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Assessment of Groundwater Quality in and Around Bellary City of Karnataka, India

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ABSTRACT

The quality of groundwater in and around Bellary city of Karnataka has been studied. Various parameters, viz., turbidity, pH, electrical conductance, total hardness, total alkalinity, total dissolved solids, chloride, carbonate, bicarbonate, fluoride, sulphate, nitrate, calcium, magnesium, sodium, potassium, iron, zinc, manganese and coliform bacteria have been determined to evaluate its suitability for domestic and irrigation applications. The higher values of certain parameters at various locations indicate the influence of geological formation and infiltration making the water unsuitable for domestic applications. The values of sodium adsorption ratio indicate that majority of samples fall under the category of low to medium sodium hazards. The groundwater of the study area has also been classified on the basis of Piper trilinear and US Salinity Classification schemes. The presence of *E. coli* in six samples indicates dangerous faecal contamination, which require immediate attention.

INTRODUCTION

Groundwater, used for domestic supply, industries and agriculture in most parts of the word, is a replenishable resource having inherent advantages over surface water. There has been a tremendous increase in the demand for freshwater quality due to increase in population. The rapid growth of urban areas has affected the groundwater quality due to overexploitation of resources and improper waste disposal practices. Hence, there is always a need and concern for the protection and management of groundwater quality.

Ravichandran & Pundalikanthan (1991) have studied groundwater quality in Chennai with the context of polluted waterways of the city and confirmed the increasing concentration of chloride near coasts due to saline intrusion. Ramaswami & Rajaguru (1991) have conducted study on groundwater at Tirupur town in Coimbatore district of Tamil Nadu and reported several parameters exceeding the permissible limits for various uses pointing out to the necessity of proper treatment and disposal of wastes in the area. Govardhan (1990) carried out the study on groundwater pollution in different Mandals of district Nalgonda in Andhra Pradesh. Muralikrishna & Sumalatha (1992) have conducted some preliminary studies on the quality of groundwater of Kakinada town and recommended that any water source must be thoroughly analysed and studied before being used for domestic purposes. In Karnataka, there is no significant work has been conducted on groundwater except few analyses. Narayan & Suresh (1989) have studied the chemical quality of groundwater of Mangalore city and reported two distinct groundwater zones in the city. Ayed (2002) has studied quality of two freshwater bodies near Mysore and reported that water is not suitable for domestic purpose. Jayalakshmi Devi et al. (2005) have carried out the pollution studies of groundwater of

Mandya district in relation to waste disposal and reported that few of the groundwater samples are not suitable for the purpose of drinking, irrigation and industrial utilization.

Bellary, being a fast growing city, the groundwater quality of the area is deteriorating due to water logging, domestic and industrial contamination, etc. Due to rapid urbanization of Bellary city because of heavy mining activities, the quality of groundwater may deteriorate further in future. So far, no detailed investigation on groundwater quality of this region has been carried out. Hence, in the present study an investigations has been made to understand the chemical characteristics of groundwater of this region.

GEOLOGY OF THE STUDY AREA

Bellary city is one of the major towns of mining area. It lies between 15°09' to 15°30' N latitude and 76°16' to 76°55' E longitude. It covers an area about 81 km^2. The city has a population of about 4,24,105. The average annual rainfall of the study area is 447.4 mm. The average annual maximum temperature is 39°C and minimum is 26°C.

The study area is covered by Archean granite and schists. The major portion of the city comprises of pink granite and phyllitic rocks forming the major lithological units. 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 up to 20 meters. Secondary porosity weathered zone, joints fresh hard rock, provide room for groundwater storage.

MATERIALS AND METHODS

The study provides a detailed description of the chemical criteria of groundwater. Forty representative samples were collected during postmonsoon, 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 calculated. The techniques and methods followed for collection, preservation, analysis and interpretation are those given by Rainwater & Thatcher (1960), Brown et al. (1970) and APHA (1995).

