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Quality of Bore-Well Water in Udupi Municipal Area

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Abstract

Groundwater is the largest source of usable fresh water in the world. A special significance is emphasized on study of groundwater quality for drinking, industrial and domestic water supply. Most of the population of Udupi district completely depends on groundwater for their drinking, domestic and irrigation purposes. Hence, in this study, about 35 bore-well water samples were collected from 35 different wards of Udupi municipal area. For each groundwater sample, about 26 water quality parameters, such as pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness, total alkalinity, sodium, ammonium, potassium, magnesium, calcium, fluoride, chloride, nitrate, sulphate, phosphate, hydroxide, bicarbonate, carbonate, copper, chromium, manganese, iron, cobalt, nickel, cadmium and lead were determined. Conductivity and pH meter were used for the analysis of pH, electrical conductivity and total dissolved solids. Titration was used for analysis of total hardness and total alkalinity. Ion chromatography method was used for analyzing groundwater samples for cations and anions. Whereas, atomic absorption spectrometer was used for the analysis of groundwater samples for heavy metals. The study aims at studying the hydrogeochemical relationship of groundwater using Piper's trilinear diagram and understanding the suitability of groundwater for drinking and irrigation purposes. Also, ArcGIS-9.2 software was used to represent the spatial distribution of water quality index in the study area.

Keywords: ***Bore-wells; Groundwater quality; Inverse distance weighing method; Piper's trilinear diagram; Water quality index (WQI)***

Introduction

Groundwater is a major source for drinking, domestic and irrigation purposes in Udupi municipal area. It is considered as one of the purest forms of water available in nature and meets most of the demands of both rural and urban population [1]. Accordingly, it is absolutely essential to preserve the available groundwater resources and maintain their quality. However, the quality of groundwater is found to be controlled by rock-water interaction and residence time of water in groundwater aquifers [2]. It is also virtually affected by almost every activity of the society such as excessive draining of groundwater or addition of wastes and chemicals through various industries, agro effluents and so on, thereby making groundwater protection very complicated [3]. It should be noted that protection of groundwater is always easier than restoring already polluted aquifer. Hence, the study of groundwater quality is essential. In order to assess the quality of groundwater in the study area, the following objectives are envisaged:

- To assess the physico-chemical characteristics of bore-well water samples.

- To categorize the quality of groundwater and to study the hydrogeochemical relationship of groundwater, by making use of Piper's trilinear diagram.
- To compute water quality index (WQI), in order to assess the suitability of groundwater for drinking purposes.
- To assess the suitability of groundwater for irrigation purposes.
- To construct spatial distribution map, in order to study spatial distribution of WQI in the study area.

Study area

The considered area for study is Udupi municipal area (FIG. 1 and 2). Udupi, which is located in the South-Western part of Karnataka, with the co-ordinates 13° 20' 18" N and 74° 44' 54" E. It is the headquarters of Udupi district. With an elevation of 39 m above sea level and a total area of 68.23 km^2. Udupi roughly has a population density of 2,400 per km^2.

FIG. 1. **Location of Udupi.**

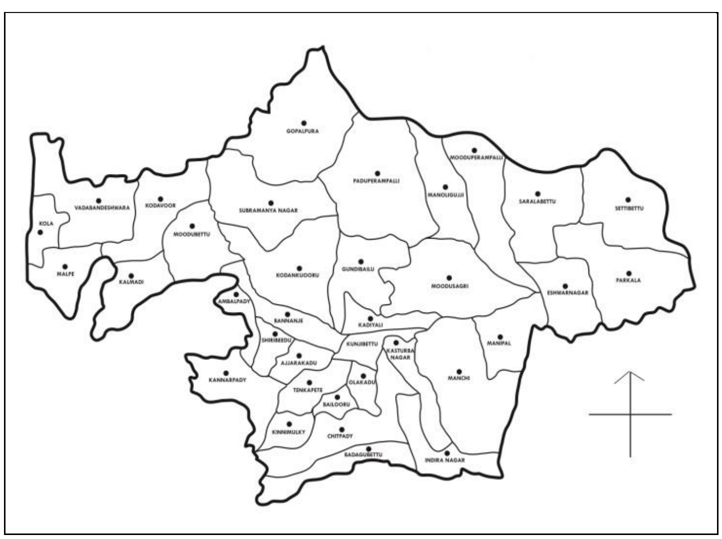

FIG. 2. **Udupi municipal area.**

Udupi Municipal area consists of 35 wards. The climate in Udupi is usually tropical and shares the wider climatic pattern of the other west coast places in India. During the greater part of the year, it is characterized by excessive humidity (approximately 78%). The temperature in Udupi is usually between 32°C and 20°C, with a maximum of 40°C during summer season.

