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# MULTIVARIATE ANALYSIS TO EVALUATE GEOCHEMISTRY OF GROUNDWATER IN VARAHI RIVER BASIN OF UDUPI IN KARNATAKA (INDIA)

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## ABSTRACT

The Varahi Irrigation project dam site is located at approximately 6km from Siddapura, Kundapura taluk, Udupi district with latitude of 13°39′ 15" N and a longitude of 74°57′E. Groundwater quality in the study area was evaluated for its suitability for drinking and irrigation purposes by collecting 36 samples during pre-monsoon period of the year 2005. The quality assessment was made by estimating physico-chemical parameters, major cations and anions, besides irrigation quality parameters like SAR, % Na and RSC. It was also noticed that alkaline earth elements exceeded alkalies concentration and weak acids exceeded the strong acid element and $HCO_3^-$ was the predominant among anions, while Ca-Mg dominates cations. Classification of water samples based on SAR and Salinity Hazard revealed that majority of the samples were under excellent (S1, 88.88 %) and excellent (C1, 80.56 %) to good (C2, 8.33 %) categories respectively. Gibbs' ratio illustrates that majority of water samples fall in the precipitation dominance field, giving an indication that the aquifer recharging is by means of rain / river water.

**KEY WORDS**
Varahi River
Salinity
Cluster analysis
Gibb's plot
Correlation matrix

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## INTRODUCTION

Water is very vital for nature and can be a limiting resource to human and other living beings. Without a well functioning water supply, it is difficult to imagine productive human activity be it agriculture or livestock. Groundwater is the main source of irrigation in arid and semi-arid regions in the world. The quality of water is of at most importance to quantity in any water supply planning and its quality is influenced by natural and anthropogenic effects including local climate, geology and irrigation practices. The quality of any groundwater is a function of the physical, chemical and biological parameters, and could be subjective, since it depends on a particular intended use (Tatawat and Chandel, 2008). Over the few decades, competition for economic development, associated with rapid growth in population and urbanization, has brought in significant changes in land use, resulting in more demand of water for agriculture, domestic and industrial activities. Irrigated lands contribute significantly to the world agriculture output and food supply. India is one of the agriculture based countries. Water used for irrigation can vary greatly in quality depending upon the type and quantity of dissolved salts. Salts present in irrigation water in relatively small but significant amounts, usually originate from dissolution or weathering of the rocks and soil, including dissolution of lime, gypsum and other soil minerals. These salts are carried with the water to wherever it is used. In the case of irrigation, the salts are applied with the water and remain behind in the soil as water evaporates or is used by the crop. In irrigated agriculture, the hazard of salt water is a constant threat. Poor quality irrigation water is of concern in arid climatic conditions. Besides affecting crop yield and soil physical conditions, irrigation water quality affects fertility needs, irrigation system performance and longevity and how the water can be applied (Ayers and Westcot, 1994). Due to inadequate availability of surface water, to meet the requirement of human activities, groundwater remains the only option to supplement the ever-increasing demand of water (Tyagi *et al.*, 2008). The quality of the groundwater has also been affected by over-abstraction (Wang *et al.*, 1999; Tang and Zhang, 2001; Ding and Zhang, 2002). Hence, the suitability of groundwater for agricultural, municipal, industrial and domestic water supplies can be determined by evaluating physico-chemical parameters along with some calculated hydrogeochemical/ hydrochemical parameters and graphical representations. Despite the importance of groundwater in the Varahi River Basin, little is known about the natural processes that govern the chemical composition of the groundwater or the anthropogenic factors that currently affect it. Hence, the present study aimed at understanding the prevailing groundwater quality in the command area of Varahi Irrigation Project area during the pre-monsoon season of the March, 2005 by employing multivariate statistical analysis. The suitability of groundwater for drinking and agricultural purpose was also evaluated.

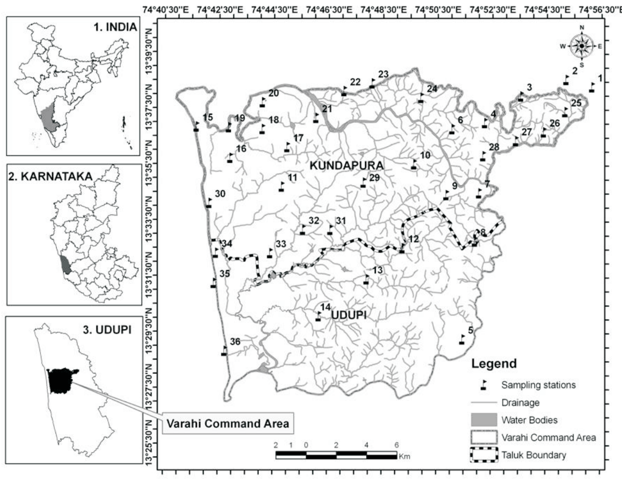


**Figure 1: Location map of varahi command area**

**Study Area**

River Varahi is a major west flowing river in the west coast in Udupi district, which originates from the high peaks of the Western Ghats near Guddakoppa village in Hosanagar taluk of Shimoga district at an altitude of about 761m above MSL and flows for a length of 88 km. The Varahi Irrigation project site is located at approximately 6 km from Siddapura village, Kundapura taluk, Udupi district with a total drainage area of the river being 755.2 $Km^2$ and the proposed dam site is located at a 13º-39′-15" N latitude and 74º-57′-0" E longitude. Heavy rainfall from the hilly region around Agumbe and Hulikal along with tributaries like Hungedhole, Kabbenahole, Dasnakatte, Chakranadi etc., will join Varahi before emptying into the Arabian Sea. The river Varahi has been one of the major sources of water for Mani Dam near Mani village, with diversion weir and Forebay Dam for generation of electricity at the Varahi Hydroelectricity Power Station. In the process of electric generation, there is continuous tail race water discharge of about 1100 cusecs throughout the year that can be utilized for irrigation of 15,702 ha of land. Hence, Varahi Irrigation Project is envisaged to harness this water for the irrigation purposes by constructing diversion weir across the river Varahi at Horriabbe near Siddapur in the Udupi district. The study area is having a catchment area of 293.0 $Km^2$ (29300 ha) and command areas of 157.02 $Km^2$ (15,702 ha), covering part of Kundapura (83.24 $Km^2$) and Udupi (73.78 $Km^2$) taluks of Udupi District (Fig 1). The reservoir water has been directed via Varahi Left Bank Canal (VLBC, 33 Km) and Varahi Right Bank Canal (VRBC, 44.70 Km) to irrigate an area of around 27.23 $Km^2$ (2723 ha) and 19.92 $Km^2$ (1992 ha) respectively. The net irrigable command area is 129.79 $Km^2$ (12,979 ha) by flow irrigation and correspondingly 27.23 $Km^2$ (2723 ha) by lift irrigation, to provide enhanced irrigation facilities and an improved drinking water system to the villages of two taluks of Udupi district. The climate of the area is moderately hot and enjoys a pleasant temperature range from the highest mean maximum of 35ºC to lowest mean maximum of 23ºC with a mean temperature of 27ºC. South Canara is a thickly populated area in general and Udupi district in particular which receives plenty of rainfall during South West Monsoon. The mean annual rainfall is 539.97 cm with a maximum of 632 cm and a minimum of 318 cm, while the mean relative humidity is 76%.

