Evaluation of Groundwater Quality in Shallow and Deep Aquifers in Parts of Uttatra Kannada District, Karnataka

Manjunatha S.*, Davithuraj J.**

*Department of Geology, Karnatak Science College, Dharwad 580 003, Karnataka, INDIA.

**CGWB, SUO, Belgaum 590 0019, Karnataka, INDIA.

*Correspondence Address:

*manjunathas29@yahoo.in, **davithuraj@rediffmail.com

Research Article

Abstract: The present study is aimed at assessing the groundwater quality in shallow and deep aquifers in parts of Uttatra Kannada district, Karnataka. This has been determined by collecting 49 groundwater samples from dug wells (shallow aquifer) and 49 bore wells (deeper aquifer) in the year 2011 (May). The physical and chemical parameters such as (pH), Total dissolved salt (TDS) and Total hardness (TH) were measured in addition to major cation and anion concentration of groundwater samples collected from the shallow and deep aquifer in parts of Uttatra Kannada district, Karnataka. The usefulness of these parameters in predicting groundwater quality characteristics were discussed. Result shows the ground waters of both aquifers is found to be alkaline in nature and are suitable for drinking purposes. The important constituents that influence the water quality for irrigation such as Electrical Conductivity (EC), Total Dissolved Solids (TDS), Sodium Adsorption Ratio (SAR), Sodium percentage (Na%), Residual Sodium Carbonate (RSC) were assessed and compared with their respective standard limits. Most of the samples fall in alkaline earths (Ca+Mg) exceeds alkalies followed by strong acids exceeds weak acids as per pipers trilinear diagram. The plotting of SAR values in USSL diagram indicate that all the samples have low SAR and occurred within C3-S1 category. These categories are suitable for irrigation purposes. Plotting different graphical presentations such as US salinity laboratory's, Wilcox diagram and % of Na used for evaluating the water quality for irrigation purposes. An overview of all the ground water samples of the study area indicates that they are suitable for drinking, irrigation purposes except for few locations which exceed the permissible limits.

Introduction

Ground water is an essential and vital component of our life support system. The ground water resources are being utilized for drinking, irrigation and industrial purposes. However, due to rapid growth of population, urbanization, industrialization and agriculture activities, quality and quality of groundwater has been affected in many regions. Groundwater quality is as important as the quantity. Poor quality of water adversely affects the plant growth and human health (Wilcox 1948; Thorne and Peterson 1954; US Salinity Laboratory Staff 1954; Holden 1971; Todd 1980; ISI 1983; WHO 1984; Hem 1991; Karanth 1997). According to World Health Organization reports, about 80% of all the diseases human beings are caused by water. Moreover, restoration of the contaminated water to its natural composition is a difficult task. Hence regular monitoring of water sources and halting the entry of pollutants into the water body is highly necessitated. Understanding its importance, numerous studies on groundwater quality with regard to drinking and irrigation purposes have been carried out in different parts of the country (Durvey *et al*. 1991; Agrawal and Jagetia 1997; Niranjan Babu *et al*. 1997; Subba Rao *et al*. 1999; Majumdar and Gupta 2000; Khurshid *et al*. 2002; Sreedevi 2004; Subba Rao and John Devadas 2005). In addition to the anthropogenic activities, water qualities also depend upon the geochemical properties of groundwater. The main aim of the present study is to evaluate the groundwater quality in shallow and deep aquifers in parts of Uttatra Kannada district for the purposes of drinking and irrigation.

Study Area

The study area comprise three adjacent taluks viz; Halyal, Joida and Yellapur of Uttara Kannada district and these taluks are falls in the northern part the district.. The area is bounded by latitudes 14°45'00'' N and 15°31'30'' N, and between Longitudes 74°15'00''E and 74°56'30''E, which falls in the survey of India toposheet No. 48I/5, 48I/6, 48I/7, 48I/8, 48I/11, 48I/12, 48I/15, 48I/16, 48J/9 and 48J/13. Administratively, the area is bounded on East by Dharwad district and Mudgod taluk of Uttatra Kannada district, on North by Belgaum district, on the south by Karwar taluk of Uttara Kannada district and on West by Goa state.

Material and Methods

To evaluate the quality of groundwater, groundwater samples have been collected from 49 dug wells (shallow aquifer) and from 49 bore wells (deeper aquifer) during the May-2011 and locations of groundwater samples are shown in Fig.1. The analytical results of chemical analyses of groundwater samples from shallow and deeper aquifers have been analyzed and analytical results are given in the Table 7 and 8. The analytical data have been considered to assess the chemical quality of ground water and its suitability for drinking, domestic and irrigational purposes.

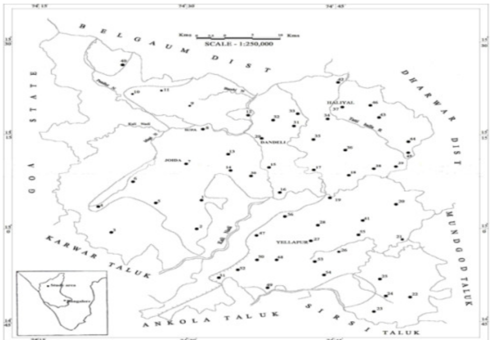

Figure 1: Location map of the Study area

Results and Discussions

Suitability of Groundwater for Drinking Purposes

Aanalytical results of physical and chemical parameters of the of groundwater were compared with the standard guideline values as recommended by the BIS (1991) and ISI (1983) for drinking and public health purposes. The concentration of cation and anions are within the maximum desirable and allowable limits for drinking except few samples.