Material and Method

A total of 35 bore-well water samples were collected from 35 wards of Udupi municipal area, at a count of one bore-well water sample per municipal ward. The samples were collected in properly cleaned polythene bottles of 500 ml capacity.

The groundwater samples were analyzed for pH, electrical conductivity, total dissolved solids, total hardness, total alkalinity (bicarbonates, carbonates, hydroxides), fluoride, chloride, nitrate, sulphate, phosphate, sodium, ammonium, potassium, magnesium, calcium, copper, chromium, manganese, iron, cobalt, nickel, cadmium and lead [4]. All the samples were analyzed using standard procedures as specified by Central Pollution Control Board. pH was analyzed by pH meter, electrical conductivity and total dissolved solids were analyzed using conductivity meter, and total hardness and total alkalinity (bicarbonates, carbonates, hydroxides) were analyzed by titration method. All cations and anions were analyzed by ion chromatography method and all heavy metals by using atomic absorption spectrometer.

Piper's trilinear diagram was plotted to categorize the groundwater quality and to study the hydrogeochemical relationship of groundwater. Also, all the samples were checked for suitability for drinking and irrigation purposes. Finally, spatial distribution map was constructed using ArcGIS 9.2 software.

Results and Discussion

Physico-chemical analysis results of bore-well water samples of Udupi municipal area are given in TABLE 1. Most of the parameters are well within the permissible limits of IS: 10500-2012 [5], except for sodium, ammonium, potassium, calcium, phosphate, chromium and iron.

Sodium concentration in groundwater samples varied from 2.799 mg/L to 224.646 mg/L, with an average of 39.978 mg/L. Only two water samples have crossed the permissible limit. High sodium concentration in water limits its use for irrigation.

Ammonium concentration in groundwater samples varied from 0 mg/L to 4.212 mg/L, with an average of 0.517 mg/L. About 9 water samples have crossed the permissible limit. Ammonium in drinking water is not of immediate health relevance, however alters the odour and taste of water. But, excess of ammonium in groundwater might lead to nitrification or chlorine residuals loss.

Potassium concentration in groundwater samples varied from 0.67 mg/L to 144.853 mg/L, with an average of 11.321 mg/L. About 7 water samples have crossed the permissible limit. Potassium is a dietary requirement for most of the organisms. Also, potassium plays a critical role in plant growth. However, excess potassium in hazardous in water as it spreads rapidly because of its high mobility.

Calcium concentration in groundwater samples varied from 2.931 mg/L to 313.619 mg/L, with an average of 40.371 mg/L. Only one water sample has crossed the permissible limit. Excess calcium in water is not suitable for domestic and drinking purposes, as it leads to intestinal diseases and stone problems.

Phosphate concentration in groundwater samples varied from 0 mg/L to 3.396 mg/L, with an average of 0.322 mg/L. About 10 water samples have crossed the permissible limit. Phosphate is one of the key requirements for plant growth.

Chromium concentration in groundwater samples varied from 0.004 mg/L to 0.056 mg/L, with an average of 0.035 mg/L. Only two water samples have crossed the permissible limit. The fate of chromium in groundwater depends on the form of chromium present (trivalent or hexavalent).

Trivalent chromium is considered as a required nutrient and is not toxic. Whereas, hexavalent chromium is proven to be carcinogenic.

TABLE 1. **Analysis results and permissible limits as per IS: 10500-2012.**

S. No.	Parameter	Maximum	Minimum	Average	Permissible limits (IS: 10500- 2012)
1	pH	7.69	4.93	6.35	6.5-9.2
2	Electrical conductivity (µS cm-1)	975.2	30.7	374.06	1000
3	Total dissolved solids (mg/L)	465.2	46.62	183.37	2000
4	Total hardness (mg/L)	208.8	18	77.24	600
5	Total alkalinity (mg/L)	212	32	77.82	600
6	Sodium (mg/L)	224.646	2.799	39.978	150
7	Ammonium (mg/L)	4.212	0	0.517	0.5
8	Potassium (mg/L)	144.853	0.67	11.321	12
9	Magnesium (mg/L)	28.428	0.796	8.199	100
10	Calcium (mg/L)	313.619	2.931	40.371	200
11	Fluoride (mg/L)	1.422	0	0.22	0.6-1.5
12	Chloride (mg/L)	62.105	0.764	14.973	1000
13	Nitrate (mg/L)	17.563	0	3.238	45
14	Sulphate (mg/L)	9.282	0	2.098	400
15	Phosphate (mg/L)	3.396	0	0.322	0.1
16	Copper (mg/L)	0.782	0.002	0.058	1.5
17	Chromium (mg/L)	0.056	0.004	0.035	0.05
18	Manganese (mg/L)	0.205	0.005	0.055	0.3
19	Iron (mg/L)	1.894	0.008	0.644	0.3
20	Cobalt (mg/L)	BDL	BDL	BDL	0.002
21	Nickel (mg/L)	BDL	BDL	BDL	0.02
22	Cadmium (mg/L)	BDL	BDL	BDL	0.003
23	Lead (mg/L)	BDL	BDL	BDL	0.01