RESULTS AND DISCUSSION

Water quality evaluation for domestic purposes: The results obtained from the analysis of water samples from different places of Bellary city are given in Table 1. Standard methods (APHA 1975) were employed in analysis of the water samples. A comparison of the physicochemical characteristics of groundwater samples has been made with WHO (1988) and ISI (1991) drinking water standards. Table 2 shows the geochemical parameters of groundwater samples of Bellary city.

pH: The pH values of groundwater varied from 7.1 to 8.4 indicating slightly alkaline nature. 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.

Electrical conductance (EC): 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 240 to 4300 μmhos/cm. The US Salinity Laboratory (1954) classi-

Table 1: Hydrochemical data for the groundwater samples of Bellary city.

S.N.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1.20	7.1	290	118	48.0	28.0	68.0	2.8	19.0	0.0	70.0	0.68	120.0	102	260	0.90	13.0	0.69	0.02	1
2	1.70	8.0	4300	504	36.0	23.0	71.0	4.3	193.0	9.0	365.0	1.09	290.0	360	2700	ND	66.0	0.49	0.06	-
3	1.20	7.6	3100	685	46.0	42.0	107.0	8.9	134.8	27.0	265.0	0.89	200.0	336	2160	ND	65.0	0.90	0.04	-
4	1.90	7.9	4050	765	24.0	18.0	63.0	2.0	86.0	15.0	352.0	2.00	160.0	365	2600	0.27	33.2	0.68	0.03	-
5	1.10	7.5	1400	245	88.0	36.0	51.0	1.6	96.0	4.8	218.0	1.01	110.0	242	720	ND	7.8	0.60	0.02	-
6	1.07	7.3	750	300	153.0	53.0	103.0	9.2	41.0	7.0	134.0	0.55	230.0	206	300	ND	69.0	0.87	0.04	-
7	2.30	7.9	2700	778	164.0	19.0	58.0	2.3	54.0	0.0	391.0	0.61	80.0	306	2500	ND	43.2	1.03	0.02	-
8	1.50	7.3	680	255	102.0	36.0	58.0	2.1	63.0	9.0	130.0	0.92	76.0	236	520	ND	54.0	0.84	0.04	-
9	1.20	7.4	1300	265	83.0	26.0	43.0	3.8	51.5	0.0	168.0	0.75	192.0	212	960	ND	11.7	0.69	0.04	-
10	1.41	7.5	730	450	195.0	32.0	65.0	1.9	21.0	0.0	228.0	0.11	82.0	362	500	ND	55.0	0.76	0.04	-
11	2.50	8.0	3250	920	26.0	43.0	38.0	15.0	204.0	0.0	414.0	1.34	268.0	621	2710	0.18	34.4	0.63	0.04	-
12	1.50	7.7	3920	575	24.0	34.0	69.0	1.7	83.0	0.0	230.0	1.43	106.0	368	2320	0.45	65.0	0.73	0.04	16
13	1.10	7.2	540	490	56.9	37.0	58.0	2.5	50.5	6.0	112.0	0.84	211.0	421	360	ND	13.0	0.69	0.02	-
