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Original Research Paper

Physico-Chemical Characteristics of Borewell Waters of Bellary Taluk, Karnataka, India

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ABSTRACT

The study area was undertaken in the serial hillocks mining area of Bellary taluk located in the Bellary district, Karnataka. The important geological formations in this area were Archean granites (pink to grey), schists/phyllites and peninsular gneiss. The assessment of water quality for its suitability for agricultural and domestic purposes was carried out. The results of chemical analysis for the major ions of 40 water samples, collected from the study area of Bellary taluk, have been evaluated. The quality analysis was performed through the estimation of calcium, magnesium, sodium, potassium, iron, zinc, manganese, carbonate, bicarbonate, sulphate, chloride, fluoride, nitrate, total alkalinity, total dissolved solids, turbidity, pH, electrical conductance and total hardness. Based on the analysis, certain parameters like sodium adsorption ratio, percent sodium and magnesium ratio were calculated. The bicarbonates (68 to 630 mg/L) and total alkalinity (241 to 429 mg/L) were medium and this may be due to the presence of crystalline schists and granitic gneiss in the study area. Based on the Piper trilinear diagram, it is confirmed that the dug wells were characterized by high amount of calcium and magnesium in the mining areas. In the study area 70% of the water samples fall under mainly C_2S_1, C_3S_1 and C_3S_2, which were suitable for irrigation of most crops as per USSL. The remaining 30% samples falling in C_3S_3, C_4S_2, C_4S_3 and C_4S_4 were not suitable for irrigation. From SAR classification, 75% of the water samples contained carbonate hardness and only 25% contained non carbonate hardness. The presence of *E.coli* in only seven dug wells indicated potential and dangerous faecal contamination, which require immediate attention. Fluoride was most dominant ion responsible for contamination of the groundwater. Seven water samples of the study area were prone to excess fluoride concentration (>1.2 mg/L) and not suitable for drinking purpose. These studies indicate that the water quality of 70% of the dug wells is suitable for both domestic and irrigation purposes, where as in the 30% of the water samples, one or the other chemical constituent was found beyond WHO permissible limits. The study indicates the need for periodic monitoring of groundwater in the study area.

INTRODUCTION

As the human population increases, people express their desire for a better standard of living, and as economic activities continue to expand in scale and diversity, the demand for freshwater resources continue to grow. Among the various sources of water, groundwater is said to be the safest water for drinking and domestic purposes. Nevertheless, several factors like discharge of agricultural, domestic and industrial wastes, land use practices, geological formation, rainfall patterns and infiltration rate are reported to affect the quality of groundwater in an area (APHA 1975). As groundwater moves along flow lines from recharge to discharge areas, its chemistry is altered by the effect of a variety of geochemical processes (Freeze & Cherry 1979). In Karnataka, there is no significant work on water quality except by Jayanthi (1993), Ayed (2002) and Jayalakshmi Devi et al. (2005). Water quality assessment studies in Karnataka, especially in Bellary district are inadequate, therefore, the present study has been undertaken to assess the water quality in this region.

GEOLOGY OF THE STUDY AREA

Bellary taluk lies between 14°59' to 15°26' N latitude and 76°10' to 77°38' E longitude. It covers an area about 1689 sq. km. The taluk has a population of about 6,25,494. The average annual rainfall of the study area is 495 mm. The average annual maximum temperature is 40°C, and minimum 26°C.

The study area is covered by Archean granite, peninsular gneiss and schists. The major portion of the taluk comprises of schists and phyllitic rocks, which are associated with iron and manganese ore bands. They almost standout in the form of serial hillocks and are being commercially exploited. The rock formations are joined and traversed by doleritic dykes. Weathering in hard rocks is limited to 5 meters from ground level whereas in schist and phyllite it extends upto 20 meters. Secondary porosity weathered zone, joints fresh hard rock, and provide room for groundwater storage.

MATERIALS AND METHODS

Forty representative samples were collected during post monsoon in November 2007 and analysed for calcium, magnesium, sodium, potassium, iron, zinc, manganese, chloride, carbonate, bicarbonate, fluoride, sulphate, nitrate, total hardness (TH), total alkalinity (TA), total dissolved solids (TDS), pH, electrical conductance (EC), turbidity and coliform bacteria. Further, the sodium adsorption ratio (SAR), corrosivity ratio (CR), percent sodium and magnesium ratio were also calculated. The techniques and methods followed for collection, preservation, analysis and interpretation are those given by Rainwater & Thatcher (1960), Brown et al. (1970), ICMR (1975), Hem (1985) and APHA (1995). The sample locations in the study area are depicted in Fig. 1. Various methods and graphs were used to study and interpret the water analysis data are shown in Figs. 2-7.