Iron concentration in groundwater samples varied from 0 mg/L to 0.644 mg/L. Only three water samples indicated the presence of iron, which may be due to corrosion of bore-well equipment because of low pH water.

Hydro-geochemical relationship and water type

It is evident from Piper's trilinear diagram (FIG. 3) that sodium and potassium were dominant among all the cations, suggesting that 42.85% of the samples were sodium and potassium rich water. About 37.14% of samples have no dominant cation, indicated by those plotted near the central zone. Also, 5.7% of samples were magnesium rich and 14.28% were calcium rich. Also, all the samples are categorized as bicarbonate rich water, as bicarbonate is the dominant ion in all the samples. None of the samples showed a concentration of chloride and sulphate ions.

It is also evident from that out of 35 samples, 54.29% of the samples belong to Ca^{2+}-Mg^{2+}-HCO_3^- type and 45.71% samples fall under Na^+-K^+-HCO_3^- category, illustrating the presence of temporary hardness in the groundwater of Udupi municipal area. The diagram also demonstrates the dominance of alkaline earths over alkali ((Ca+Mg)>((Na+K)) in 54.29% of samples and the dominance of alkali over alkaline earths ((Na+K)>(Ca+Mg)) in 45.71% of samples. Also, in all the samples, weak acidic anions exceed strong acidic anions ((CO_3+HCO_3)>(SO_4+Cl)).

It is observed that 45.71% of the samples are in the mixing zone, where type of groundwater can neither be identified as anion nor cation domination [6]. Remaining 54.29% samples belong to the temporary hardness class, confirming the observation made earlier, and exhibited magnesium bicarbonate type having carbonate hardness, illustrating reverse ion exchange responsible for controlling the chemistry of the groundwater [6]. None of the samples fall under the types originating from halite dissolution (saline) or alkali carbonates enrichment.

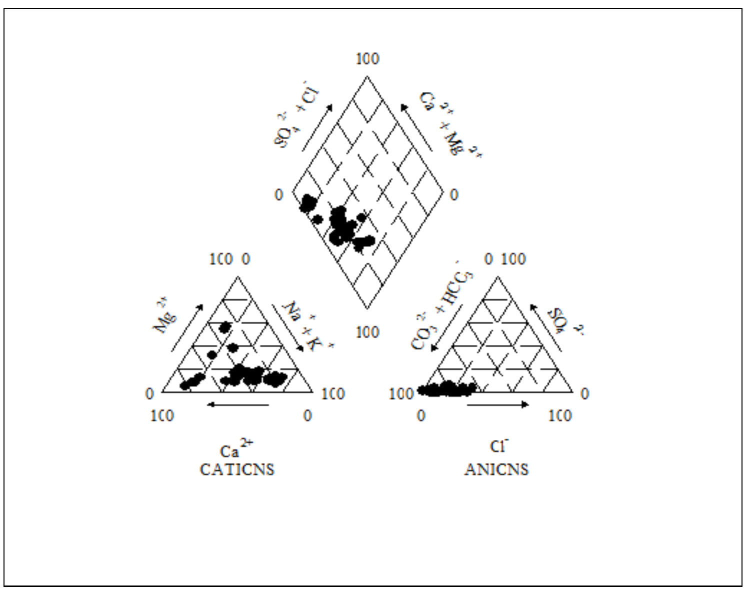

FIG. 3. **Piper's trilinear diagram.**

Suitability of groundwater for drinking purposes

The procedure adopted for developing water quality index to determine the suitability of groundwater for drinking purposes is as per the world health organization (WHO) standards [7,8]. For the calculation of water quality index, 13 important parameters namely pH, total dissolved solids, total hardness, total alkalinity, bicarbonates, calcium, magnesium, sodium, potassium, chloride, nitrate, fluoride and sulphate are chosen.