## MATERIALS AND METHODS

A total of 36 groundwater samples were collected in the command area of Varahi Irrigation Project during pre-monsoon season (March 2005), covering villages of Kundapur and Udupi taluks in the Udupi district. The water samples were collected after 10 mins of pumping and transferred into pre-

**Table 1: Physico-chemical and irrigation quality parameters**

| S. N. | Parameters | Characteristics | Analytical method | Unit | BIS limits (1998) |
|---|---|---|---|---|---|
| 1 | General | pH | Electrode | ——- | 6.5-8.5 |
| 2 | | Electrical Conductivity (EC) | Conductivity-TDS meter | µS/cm | 3000 |
| 3 | | Total Dissolved Solids (TDS) | Conductivity-TDS meter | mg/L | 2000 |
| 4 | | Total Alkalinity (as $Ca(OH)_2$ | Titrimetric | mg/L | 600 |
| 5 | | Total hardness (as $CaCO_3$) | EDTA Titrimetric | mg/L | 600 |
| 6 | | Calcium hardness (as $CaCO_3$) | EDTA Titrimetric | mg/L | 200 |
| 7 | | *E.Coli* | Membrane Filtration | CFU/100mL | Zero |
| 8 | | Iron | HACH Colorimetric | mg/L | 0.3 |
| 9 | Major Cations | Calcium (as $Ca^{2+}$) | EDTA Titrimetric | mg/L | 200 |
| 10 | | Magnesium (as $Mg^{2+}$) | EDTA Titrimetric | mg/L | 100 |
| 11 | | Sodium (as $Na^{+}$) | Flame photometric | mg/L | 200 |
| 12 | | Potassium (as $K^{2+}$) | | mg/L | 10 |
| 13 | Major Anions | Bicarbonates (as $HCO_3^-$) | Titrimetric | mg/L | NA |
| 14 | | Chlorides (as $Cl^-$) | Argentometric | mg/L | 1000 |
| 15 | | Nitrates (as $NO_3^-$) | ISE (Ion Selective electrode) | mg/L | 45 |
| 16 | | Fluoride (as $F^-$) | | mg/L | 1.5 |
| 17 | | Phosphates (as $PO_4^{3-}$) | Stannous chloride | mg/L | 0.3 |
| 18 | | Sulphates (as $SO_4^{2-}$) | Barium chloride | mg/L | 400 |
| 19 | Irrigation Water Quality | Hardness (as $CaCO_3$) | EDTA Titrimetric | mg/L | < 75 |
| 20 | | Sodium Absorption Ratio (SAR) | ByCalculation using equations | —- | < 18 |
| 21 | | Residual Sodium Carbonate (RSC) | | meq/L | <1.25 |
| 22 | | Percent Sodium (% Na) | | % | < 40 |

Note: NA - Not Available

cleaned polyethylene bottles and stored at 10°C. The conductivity, pH, temperature, redox potential (Eh), dissolved oxygen (DO) and total dissolved solids (TDS) were measured in the field immediately after sampling, while major anionic and cationic concentrations were determined in the laboratory following standard analytical procedures (Table 1) as recommended by APHA (2005). Based on the physico-chemical analyses, irrigation quality parameters like SAR, % Na and RSC were calculated. The suitability of the water from the groundwater sources for drinking and irrigation purposes were evaluated by comparing the values of different water quality parameters with the Bureau of Indian standards (BIS, 1991) and World Health Organization (WHO, 1984) drinking water guideline values. Different graphical representation such as Piper (1994) and Gibbs (1970) were constructed to ascertain various factors on which the chemical characteristics of water depend. The complete analytical results of the water samples were transferred onto STATISTICA v7.0 and SPSS v11.4 statistical platforms, to carry out multivariate statistical analysis such as Pearson's correlation matrix of the hydrochemical data and cluster analysis.

## RESULTS AND DISCUSSION

The analytical results for all the physico-chemical parameters for the pre-monsoon water samples from the study area are presented in Table 2. The pH of the water samples ranged between 4.35 and 6.69. The lowest pH value of 4.35 was noticed in sample No. RV25 (Ullur Hamsavadi village), which is very much towards acidic range and a maximum pH value of 6.69 was noticed in sample No. RV9 (*i.e.,* Hardali-Mandalli village). Conductivity values in the study area ranged between 66.6 and 4562 $\mu$S/cm, with a minimum value being observed in sample No. RV32 (*i.e.,* Shirur village) and maximum EC value was being observed in Sample No. RV17 (*i.e.,* Koni village). Only one sample showed EC value, exceeding the prescribed limits of 3000 $\mu$S/cm (BIS, 1991). Total Dissolved Solids is usually due to presence of dissolved salts present in water. In the study area, TDS values were found to range between 16.53 and 2369 mg/L. The lowest TDS value was noticed in the sample No. RV4 (*i.e.,* Kulanji village), while the highest value was found in sample No. RV17 (*i.e.,* Koni village), exceeding the permissible limit of 2000 mg/L (BIS, 1991).

Total hardness (as $CaCO_3$) was found to be in the range of 29.4 to 529.2 mg/L with a minimum value of 29.4 mg/L, noticed in sample No. 32 (*i.e.,*Shirur village) and the maximum value of 529.2 mg/L in sample No.17 (Koni village). All the samples showed total hardness well within the prescribed limits of 600 mg/L for drinking (BIS, 1991). The presence of calcium and magnesium bicarbonates contributes to hardness in the ground water Calcium hardness (as $CaCO_3$) ranged from 9.8 to 186.2 mg/L. The minimum Calcium hardness of 9.8 mg/L being seen in sample no. RV4, RV24, and RV32 (viz., Kulanji Amparu, Kolkebylu respectively) and the highest Calcium hardness of 186.2 mg/L was noticed in Sample No.RV1 (*i.e.,* Machattur village). Alkalinity values ranged between 30 and 1000 mg/L. Minimum alkalinity values of 30 mg/L was noticed in samples RV1 (*i.e.,* Machattu village), while highest 1000 mg/L was noticed in sample No. RV12 (Haladi-Harkadi village). Iron (as $Fe^{2+}$) concentration in the present study area varied from 0.01 to 20.1 mg/L, with 9 samples with exceeded iron concentration above the permissible limit of 0.3 mg/L (BIS, 1991). The *E.coli* count varied from 7 to 243 CFU/100mL and it was found that majority of the samples showed *E.coli* count exceeding the limits. DO and BOD values of three surface water samples collected in the study area varied from 7.2 to 8.4 mg/L and 1.0 to 1.4 mg/L respectively (Table 2), while the E.Coli count was in the range of 7 to 243 CFU / 100 mL of the water sample.

### Cation chemistry

Calcium (as $Ca^{2+}$) and magnesium (as $Mg^{2+}$) ranged from 3.2 to 74.48 mg/L and 4.78 to 86.08 mg/L and it was found that all the samples showed calcium and magnesium concentration within the permissible limit of 200 and 100 mg/L (BIS, 1991) respectively. Sodium values ranged from 1.9 to 690 mg/L, while potassium values ranged from 0.1 to 33.2 mg/L. Out of 36 samples, 4 samples showed sodium concentration, exceeding the permissible limit of 100 mg/L (BIS, 1991), while 5 samples showed potassium concentration exceeding the permissible limit of 10 mg/L (BIS, 1991).

### Anion chemistry

The concentration of fluoride ranged between 0.01 and 0.52 mg/L and all the samples showed fluoride concentration within the permissible limit of 1.5 mg/L (WHO, 1984). The Nitrate values ranged from 0.013 and 1.911 mg/L, lowest level being recorded in sample No.RV30 (*i.e.,* Anatha Mogere village) and the highest concentration was noticed in sample No.RV34 (*i.e.,* Kota (Manurur) village). All the samples showed nitrate value within the permissible limit of 45 mg/L. The sulphate values in the sampling sites ranged between 0.19 and 45.71 mg/L and all the samples showed sulphate concentration within the permissible limit of 400 mg/L (BIS, 1991). The lowest value of 0.19 mg/L was found in the sample RV20. (*i.e.,* Basrur village) and highest sulpahte concentration of 45.71 mg/L has been observed in sample RV17 (*i.e.,* Koni village). Chloride contents were found to be varying from 19 to 1377.5 mg/L and all the samples showed chloride values within the permissible limit of 1000 mg/L except for one sample (viz., RV17, Koni village). Phosphate values varied from 0.001 to 0.685 mg/L and all the samples were having phosphate value within the limit of 0.3 mg/L except for one sample (RV4, Kulanje village).