RESULTS AND DISCUSSION

The results obtained from the analysis of water samples of different villages of Bellary taluk are given in Table 1. A comparison of the physico-chemical data of groundwater samples has been made with WHO (1988) and ISI (1991) drinking water standards (Table 2). Table 3 shows the different types of waters in the study area according to hydrochemistry classification.

pH: The pH values of groundwater varied from 7.0 to 8.2 indicating slightly alkaline nature. Groundwaters with pH value of about 10 are exceptional and may reflect contamination by strong bases such as NaOH and $Ca(OH)_2$ (Langmuir 1997). The range of desirable pH of water prescribed for drinking purpose by ISI (1991) and WHO (1988) is 6.5 to 8.5. The groundwater samples are within the permissible limits. There is no distinct variation of pH in different wells selected for the present study indicating that the groundwater is tapping from aquifers of a single formation. The slight alkaline nature of groundwater may be due to the presence of fine aquifer sediments mixed with clay and mud, which are unable to flush off the salts during monsoon rains, and hence, retained longer on other seasons.

Electrical Conductance (EC): The mineral components of the water are directly related to

Table 1: Analysis of physico-chemical factors of water samples of Bellary taluk, Karnataka.

B.N.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1.00	7.1	1500	650	51.0	56.0	92.0	6.3	337.0	14.0	348.5	0.91	80.0	51.0	262	1320	0.18	0.99	0.04	-
2	1.60	8.2	3410	1264	66.0	38.0	81.0	2.2	840.0	32.0	522.0	0.78	330.0	59.8	279	1650	-	0.64	0.05	-
3	2.05	7.7	4500	2420	24.0	16.0	106.0	1.2	114.0	0.0	296.0	1.12	500.0	24.9	348	3180	-	0.80	0.07	-
4	1.18	7.1	1900	440	58.2	36.0	108.0	4.3	295.5	0.0	94.0	1.20	164.0	26.0	241	1160	-	1.06	0.04	-
5	0.60	7.6	550	215	23.6	8.0	64.0	1.6	20.0	0.0	230.0	1.86	120.0	63.0	326	360	0.09	0.55	0.06	-
6	1.00	7.4	1300	460	65.1	48.0	62.0	2.2	130.5	12.0	142.0	1.71	125.0	63.0	312	1080	-	0.77	0.02	-
7	1.00	7.6	730	250	72.0	30.0	82.0	1.6	21.0	11.0	186.0	1.11	82.0	55.0	318	500	-	0.58	0.06	-
8	1.00	8.0	4120	1290	164.3	24.0	67.0	1.8	135.0	0.0	590.0	0.23	42.0	68.0	324	2980	-	0.53	0.06	-
9	0.20	7.1	310	160	72.0	22.0	61.0	2.0	24.5	0.0	84.0	0.61	73.0	27.0	395	520	-	0.68	0.20	150
10	1.80	7.8	2100	645	64.1	32.0	74.0	2.3	152.0	0.0	168.0	1.20	190.0	67.0	361	1340	-	0.74	0.24	108
11	1.02	8.0	1000	294	60.5	38.0	73.0	1.8	103.5	10.0	96.0	2.07	86.0	48.0	381	540	0.09	0.61	0.05	-
12	1.00	7.3	860	225	62.5	22.0	60.0	21.0	58.5	0.0	124.0	2.47	50.0	16.0	402	530	-	0.68	0.20	-
13	1.00	7.5	1100	266	83.8	28.0	48.0	2.4	71.0	0.0	168.0	2.10	90.0	19.0	372	620	-	0.89	0.05	-
14	1.00	7.9	1100	398	107.4	21.0	58.0	2.0	132.0	0.0	232.0	0.84	4.0	28.0	398	440	-	0.68	0.21	4
15	1.96	8.1	2600	658	84.2	32.0	168.0	1.6	455.5	0.0	436.0	1.19	300.0	27.0	301	1780	-	0.60	0.01	-
16	1.00	7.4	650	120	64.2	24.0	56.0	3.8	37.5	14.0	82.5	1.21	10.0	64.0	376	360	0.18	0.55	0.06	-
17	1.00	7.6	800	286	85.8	44.0	118.0	3.2	129.5	10.0	110.0	1.10	40.0	15.0	318	620	0.18	0.49	0.06	-
18	1.36	7.6	2000	565	120.0	26.0	48.0	2.0	165.0	9.0	212.0	0.82	115.0	50.0	329	1340	-	0.86	0.04	-
19	1.20	7.9	1800	765	68.1	36.0	58.0	1.8	176.5	5.0	148.0	1.31	210.0	5.0	379	1120	-	0.69	0.02	-
20	1.80	7.8	3000	1412	82.2	23.0	74.0	0.9	129.0	0.0	190.0	1.50	160.0	69.0	368	2040	2.37	1.05	0.04	-
21	1.60	7.5	3500	326	436.9	11.0	52.0	1.7	126.0	0.0	130.0	0.35	135.0	54.3	260	1200	0.72	0.68	0.05	-
22	1.65	7.8	2300	770	132.3	22.0	75.0	0.8	102.0	0.0	210.5	0.62	142.5	22.8	349	1465	-	0.98	0.04	-
23	2.00	7.7	1600	803	44.0	21.0	64.0	1.8	81.0	19.0	206.0	1.16	280.0	23.0	336	1320	0.27	0.62	0.04	-
24	1.00	7.6	500	265	94.2	44.0	118.0	3.2	39.0	10.0	103.0	0.32	10.0	61.0	326	440	1.80	0.49	0.06	3
25	1.00	8.1	795	235	18.2	20.0	58.0	2.2	59.0	0.0	180.0	1.01	35.0	63.0	395	565	-	0.58	0.07	-
26	1.98	8.0	2700	810	117.0	23.0	61.0	2.0	108.5	0.0	232.0	1.26	145.0	40.8	383	1900	-	0.69	0.20	-
27	1.30	8.1	1100	450	128.3	64.0	83.0	4.3	91.5	7.0	312.0	0.66	24.0	66.0	314	740	0.36	0.84	0.03	-
28	1.07	7.0	1050	255	46.1	22.0	46.0	4.0	64.5	14.0	124.0	1.19	140.0	65.0	376	440	0.09	0.55	0.05	-
29	1.00	7.8	860	190	74.1	14.8	52.0	3.2	30.0	12.0	104.0	1.50	36.0	66.0	368	630	-	0.96	0.03	-
30	1.20	7.9	860	250	29.3	20.0	54.0	1.3	31.5	8.0	206.0	1.94	84.0	18.0	391	500	0.09	0.64	0.07	-
31	1.00	7.2	500	158	41.7	28.0	51.0	2.7	27.0	0.0	68.0	0.44	49.0	17.0	358	220	0.36	0.89	0.05	-
32	2.10	7.1	4200	2400	45.0	22.0	168.0	10.6	102.0	0.0	208.0	1.14	55.0	27.0	429	3600	0.18	0.68	0.06	-
33	1.00	7.4	3000	896	168.3	54.0	126.0	1.9	396.0	5.0	248.0	1.07	70.0	55.0	262	1500	0.09	1.25	0.04	5
34	1.00	8.1	3100	910	105.8	36.0	98.0	2.4	376.5	10.0	348.0	0.69	125.0	68.0	395	2440	0.09	0.77	0.03	-
35	1.00	7.9	300	196	138.0	14.0	52.0	4.2	11.5	16.0	236.0	0.41	35.0	9.0	372	220	0.09	0.55	0.05	-