Hydrogen Ion Concentration (pH)

The present investigation reveals that the pH values of groundwater in the area range from 7.5 to a maximum of 8.2 and from 7.7 to 8.8 for shallow aquifer and deeper aquifer receptively. The average pH value of the samples in the area is 7.9 and indicating that the ground water is alkaline in nature. All the samples are within permissible limit as per standards prescribed by ISI and are suitable for drinking purpose except 12 samples, which are having pH value more than permissible limit.

Total Dissolved Solids (TDS)

The total concentration of dissolved minerals in water is a general indication of its suitability for any particular purposes. TDS value in ground water samples of the area ranges from 91 to 617.5 (shallow aquifer) and 83.2 to 1248 (deeper aquifer). All the samples have TDS value within permissible limit as per standards prescribed by ISI for drinking purpose.

Total Hardness (TH)

Hardness is an important criterion for determining the usability of ground water for drinking and domestic purposes. Hardness in water is caused primarily by calcium and magnesium cations. The ground water samples have been classified based on total hardness. The total hardness of ground water in the area varies between 50 mg/l to 240 mg/l (Shallow Aquifer) and 40mg/l to 720mg/l (Deeper Aquifer). The perusal of Table 1 reveals that 12% (Shallow Aquifer) and 47 (Deeper Aquifer) of ground water samples fall in "Hard and very Hard Water" category. Hence, there is a need for softening of this two-category water if it is to be used for drinking and domestic purposes. Rest of the ground ware samples are falling in soft and moderately soft category. All the samples are within permissible limit as per standards prescribed by ISI and are suitable for drinking purpose.

Table 1: Classification of Ground water based on Total Hardness (After Sawyer and McCarty, 1967)

Hardness as $CaCo_3$ (mg/l)	Water Class	No. of Wells		Percentage		Remarks
		Shallow Aquifer	Deeper Aquifer	Shallow Aquifer	Deeper Aquifer	
0 – 75	Soft	16	9	33	18	Require little or no softening
75 - 150	Moderately Hard	27	17	55	35	Require little or no softening
150 – 300	Hard	6	14	12	29	Require softening
Above 300	Very Hard	Nil	9	Nil	18	Require softening

Calcium

Calcium is one of the freely dissolving ions from many rocks and soils. The calcium presence in ground water of the area ranges from 8 mg/l to 52 mg/l and 8mg/l to 12 mg/l for shallow aquifer and deeper aquifer respectively. All the samples are within permissible limit as per standards prescribed by ISI for drinking purpose.

Magnesium

Magnesium is commonly associated with calcium and causes hardness of water. The concentration of magnesium in ground water of area ranges from 2 mg/l to 46 mg/l (Shallow aquifer) and from 2mg/l to 116mg/l(Deeper Aquifer). The quality of ground water samples have been examined with help of standards prescribed by BIS (1991), all the samples are within limits, except two samples.

Sodium and Potassium

The concentration of sodium in ground water of the area ranges from 8mg/l to 105 mg/l (shallow aquifer) and from 13 to 157 mg/l (deeper aquifer). The concentration of potassium in ground water of the state ranges from 0.4mg/l to 15.2 mg/l (shallow aquifer) and from 0.8 to

22.6 mg/l (deeper aquifer). No permissible limit is prescribed by ISI standards.

Bicarbonate and Carbonate

Most of the carbonates and bicarbonates ions in ground water are derived from the carbon dioxide in the atmosphere, carbon dioxide in soil and solution of carbonate rocks. These two constituents along with hydroxides are responsible for the alkalinity of water. The carbonate in ground water of the area is nil in shallow aquifer whereas deeper aquifer ranges 0.0 to 18 mg/l. The bicarbonates ranges from 37 to 25 mg/l (shallow Aquifer) and 37 to 299 (Deeper Aquifer).

Chloride

Chloride is a minor constituent of the earth's crust, but a major dissolved constituent of most natural water. The chloride content in ground water of the area ranges from 14 mg/l to 234 mg/l (shallow aquifer) and from 14 to 454 mg/l (deeper aquifer). All the samples are within permissible limit as per standards prescribed by ISI for drinking purpose.

Sulphate

The concentration of sulphate in ground water of the area varies from 4 to 42mg/l (shallow aquifer) and from 2 mg/l to 132mg/l (deeper aquifer). The quality of ground water samples have been examined with help of standards prescribed by BIS 1991, all the samples are within limits and suitable for all the purposes.

Nitrate

Nitrate (No^-_3) is most common contaminant. Originates on land surface, in the soil zone where nitrogen rich wastes are buried. Nitrate is very mobile. Nitrate moves with ground water with no transformation, and little or no retardation. The concentration of nitrate in ground water of the area ranges from 1 mg/l to 19 mg/l (shallow aquifer) and from 1mg/l to 60mg/l (deeper aquifer). The quality of ground water samples have been examined with help of standards prescribed by BIS (1991), all the samples are within limits and suitable for drinking purpose, except three samples from deeper aquifer.