### Hydrochemical facies

To know the hydrochemical regime of the study area, the analytical values obtained from the water samples are plotted on Piper (1994) trilinear diagram. These plots include two triangles, one for plotting cations and the other for plotting anions. The cations and anion fields are combined to show a single point in a diamond-shaped field, from which inference is drawn on the basis of hydro-geochemical facies concept. The diamond shape field of Piper diagram can be further classified into (I) $Ca^{2+}$-$Mg^{2+}$-$Cl^-$-$SO_4^{2-}$, (II) $Na^+$-$K^+$-$Cl^-$-$SO_4^{2-}$, (III) $Na^+$-$K^+$-$HCO_3^-$ and (IV) $Ca^{2+}$-$Mg^{2+}$-$HCO_3^-$. These tri-linear diagrams are useful in bringing out chemical relationships among water samples in more definite terms rather than with other possible plotting methods. Hydrochemical facies are distinct zones that possess cation and anion concentration categories and this concept helps to understand and identify the water composition in different classes.

**Table 2: Analytical results of surface and groundwater samples in the Varahi command area (pre-monsoon, 2005)**

| ID | Village name | Source | pH | EC | TDS | E.Coli | TH | CaH | MgH | TA | $Fe^{2+}$ | DO | BOD | Major Cations $Ca^{2+}$ | $Mg^{2+}$ | $Na^{+}$ | $K^{+}$ | $F^{-}$ | $Cl^{-}$ | Major Anions $HCO_3^-$ | $NO_3^-$ | $SO_4^{2-}$ | $PO_4^{3-}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RV1 | Machattur | OW | 6.4 | 170 | 103 | 55 | 274.4 | 186.2 | 88.2 | 30 | 0.24 | 7.8 | 1.2 | 74.48 | 21.52 | 1.8 | 0.3 | 0.01 | 19 | 36.6 | 0.084 | 0.38 | 0.001 |
| RV2 | Hosangadi | OW | 5.35 | 220.6 | 132.3 | 44 | 78.4 | 29.4 | 49 | 100 | 0.01 | —- | —— | 11.76 | 11.96 | 2.5 | 0.6 | 0.02 | 19 | 122.0 | 0.029 | 0.38 | 0.003 |
| RV3 | Hosangadi | OW | 5.67 | 72.78 | 37.9 | 21 | 98 | 39.2 | 58.8 | 130 | 0.02 | —- | —— | 15.68 | 14.35 | 6.7 | 0.6 | 0.02 | 19 | 158.6 | 0.193 | 0.48 | 0.002 |
| RV4 | Kulanji | OW | 4.76 | 32.66 | 16.53 | 94 | 49 | 9.8 | 39.2 | 50 | 0.03 | —- | —— | 3.92 | 9.56 | 2.2 | 0.6 | 0.03 | 19 | 61.0 | 0.103 | 0.29 | 0.685 |
| RV5 | Shankar Narayana | OW | 4.6 | 35.4 | 18.83 | 29 | 98 | 19.6 | 78.4 | 50 | 0.02 | —- | —— | 7.84 | 19.13 | 2.6 | 0.2 | 0.01 | 38 | 61.0 | 0.119 | 0.48 | 0.004 |
| RV6 | Shankar Narayana | Bore | 5.83 | 272.3 | 101.3 | 49 | 88.2 | 19.6 | 68.6 | 360 | 5.82 | —- | —— | 7.84 | 16.74 | 6.6 | 0.4 | 0.04 | 38 | 439.2 | 0.06 | 9.71 | 0.001 |
| RV7 | Haladi | RW | 6.65 | 51.91 | 139.9 | 48 | 137.2 | 88.2 | 49 | 860 | 0.1 | —- | —— | 35.28 | 11.96 | 8.5 | 1.3 | 0.28 | 28.5 | 1049.2 | 0.101 | 0.38 | 0.005 |
| RV8 | Haladi | OW | 6.6 | 231.3 | 119 | 77 | 137.2 | 78.4 | 58.8 | 620 | 0.05 | —- | —— | 31.36 | 14.35 | 7.3 | 6.7 | 0.08 | 28.5 | 756.4 | 1.131 | 1.33 | 0.008 |
| RV9 | Hardahalli-Mandahalli | Bore | 6.69 | 205.2 | 105.3 | 56 | 166.6 | 78.4 | 88.2 | 490 | 0.06 | —- | —— | 31.36 | 21.52 | 8.9 | 5 | 0.02 | 38 | 597.8 | 1.253 | 0.57 | 0.006 |
| RV10 | Malahalli | Bore | 6.02 | 208.1 | 107.4 | 16 | 186.2 | 88.2 | 98 | 610 | 4.48 | —- | —— | 35.28 | 23.91 | 10.8 | 3.6 | 0.05 | 28.5 | 744.2 | 0.05 | 8.48 | 0.013 |
| RV11 | Hainalli | Bore | 5.95 | 136.7 | 70.46 | 14 | 98 | 39.2 | 58.8 | 380 | 0.03 | —- | —— | 15.68 | 14.35 | 8 | 1.2 | 0.05 | 28.5 | 463.6 | 0.103 | 0.57 | 0.01 |
| RV12 | Haladi-Harkadi | OW | 6.55 | 309.5 | 159.7 | 87 | 264.6 | 127.4 | 137.2 | 1000 | 2.19 | —- | —— | 50.96 | 33.48 | 18.8 | 3.1 | 0.09 | 38 | 1220 | 0.131 | 6.48 | 0.01 |
| RV13 | Shiriyur | OW | 5.37 | 210.2 | 108.4 | 8 | 117.6 | 49.0 | 68.6 | 200 | 0.04 | —- | —— | 19.6 | 16.74 | 15.9 | 12.4 | 0.02 | 47.5 | 244.0 | 0.298 | 5.05 | 0.001 |
| RV14 | Kajrahalli | OW | 5.16 | 54.11 | 27.84 | 44 | 98 | 39.2 | 58.8 | 160 | 0.09 | —- | —— | 15.68 | 14.35 | 5 | 0.2 | 0.01 | 28.5 | 195.2 | 0.185 | 1.14 | 0.002 |
| RV15 | Vaderahobli | OW | 6.21 | 1428 | 731.5 | 29 | 245 | 137.2 | 107.8 | 440 | 0.03 | —- | —— | 54.88 | 26.3 | 241.9 | 12.4 | 0.17 | 513 | 536.8 | 1.889 | 4.19 | 0.008 |
| RV16 | Koni | OW | 6.37 | 1562 | 803.3 | 24 | 294 | 156.8 | 137.2 | 900 | 0.08 | —- | —— | 62.72 | 33.48 | 256.5 | 22.6 | 0.29 | 427.5 | 1098 | 1.398 | 15.14 | 0.009 |
| RV17 | Koni | Lake | 1.18 | 4562 | 2369 | 38 | 529.2 | 176.4 | 352.8 | 800 | 20.1 | 7.2 | 1.4 | 70.56 | 86.08 | 690 | 30.7 | 0.52 | 1377.5 | 976.0 | 0.036 | 45.71 | 0.012 |
| RV18 | Koni | OW | 6.51 | 2364 | 1209 | 194 | 303.8 | 107.8 | 196 | 200 | 0.08 | —- | —— | 43.12 | 47.82 | 392 | 12 | 0.27 | 712.5 | 244.0 | 1.139 | 37.71 | 0.007 |
| RV19 | Mudlakatte | OW | 5.4 | 245.2 | 126.2 | 136 | 98 | 39.2 | 58.8 | 80 | 0.12 | —- | —— | 15.68 | 14.35 | 22.5 | 6.1 | 0.02 | 76 | 97.6 | 0.408 | 2.19 | 0.01 |
| RV20 | Basur | OW | 5.16 | 41.96 | 22.3 | 59 | 98 | 29.4 | 68.6 | 70 | 0.1 | —- | —— | 11.76 | 16.74 | 4.2 | 0.6 | 0.01 | 28.5 | 85.4 | 0.782 | 0.19 | 0.02 |
| RV21 | Ballur | Bore | 5.62 | 95.53 | 49.3 | 48 | 78.4 | 29.4 | 49 | 230 | 2.8 | —- | —— | 11.76 | 11.96 | 12.5 | 2.7 | 0.03 | 38 | 280.6 | 0.072 | 7.05 | 0.022 |
| RV22 | Mullugadde | Bore | 5.06 | 79.45 | 41.2 | 148 | 137.2 | 88.2 | 49 | 140 | 5.8 | —- | —— | 35.28 | 11.96 | 2 | 0.3 | 0.01 | 28.5 | 170.8 | 0.06 | 9.33 | 0.019 |
| RV23 | Nalligatte | OW | 6.33 | 92.32 | 47.74 | 18 | 68.6 | 29.4 | 39.2 | 280 | 0.08 | —- | —— | 11.76 | 9.56 | 2.4 | 0.7 | 0.01 | 28.5 | 341.6 | 0.084 | 0.67 | 0.002 |
| RV24 | Amparu | OW | 4.5 | 92.23 | 47.7 | 74 | 49 | 9.8 | 39.2 | 40 | 0.04 | —- | —— | 3.92 | 9.56 | 1.9 | 0.1 | 0.03 | 47.5 | 48.8 | 0.141 | 0.57 | 0.003 |
| RV25 | Hamsadi-Ullur | OW | 4.35 | 32.58 | 16.6 | 84 | 98 | 19.6 | 78.4 | 40 | 0.02 | —- | —— | 7.84 | 19.13 | 2.8 | 0.2 | 0.18 | 47.5 | 48.8 | 0.024 | 0.95 | 0.004 |
| RV26 | Muchattu | OW | 5.73 | 17.19 | 38.3 | 34 | 98 | 29.4 | 68.6 | 240 | 0.19 | —- | —— | 11.76 | 16.74 | 3.4 | 0.1 | 0.02 | 47.5 | 292.8 | 0.084 | 1.14 | 0.005 |
| RV27 | Amasebylu | Bore | 5.08 | 49.07 | 24.8 | 12 | 68.6 | 19.6 | 49 | 110 | 6.54 | —- | —— | 7.84 | 11.96 | 3.4 | 0.4 | 0.04 | 47.5 | 134.2 | 0.193 | 12.19 | 0.041 |
| RV28 | Barath Kal | RW | 6.3 | 38.9 | 19.6 | 53 | 68.6 | 19.6 | 49 | 110 | 0.09 | 8.4 | 1.0 | 7.84 | 11.96 | 2 | 0.5 | 0.03 | 47.5 | 134.2 | 0.122 | 1.62 | 0.005 |
| RV29 | Yodyadi Mathyadi | OW | 6.18 | 228.8 | 115.6 | 40 | 78.4 | 19.6 | 58.8 | 550 | 0.09 | —- | —— | 7.84 | 14.35 | 13.4 | 0.9 | 0.12 | 47.5 | 671.0 | 0.376 | 1.43 | 0.003 |
| RV30 | Anatha Mogere | OW | 5.44 | 33.22 | 16.95 | 112 | 98 | 19.6 | 78.4 | 90 | 0.06 | —- | —— | 7.84 | 19.13 | 2.9 | 0.1 | 0.05 | 38 | 109.8 | 0.013 | 1.52 | 0.008 |
| RV31 | Eskattur-Hyradi | Bore | 6.55 | 238.8 | 120.6 | 48 | 137.2 | 78.4 | 58.8 | 720 | 1.62 | —- | —— | 31.36 | 14.35 | 9.6 | 4 | 0.02 | 38 | 878.4 | 0.107 | 6.29 | 0.019 |
| RV32 | Kolkebylu-Shiriyur grama | OW | 5.58 | 66.6 | 33.97 | 108 | 29.4 | 9.8 | 19.6 | 300 | 0.16 | —- | —— | 3.92 | 4.78 | 5.7 | 0.3 | 0.13 | 47.5 | 366.0 | 0.084 | 1.33 | 0.022 |
| RV33 | Belur | OW | 6.53 | 148.5 | 75.07 | 243 | 98 | 39.2 | 58.8 | 290 | 0.11 | —- | —— | 15.68 | 14.35 | 10.9 | 0.7 | 0.12 | 95 | 353.8 | 0.474 | 2.38 | 0.046 |
| RV34 | Kota- Manurur | OW | 6.22 | 423 | 219.8 | 10 | 147 | 98 | 49 | 540 | 0.13 | —- | —— | 39.2 | 11.96 | 24.2 | 33.2 | 0.07 | 123.5 | 658.8 | 1.911 | 13.24 | 0.047 |
| RV35 | Kota-Manurur | OW | 5.6 | 161.4 | 83.37 | 7 | 68.6 | 29.4 | 39.2 | 210 | 0.08 | —- | —— | 11.76 | 9.56 | 13.6 | 6 | 0.15 | 47.5 | 256.2 | 1.045 | 4.86 | 0.008 |
| RV36 | Gundmi (Udupi) | OW | 5.56 | 185.8 | 96.85 | 98 | 78.4 | 39.2 | 39.2 | 200 | 1.4 | —- | —— | 15.68 | 9.56 | 14.7 | 2.6 | 0.02 | 95 | 244.0 | 0.367 | 2.57 | 0.006 |