Table cont....

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36	1.00	8.1	2100	770	116.2	21.0	58.0	1.6	117.5	8.0	238.0	1.28	180.0	25.0	402	1820	0.18	0.64	0.07	2
37	1.00	8.1	2250	680	112.2	38.0	98.0	2.6	168.0	10.0	220.0	0.89	115.0	5.0	391	1680	-	0.85	0.04	2
38	1.00	8.2	1900	348	82.6	50.0	78.0	0.7	197.0	5.0	208.5	1.01	150.0	3.0	411	940	-	1.49	0.04	-
39	1.00	8.2	1600	642	108.0	9.0	46.0	0.5	137.0	10.0	194.0	0.47	140.0	20.0	419	1540	0.36	0.87	0.02	-
40	1.00	7.9	950	398	106.6	8.0	84.0	0.5	109.5	10.0	268.0	0.77	150.0	8.0	376	460	0.00	1.08	0.05	-
Min.	0.20	7.0	300	120	18.2	8.0	46.0	0.5	11.5	0.0	68.0	0.23	4.0	3.0	241	220.0	0.00	0.49	0.01	2.0
Max.	2.10	8.2	4500	2420	436.9	64.0	168.0	21.0	840.0	32.0	590.0	2.47	500.0	69.0	429	3600.0	2.37	1.49	0.24	150
SD	0.42	0.4	1143	529	67.1	13.6	30.1	3.4	154.5	7.1	113.6	0.52	98.3	47.6	827	0.6	22.51	0.22	0.06	63

1. Turbidity (NTU), 2. pH, 3. EC (µmhos/cm), 4. TH (mg/L), 5. Ca (mg/L), 6. Mg (mg/L), 7. Na (mg/L), 8. K (mg/L), 9. Cl (mg/L), 10. CO_3 (mg/L) 11. HCO_3 (mg/L), 12. F (mg/L), 13. SO_4 (mg/L), 14. NO_3 (mg/L), 15. TA (mg/L), 16. TDS (mg/L), 17. Fe (mg/L), 18. Zn (mg/L), 19. Mn (mg/L), 20. Coliform Bacteria (MPN/100mL), B.N. = Borewell No.

Table 2: Comparison of ground water quality of Bellary taluk with the WHO and ISI drinking water standards.