Suitability of Groundwater for irrigation purpose

Apart from domestic consumption, irrigation is consuming a major share of ground water for agricultural activities. The quality of water used for irrigation is an important factor in productivity and quality of irrigated crops. The quality of irrigation water depends primarily on the presence of dissolved salts and their concentrations. Sodium Absorption Ratio (SAR) and Residual Sodium Carbonate (RSC) are the most important quality criteria, which influence the water quality and its suitability for irrigation.

Electrical conductivity (EC)

The ability of water to conduct an electrical current is called its electrical conductance or conductivity. Electrical conductivity is very useful for determining water quality, because it is an indicator of salinity in water, which affects the taste and has an impact on the user acceptance of water as potable. The major chemical constituents, which contribute to the electrical conductance, are components of hardness (Ca++ and Mg ++). Other components that also contribute to the electrical conductance are nitrate, chloride and sulphates. Classified ground water based on EC values, for irrigation purpose and is given in Table-2.

Table 2: Suitability of ground water based on EC for irrigation purpose

Sl. No.	Conductivity (μmhos/cm)	Suitability for irrigation	Percentage of sample	
			Shallow Aquifer	Deeper Aquifer
01	Below 250	Entirely safe	41	20
02	250 – 750 (Moderately Saline)	Safe under practically all conditions	53	47
03	750-2250 (Medium to high salinity)	Safe only with permeable soil and moderate leaching	6	33
04	Above 2250 a) 2250 - 4000 (High salinity) b) 4000 - 6000 (Very high salinity) c) Above 6000 (Excessive salinity)	Unfair for irrigation	Nil	Nil

According to this classification, 100% of ground water samples from shallow aquifer and deeper aquifer is having EC value less than 750 μmhos/cm and falls in safe category. 6% of ground water samples from shallow aquifer and 33% samples from deeper aquifer have EC value between 750- 2250 μmhos/cm and falls in medium salinity to high salinity category. Isocone maps have been prepared based on EC value of ground water from dug wells and bore wells and also given in Fig. 3. Iso cone map depicts that southern and extreme northern parts the area having EC value between 750 and 2250 μmhos/cm and falls under medium to high salinity, The water is safe only with permeable soil and moderate leaching practices for salt removal. The salt tolerant crops can be grown in this area.

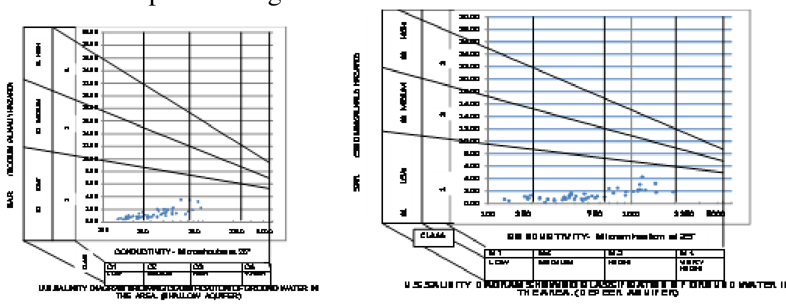

Figure 3 : U S salinity diagram showing classification of ground water in Shallow and deeper aquifer

Chloride

The suitability of ground water based on chloride concentration has been suggested by scofield (1933) and it has been used for this study. The summarized results of the classification is tabulated in Table-3.

Table 3: Classification Ground water Based on Chloride (Scofield 1933)

S. No.	Water Class	Chloride Concentration (ppm)	Percentage of sample	
			Shallow Aquifer	Deeper Aquifer
1	Class I	<150	98	76
2	Class II	150-500	2	24
3	Class III	>500	nil	Nil

According to Scofield classification, 100% of samples from shallow aquifer and from deeper aquifer are representing class I and class II and indicating that the ground water of the area is suitable for irrigation under ordinary condition of soil and climate. .

Sodium percentage (%Na)

Sodium is very important from agricultural point of view because sodium reacts with soil to reduce its permeability. Soil containing a large proportion of sodium with carbonates as the predominant anion is termed alkali soils; those with chloride or sulphate as the predominant anion are saline soils. Sodium content is usually expressed in terms of percent sodium and it is estimated using the formula.

Na % = <u>(Na + K) 100</u> (all values in epm)
Ca+Mg+Na+k

According to above Table-6, indicating that 98% of the ground water samples from shallow aquifer and 100% samples from deeper aquifer are having sodium percentage less than 60. Hence, all the samples are within the safe limit and are suitable for agricultural practices.

Table 4: Classification based on Sodium percentage (Eation 1950)

Sl No	Na%	Water Class	No. of Samples		Percentage samples	
			Shallow Aquifer	Deeper Aquifer	Shallow Aquifer	Deeper Aquifer
1	Na% < 60	Safe	48	49	98	100
2	Na% >60	Unsafe	1	Nil	2	Nil

Sodium Adsorption Ratio (SAR)

The Sodium Adsorption Ratio (SAR) is calculated from the ionic concentration of sodium, calcium and magnesium according to the following relationship.

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

SAR values can be used to predict the degree to which irrigation waters tend to enter into cation exchangesection in soil. The higher values of SAR indicate soil structural damage. Ground water has been classified into four groups based on SAR values and given in the Table 5. It is observed that Ugwa and Gusur bore well samples and Dhaigaon dug well sample have SAR values more than 26, is indicating that ground water is likely to cause sodium hazard when used for irrigation.