All the values are in mg/L except Conductivity ($\mu$S/cm), pH and *E.coli* (CFU/100mL).

**Table 3: Characterization of water samples of Varahi river basin based on Piper tri-linear diagram**

| Subdivision of the diamond | Characteristics of corresponding subdivisions of diamond-shaped fields | Number and Percentage of samples in the category No. | % |
|---|---|---|---|
| 1 | Alkaline earth (Ca+Mg) exceed alkalies (Na+K) | 31 | 86.12 |
| 2 | Alkalies exceeds alkaline earths | 05 | 13.88 |
| 3 | Weak acids ($CO_3$+$HCO_3$) exceed Strong acids ($SO_4$+Cl) | 34 | 94.44 |
| 4 | Strong acids exceeds weak acids | 02 | 5.56 |

**Table 4: Variation in hydrochemical facies in the study area**

| Water Types | Sample no. | % |
|---|---|---|
| Mg-Ca-$HCO_3$-Cl | RV30, RV27, RV28, RV33, RV35, RV36 | 16.66 |
| Ca-Mg-$HCO_3$-Cl | RV1, RV34, | 5.55 |
| Mg-Ca-$HCO_3$ | RV2, RV3, RV8, RV9, RV10, RV11, RV12, RV13, RV14, RV20, RV21, RV23, RV26, RV31 | 38.89 |
| Mg-$HCO_3$ | RV4, RV6, RV29 | 8.34 |
| Mg-Ca-Cl-$HCO_3$ | RV5, RV19 | 5.55 |
| Ca-Mg-$HCO_3$ | RV7, RV22 | 5.55 |
| Na-Mg-Ca-Cl-$HCO_3$ | RV15 | 2.78 |
| Mg-Na-Ca-$HCO_3$-Cl | RV16 | 2.78 |
| Na-Mg-Cl-$HCO_3$ | RV17 | 2.78 |
| Na-Mg-Cl | RV18 | 2.78 |
| Mg-$HCO_3$-Cl | RV32 | 2.78 |
| Mg-Cl-$HCO_3$ | RV24 | 2.78 |
| Mg-Ca-Cl | RV25 | 2.78 |

Majority of the samples belong to $Ca^{2+}$-$Mg^{2+}$-$HCO_3^-$ type followed by $Ca^{2+}$-$Mg^{2+}$-$Cl^-$-$SO_4^{2-}$ in the study area (Fig 2). Ca-Mg type of water predominated during pre-monsoon season, accounting to 86.12% of the samples (Table 3). Similarly, for anion concentration, $HCO_3$–type of water predominated