Parameters	WHO Standards 1988		ISI 1991		Observed Values	
	P	E	P	E	Minimum	Maximum
pH	7.0-8.5	6.5-9.2	7.0-8.5	6.5-9.2	7.1	8.3
Turbidity	500	1500	5	10	0.60	2.1
TDS	-	-	500	2000	220	3600
TH	-	-	300	600	100	1491
EC	-	-	-	-	300	4500
TA	75	200	200	600	241	429
Ca	50	150	75	200	18.2	436.9
Mg	200	-	30	100	8.0	64.0
Na	-	-	150	-	46.0	168.0
K	-	-	-	-	0.5	21.0
Fe	-	-	0.3	1.0	0.09	2.37
Zn	-	-	5	10	0.49	1.49
Mn	0.4	-	0.4	1.0	0.01	0.24
Cl	200	600	250	1000	11.5	840
F	0.5	1.0-1.5	0.6-1.2	1.5	0.32	2.47
NO_3	45	100	50	100	3.0	69.0
SO_4	-	-	-	-	4.0	500.0
CO_3	-	-	-	-	0.0	32.0
HCO_3	-	-	-	-	68.0	590.0

Note: P = Permissible Limit, E = Excessive Limit

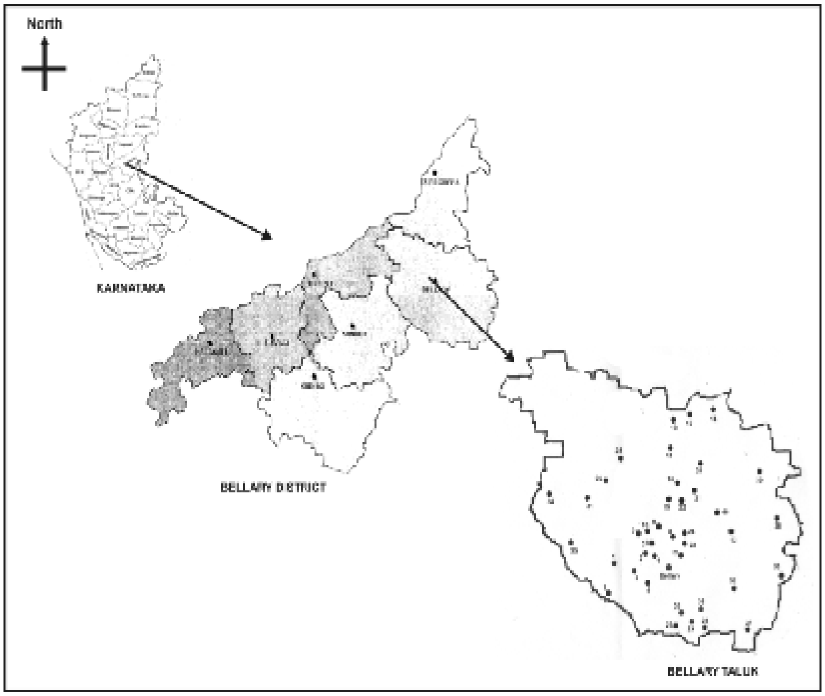

Fig 1: Location map of water sampling sites of Bellary taluk.

agricultural utility and its parametric value decides the suitability for drinking and irrigation purposes. Wilcox (1955) classified the quality of water with respect to irrigational use by taking into consideration the sodium and electrical conductance as vital parameters. It is well known that electrical conductance is a good measure of dissolved solids, and excessive presence of sodium in water is not only unsafe for irrigation but also makes the soil uncultivable (Neeraj Verma 1994). In the present investigation, the electrical conductivity of the samples varies from 300 to 7120 µmhos/cm (Fig. 2). This is within the permissible limit for 24 samples as per WHO standards. However, the higher values of EC (>2000 µmhos/cm) for 14 samples may be due to the long residence time and factors of lithology of water bodies (Harish Babu et al. 2004).

Total Dissolved Solids (TDS): TDS indicate the nature of water quality for salinity. The water samples in the study area fall in the range of 220 to 3600 mg/L. Out of the 40 samples collected, 20 samples fall into the 'freshwater' category, 18 samples into 'brackish water' category and 2 samples into moderately saline category. Waters can be classified based on the concentration of TDS (Wilcox 1955, ICMR 1975) as given below:

Up to 500 mg/L	Desirable for drinking
Up to 1000 mg/L	Permissible for drinking
Up to 2000 mg/L	Useful for irrigation
Above 3000 mg/L	Not useful for drinking and irrigation

Based on the above classification only 50% samples in the study area come under desirable and permissible for drinking (Fig. 3).

Total Hardness: Total hardness is due to the presence of divalent cations, of which Ca and Mg are

Table 3: Hydrogeochemical classification of water samples.