14	1.52	7.5	2000	585	102.0	35.0	45.0	2.7	70.0	0.0	258.0	1.00	182.5	351	1140	ND	22.6	0.75	0.03	6
15	1.20	7.4	2800	552	107.6	64.0	96.0	6.8	80.0	0.0	212.0	0.81	60.0	375	1940	ND	24.4	0.69	0.03	-
16	2.36	8.0	2100	968	231.0	67.0	65.0	1.8	81.0	10.0	452.0	0.62	90.0	306	1280	0.27	29.3	0.81	0.05	-
17	1.10	7.6	600	266	150.0	29.0	68.0	2.3	43.0	0.0	286.0	0.83	12.7	198	420	0.09	44.0	0.74	0.02	52
18	1.14	7.5	2000	511	165.0	43.0	74.0	5.8	23.3	13.0	210.0	0.93	80.0	345	1200	0.18	18.0	0.75	0.05	12
19	1.16	7.5	500	220	170.0	19.0	48.0	1.0	18.5	0.0	265.0	0.90	6.0	201	440	0.18	18.0	0.54	0.36	36
20	1.18	7.6	1100	194	22.1	36.0	58.0	2.8	67.0	7.0	212.0	0.80	180.0	432	820	ND	12.3	0.65	0.01	-
21	1.10	7.2	790	311	111.0	32.0	53.0	2.4	58.0	0.0	86.0	0.44	10.0	268	480	ND	61.0	0.86	0.04	-
22	1.14	7.4	800	350	36.2	22.0	48.0	2.1	34.5	0.0	210.0	0.66	10.0	252	700	0.09	38.0	0.96	0.03	84
23	1.10	7.4	800	374	110.4	18.0	63.0	4.3	40.0	9.0	240.0	0.63	11.0	269	620	ND	17.7	0.54	0.04	-
24	2.10	8.0	2500	230	74.4	16.0	71.0	7.0	56.0	10.0	356.0	1.19	174.0	343	1840	0.36	23.3	0.68	0.05	-
25	2.20	8.2	2200	1137	55.0	20.0	58.0	2.6	48.0	0.0	540.0	0.56	168.0	351	1750	0.09	35.3	0.90	0.03	-
26	1.10	7.5	2400	455	84.0	19.0	63.0	4.2	82.0	10.0	234.0	0.83	250.0	391	1700	0.09	4.0	0.48	0.04	8
27	1.18	7.6	1100	390	56.0	23.0	61.0	2.8	44.0	0.0	240.0	1.26	130.0	256	880	ND	33.0	0.61	0.20	5
28	2.10	8.3	2800	1292	96.0	34.0	93.0	0.9	87.0	14.0	562.0	0.79	170.0	341	2260	ND	40.8	0.88	0.03	-
29	1.06	7.3	1000	270	146.0	68.0	112.0	1.2	45.5	0.0	121.0	0.92	51.0	217	640	0.93	69.0	0.82	0.07	-
30	1.00	7.2	260	175	160.0	44.0	106.0	2.0	43.0	10.0	106.0	0.82	20.0	125	180	0.18	40.0	0.58	0.06	-
31	1.00	7.4	680	300	114.2	46.0	68.0	2.6	86.0	13.0	278.0	0.24	5.0	246	400	0.09	10.3	0.79	0.03	-
32	2.40	8.4	2700	1025	84.0	37.0	78.0	2.4	140.0	24.0	598.0	0.51	100.0	320	1300	0.04	28.7	0.62	0.06	-
33	1.10	7.6	1060	364	112.6	36.0	91.0	0.9	69.0	21.0	269.0	0.87	48.0	248	820	0.38	59.0	0.98	0.03	-
34	1.16	7.6	1050	255	96.0	39.0	76.0	1.6	64.5	12.0	298.0	0.79	140.0	206	440	0.29	65.0	0.69	0.05	-
36	1.68	7.8	500	258	141.0	69.0	110.0	1.2	27.0	0.0	298.0	0.44	49.0	217	220	0.36	17.0	0.82	0.06	-
37	1.12	7.8	2800	650	98.0	36.0	58.0	1.6	81.5	5.0	243.0	0.87	50.0	278	2340	0.54	14.0	0.68	0.02	-