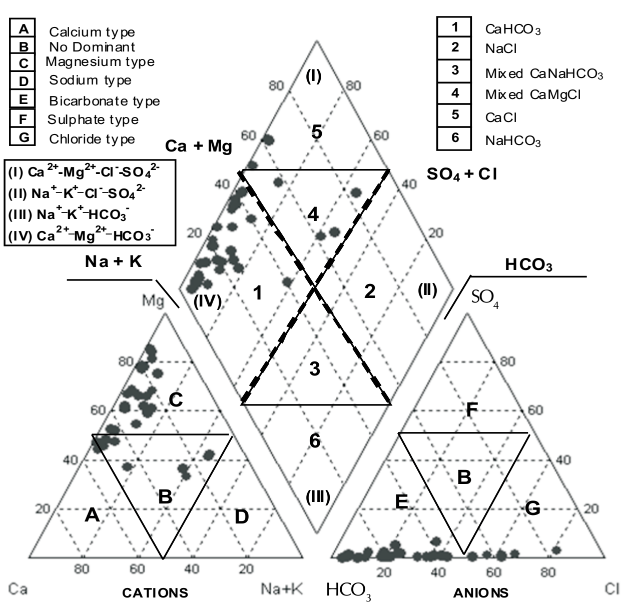


**Figure 2: Piper trilinear diagram**

**Table 5: Irrigation water quality parameters of water samples from the Varahi command area (pre-monsoon, 2005)**

| Sample ID | Percent Sodium (% Na) | Sodium Absorption Ratio (SAR) | Residual Sodium Carbonate (RSC) |
|---|---|---|---|
| RV1 | 16.74 | 0.15 | -4.887 |
| RV2 | 5.70 | 0.40 | 0.429 |
| RV3 | 7.00 | 0.96 | 0.637 |
| RV4 | 3.92 | 0.44 | 0.018 |
| RV5 | 7.62 | 0.37 | -0.965 |
| RV6 | 6.82 | 0.99 | 5.430 |
| RV7 | 8.65 | 1.03 | 14.452 |
| RV8 | 9.11 | 0.88 | 9.652 |
| RV9 | 11.48 | 0.98 | 6.463 |
| RV10 | 12.74 | 1.12 | 8.470 |
| RV11 | 7.01 | 1.14 | 5.636 |
| RV12 | 17.91 | 1.63 | 14.699 |
| RV13 | 8.59 | 2.07 | 1.644 |
| RV14 | 6.99 | 0.71 | 1.236 |
| RV15 | 16.22 | 21.86 | 3.896 |
| RV16 | 19.88 | 21.16 | 12.112 |
| RV17 | 38.80 | 42.42 | 5.395 |
| RV18 | 22.00 | 31.81 | -2.086 |
| RV19 | 7.14 | 3.21 | -0.363 |
| RV20 | 7.32 | 0.60 | -0.564 |
| RV21 | 5.76 | 2.00 | 3.028 |
| RV22 | 8.63 | 0.24 | 0.055 |
| RV23 | 4.90 | 0.41 | 4.226 |
| RV24 | 3.91 | 0.38 | -0.182 |
| RV25 | 7.62 | 0.40 | -1.165 |
| RV26 | 7.30 | 0.49 | 2.835 |
| RV27 | 5.21 | 0.58 | 0.824 |
| RV28 | 5.21 | 0.34 | 0.824 |
| RV29 | 6.03 | 2.14 | 9.426 |
| RV30 | 7.62 | 0.41 | -0.165 |
| RV31 | 9.04 | 1.16 | 11.652 |
| RV32 | 2.30 | 1.49 | 5.410 |
| RV33 | 7.00 | 1.56 | 3.836 |
| RV34 | 9.96 | 2.82 | 7.858 |
| RV35 | 5.03 | 2.32 | 2.826 |
| RV36 | 5.44 | 2.35 | 2.430 |

**Table 6: Classification of waters based on of EC (Handa, 1969)**

| EC (mS/cm) | Water Salinity | Range (No. of samples) | % |
|---|---|---|---|
| 0-250 | Low (Excellent quality) | 17.19-245.2 (29 samples) | 80.55 |
| 251-750 | Medium (Good quality) | 272.3-423 (03 samples) | 8.33 |
| 751-2250 | High (Permissible quality) | 1428-1562 (02 samples) | 5.56 |
| 2251-6000 | Very High | 2364-4562 (02 samples) | 5.56 |
| 6001-10000 | Extensively High | —— | —— |
| 10001-20000 | Brines weakly conc. | —— | —— |
| 20001-50000 | Brines moderately conc. | —— | —— |
| 50001-100000 | Brines highly conc. | —— | —— |
| > 100000 | Brines extremely high conc. | —- | —- |

during pre-monsoon with 94.44 % samples. There is no significant change in the hydro-chemical facies noticed during the study period, which indicates that most of the major ions

**Table 7: Salinity classification based on total dissolved solids**

| TDS (mg/L) | Classification | Range (No. of samples) |
|---|---|---|
| <1,000 | Fresh | 16.53-803.3 (34 samples) |
| 1,000–3,000 | Slightly saline | 1209-2369 (02 samples) |
| 3,000–10,000 | Moderately saline | ——- |
| 10,000–35,000 | High saline | ——- |

**Table 8: Salinity hazard classes**

| Salinity hazard class | EC in (mS/cm) | Remark on quality | Range (No. of samples) |
|---|---|---|---|
| C1 | 100-250 | Excellent | 136.7-245.2 (13) |
| C2 | 250-750 | Good | 272.3-426 (03) |
| C3 | 750-2250 | Doubtful | 1428-1562 (02) |
| C4 & C5 | >2250 | Unsuitable | 2364-4562 (02) |

**Table 9: Sawyer and McCarty's classification for water based on hardness**

| TH as $CaCO_3$ (mg/L) | Water classes | Range (No. of samples) | % |
|---|---|---|---|
| < 75 | Soft | 29.4-68.6 (07) | 19.44 |
| 75-150 | Moderately hard | 78.4 – 147 (21) | 58.34 |
| 150-300 | Hard | 166.6-294.0 (06) | 16.66 |
| > 300 | Very hard | 303.8-529.2 (02) | 5.56 |

**Table 10: Classification of water based on SAR values (Todd, 1959; Richards, 1954) and Sodium hazard classes based on USSL classification**

| SAR values | Sodium Hazard class | Remark on quality | Range (No. of samples) |
|---|---|---|---|
| < 10 | S1 | Excellent | 0.15 – 3.21 (32 samples) |
| 10 - 18 | S2 | Good | —— |
| 19-26 | S3 | Doubtful/Fair poor | 21.16-21.86 (02 samples) |
| >26 | S4 and S5 | Unsuitable | 31.81-42.42 (02 samples) |

**Table 11: Sodium percent water class**

| Wilcox's (1955) Classification | | | Eaton's (1950) Classification | | |
|---|---|---|---|---|---|
| %Na | Water class | Range (No. of Samples) | % Na | Water class | Range (No. of Samples) |
| <20 | Excellent | 2.3 – 19.88 (34) | >60 | Unsafe | ——- |
| 20-40 | Good | 22.0-38.8 (02) | <60 | Safe | 2.3-38.8 (36) |
| 40-60 | Permissible | ——- | | | |
| 60-80 | Doubtful | ——- | | | |
| >80 | Unsuitable | ——- | | | |

**Table 12: water quality based on RSC (after Richards, 1954)**

| RSC (epm) | Remark on quality | Range (No. of Samples) |
|---|---|---|
| <1.25 | Good | (-4.88)-1.236 (15 samples) |
| 1.25-2.50 | Doubtful | 1.644-2.43 (02 samples) |
| >2.50 | Unsuitable | 2.826- 16.69 (19 samples) |

are natural in origin. The reason is water passing through igneous rocks dissolves only small quantities of mineral matters because of the relative insolubility of the rock composition.