Sample No.	Percent Sodium	SAR	CR	USSL Salinity	Magnesium Ratio
1	44.8	12.60	1.52	C_3S_2	27.2
2	43.2	11.50	2.74	C_4S_4	20.3
3	72.0	16.80	0.93	C_4S_4	10.8
4	52.3	15.74	1.99	C_3S_3	17.4
5	65.8	40.15	0.66	C_2S_1	58.2
6	34.0	8.25	2.03	C_3S_2	27.1
7	44.2	11.48	0.61	C_2S_2	16.2
8	26.0	6.98	0.39	C_4S_2	9.3
9	38.9	6.50	1.31	C_2S_1	14.0
10	42.9	11.01	2.40	C_3S_2	18.6
11	42.1	10.41	2.21	C_3S_2	21.9
12	36.3	9.25	1.08	C_3S_2	13.3
13	29.6	6.42	1.15	C_3S_1	17.3
14	30.8	7.42	0.81	C_3S_1	11.1
15	58.8	22.10	2.18	C_4S_4	11.2
16	37.8	8.48	0.64	C_2S_1	16.2
17	47.0	14.65	1.82	C_3S_2	17.5
18	24.5	5.62	1.52	C_3S_2	13.3
19	35.4	8.04	3.05	C_3S_1	22.0
20	41.1	10.20	1.82	C_4S_2	12.7
21	10.4	3.47	3.23	C_4S_1	2.2
22	32.6	8.54	3.89	C_4S_2	9.6
23	48.9	11.22	3.05	C_3S_2	16.1
24	45.5	14.19	0.57	C_2S_2	16.9
25	58.9	13.27	0.66	C_3S_2	20.4
26	30.0	7.24	4.35	C_4S_2	11.3
27	29.7	8.46	0.48	C_3S_2	22.9
28	38.9	7.89	1.71	C_3S_1	18.6
29	36.0	7.80	0.64	C_3S_1	10.3
30	51.6	10.88	0.61	C_3S_2	19.2
31	41.3	8.60	1.30	C_3S_1	22.7
32	68.4	29.06	2.81	C_4S_4	9.0
33	36.0	11.95	2.49	C_4S_4	15.4
34	40.5	11.63	1.84	C_4S_4	14.9
35	24.9	5.88	0.20	C_2S_1	6.7
36	29.4	6.98	1.42	C_4S_2	10.7
37	39.1	11.31	1.54	C_3S_2	15.2
38	36.7	9.58	2.03	C_3S_2	23.7
39	28.2	6.02	1.65	C_4S_2	5.5
40	42.2	11.11	1.11	C_3S_2	4.0

Note: SAR = Sodium Adsorption Ratio, CR = Corrosivity Ratio, USSL = US Salinity Laboratory

the most abundant in groundwaters. The waters of the study area are classified according to hardness as suggested by Hem (1985). In the present study, the total hardness of water samples ranged from 100 to 1491 mg/L. This indicates that out of 40 samples, only 18 samples have total hardness content within ISI permissible limit (300 mg/L), 15 samples have excessive limit (600 mg/L), and 7 samples fall into the very hard category. The total hardness values well correlate with TDS (Fig. 3).

Total Alkalinity (TA): Most of the groundwaters contain substantial amounts of dissolved carbon dioxide, bicarbonates and hydroxides. These constituents are the results of dissolution of minerals in the soil and atmosphere (Nagaraju et al. 2006). In the present study, alkalinity ranges from 241 to 429 mg/L. The high amount of alkalinity in the study area samples may be due to the presence of country rocks.

Chloride (Cl^-): Chloride occurs in all natural waters in widely varying concentrations. The origin of chloride in surface and groundwaters may be from diverse sources such as weathering and leaching of sedimentary rocks and soils, domestic and industrial waste discharge, etc. Excessive chloride in potable water is not particularly harmful and the criteria set for this ion are based primarily on palatability and its potentially high corrosiveness (Bhujangaiah & Vasudeva Nayak 2005). Chloride in excess (>250 mg/L) imparts a salty taste to water and people who are not accustomed to high chlorides may be subjected to laxative effects. The chloride content in the study area ranged between 11.5 and 840.0 mg/L. The WHO and ISI permissible limits of chloride for drinking water are 200 and 250 mg/L respectively. The chloride value of the water samples is well within the permissible limit of WHO and ISI for 34 samples, while 6 samples have high value.

Fluoride (F^-): High concentration of fluoride, often significantly above 1.5 mg/L, constitute a severe problem in large parts of Karnataka (Handa 1975, 1988). Teotia et al. (1984) found variations in fluoride concentration with depth in groundwater from two Indian villages affected by fluorosis. Shallow groundwaters (12-15m) have concentrations of around 4 mg/L to 11.5 mg/L, while deeper groundwaters (15-33m) have mostly less than 1mg/L. The decrease with depth showed corresponding decrease in alkalinity. The trend is contrary to observations from high fluoride groundwaters elsewhere.

Long term use of groundwater for drinking has resulted in the onset of widespread fluorosis from mild forms of dental fluorosis to crippling skeletal fluorosis. High fluoride concentrations in the groundwater of study area correlate positively with alkalinity (bicarbonate concentration), pH and sodium. The concentration of fluoride in the study area varies from 0.32 to 2.47 mg/L (Fig. 4). The fluoride value of the water samples is well within the permissible limit of ISI for 27 samples, whereas 13 samples have high value of fluoride (>1.2 mg/L), and are not safe for drinking purpose.