Table 5: Classification of ground water based on SAR values (Richards, 1954)

SAR Values	Classification	Percentage of Samples		Suitability for irrigation
		Shallow Aquifer	Deeper Aquifer	
<10	Excellent	100	100	Suitable for all soils and all crops except those which are highly sensitive to sodium
10-18	Good	-	-	
18-26	Fair	-	-	
>26	Poor	-	-	

Residual Sodium Carbonate (RSC)

Water containing CO_2 on way gets saturated with more CO_2 to form bicarbonates. The bicarbonates of Mg and Ca are precipitated out as carbonates whereas relative proportion of Na increases by base-exchange reaction. This produces impermeability to the topsoil. Bicarbonate concentration of water has been suggested as additional criteria of suitability for irrigation water. Residual Sodium Carbonate (RSC) is determined by using the formula (Richard's 1954).

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

Where the concentration are expressed in milliequivalent per liter. Ground water can also be evaluated for agricultural purposes based on Residual Sodium Carbonates (Eaton. 1950). The ground water of the area has been classified based on RSC and it is given in Table 8. It is observed that 18 % of the water samples from shallow aquifer and 38% samples from deeper aquifer are showing RSC values more than 2.5 and falls under unsuitable class. Rest of the samples is found within safe limit and is good for agricultural practices.

Table 6: Classification of Ground water based on RSC index (After Eation, 1950)

Sl. No.	RSC (epm)	Irrigational suitability	%of samples in study area	
			Shallow Aquifer	Deeper Aquifer
01	<1.25	Suitable	100	100
02	1.25 - 2.5	Marginal	-	-
03	>2.5	Not Suitable	-	-

Graphical Representation and Classification

Geochemical studies generally involve interpretation of large number of analytical data for the classification of waters of different geochemical characteristics to study their suitability for different purposes. Analytical data when presented in tabular form becomes difficult to compare, correlate and interpret and also fails to bring out the salient geochemical aspects. Thus, to have easy and quick comparison of different chemical constituents analytical data are represented by diagrams, various graphic techniques are being used to represent major chemical constituents. Graphical representations of the concentration of different ions in a water sample have been developed from time to time. The method of representing the chemistry of waters as 'Collins' bar diagrams (Hem, 1991), radiating vectors of 'Maucha (1949) have been used in many parts of the world to show the proportions of ionic concentration in individual samples. For representing a large number of analyses and for showing the effects of mixing between two waters derived from different sources, trilinear plots reported by Hill (1940) and Piper (1944) are widely used. Hence, the classification of groundwater for the study area are made using this classification and discussed in the following section.

Piper's Diagram

The trilinear diagrams of piper are very useful in highlighting the chemical relationships of groundwater in more definite terms than that possible with any other plots (Watton,1970). Piper's (1953) trilinear diagram (Fig. 2) has been extensively used to understand problems about the geochemical evolution of groundwater. The diagram consists of three distinct fields - two triangular fields and a diamond shaped field. In the triangular fields, plotted separately are the percentage epm values of anions, Ca and Mg (alkaline earths) and Na+k (alkali) and a anions, Hco_3, Co_3 (Weak acid) and So_4 and Cl (Strong acid). The overall characteristic of the groundwater is represented in the diamond shaped field by projecting the position of the plots in the triangular fields.

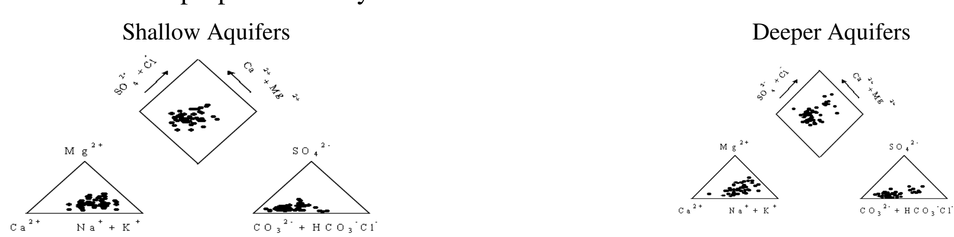

Figure 2: Piper's trilinear diagram of Shallow aquifers and deeper aquifers

USSL Classification

The classification of water suitability based on the relation between SAR and EC (Fig.3) The classification proposed by the United States salinity lab is in wide use as it takes into account both salinity and sodium hazards. The diagram gives the classification of water samples into C_1, C_2, C_3 etc., which represent water classes with increasing salinity hazards. Also S_1, S_2, S_3 etc., represent water classes with increasing hazards of exchangeable sodium accumulation in irrigated soils.

Salinity Hazard

Low salinity water (C_1) can be used for irrigation of most crops on most of soils, medium salinity water (C_2) can be used if a moderate amount of leaching occurs. Plant with moderate salt tolerance can be grown in most cases without special practices for salinity control. High salinity water (C_3) cannot be used on soil with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerances should be selected very high salinity water (C_4) is not suitable for irrigation under varied circumstances. The soil must be permeable drainage adequate, irrigation water applied in excess to provide considerable leaching and only salt tolerant crops selected.