The Piper trilinear graphical representation of chemical data of representative samples from the study area during pre-monsoon season (2005), clearly explains that the variations or domination of cation and anion concentrations, similarities/

**Table 13: Correlation matrix of analyzed groundwater quality parameters**

| | pH | EC | TDS | E.Coli | TH | CaH | MgH | TA | $Fe^{2+}$ | $Ca^{2+}$ | $Mg^{2+}$ | $Na^{+}$ | $K^{+}$ | $F^{-}$ | $Cl^{-}$ | $HCO_3^{-}$ | $NO_3^{-}$ | $SO_4^{2-}$ | $PO_4^{3-}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | 1.000 | | | | | | | | | | | | | | | | | | |
| EC | -.493 | 1.000 | | | | | | | | | | | | | | | | | |
| TDS | -.491 | .999 | 1.000 | | | | | | | | | | | | | | | | |
| E.Coli | .085 | .045 | .040 | 1.000 | | | | | | | | | | | | | | | |
| TH | -.272 | .868 | .872 | .006 | 1.000 | | | | | | | | | | | | | | |
| CaH | .036 | .627 | .635 | -.042 | .896 | 1.000 | | | | | | | | | | | | | |
| MgH | -.487 | .932 | .932 | .045 | .927 | .665 | 1.000 | | | | | | | | | | | | |
| TA | .209 | .388 | .401 | -.189 | .538 | .578 | .418 | 1.000 | | | | | | | | | | | |
| Fe | -.693 | .684 | .683 | -.084 | .596 | .359 | .700 | .288 | 1.000 | | | | | | | | | | |
| Ca | .036 | .627 | .635 | -.042 | .896 | 1.000 | .665 | .578 | .359 | 1.000 | | | | | | | | | |
| Mg | -.487 | .932 | .932 | .045 | .927 | .665 | 1.000 | .418 | .700 | .665 | 1.000 | | | | | | | | |
| Na | -.483 | .995 | .994 | .063 | .853 | .609 | .922 | .355 | .647 | .609 | .922 | 1.000 | | | | | | | |
| K | -.233 | .717 | .715 | -.187 | .664 | .609 | .605 | .478 | .396 | .609 | .605 | .691 | 1.000 | | | | | | |
| F | -.361 | .831 | .845 | .077 | .719 | .530 | .763 | .529 | .518 | .530 | .763 | .840 | .602 | 1.000 | | | | | |
| Cl | -.518 | .993 | .992 | .072 | .837 | .587 | .913 | .333 | .672 | .587 | .913 | .995 | .697 | .833 | 1.000 | | | | |
| $HCO_3$ | .209 | .388 | .401 | -.189 | .538 | .578 | .418 | 1.000 | .288 | .578 | .418 | .355 | .478 | .529 | .333 | 1.000 | | | |
| $NO_3$ | .336 | .248 | .240 | -.049 | .253 | .375 | .109 | .259 | -.237 | .375 | .109 | .257 | .602 | .221 | .252 | .259 | 1.000 | | |
| $SO_4$ | -.419 | .895 | .890 | .116 | .769 | .531 | .846 | .328 | .713 | .531 | .846 | .886 | .683 | .722 | .878 | .328 | .184 | 1.000 | |
| $PO_4$ | -.144 | -.074 | -.076 | .127 | -.156 | -.171 | -.118 | -.159 | -.050 | -.171 | -.118 | -.064 | -.059 | -.083 | -.067 | -.159 | -.071 | -.077 | 1.000 |
| | ± .329 | critical value .05 (two-tail) | | | | sample size = 36 | | | | | | | | | | | | | |
| | ± .424 | critical value .01 (two-tail) | | | | | | | | | | | | | | | | | |

**Table 14. Group of clustered stations during pre-monsoon season**

| Groups | Sampling stations |
|---|---|
| A | RV1, RV2, RV3, RV4, RV5, RV6, RV7, RV8, RV9, RV10, RV11, RV12, RV13, RV14, RV19, RV20, RV21, RV22, RV23, RV24, RV25, RV26, RV27, RV28, RV29, RV30, RV31, RV32, RV33, RV34, RV35, RV36. |
| B | RV 15, RV16, RV18 |
| C | RV17 |

dissimilarities and different water types (viz., hydrochemical facies) in the study area, which are identified and listed in Table 4.

### Irrigational Quality Parameters

Irrigation water Quality Parameters of water samples collected in the Varahi command area during Pre-monsoon season (March, 2005) is given in Table 5.

### Salinity Index

The water samples can classified into various classes based on Handa's Classification and it was found that the pre-monsoon samples were categorized under low to very high extensive salinity classes (Table 6). Majority of samples belongs to low (80.55 %) and medium (8.33 %) salinity category indicating that the water is of excellent to good quality. Similarly, it is apparent from the salinity classification based on total dissolved solids that majority of the samples belong to fresh (94.44 %) to slightly saline (5.56 %) category (Table 7).

### Salinity Hazard

The total concentration of soluble salts (salinity hazard) in irrigation water can be expressed in terms of specific conductance (*i.e.,* conductivity) and the samples that fall in the low salinity hazard class (C1) can be used for irrigation of most crops and majority of soils. However, some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability. The samples that fall in medium salinity hazard class (C2) can be used if a moderate amount of leaching occurs. High salinity/low sodium water (C4 and C5) can be suitable for plants having good salt tolerance but restricts its suitability for irrigation, especially in soils with restricted drainage (Karanth, 1989; Mohan *et al.*, 2000). High salinity water (C3, C4, and C5) cannot be used in soils with restricted drainage. Even with adequate drainage, special management / attention for salinity control is required and crops with good salt tolerance should be selected. It is apparent from the classification based on salinity hazard (Table 8) that 16 samples were found to be excellent (C1) to good (C2) for irrigation purposes during pre-monsoon season and only four samples each belongs to doubtful to unsuitable category. Remaining 16 samples having EC value less than 100 mS/cm (viz., 17.19 to 95.53 mS/cm) could also be considered as suitable for irrigation.

### Total Hardness (TH)

In determining the suitability of water for domestic and industrial purposes, hardness is also an important criterion as it is responsible for making the water hard. Hence, classification of water of the study area based on hardness (Sawyer and McCarthy, 1967) has been carried and is presented in Table 9. Accordingly 21 samples (58.34 %) collected during pre-monsoon season of the year 2005 fall under moderately hard category, while 7 samples belongs to soft and remaining 8 samples to hard to very hard category.

### Sodium Absorption Ratio (SAR)

Sodium absorption ratio (SAR) is considered as a better measure of sodium (alkali) hazard in irrigation as SAR of water is directly related to the adsorption of sodium by soil and is a valuable criterion for determining the suitability of the water for irrigation. Excessive sodium content relative to the calcium and magnesium may deteriorate the soil characteristics, thereby reduces the soil permeability and inhibits the supply of water needed for the crops. The SAR measures the relative proportion of sodium ions in a water sample to those of calcium and magnesium. The SAR is used to predict the sodium hazard of high carbonate waters especially if they contain no residual alkali. The excess sodium or limited calcium and magnesium are evaluated by SAR (Kalra and Maynard, 1991) which is computed as

$$SAR = \frac{Na^+}{\sqrt{(Ca^{2+} + Mg^{2+})/2}} \quad \text{..... Equation (1)}$$

where all cationic concentrations are expressed in epm or meq/L.

According to the classification of water samples (Table 10) from the study area with respect to SAR (Todd, 1959), majority of the samples (88.88 %) were under excellent category (S1).

### Percent sodium (% Na)

Methods of Wilcox (1995) and Richards (1954) have been used to classify and understand the basic character of the chemical composition of water, since, the suitability of the water for irrigation depends on the mineralization of water and its effect on plants and soil. Percent sodium can be determined using the following formula:

$$\%Na = \frac{(Na^+ + K^+)X100}{(Ca^{2+} + Mg^{2+} + Na^+ + K^+)} \quad \text{.......... Equation (2)}$$

where the quantities of $Ca^{2+}$, $Mg^{2+}$ $Na^+$ and $K^+$ are expressed in milliequivalents per litre (meq/L).