Nitrate (NO_3^-): The WHO health-based guideline value for nitrate in drinking water is 45 mg/L. The concentration of nitrate in the present water samples varies from 3.0 to 69.0 mg/L. The determination of nitrate is important particularly in drinking water as it has adverse effects on health above 50 mg/L. When water with high nitrogen concentration is used for drinking, it causes diseases like methaemoglobinaemia. Scanty data are available for concentration of nitrate in groundwaters from Karnataka. Manjappa et al. (2003) found values between 0.08 mg/L and 308 mg/L for groundwaters from Davanagere taluk in Karnataka. The presence of nitrate in water is due to domestic activities and agricultural runoff, which dissolved in rain water leaches into the wells (Zutshi et al. 1998). Nitrate is basically non-toxic but when ingested with food and water, it is reduced by bacterial action to nitrite and then to ammonia, which are toxic. In the present study, out of 40 samples collected, 23 samples are within the permissible limit of ISI, while 17 samples have excessive limit.

Iron: In the present study, iron varied from 0.09 to 2.37 mg/L. The permissible limit for iron is 0.3 to 1.0 mg/L. The concentration of iron in 2 water samples is high, whereas in the remaining samples it is well below the permissible limit.

Zinc: The concentration of zinc in water samples varied from 0.49 to 1.49 mg/L. The permissible limit of zinc is 5 mg/L. These results are well below the permissible limit.

Manganese: The manganese ranged from 0.01 to 0.24 mg/L. The permissible limit for manganese is

Table 4: Sodium adsorption ratio.

Sodium Adsorption Ratio (SAR)	Water Type
<10	Excellent
10-18	Good
18-26	Fair
>26	Poor

Table 5: USSL classification.

Salinity	Hazard	Sodium	Hazard
S_1	Low	C_1	Low
S_2	Medium	C_2	Medium
S_3	High	C_3	High
S_4	Very High	C_4	Very High

0.4 mg/L. The results indicate that all the samples of the study area are within the permissible limit.

Sodium Adsorption Ratio (SAR): Excessive sodium in waters produces the undesirable effects of changing soil properties and reducing soil permeability (Kelly 1951). Hence, the assessment of sodium concentration is necessary while considering the suitability for irrigation. The degree to which irrigation water tends to exchange cations in soils and cations in the irrigation water can be represented by the sodium adsorption ratio (US Salinity Laboratory 1954). Sodium replacing adsorbed calcium and magnesium is a hazard as it causes damage to the soil structure. It becomes compact and impervious. SAR is an important parameter for determination of the suitability of irrigation water because it is responsible for the sodium hazard (Todd 1980). The waters were classified in relation to irrigation based on the ranges of SAR values (Richards 1954). Based on Table 4, out of 40 samples, 24 samples are suitable for irrigation, while remaining 16 samples are unsuitable for irrigation. SAR values of the water samples vary from 4.15 to 29.06 (Table 3).

US Salinity Laboratory (USSL) Classification: According to a method formulated by the US Salinity Laboratory (1954), water used for irrigation can be rated based on salinity hazards and sodium or alkali hazard. When the sodium hazards ratio and electrical conductivity of water are known, the classification of water for irrigation can be done by plotting these results on the graph (Fig. 5). Low salinity water can be used for irrigation of most crops on most soils with little likelihood that salinity will develop. According to USSL classification (Table 5), out of 40 samples of the groundwaters, 5 samples fall into C_2S_1 (medium salinity with low sodium), 2 samples into C_2S_2 (medium salinity with medium sodium), 6 samples into C_3S_1 (high salinity with low sodium), and 14 samples into C_3S_2 (high salinity with medium sodium). Out of 40 samples, 27 samples are suitable for irrigation in almost all soil types, and they facilitate good soil drainage. However, remaining 13 samples (C_3S_3, C_4S_1, C_4S_2 and C_4S_4) have very high sodium. Therefore, they are not suitable for irrigation (Table 3).

Percent Sodium: Sodium concentration is important in classifying the irrigation water because sodium reacts with soil to reduce its permeability. Soils containing a large proportion of sodium with carbonate as the predominant anion are termed alkali soils; and those with chloride or sulphate as the predominant anion are saline soils. The role of sodium in the classification of groundwater for irrigation was emphasized because of the fact that sodium reacts with soil and as a result clogging of particles takes place, thereby reducing the permeability (Todd 1980, Demenico & Schwartz 1990). Percent sodium in water is a parameter computed to evaluate the suitability for irrigation (Wilcox 1948). The percent sodium values of the water samples vary from 1.36 to 72.00. Percent sodium is plotted against electrical conductance, which is designated as Wilcox diagram (Fig. 6). From this, it is clear that 9 samples fall into the category of 'excellent to good', 15 samples into the category of 'good to permissible', 8 samples into the category of 'doubtful to unsuitable', and 8 samples into the category of 'unsuitable'.