Sodium Hazard

Low Sodium Water (S_1) can be used for irrigation on almost all soils. Medium sodium water (S_2) will present on appreciable sodium hazard in fine textured soils having high cation - exchange capacity. This water may be used on coarse textured or organic soils with good permeability. High sodium water (S_3) may product harmful levels of exchangeable sodium in most soils and will require special soil management (good drainage, high leaching and organic matter additions). Very high sodium water (S_4) is generally unsatisfactory for irrigation purposes, except a low and perhaps medium salinity. The classification of water suitability based on the relation between SAR and EC (Richards, 1954) is shown in Fig 3. The classification proposed by the United States Salinity Lab (Richards, 1954) is in wide use as it takes into account both salinity and SAR. The analytical results of groundwater samples have been plotted separately on USSL diagram. Wilcox (1948) categorized five types of water based on a plot of "Na" % "Vs" "Ec". The number of water samples falling in each category is shown in Fig 4. The analysis indicates that 35% of samples fall within the excellent to good and 24% of samples are not suitable for irrigation purposes. The unsuitable groundwater can be used to growing salt tolerant crops like; cotton, sunflower, wheat, chilly, coconut etc.

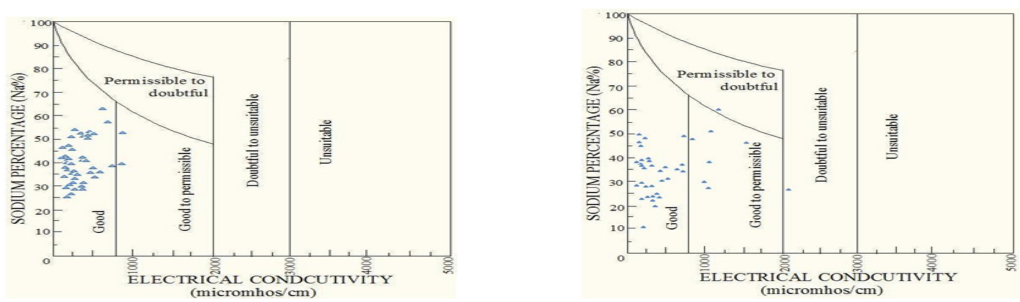

Figure 4: Wilcox diagram for Shallow Aquifers and Deeper aquifers.

Conclusions

The result of assessment of groundwater quality in shallow and deep aquifers of Uttara Kannada district, Karnataka has revealed that, pH values of groundwater ranging from 7.5 to 8.2 and 7.7 to 8.8 for shallow and deeper aquifer respectively. The average pH values of the study area is 7.9 and indicating the groundwater is alkaline in nature and are suitable for drinking purposes according BIS and ISI standard. For the shallow aquifers the observed TDS was 91 to 617.5 and 83.2 to 1248 for the deep aquifers falling slightly saline to moderately saline water. The total hardness of groundwater in the study area varies between 50mg/l to 240 mg/l (shallow aquifer) and 40 mg/l to 720 (deep aquifer). 12% (shallow aquifer) and 47% (deep aquifer) of groundwater samples fall in "Hard and hard water category. Hence there is a need for softening of this two category water if it is to be for drinking and domestic purpose. The values of Ca^{++}, Mg^{++} and Na^{+} ion concentration with in permissible as per standards prescribed by ISI and are suitable for drinking purposes. The value of Cl^{-} and SO_4 concentration is within the limits in majority of the samples. The suitability of water for irrigation is based on SAR, SSP and RSC. The values of Sodium adsorption ratio (SAR), Sodium soluble percentage (SSP) and Residual sodium carbonate (RSC) are within Permissible limit indicating groundwater is suitable for irrigation. The values of EC and SAR of groundwater samples from shallow and deep aquifer have been plotted in U.S. salinity diagram indicating that all samples fall in C2-S1, C3-S1 and C4-S1 category showing moderate to very high salinity and low sodium hazard (C3S1). The Wilcox diagram (1948) has 35% of samples fall within the excellent to good and 24% of samples are not suitable for irrigation purposes. Thus, the over all the groundwater quality in shallow deep aquifer of the study area is suitable for the drinking and irrigation purpose except few which indicates signs of deterioration in the study area.