Based on the classification of water samples with respect to percent sodium (Table 11), all the samples (100 %) belong to excellent to good category. Based on Eaton's (1950) classification, all the samples belong to safe category (Table 10).

### Residual Sodium Carbonate (RSC)

In addition to the SAR and % Na, the excess sum of carbonate and bicarbonate in water over the sum of calcium and magnesium also influences the suitability of water for irrigation. Because, 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. An excess quantity of sodium bicarbonate and carbonate is considered to be detrimental to the physical properties of soils as it causes dissolution of organic matter in the soil, which in turn leaves a black stain on the soil surface on drying. As a result, the relative proportion of sodium in the water is increased in the form of sodium carbonate and this excess is denoted by Residual Sodium Carbonate (RSC) is calculated as follows (Eaton, 1950; Ragunath, 1987):

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+}) \quad \text{....... Equation (3)}$$

where all ionic concentrations are expressed in epm or meq/L. Classification of water samples on the basis of RSC is given in Table 12 and accordingly, only 15 samples (41.66 %) showed RSC values less than 1.25 meq/L indicating that water samples were good for irrigation purpose, while other samples were considered to be doubtful or unsuitable for irrigation. The positive RSC values in 28 samples indicated that dissolved $Ca^{2+}$ and $Mg^{2+}$ ions were less than that of $CO_3^{2-}$ and $HCO_3^-$ contents.

**Mechanisms controlling groundwater chemistry**

Lastly, to know the groundwater chemistry and relationship of the chemical components of water from their respective aquifers such as chemistry of the rock types, chemistry of precipitated water and rate of evaporation, Gibbs (1970) has suggested a diagram in which ratio of dominant anions and cations are plotted against the value of total dissolved solids (TDS). Gibbs diagrams, representing the ratio-I for cations [(Na+K)/(Na+K+Ca)] and ratio-II for anions [Cl/(Cl+ $HCO_3$)] 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 (Gibbs, 1970). The chemical data of groundwater samples are plotted in Gibbs diagram (Fig. 3, 4). Majority of the water samples suggest that the chemical weathering of rock-forming minerals are influencing the groundwater quality

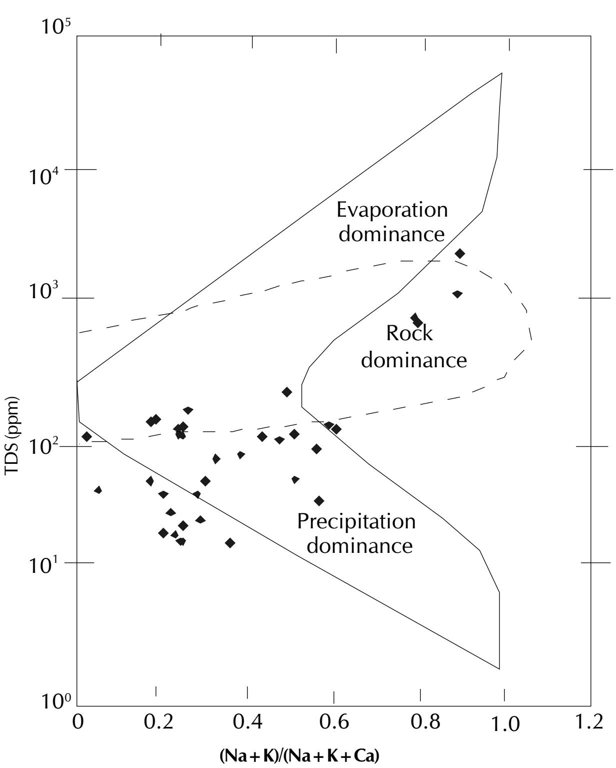


**Figure 3: Gibbs variation diagram (TDS vs. [(Na+K)/(Na+K+Ca)]**

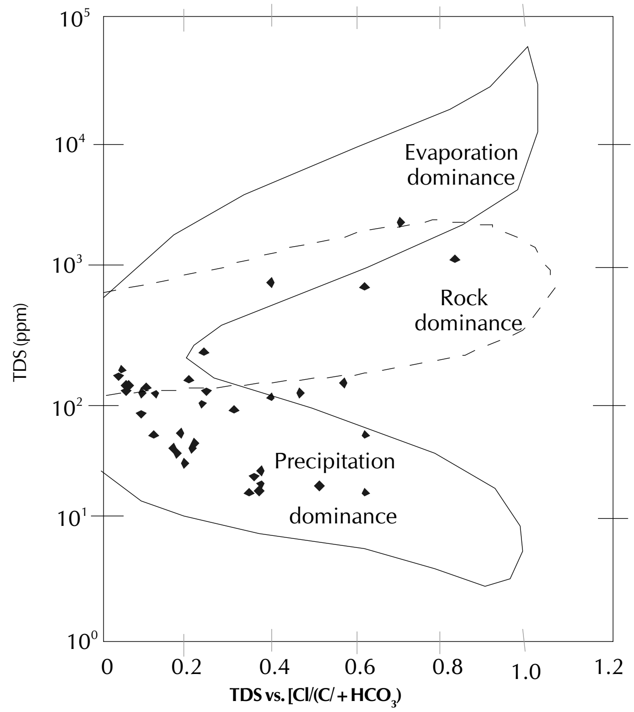


**Figure 4: Gibbs variation diagram (TDS vs. [Cl/(C/+$HCO_3$)])**

by dissolution of rock through which water is circulating, although, few samples represent precipitation dominance. Most of the samples falling in the precipitation dominance give an indication that the aquifer recharging is by means of rain / river water.

**Statistical analysis**

**Correlation matrix**

The Pearson's correlation matrix to find the relationships between two or more variables was carried out using STATISTICA v7.0 (Swan and Sandilands, 1995) as it describes the interrelationship among various variables (Fig. 5). The correlation matrix of analyzed groundwater quality parameters are presented in Table 13 and it was found that samples showing $r > 0.424$ were considered to be strongly correlated at a significance level (p) of $<0.01$, whereas other significant correlation ($r > 0.329$–$0.424$) shows moderate correlation at a significance level (p) of $<0.05$. Correlation analysis of the data shows that some parameters have strong association with other parameters and they share a common origin source and their tendency to follow a similar trend (e.g., due to concentration by water–rock interaction and ion exchange). Other significant correlation (samples showing $r < 0.329$, at a significance level (p) of $<0.05$) was also exhibited between the parameters as shown in Table 13.

**Cluster analysis (CA)**

Cluster analysis (CA) is a multivariate technique, whose primary purpose is to classify the objects of the system into categories or clusters based on their similarities, and the objective is to find an optimal grouping for which the observations or objects within each cluster are similar, but the clusters are dissimilar to each other. CA was applied to water quality data using a single linkage method, wherein the distances or similarities between two clusters A and B are defined as the minimum


**Figure 5: Pearson's correlation matrix of the hydrochemical data**

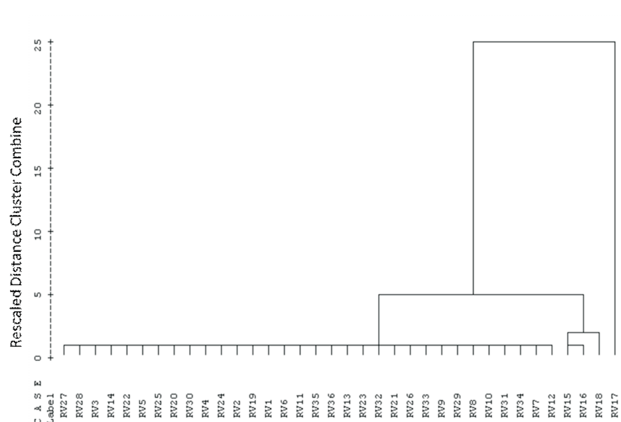


**Figure 6: Dendrogram showing clustering of sampling sites in the Varahi river basin**

distance between a point in A and a point in B:

**D(A, B) = min {d($x_i$, $x_j$), for $x_i$ in A and $x_j$ in B}** .... Equation (4)

where d(xi, xj) is the Euclidean distance in Equation (4). At each step the distance is found for every pair of clusters and the two clusters with smallest distance (largest similarity) are merged. After two clusters are merged the procedure is repeated for the next step: the distances between all pairs of clusters are calculated again, and the pair with minimum distance is merged into a single cluster. Eventually as the similarity decreases, all subgroups are merged into a single cluster (Lattin *et al.,* 2003; McKenna, 2003). The Euclidean distance usually gives the similarity between two samples, and a distance can be represented by the difference between transformed values of the samples (Otto, 1998). The result of a hierarchical clustering procedure can be displayed graphically using a tree diagram, also known as a dendrogram (Johnson and Wichern, 2002; Alvin, 2002).