Corrosivity Ratio (CR): Corrosion is an electrolytic process that takes place on the surface of metals, which severely attacks and corrodes away the metal surface. Most of the problems are associated

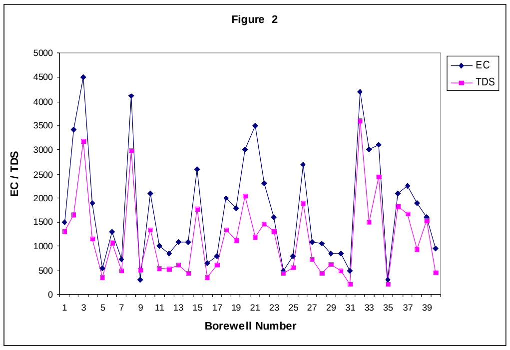

Fig. 2: EC/TDS vs. borewell water samples of Bellary taluk.

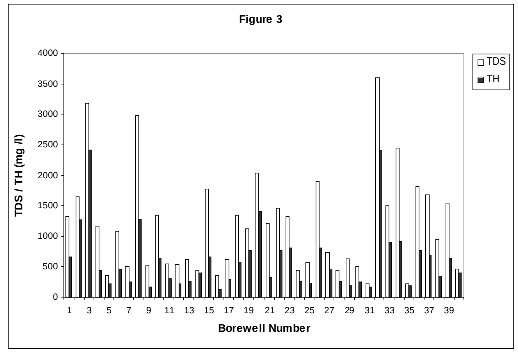

Fig. 3**:** TDS/TH vs. borewell water samples of Bellary taluk.

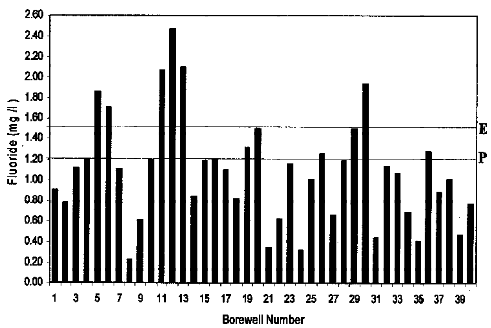

Fig. 4: Levels of fluoride contamination in groundwaters of Bellary taluk.

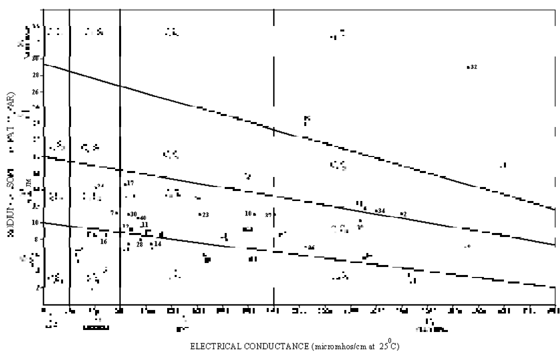

Fig. 5: The quality of Bellary taluk water in relation to salinity and sodium hazard (against US salinity Laboratory, 1954.)

with salinity and encrustation problems. Water samples having corrosivity ratio of less than 1 are considered to be non-corrosive, while the value above 1 is corrosive (Jayalakshmi Devi & Belagali 2006). In the present study, 28 samples are corrosive, while the remaining 12 samples are non-corrosive (Table 3).

Magnesium Ratio: Generally, calcium and magnesium maintain a state of equilibrium in most waters. In equilibrium more magnesium in waters will adversely affect crop yields. As the rocks of the study area consist of Archean granite, schists and peninsular gneisses, it is observed that most waters contain less Mg than Ca. In the present study, all the samples contain Mg ratio less than 30. This would not affect the crop yield. The 'Magnesium Ratio' values vary from 2.19 to 27.20 in the water samples (Table 3).

Graphical methods of representing analysis (Piper diagram): Collins (1923) first proposed a graphical method of representation of chemical analysis, which was later modified by Piper (1944, 1953) based on concentration of dominant cations and anions, and trilinear diagram was proposed to show percentage of cations and anions in water samples in milliequivalents per litre. The Piper diagram was later modified by Davis & Dewiest (1967). The trilinear diagram of Piper is very useful in bringing out chemical relationships among groundwaters in more definite terms (Walton 1970). This is useful to understand total chemical character of water samples in terms of cation-anion pairs.

The piper diagram consisting of 2 triangular and 1 intervening diamond-shaped fields is shown

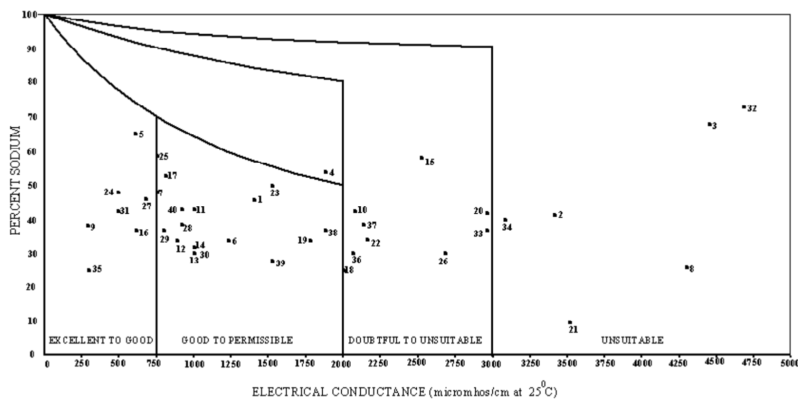

Fig. 6: The quality of Bellary taluk water in relation to electrical conductance and percent sodium (Wilcox diagram).