References

1. Agrawal, V. and Jagetia M., Hydrogeochemical assessment of groundwater quality in Udaipur City,

Rajasthan, India. Proceedings of national conference on ‘‘Dimensions of Environmental Stress in India’’, Department of Geology, MS University, Baroda, India, pp 151–154, 1997.
2. BIS. Specifications for Drinking Water, IS: 10500: 1991, Bureau of Indian Standards, New Delhi, India, 1991.
3. Durvey V.S, Sharma L.L, Saini V.P, Sharma B.K., Handbook on the methodology of water quality assessment. Rajasthan Agriculture University, India, 1991.
4. Eaton, F.M, Mclean G.W, Bredell G.S. and Doner HE., Significance of silica in the loss of magnesium from irrigation waters. Soil Sci 105:260–280,1968.
5. Hem J.D., Study and interpretation of the chemical characteristics of natural water. Book 2254, 3rd edn. Scientific Publishers, Jodhpur, India, 1991.
6. Hill, R.A., Geochemical patterns in Coachella vally Colofornia, Am. Geoph. union Trans. Vol.21, pp.46-53, 1940
7. Holden, W.S., Water treatment and examination. J and Churchill Publishers, London.
8. ISI. Indian standard specification for drinking water. IS : 10500, Indian Standard Institution, pp. 1-5, 1983
9. Karanth, K.R., Groundwater assessment, development and management. Tata McGraw-Hill Publishing Company Limited, New Delhi, India, 1997.
10. Khurshid, S.H, Hasan, N., and Zaheeruddin., Water quality status and environmental hazards in parts of Yamuna-Karwan sub-basin of Aligarh-Mathura district, Uttar Pradesh, India. J Appl. Hydrol XV (4):30–37, 2002.
11. Majumdar, D. and Gupta N., Nitrate pollution of groundwater and associated human health disorders. Indian J Environ Health 42(1):28–39, 2000.
12. Maucha, R., The graphic symbolization of the chemical composition of natural waters. Hiderol, Kozlony, v.29, pp.28-30, 1949.
13. Niranjan Babu, P. Subba Rao N, Chandra Rao P., and Prakasa Rao J Groundwater quality and its importance in the land developmental programmes. Indian J Geol 69(4):305–312, 1997.
14. Piper, A. M., A graphic procedure in the geochemical interpretation of water analyses. Am Geophy Union Trans 25:914–923, 1944.
15. Piper, A.M., A graphic procedure in the geochemical interpretation of water analyzes. Trans. Amer. Geophys. Union, vol.25, pp. 914-928, 1953.
16. Richards, L.A., Diagnosis and improvement of saline and alkali soils. U.S. Dept., of Agri. Handbook., no. 60, U.S. Govt. Printing Press, Washington D.C, 1954.
17. Scofield, C.S., South Coastal Basin Investigation, quality of irrigationwaters’, California Department of Public works Division of water Resources, Bull. No. 40, pp.22-24, USA, 1933.
18. Sreedevi, P.D., Groundwater quality of Pageru river basin, Cuddapah district, Andhra Pradesh. J Geol Soc India 64(5):619–636, 2004.
19. Subba Rao, N, Srinivasa Rao G, Venkateswara Rao S, Madhusudhana Reddy P and John Devadas D., Environmental control of groundwater quality in a tribal region of Andhra Pradesh, India. Indian J Geol 71(4):299–304, 1999.
20. Subba Rao, N. and John Devadas D., Quality criteria for groundwater use for development of an area. J Appl Geochem 7(1):9–23, 2005.
21. Todd, D.K., Groundwater hydrology. Wiley, New York, 1980.
22. Thorne, D.W. and Peterson HB., Irrigated soils. Constable and Company Limited, London, 1954.
23. US Salinity Laboratory Staff., Diagnosis and improvement of saline and alkali soils. US Department of Agricultural Hand Book 60, Washington, 1954.
24. Walton, W.C., Groundwater resources evaluation. McGraw Hill Book Company, New York, 664p. 1970.
25. WHO. Guidelines for drinking water quality. World Health Organization, Geneva, 1984.
26. Wilcox, L.V., The quality of water for irrigation use. US Department of Agricultural Technical Bulletin, Washington, USA, 1948.

Table 7: Hydrochemical data of ground water from shallow aquifers of Uttatra Kannada district