In the present study, hierarchical CA was performed on the standardized data using single linkage method (linkage between groups) with Euclidean distances as a measure of similarity and was amalgamated into dendrogram plot. All the physico-chemical characteristics were used as variables to show the spatial heterogeneity among the stations as a result of sequence in their relationship and the degree of contamination. Accordingly, Dendrogram classified the 36 monitoring sites in the Varahi river basin into three groups (Group A, Group B, and Group C) based on similarities of water quality characteristics (Fig. 6; Table 14). The group classifications varied with significance level, because the sites in these groups had similar features and natural backgrounds that were affected by similar sources. It is evident from the Fig 6 that sampling stations in Group A were free from major point and non-point pollution sources, could be categorized as less polluted and less noticeable spatial variation. The sampling stations in Groups B even though appears to have less noticeable spatial variation, they formed different cluster. It is also apparent from the Spatial-CA as enunciated by Euclidian distance that, sampling station, RV17 in Group C alone formed a group with highest Euclidian distance compared to other cluster groups reflecting noticeable spatial variation in the physicochemical parameters and appears to be highly polluted, marginally free from major point and non-point pollution sources.

## CONCLUSIONS

The groundwater sources in the Varahi River Basin, Udupi District were evaluated for their chemical composition and suitability for drinking and irrigation purposes. TDS value indicates that the water samples are fresh to slightly saline in nature. The groundwater in the region is classified as soft to very hard category based on hardness. The suitability of groundwater for irrigation was evaluated based on the irrigation quality parameters like SAR, % Na and RSC. Based on SAR and Percent sodium values, majority of the samples were safe and excellent for irrigation respectively, while RSC values indicated that the major portion of the samples were unsuitable for Irrigation purpose. Positive value of RSC in majority of samples signifying higher concentration of $HCO_3$ over alkaline earths indicates that groundwater from are base exchange-softened water as there is exchange of alkaline earths for $Na^+$ ions. Water samples that are not suitable based on the above classification may be suitable in well-drained soils. Further, Gibbs plot indicates that the chemistry of groundwater of the area is predominantly controlled by precipitation, as majority of the samples falls in the precipitation dominance giving an indication that the aquifer recharging is by means of rain / river water. In addition to this, an interaction exists between the lithological units and the percolating water into the subsurface as depicted by few samples in the rock dominance zone. Hence, it can be concluded that the overall quality of groundwater is controlled by lithology apart from other local environmental conditions and anthropogenic activities.

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## REFERENCES

**Alvin, C. R. 2002.** Methods of multivariate analysis. Wiley INC, USA.

**American Public Health Association (APHA). 2005.** Standard method for examination of water and wastewater, 21st Edn. APHA, AWWA, WPCF, Washington DC, USA.

**Ayers, R. S. and Westcot, D. W. 1994.** *Water quality for agriculture: FAO Irrigation and Drainage Paper 29. Rev. 1* (pp. 1–130).

**BIS. 1991.** Drinking Water Specifications. Bureau of Indian Standards, IS: 10500 (Revised 2003).

**Ding, H. and Zhang, J. 2002.** The problem of environment caused by groundwater level continuous decline in the inland basins of arid area, Northwest China—an example in middle reaches of Heihe river basin (in Chinese). *Hydrogeol Eng. Geol.* **3:**71–75.

**Eaton, E. M.1950.** Significance of carbonate in irrigation water. *Soil Sci.* **69:** 12-133.

**Gibbs, R. J. 1970.** Mechanism controlling world water chemistry. *Science.* **170:**1088-1090.

**Johnson, R. A. and Wichern, D. W. 2002.** Applied multivariate statistical analysis. Prentice-Hall, London.

**Kalra, Y. P. and Maynard, D. G. 1991.** Methods Manual for Forest Soil and Plant Analysis, *Information Report NOR-X-319*, Northwest Region, Northern Forestry Centre, Forestry Canada.

**Karanth, K. R. 1989.** Hydrogeology. Tata Mc Graw Hill Publ. Co. Ltd., New Delhi. pp. 1-455.

**Lattin, J., Carroll, D. and Green, P. 2003.** Analyzing Multivariate Data. New York, Duxbury.

**Mohan, R., Singh, A. K., Tripathi, J. K. and Choudhry, G. C. 2000.** Hydrochemistry and quality assessment of ground water in Naini industrial area Allahabad District, Uttar Pradesh. *J. the Geological Society of India.* **55:** 77–89.

**McKenna, J. E., Jr. 2003.** An enhanced cluster analysis program with bootstrap significance testing for ecological community analysis. *Environmental Modelling and Software.* **18(2):** 205–220. (DOI:10.1016/S1364- 8152(02)00094-4).

**Otto, M. 1998.** Multivariate methods. In: Kellner, R., Mermet, J. M., Otto, M. and Widmer, H. M. (Eds.), Analytical chemistry. Weinheim: Wiley-VCH.

**Piper, A. M. 1994.** A geographic procedure in the geochemical interpretation of water analysis. *Trans. Am. Geophysics Union.* Washington, D.C.v.**25.**pp. 914-928, Washington D.C.v.25

**Ragunath, H. M. 1987.** Groundwater. Wiley Eastern, New Delhi, p. 563.

**Richards, L. A. (U.S. Salinity Laboratory) 1954.** Diagnosis and improvement of saline and alkaline soils, U.S. Department of Agriculture Hand Book. p. 60.

**Sawyer, G. N. and McCarthy, D. L. 1967.** Chemistry of Sanitary Engineers, 2nd Ed, McGraw Hill, New York, p. 518.

**Swan, R. H. and Sandilands, M. 1995.** Introduction to geological data analysis, Blackwell, Inc., USA.

**Tang, Q. and Zhang, J. 2001.** Water resources and eco-environment protection in the arid regions in northwest of China (in Chinese). *Prog. Geogr.* **20(3):** 227–233

**Tatawat, R. K. and Chandel, C. P. S. 2008.** A hydrochemical profile for assessing the groundwater quality of Jaipur City. *Environ. Monit. Assess.* **143:** 337–343.

**Todd, D. K. 1959.** Groundwater Hydrology. John Wiley and Sons. p. 535.

**Tyagi, S. K., Datta, P. S. and Pruthi, N. K. 2008.** Hydrochemical appraisal of groundwater and its suitability in the intensive agricultural area of Muzaffarnagar district, Uttar Pradesh, India. *Environ Geol., (*DOI 10.1007/s00254-008-1190-7).

**Wang, G., Cheng, G. and Yang, Z. 1999.** The utilization of water resources and its influence on eco-environment in the northwest arid area of China (in Chinese). *J. Nat. Resour.* **14(2):** 109–116.

**WHO. 1984.** Guidelines for Drinking Water Quality in Health Criteria and other supporting informations. **2:** 336. World Health Organization, Geneva.

**Wilcox, L. V. 1995.** Classification and use of irrigation waters, US Department of Agriculture, *Washington DC*. p. 19.