As per the results obtained (TABLE 2), about 5.71% of the samples below to "Excellent Water Quality" category (0% to 25%), 48.58% of samples belong to "Good Water Quality" category (25% to 50%), 37.14% of samples belong to "Poor Water Quality" category (50% to 75%), 5.71% of samples belong to "Very Poor Water Quality" (76% to 100%) and 2.86% of samples belong to "Unsuitable for Drinking" category (>100%).

Suitability of groundwater for irrigation purposes

Groundwater serves as a major source of water for irrigation in most parts of India. According to IS: 11624-1986 [9], the quality of irrigation water is to be evaluated in terms of degree of harmful effects on soil properties with respect to the soluble salts it contains in different concentrations and crop yield.

TABLE 2. **Analysis results of WQI in groundwater samples.**

Sample No.	WQI (%)	Sample No.	WQI (%)	Sample No.	WQI (%)	Sample No.	WQI (%)	Sample No.	WQI (%)
1	31.99	8	28.86	15	52.99	22	35.11	29	53.30
2	41.646	9	79.40	16	32.16	23	65.93	30	59.67
3	36.82	10	34.74	17	63.91	24	39.23	31	21.28
4	61.03	11	29.09	18	60.50	25	48.65	32	47.75
5	12.56	12	87.09	19	55.68	26	56.00	33	49.32
6	50.34	13	42.67	20	30.55	27	62.93	34	30.30
7	52.42	14	120.16	21	44.60	28	57.57	35	38.94

So, a detailed study of the physico-chemical parameters of groundwater is absolutely necessary. For the purpose of this project, the following parameters are studied in detail, as per IS: 11624-1986 [9] and WHO standards [10,11].

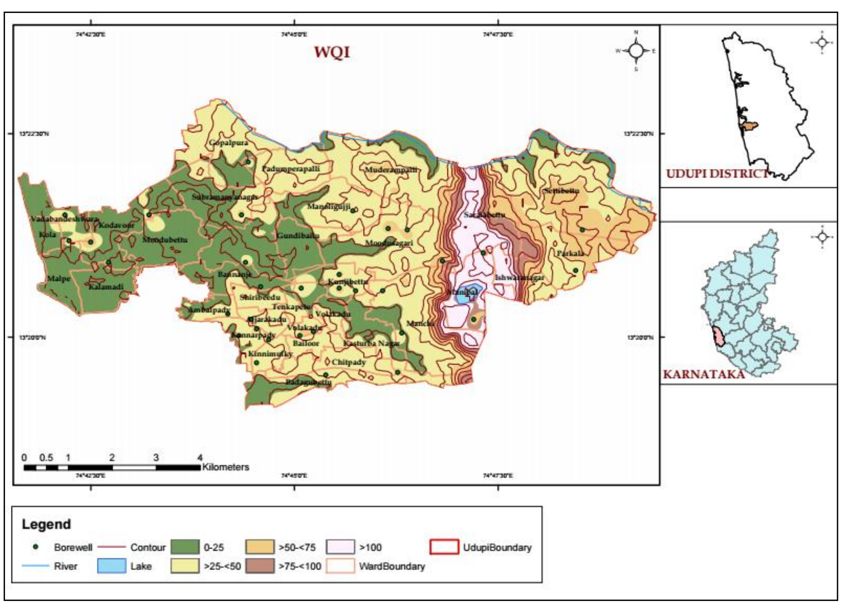

FIG. 4. **Spatial distribution map for WQI.**

Total salt concentration is expressed as the electrical conductivity (EC). The salts present in the water, affects the plants growth directly and the soil structure, permeability and aeration, which indirectly affects the plant growth. In relation to hazardous effects of the total salt concentration, irrigation water can be classified into four major groups as shown in TABLE 3.

Sodium absorption ratio (SAR) is quantified as the proportion of sodium to calcium and magnesium, which affects the availability of water to crops. In relation to the hazardous effects of sodium absorption ratio, irrigation water quality rating is as shown in TABLE 4.

Kelley's ratio is the level of sodium measured against calcium and magnesium. It is used to measure the suitability of water to irrigation. In relation to the hazardous effects of excess of sodium content in water, irrigation water quality rating is as shown in TABLE 5.