Table cont...

...cont Table 1

38	2.14	8.1	3610	1158	112.0	32.0	71.0	2.3	49.0	0.0	596.0	1.00	190.0	375	2560	ND	15.1	0.72	0.02	-
39	1.16	7.6	1900	322	74.0	21.0	42.0	1.8	38.0	0.0	162.0	2.00	200.0	282	1500	0.09	34.0	0.82	0.05	-
40	1.14	7.5	1100	386	58.0	68.0	110.0	1.6	92.0	0.0	194.0	1.84	110.0	320	660	0.18	60.0	0.81	0.07	-
Mln	1.00	7.10	260	118	22.05	16.00	38.0	0.9	18.50	0.0	70.0	0.11	5.00	102	180	0.04	4.00	0.48	0.012	1.0
Max	2.50	8.4	4300	1292	231.0	69.0	112.0	15.0	204.0	27.0	598.0	2.00	290.0	621	2710	0.93	69.0	1.03	0.36	84
SD	0.5	0.3	1102	298	57.1	14.8	20.7	3.2	37.5	6.7	124.3	0.4	80.4	98	803	0.2	19.6	0.1	0.1	28.2

1-Turbidity (NTU); 2-pH, 3-EC (μmhos/cm), 4-TH (mg/L), 5-Ca $^{2+}$ (mg/L), 6-Mg^{2+} (mg/L), 7-Na^{+} (mg/L), 8-K^{+} (mg/L), 9-Cl^{-} (mg/L), 10-CO_3^{2-} (mg/L), 11-HCO_3^{-} (mg/L), 12-F^{-} (mg/L), 13-SO_4^{2-} (mg/L), 14- TA (mg/L), 15-TDS (mg/L), 16-Fe $^{2+}$ (mg/L), 17-NO_3^{-} (mg/L), 18-Zn^{2+} (mg/L), 19-Mn^{2+} (mg/L), 20-Coliform bacteria (MPN/100mL)

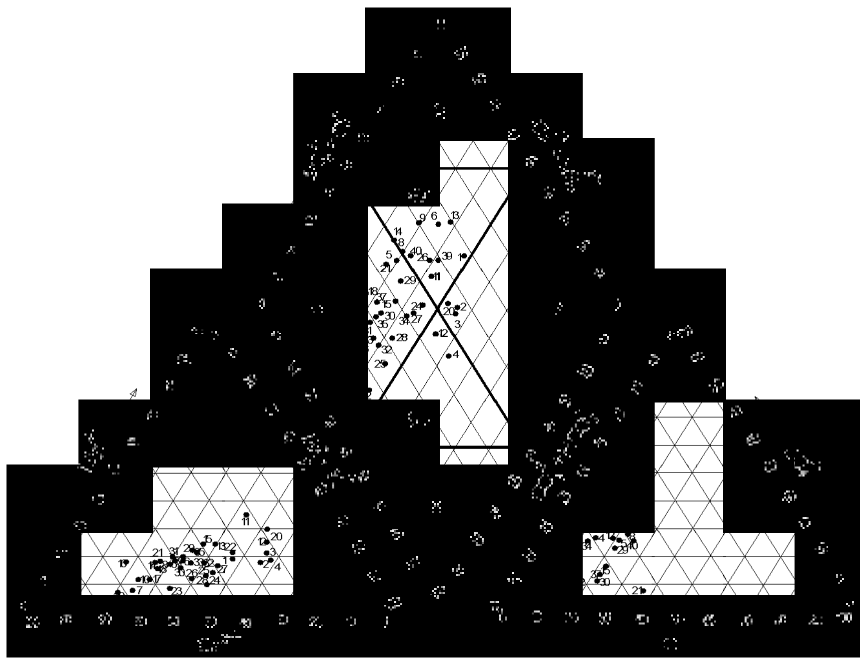

Fig. 1: Piper trilinear digagram of borewell samples of Bellary city.

fied groundwaters on the basis of electrical conductivity: up to 250 µmhos/cm as excellent; 250 to 750 µmhos/cm as good; 750 to 2250 µmhos/cm as fair and >2250 µmhos/cm as poor category. Based on this classification, 45% of the water samples belong to fair category, 30% to poor category and remaining 25% to good category.

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 4100 mg/L. According to WHO specification, TDS up to 500 mg/L is highest desirable, and up to 1000 mg/L is maximum permissible category, thus 72% of water samples belong to maximum permissible category, and 28% to below the WHO specification. Based on the concentration of TDS, groundwater can be classified as follows (Wilcox 1955): up to 500 mg/L as desirable for drinking; up to 1000 mg/L as permissible for drinking and up to 3000 mg/L as useful for irrigation. Based on this classification, it was observed that out of 40 samples 11 are desirable for drinking, 9 are permissible for drinking and remaining 20 are not fit for drinking.

Total hardness (TH): In the present study, the hardness of water samples ranged from 118 to 1292 mg/L. The waters of the study area are classified according to hardness (WHO 1988), which revealed that 58% of samples belong to permissible limit and 42% to out of permissible limit.