Sr. No.	VILLAGE	pH	EC	TDS	TH	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	Cl^{-}	SO_4^{--}	$NO3^{-}$	F	SAR	%Na
1	Marda	8.1	350	227.5	130	20	19	19.5	4.0	0	159	21	10	2	0.8	0.75	26.8
2	Ulvi	7.9	140	91	50	16	2	8	1.4	0	43	14	9	2	0.9	0.50	27.8
3	Anshi	7.8	240	156	80	20	7	16	2.7	0	92	21	8	1	0.9	0.78	32.3
4	Nunji	7.9	230	149.5	80	12	12	15	0.9	0	79	21	14	1	1.0	0.73	29.7
5	Kalasai	8.0	230	149.5	80	20	7	15	1.3	0	79	28	4	2	1.0	0.73	30.0
6	Khumbharwada	7.9	220	143	70	20	5	16	2.0	0	98	14	4	3	1.0	0.83	34.8
7	Jolda	8.1	250	162.5	80	24	5	19	1.9	0	85	28	6	5	0.75	0.92	35.4
8	Ganeshgudi	8.0	280	182	100	20	12	15	3.7	0	104	21	16	7	1.1	0.65	27.2
9	Jagalbhet	8.1	290	188.5	100	28	7	18	4.6	0	110	21	12	10	0.6	0.79	31.1
10	Borehalli	7.8	170	110.5	50	12	5	12	6.7	0	37	28	10	1	1.2	0.73	41.0
11	Barchi	8.0	540	351	170	16	31	42	6.9	0	250	21	24	4	0.9	1.41	37.1
12	Pradhanhi	8.2	220	143	80	12	12	11	2.4	0	85	21	6	2	0.7	0.54	25.2
13	Virnoli	7.9	230	149.5	60	12	7	24	0.5	0	61	36	8	1	1.1	1.36	46.8
14	Kulgi	8.2	710	461.5	220	16	44	58	1.0	0	183	114	30	10	1.2	1.70	36.7
15	Ambika Nagar	8.2	490	318.5	160	12	31	37	3.0	0	177	50	18	6	1.3	1.28	34.5
16	Bommanhalli	8.1	420	273	130	20	19	27	15.1	0	140	50	14	4	1.3	1.04	37.5
17	Bhagavati	8.2	490	318.5	120	20	17	52	8.3	0	122	85	12	9	1.2	2.06	50.8
18	Tatwal	8.2	950	617.5	280	36	46	87	3.8	0	134	234	16	16	1.4	2.26	41.0
19	Kirvati	8.1	490	318.5	140	16	24	42	6.6	0	128	78	18	8	1.1	1.55	41.1
20	Sidalgundi	8.2	410	266.5	120	16	19	37	1.5	0	116	64	10	7	0.6	1.48	40.7
21	Barathalli	7.9	260	169	70	12	10	22	8.6	0	79	36	9	2	0.7	1.13	45.7
22	Chavati	7.6	220	143	70	8	12	17	1.0	0	73	28	6	1	0.7	0.89	35.3
23	Umachi	7.6	190	123.5	60	8	10	14	2.7	0	55	21	14	2	0.7	0.78	36.1
24	Manchikeri	7.4	170	110.5	50	12	5	14	2.5	0	30	28	10	8	1.0	0.86	40.2
25	Savenkeri	8.2	320	208	100	16	14	26	1.2	0	104	36	14	4	1.0	1.14	36.7
26	Yellapur	8.2	600	390	100	24	10	81	18.3	0	104	135	12	10	0.9	3.50	66.6
27	Kannigeri	8.0	280	182	90	12	14	22	0.76	0	85	28	14	12	0.9	1.02	35.16
28	Dondeli	7.6	180	117	50	8	7	17	1.7	0	37	21	21	4	1.3	1.06	43.91
29	Pansoli	8.1	440	286	110	20	14	47	4.8	0	116	78	10	2	1.2	1.97	49.62
30	Alur	8.2	350	227.5	120	20	17	23	1.2	0	110	43	16	6	1.3	0.91	30.04
31	Shirgur	8.2	350	227.5	80	20	7	43	1.2	0	134	36	10	1	1.3	2.11	54.28
32	Ajgaon	8.1	670	435.5	220	52	22	44	15.2	0	244	71	24	3	1.1	1.29	34.36
33	Kasaroli	8.2	790	513.5	240	24	43	69	1.8	0	128	192	10	5	1.2	1.95	38.82
34	Gardoli	8.0	390	253.5	120	28	12	33	1.4	0	128	43	9	19	1.3	1.31	38.00
35	Sambrani	8.2	430	279.5	120	32	10	40	4.9	0	134	57	11	9	1.1	1.58	43.73
36	Halyal	7.9	890	578.5	200	20	36	105	12.9	0	159	185	42	2	1.4	3.24	55.04
37	Pandarval Hosur	8.2	380	247	102	24	14	30	3.0	0	85	50	40	3	1.0	1.20	40.37
38	Tattageri	7.9	730	474.5	150	20	24	97	1.3	0	207	114	24	2	1.3	3.46	58.62
39	Baralkod	7.9	180	117	60	12	7	11	3.7	0	55	14	10	10	1.4	0.62	32.32
40	Madanalli	7.8	410	266.5	100	20	12	47	0.4	0	98	64	24	4	1.4	2.05	50.66
41	NagesheetiKoppa	8.2	500	325	120	12	22	58	0.9	0	122	92	11	8	0.6	2.30	51.46
42	Belvategi	8..2	360	234	90	20	10	40	1.4	0	122	43	14	2	0.7	1.82	49.63
43	Lagundi	7.6	250	162.5	60	12	7	28	1.7	0	61	36	16	5	1.0	1.59	51.24

Sr. No.	VILLAGE	pH	EC	TDS	TH	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	Cl^{-}	SO_4^{--}	$NO3^{-}$	F	SAR	%Na
44	Arabali	7.6	160	104	60	16	5	8	0.7	0	55	14	6	3	1.2	0.45	23.41
45	Telanger	7.5	310	201.5	110	24	12	20	0.8	0	116	28	10	5	0.5	0.83	28.77
46	Basal	7.5	170	110.5	60	16	5	9	3.4	0	61	14	10	1	0.6	0.50	28.51
47	Vajralli	8.0	170	110.5	60	8	10	10	0.95	0	55	21	6	2	0.6	0.56	27.67
48	Nandolli	7.8	200	130	60	20	2	17	2.0	0	43	28	16	4	1.4	0.97	39.71
49	Magod	7.9	150	97.5	50	12	5	10	2.1	0	37	21	12	1	0.2	0.61	32.82

Table 8: Hydrochemical data of ground water from deeper aquifers of Uttatra Kannada district