in Fig. 7. All 3 sides of the 2 triangular fields and the 4 sides of the diamond-shaped field are divided into 100 parts. The percentage reacting values at the 3 cation groups, Ca, Mg and (Na + K) are plotted as a single point in the left triangular field and the 3 anion groups, (HCO_3 + CO_3), SO_4 and Cl^- similarly on the right triangular field. The 2 points in each triangular field show the relative concentration of several dissolved constituents of the water sample. Later a third point is plotted in the central diamond-shaped field after computing percentage reacting values for anions and cations separately. This field shows the complete chemical character of the water samples that gives the relative composition of groundwater about the cation-anion point. These 3 fields reflect the chemical character of groundwater according to the relative concentration of its constituent but not according to the absolute concentrations. Piper (1953) later classified the diamond-shaped field of the trilinear diagram into 9 areas to know quickly the quality of water as given below.

Area-1: Alkaline earths (Ca + Mg) exceed alkalies (Na + K) (includes areas 5, 6 and 9a).
Area-2: Alkalies exceed alkaline earths (includes areas 7, 8 and 9b).
Area-3: Weak acids (CO_3 + HCO_3) exceed strong acids (SO_4 + Cl + F) (includes areas 5, 8 and 9b).
Area-4: Strong acids exceed weak acids (includes areas 6, 7 and 9b).
Area-5: Carbonate hardness (secondary alkalinity) exceeds 50%.
Area-6: Non-carbonate hardness (secondary salinity) exceeds 50%.
Area-7: Non-carbonate alkali (primary salinity) exceeds 50%.
Area-8: Carbonate alkali (primary alkalinity) exceeds 50%.
Area-9: None of the cation and anion pairs exceed 50%.

In the present study, it is noted that most of the samples fall under area-1, 7 samples fall under area-2; 12 samples fall under area-3; 28 samples fall under area-4; 10 samples fall under area-5; 20 samples from study area fall under area-9; 4 samples fall under area-7; while no sample fall under area-8.

Most of the water samples of the study area exhibit higher amount of Ca and Mg ions among the cations and bicarbonates among anions. This may be due to the dissolution of carbonates of Ca and Mg. Groundwaters of the study area are characterized by both temporary and permanent hardness. However, 80% of the water samples have temporary hardness. Concentration of Ca in groundwater samples ranges from 23.0 to 436.9 mg/L. It is observed that samples around the mining areas have higher concentration of Ca.

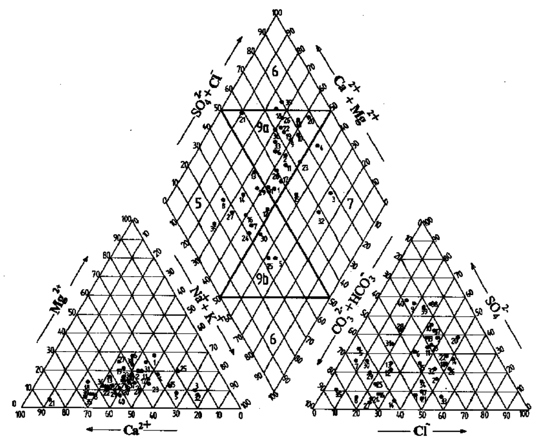

Fig. 7: Piper trilinear diagram of borewell samples of Bellary taluk.

Coliforms: Bacterial content is one of the most important aspects in drinking water quality. The most common and widespread health risk associated with drinking water is the bacterial contamination caused either directly or indirectly by human and animal excreta. *E. coli*, a typical faecal coliform, is selected as an indicator of faecal contamination. Only seven samples were found to have coliform contamination, of these only three samples (sample No. 9, 10, 13) have coliform contamination above 4/100 mL. The permissible limit of bacterial coliforms is 0/100mL as per WHO. Sample No. 9 and 10 were found to be highly contaminated with coliforms, while the others were suitable for human consumption.

CONCLUSION

Analysis of groundwater of Bellary taluk in Karnataka state shows that only 70% of water samples have physico-chemical properties well within the permissible limits. According to USSL, 27 groundwater samples fall under four types, i.e., C_2S_1, C_2S_2,C_3S_1 and C_3S_2 with moderately low salinity, six samples were of C_4S_2 type with still moderately high salinity, and 12 samples were of C_3S_3, C_4S_2, C_4S_3 and C_4S_4 types with high salinity. The value of SAR in 24 samples was in excellent type. Sixteen samples have corrosivity ratio higher than 1. According to Piper's diagram, the study area is characterized by water having both temporary and permanent hardness. The concentration of fluoride in 27 samples was well within the permissible limit, while 13 samples have high value of fluoride (>1.2 mg/L) and not safe for drinking purpose. The presence of *E. coli* in three samples of groundwater indicates potentially dangerous situation, which require immediate attention.

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