Total alkalinity (TA): Most of the groundwaters contain substantial amounts of dissolved carbon dioxide, bicarbonates and hydroxides, which are the principal source of alkalinity, which can be conveniently evaluated by acid titration. An increase in temperature or decrease in pressure causes a reduction in the solubility of CO_2 in water (Nagaraju et al. 2006). In the present study, alkalinity ranges between 102 and 421 mg/L. According to WHO classification, 52% of the samples belong to out of permissible limit, 43% to optimum permissible limit and 5% to below permissible limit.

Sulphate (SO_4^{2-}): Health concerns regarding sulphates in drinking water have been raised because of reports of diarrhoea associated with the ingestion of water with high levels of sulphates (Prasad et al. 2008). In the present study, sulphates range from 5.0 to 290.0 mg/L. According to WHO classification, 18% of the samples belong to below permissible limit, 28% to permissible limit and 54% to out of permissible limit.

Chloride (Cl^-): 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 18.5 and 204.0 mg/L. The WHO and ISI permissible limit of chloride for drinking water is 200 and 250 mg/L respectively. The chloride value of all the water samples studied is well within the permissible limit of WHO and ISI except Sample No. 11.

Fluoride (F^-): 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 concentration in groundwaters of the study area correlate positively with alkalinity (bicarbonate concentration), pH and sodium. The concentration of fluoride in the study area varies from 0.11 to 2.10 mg/L. The fluoride value of the water samples is well within the permissible limit of ISI for 34 samples, whereas 06 samples have high value of fluoride (>1.2 mg/L) and, thus, not safe for drinking purpose.

Nitrate (NO_3^-): The WHO guideline for nitrate in drinking water is 45 mg/L. The concentration of nitrate in the 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 a disease called methaemoglobinaemia (blue baby disease), which generally affects bottle-fed infants. Repeated heavy doses of nitrates on ingestion may likely to cause carcinogenic effects. Nitrate is basically nontoxic but when ingested with food or water, it is reduced to nitrite and then to ammonia, which are toxic. In the present study, out of 40 samples collected, 29 samples are well within the permissible limit of ISI and 11 samples have excessive limit.

Iron: In the present study, the iron varied from 0.04 to 0.93 mg/L. The permissible limit for iron is 0.3 to 1.0 mg/L. The concentration of iron in water samples of the study area is well below the permissible limit.

Zinc: The concentration of zinc in water samples varied from 0.48 to 1.03 mg/L. The permissible limit of zinc is 5 mg/L. The values of zinc in groundwaters are well below the permissible limit.

Manganese: The manganese ranged from 0.01 to 0.36 mg/L, which is within the permissible limit of 0.4 mg/L.

Sodium Adsorption Ratio (SAR): Excess sodium in waters produces undesirable effects of changing soil properties and reducing soil permeability (Kelly 1951). Hence, the assessment of sodium concentration in water is necessary while considering the suitability for irrigation. The degree to which irrigation water tends to exchange cations in the soil 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 suitability of irrigation water because it is responsible for the sodium hazard (Todd 1980). The waters have been classified in relation to irrigation based on the ranges of SAR values (Richards 1954). Out of 40 samples, 23 samples are excellent and remaining 17 samples are good for irrigation/gardening purpose. SAR values of the water samples vary from 4.9 to 16.1 (Table 2).

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

Classification of Water

Piper classification: Piper classification (Piper 1953) is used to express similarity and dissimilarity in the chemistry of different water samples based on the dominant cation and anions. This diagram is an effective tool in segregating analysis with respect to sources of the dissolved constituents in groundwater, modifications in the character of water as it passes through an area, and related geochemical problems. For the trilinear diagram, groundwater is treated substantially as though it contained three cation constituents (Mg, Na + K and Ca) and three anion constituents (Cl, SO_4 and HCO_3). The diagram presents graphically a group of analysis on the same plot. The chemical analysis data of samples have been plotted on trilinear diagram for the study area (Fig. 1). The cation plots in the diagram reveal that majority of the samples fall in calcium or magnesium type, followed by no dominant type. The anion plots in the diagram indicate that the samples fall in carbonate and bicarbonate followed by sulphate type. These two trilinear plots indicate that the groundwater of the study area are of calcium or magnesium, carbonate, bicarbonate and no dominant types. The diagram combines three different areas for plotting, two triangle areas (cation and anion) and an intervening diamond shaped area (combined field). Using the diagram, waters can be classified in four different hydrochemical facies. Majority of the samples of the study area falls in Ca-Mg-CO_3-HCO_3 facies.

