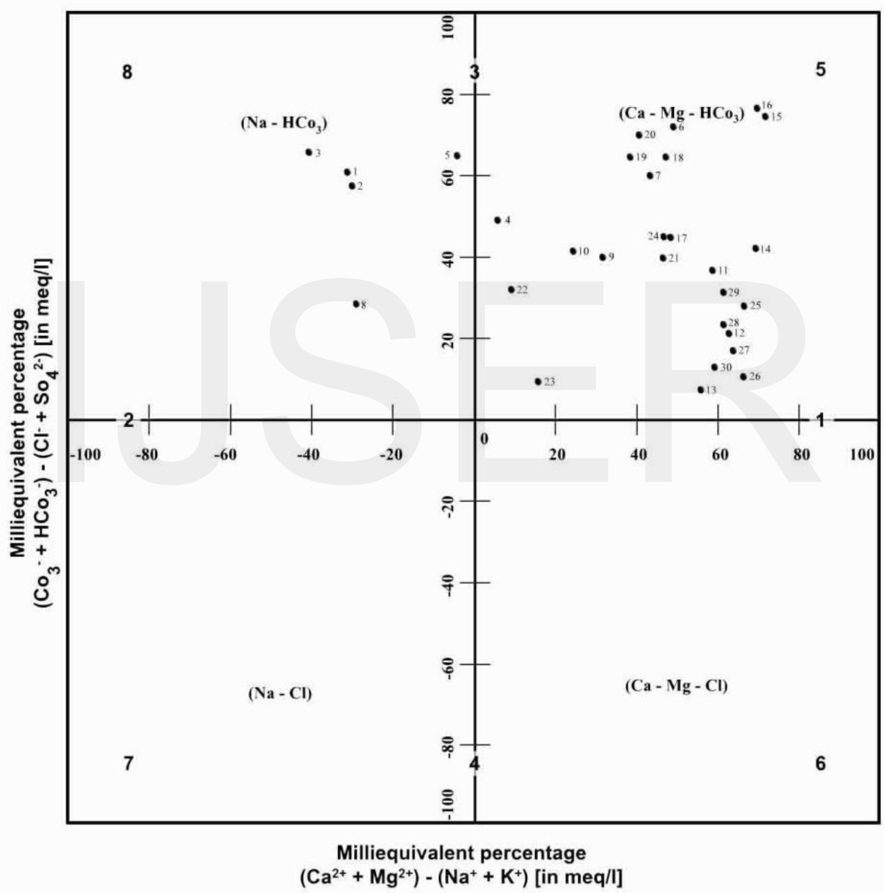

Figure 6 Chadha's diagram (modified Piper diagram)

Conclusions

In the present study, the assessment of groundwater for irrigation has been evaluated and most of the samples fall under Class II in PI calculation, revealing that most of the samples are suitable for irrigation. The Wilcox classification as observed that samples from most of the stations fall under excellent to good range. Sodium adsorption ratio (SAR) and the USSL diagram revealed that the water samples are suitable for irrigation purposes. The positive values of chloroalkaline indices are indicating as a cation–anion exchange reaction and negative values indicating that the host rocks are primary sources of dissolved solids in the water. The plot of TDS versus TH suggests that most of the samples are suitable for human consumption as they are fresh water with acceptable degrees of hardness. Distribution of the groundwater samples in different subdivisions of rectangular diagram reveals that about 83% of the groundwater samples fall under the calcium–magnesium–bicarbonate category (such water has temporary hardness) and remaining samples fall under the calcium–magnesium–chloride (such water has permanent hardness). The Gibbs diagram revealed that the hydrochemistry of groundwater falls in the rock weathering region and is due to dissolution with rock forming minerals.

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