TABLE 3. **Classification of irrigation water on the basis of their total salt concentration.**

S. No.	Class	Range of EC (micro siemens/cm)	No. of samples	Percentage of samples (%)
1	Low (excellent quality)	Below 250	15	42.86
2	Medium (good quality)	250-750	16	45.71
3	High (permissible quality)	750-2250	4	11.43
4	Very high (unsuitable)	2250-5000	-	-

TABLE 4. **Classification of irrigation water on the basis of their sodium absorption ratio.**

S. No.	Class	Range of SAR ($\sqrt{\text{millimole/litre}}$)	No. of samples	Percentage of samples (%)
1	Low (excellent)	Below 10	25	71.43
2	Medium (good)	10-18	7	20
3	High (fair/doubtful)	18-26	2	5.71
4	Very high (unsuitable)	Above 26	1	2.86

TABLE 5. **Classification of irrigation water on the basis of their Kelley's ratio.**

S. No.	Class	Kelley's ratio range (equivalents per million)	No. of samples	Percentage of samples (%)
1	Suitable for Irrigation	Less than 1	-	-
2	Unsuitable for irrigation	More than 1	35	100

Generally, in most waters, calcium and magnesium maintain a state of equilibrium. In equilibrium, presence of more magnesium ions in water can adversely affect the soil quality rendering it alkaline, resulting in adversely affecting crop yields. High level of magnesium ions is usually due to the presence of exchangeable sodium ions in irrigated soils. Magnesium index of more than 50% can badly affect the crop yield as the soils become more alkaline. About 94.28% of samples have an index of lesser than 50%, and hence are suitable for irrigation purposes. Only two ground water samples have an index of more than 50% and hence are not suitable for irrigation.

Sodium content is usually expressed in terms of percent sodium. Excess sodium and chloride combining with carbonate will lead to the formation of alkaline and saline soils respectively. Both soil types are not suitable for the growth of crops. Also, sodium reacts with soil, thereby reducing its permeability. As per the Indian standards, maximum of 60% sodium is permissible for irrigation water. Usually, minor problems occur when percent sodium values are less than 15%. When it is greater than 15%, reduced permeability will occur. The finer the soil texture and the greater the organic content, the greater will be the impact of sodium on water infiltration and aeration [12]. None of the samples have a percent sodium value of less than 15%. About, 65.71% of the samples have percent sodium values in between 15% and 60%, and hence are permissible for irrigation purposes. The remaining 34.29% of the samples have percent sodium values greater than 60% and hence are unfit for irrigation purposes.

Residual sodium carbonate (RSC) is defined as the excess of carbonate and bicarbonate amount over the alkaline earths like calcium and magnesium. It influences the suitability of water for irrigation purpose. The classification of irrigation water on the basis of their RSC is as shown in TABLE 6.

TABLE 6. **Classification of irrigation water on the basis of their residual sodium carbonate.**

S. No.	Class	RSC (milli equivalents/l)	No. of samples	Percentage of samples (%)
1	Safe	<1.25	35	100
2	Marginal	>1.25 and <2.5	-	-
3	Unsafe	>2.5	-	-

The soil permeability is affected by long-term irrigation influenced by sodium, calcium, magnesium and bicarbonate ion concentrations of the water used for irrigation. The permeability index values indicate the suitability of groundwater for irrigation. The classification of irrigation water on the basis of their permeability index is shown in TABLE 7.

TABLE 7. **Classification of irrigation water on the basis of their permeability index.**

S. No.	Quality of water	Limiting values of permeability index (%)	No. of samples	Percentage of samples (%)
1	Class-I	Above 75	14	40
2	Class-II	25-75	20	57.14
3	Class-III	Below 25	1	2.86

Conclusion

Physico-chemical analysis of bore-well water samples of Udupi municipal area conducted using various analytical methods show that the quality of groundwater does not vary to a great extent and most of the samples are within permissible limit.

It can be deduced from the Piper's trilinear diagram that majority of the groundwater samples were sodium, calcium, bicarbonate and potassium rich. The Piper's trilinear diagram suggests the dominance of alkaline earths over alkali in 54.29% of samples and it is seen that in all the samples, weak acidic anions exceed strong acidic anions. It is also evident from Piper's diagram that out of 35 samples, 54.29% of the samples belong to Ca^{2+}-Mg^{2+}-HCO_3^- type and 45.71% samples fall under Na^+-K^+-HCO_3^- category, illustrating the presence of temporary hardness in the groundwater of Udupi municipal area.

The results of WQI show that 54.29% of the groundwater samples were either excellent or good for drinking purposes. Though the suitability of water for irrigation is judged based on electrical conductivity, sodium absorption ratio, percent sodium, Kelley's ratio, magnesium hazard, permeability index and residual sodium carbonate, it is only an empirical conclusion. In addition to water quality, various factors like soil type, crop type, crop pattern, frequency and rainfall, climate etc. have an important role to play in determining the suitability of water for irrigation purposes.

Finally, the analysis reveals that the groundwater of the area, needs certain degree of treatment before consumption for drinking and irrigation purposes, and it also needs to be protected from the perils of contamination.

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