US Salinity Laboratory (USSL) Classification: The chemical analysis data have also been processed as per the US Salinity Laboratory Classification (Wilcox 1955) to examine the suitability of groundwater for irrigation/gardening purposes and the results are summarized in Table 2. It is evident from the results that out of the 40 samples analysed, one sample was of C_1S_2 (low salinity and medium SAR), five samples were of C_2S_1 type (medium salinity and low SAR, suitable for irrigation purposes), and 2 samples were of C_2S_2 type (medium salinity and medium SAR). Seven samples were of C_3S_1 type (high salinity and low SAR), which are also fit for irrigation, in general, but may cause some problems where the soil permeability is very poor. Twelve samples are of C_3S_2 type (high salinity and medium SAR), such water can not be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good tolerance should be selected. Nine samples are of C_4S_2 type (very high salinity and medium SAR), which are not suitable for gardening under ordinary conditions, but may be used occasionally under very special circumstances. The soil must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching and high salt tolerant plants should be selected. Four samples from study area were found to be of C_4S_3 type (very high salinity and high SAR), which are not suitable for irrigation purposes. Very high salinity, as observed in some places from the study area, is harmful for the plant growth, physically by reducing the uptake of water through modification of osmotic processes or chemically by metabolic reactions caused by the toxic constituents. Besides, the salinity of this magnitude changes the soil structure, permeability and aeration, which in turn affect the plant growth and yield of crops considerably. The main effect of such high concentration of sodium, as observed in the groundwater of study area, is the reduction in soil permeability and hardening of soil. Both these effects are caused by the replacement of calcium and magnesium ions by sodium ions of the soil clays and colloids. Low permeability and hardening of soil hinder plant growth.

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; 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 study area samples vary from 17.8 to 58.9. Percent sodium is plotted against electrical conductance, which is designated as Wilcox diagram. From this it is clear that 10 samples fall into the category of 'Excellent to Good', 15 samples into the category of 'Good to Permissible', 9 samples into the category of 'Doubtful to Unsuitable', and 6 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 surfaces. Most of the problems are associated with salinity and encrustation problems. Water samples having corrosivity ratio of less than 1 are considered to be noncorrosive, while the value above 1 is corrosive (Jayalakshmi Devi & Belagali 2006). In the present study, 14 samples are considered as corrosive, while remaining 26 samples are noncorrosive (Table 2).

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

Table 2: Geochemical parameters of groundwater samples of Bellary city.