Sr. No.	VILLAGE	pH	EC	TDS	TH	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	Cl^{-}	SO_4^{--}	$NO3^{-}$	F	SAR	%Na
1	Magwad	8.8	530	339.2	180	12	36	37	1.3	18	146	64	14	4	0.4	1.21	31.3
2	Kanchanhalli	8.5	1470	940.8	400	32	77	150	4.5	12	134	348	90	8	0.47	3.27	45.3
3	Dusgi	8.4	750	480	240	36	36	60	3	9	91	156	40	20	0.5	1.69	35.9
4	Nagasheetikoppa	7.7	1150	736	300	52	41	123	3.1	0	299	156	66	40	0.5	3.09	47.5
5	Tattegeri	8.1	1250	800	400	112	29	101	2.1	0	67	277	132	35	0.21	2.20	35.7
6	Ammankoppa	8.1	1950	1248	720	96	116	116	1	0	183	454	119	60	0.14	1.88	26.0
7	Shivapur	8.6	370	236.8	120	16	19	28	1.5	12	104	36	4	26	0.77	1.12	34.4
8	Dodkoppa	8.2	1110	710.4	350	56	51	89	4.5	0	146	248	68	12	0.3	2.07	36.3
9	Belvatagi	8.5	700	448	180	8	39	76	1.4	9	159	114	20	22	0.38	2.46	48.1
10	AdkeHosur	8.5	450	288	170	28	24	23	2.9	12	98	64	6	32	0.58	0.77	24.0
11	Shirugur	8.3	910	582.4	310	52	43	53	22.6	9	91	177	80	29	0.97	1.32	31.8
12	Barchi	8.5	580	371.2	200	60	12	38	4.9	18	122	85	28	7	0.31	1.17	30.8
13	Jagalbet	8.2	230	147.2	70	20	5	19	1.5	0	73	28	10	5	0.13	0.98	38.2
14	Kamre	8.5	290	185.6	110	28	10	13	3.5	12	85	28	8	2	0.4	0.54	23.0
15	Gardoli	8.3	920	588.8	290	48	41	75	3.8	12	98	149	98	55	0.42	1.92	36.7
16	Kesarolli	8.2	1160	742.4	360	76	41	99	1.3	0	116	270	80	14	0.12	2.27	37.6
17	Aiygaon	8.4	560	358.4	200	24	34	31	7.8	9	104	99	30	4	0.33	0.95	27.9
18	Pradeni	8.5	400	256	150	24	22	21	1.7	9	110	50	14	9	0.83	0.74	24.2
19	Pensoli	8.3	410	262.4	130	28	14	31	2	6	85	78	8	5	0.21	1.19	35.0
20	Kulgi	8.5	500	320	180	20	31	31	1.4	12	122	71	24	3	0.20	1.01	27.8
21	Bhagawati	8.4	1190	761.6	250	32	41	157	2.1	12	122	263	60	45	0.51	4.33	57.9
22	Bomanhalli	8.3	460	294.4	180	24	29	16	10.8	9	104	71	16	11	0.26	0.52	21.3
23	Ambikanagar	8.4	350	224	130	32	12	20	0.98	9	104	43	8	5	0.23	0.76	25.6
24	Homnalli	7.9	800	512	210	16	41	85	1.5	0	213	149	10	4	0.35	2.56	47.1
25	Arabail	7.7	190	121.6	60	12	7	15	0.2	0	43	28	12	4	0.41	0.85	35.4
26	Gearl	8.4	290	185.6	100	20	12	15	8.5	9	67	36	12	9	0.57	0.65	30.3
27	Gearl	8.1	901	121.6	50	12	5	18	2.0	0	57	28	2	4	0.76	1.10	45.47
28	Dehalli	7.8	260	166.4	90	20	10	16	2.4	0	79	36	8	2	0.4	0.73	29.61
29	Kirvati	7.8	1120	716.8	340	24	68	96	5.5	0	244	192	50	34	0.3	2.26	38.82
30	Domegeri	8.1	370	236.8	120	36	7	26	4.9	0	140	36	10	10	0.45	1.04	34.36
31	Domegeri	7.9	1490	953.6	530	24	114	96	2.9	0	220	298	120	14	0.23	1.82	28.61
32	Idugundi	8.2	140	89.6	50	16	2	8	1.2	0	43	14	10	2	0.5	0.50	27.46
33	Basal	8.5	230	147.2	70	20	5	16	7.4	9	61	21	12	4	0.87	0.83	38.74
34	Vajralli	8.1	330	211.2	120	28	12	16	6	0	122	36	10	2	0.27	0.64	26.14

Sr. No.	VILLAGE	pH	EC	TDS	TH	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	Cl^{-}	SO_4^{--}	$NO3^{-}$	F	SAR	%Na
35	Nandolli	8.4	340	217.6	110	28	10	26	0.9	9	122	21	16	7	0.12	1.07	34.38
36	Sidalgundi	8.2	650	416	240	52	27	37	1.6	0	165	121	8	5	0.23	1.04	25.58
37	Hunshettikoppa	7.9	1030	659.2	330	16	70	83	2.2	0	116	241	58	6	0.19	1.99	35.70
38	Hunshettikoppa	8.4	340	217.6	120	28	12	21	1.6	9	98	43	5	7	0.29	0.84	28.45
39	Yellapur	8.2	480	307.2	180	24	29	25	0.84	0	146	71	14	2	0.93	0.81	23.54
40	Kannigeri	8.6	370	236.8	110	24	12	32	1.7	12	104	36	26	2	0.13	1.33	39.48
41	Tatwal	8.2	470	300.8	140	20	22	43	0.53	0	146	71	8	4	0.28	1.58	40.21
42	Madanahalli	8.3	380	243.2	100	24	10	39	3	6	110	50	10	5	0.54	1.69	46.99
43	Chavati	8.2	380	243.2	110	20	14	34	2.9	0	146	28	22	2	0.14	1.43	41.37
44	Kalche	8.6	250	160	110	36	5	5	2.3	9	79	28	3	1	0.67	0.21	11.16
45	Bharathalli	8.7	260	166.4	90	8	17	15	2.4	12	49	28	24	3	0.62	0.69	28.39
46	Manchikeri	8.0	130	83.2	40	12	2	10	1.4	0	37	14	8	4	0.11	0.70	37.04
47	Yadakanbail	8.7	180	115.2	50	8	7	18	0.99	6	49	21	6	1	0.71	1.12	44.69
48	Kalasai	8.2	200	128	50	12	5	22	0.8	0	61	28	4	2	0.93	1.35	49.45
49	Joida	8.1	190	121.6	60	20	2	14	2.8	0	67	21	6	1	0.14	0.80	36.19