Sample No.	Sample Location	TDS mg/L	EC (µmhos/cm)	Percent Sodium	SAR	USSL Salinity	Mg Ratio	CR
1	Basaveswaranagar	260	290	46.3	11.0	C_2S_2	19.1	2.5
2	Bandhihatti	2700	4300	52.9	13.1	C_4S_3	17.1	1.6
3	Cowl Bazar	2160	3100	52.4	16.1	C_4S_3	20.6	1.4
4	Nehru colony	2600	4050	58.9	13.8	C_4S_3	16.8	0.8
5	Jagratinagar	720	1400	28.9	6.5	C_3S_1	20.4	1.1
6	Gandhinagar	300	750	32.4	10.1	C_3S_2	16.6	2.1
7	Belagal Road	2500	2700	23.8	6.1	C_4S_2	7.8	0.4
8	Yerritata Colony	520	680	29.3	6.9	C_2S_1	18.2	1.2
9	Renukanagar	960	1300	27.6	5.8	C_3S_1	16.7	1.6
10	ExServicemen Colony	500	730	22.1	6.1	C_3S_1	10.9	0.5
11	R.L. Beedi	2710	3250	31.4	6.5	C_3S_2	35.2	1.4
12	Parvathinagar	2320	3920	53.7	11.8	C_4S_3	26.4	1
13	Railway Colony	360	540	37.6	8.5	C_2S_1	24.0	2.4
14	S.N.Pet	1140	2000	24.4	5.4	C_3S_1	18.9	1.1
15	Allipur	1940	2800	35.0	10.4	C_4S_2	23.3	0.8
16	Bapujinagar	1280	2100	17.8	5.3	C_3S_1	18.4	0.5
17	R.K.Colony	420	600	27.3	7.2	C_2S_1	11.6	0.3
18	Vinayaknagar	1200	2000	25.7	7.3	C_3S_2	14.9	0.5
19	Nallacharuvu	440	500	20.2	4.9	C_2S_1	8.0	0.1
20	Tilaknagar	820	1100	48.8	10.7	C_3S_2	30.3	1.2
21	Jayanagar Park	480	790	26.7	6.3	C_3S_1	16.1	1.1
22	Guggarahatti	700	800	44.3	8.9	C_3S_2	20.3	0.3
23	Belagal Road	620	800	32.2	7.9	C_3S_1	9.2	0.3
24	Hussainnagar	1840	2500	42.2	10.6	C_4S_2	9.5	0.7
25	Polytechnic Hostel	1750	2200	42.7	9.5	C_3S_2	14.7	0.5
26	Ragavendra Colony	1700	2400	37.0	8.8	C_4S_2	11.2	1.5
27	Beechinagar	880	1100	42.8	9.7	C_3S_2	16.1	0.8
28	Ishwarayya Colony	2260	2800	41.5	11.6	C_4S_2	15.2	0.5
29	Harishchandranagar	640	1000	34.2	10.7	C_3S_2	20.8	1
30	Andrahal Poultry Farm	180	260	34.0	10.6	C_1S_2	14.1	0.6
31	Bislahalli	400	680	29.5	7.6	C_2S_1	19.9	0.4
32	Gonahal School	1300	2700	38.7	10.0	C_4S_2	18.4	0.5
33	OPD Hostel	820	1060	37.8	10.6	C_3S_2	15.0	0.5
34	Industrial Area	440	1050	35.7	9.3	C_3S_2	18.3	0.8
35	Netajinagar	420	790	34.8	10.8	C_3S_2	20.9	0.5
36	Siddarthanagar,	220	500	34.2	10.8	C_2S_2	21.5	0.3
37	Ganeshnagar	2340	2800	30.0	7.1	C_4S_2	18.6	0.7
38	ATP Road	2560	3610	32.7	8.4	C_4S_2	14.7	0.4
39	Devinagar	1500	1900	41.3	9.9	C_3S_2	12.7	1.7
40	S. Lingana Colony	660	1100	32.6	10.3	C_3S_2	20.1	1.3

study area consists 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 50. This would not affect the crop yield. The 'Magnesium Ratio' values vary from 7.80 to 35.20 in the study area (Table 2).

Coliforms: The bacteriological 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 or animal excreta. *E. coli*, a typical faecal coliform, is selected as an indicator of faecal contamination. In the study area nine samples were found to have coliform contamination. The permissible limit of bacterial coliforms is 4/100mL as per WHO. Sample Nos. 12, 17, 19 and 35 have high contamination of coliforms and are not suitable for human consumption without proper treatment.

CONCLUSION

From the results of the study, it is concluded that the quality of groundwater varies from place to place. It varied significantly within the same locality also. Higher values of certain constituents at various locations indicate that the water is not suitable for domestic applications. Hence, it is recommended that any water source must be thoroughly analysed and studied before being used for domestic use. The Piper trilinear diagram indicates that majority of samples fall under Ca-Mg-CO_2-HCO_3 hydrochemical facies. The US Salinity Laboratory classification of irrigation water indicates that only at few locations, water can be used safely for irrigation with most crops on most soils. At most of the other places, proper water management strategies need to be adopted for domestic and other developmental activities.

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