



GIS Based Spatial Mapping of Major Ion Chemistry of Groundwater of Ingaldhal and Surrounding Areas, Chitradurga District, Karnataka State

Annapoorna H.*† and Janardhana M. R.**

*Department of Studies in Earth Science, University of Mysore, Mysore-570 006, Karnataka, India

**Department of Geology, Yuvaraja's College, University of Mysore, Mysore-570 005, Karnataka, India

†Corresponding Author: Annapoorna H.

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 12-02-2015

Accepted: 15-03-2015

Key Words:

Ingaldhal copper mine
Groundwater
Major ions
Hydrochemical facies

ABSTRACT

In the absence of freshwater surface resources, the only alternative to quench the thirst of the human beings is groundwater. The quality criteria, set for drinking purpose, by various agencies are grossly neglected, due to paucity of groundwater owing to indiscriminate exploitation. An attempt is made here to evaluate the quality of groundwater of a socio-economically backward region located in and around the Ingaldhal copper mine area, Chitradurga District, Karnataka, for drinking purpose. Groundwater samples (n=12) collected from 7 villages, were analysed to assess their physico-chemical characteristics. TDS values range from 594-1913 mg/L, pH from 7.61-8.34 and TH from 410-1400 mg/L. Cation concentration ranges are 59-150 mg/L, 49-250 mg/L, 38-290 mg/L and 6-58 mg/L for Ca²⁺, Mg²⁺, Na⁺ and K⁺ respectively. Anion concentration ranges are 417-574 mg/L, 68-286 mg/L, 63-623 mg/L, 14-162 mg/L, 0-29 mg/L and 0.451-1.43 for HCO₃⁻, SO₄²⁻, Cl⁻, NO₃⁻, CO₃²⁻ and F⁻ respectively. The results reveal that the average abundance of the major cations and anions is in the order of Mg²⁺ > Na⁺ > Ca²⁺ > K⁺ and HCO₃⁻ > Cl⁻ > SO₄²⁻ > NO₃⁻ > CO₃²⁻ > F⁻ respectively. The identified types of hydrochemical facies of the groundwater are CaMgHCO₃ type (n=3), CaMgSO₄ type (n=3) and mixed type (n=6). The values of the major ion concentrations of the majority of the groundwater samples fall well above the recommended standard limit for drinking purpose.

INTRODUCTION

The National Water Policy (1987) states that water is a prime natural resource, basic human need, and precious national asset. In the absence of surface freshwater resources, groundwater is a potential freshwater resource for domestic and agricultural use. In India, more than 90% of the rural population depends on groundwater for all their needs. However, groundwater gets contaminated from natural sources and/or by anthropogenic activities rendering it risky to consume or use without treatment. Whether the source of contamination of groundwater is geogenic or anthropogenic, it is essential to monitor the quality of groundwater as large number of people are dependent on it.

Ingaldhal and surrounding villages in the Chithradurga district of Karnataka state are known for sulphide mineralization. These villages lack any surface water resources and the population is entirely dependent on groundwater for their drinking and agricultural needs. A reconnaissance survey was carried out by collecting the groundwater samples randomly around these sulphide mineralized areas and major ion-wise, it was found that by and large the quality of the groundwater in these villages is degraded. We present here the major ion chemistry of the groundwater in the Ingaldhal region of Karnataka state.

STUDY AREA

Ingaldhal is a small village on the outskirts of the Chithradurga town of Karnataka state. It lies within 65°28'39"–66°19'47" E longitudes and 15°70'80"–15°59'77" N latitudes (Fig. 1). The study area covers a geographical area of 100.451 sq km. The area earned fame as it once hosted commercial concentration of copper in Karnataka state. The copper mine is defunct now due to low recovery of copper and other base metals. The study area is a part of Chithradurga schist belt of Dharwar craton and displays the rock types of Hiriya formation of the Chithradurga Group (Ramakrishnan et al. 2010). The major rock types exposed are polymict conglomerate, metabasalt, greywacke-argillite and granodiorite and granites respectively in the ascending order (Fig. 2). This succession overlies the metabasalt-BIF succession. Geomorphologically, the area represents an undulating plain with linear structural hills and valleys exposing volcano-sedimentary sequence. The study area receives from 600 to 1000 mm rainfall mainly from southwest monsoon and its climate is essentially semi-arid. The aquifer is recharged by direct infiltration of precipitation, the main source of groundwater recharge. Groundwater in the study area occurs under water table conditions. The average annual temperature varies from 20°C to 40°C. Drainage of the study area is of ephemeral type and there are no surface

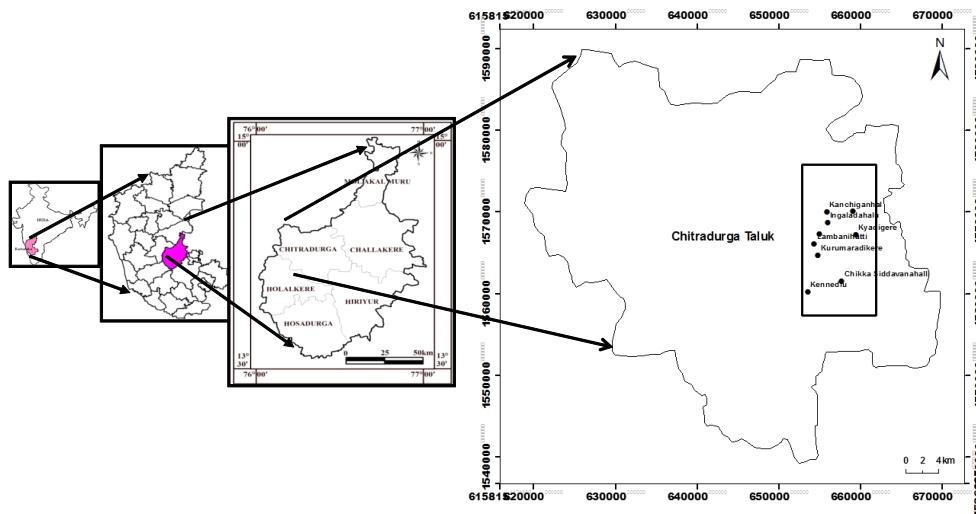


Fig. 1: Location map of the study area.

MATERIALS AND METHODS

Groundwater samples from 12 bore wells in the study area were collected in duplicate in the month of January 2013. The samples were collected in pre-cleaned polyethylene bottles of 1 L capacity. During the sampling, the bottles were rinsed thoroughly two times with the groundwater sampled. Prior to sampling, water has been pumped out from bore well for 10 minutes to remove stored groundwater in the wells. *In situ* testing like colour, odour, temperature, EC and pH were measured. Groundwater samples collected were labelled with sample id. Later the samples were sent to the laboratory for analysis for major anionic and cationic constituents. The procedures given by APHA (2005) were followed for the analysis of the groundwater samples. The analytical results are presented in Table 1. The topo sheets published by the Survey of India produced on a scale of 1:50,000 were used to prepare the base map of the study area. The produced map was digitized; projected and different types of thematic maps were prepared using Arc-GIS 10 version software for effective interpretation of the hydrochemical data.

RESULTS AND DISCUSSION

The concentration of dissolved ions in groundwater samples is generally governed by lithology, nature of geochemical reactions and solubility of interaction rocks. Hydrochemistry in terms of major cation and anion constituents of the groundwater along with other physico-chemical properties are discussed below. Suitability of groundwater for drinking purpose based on the various standards is also assessed.

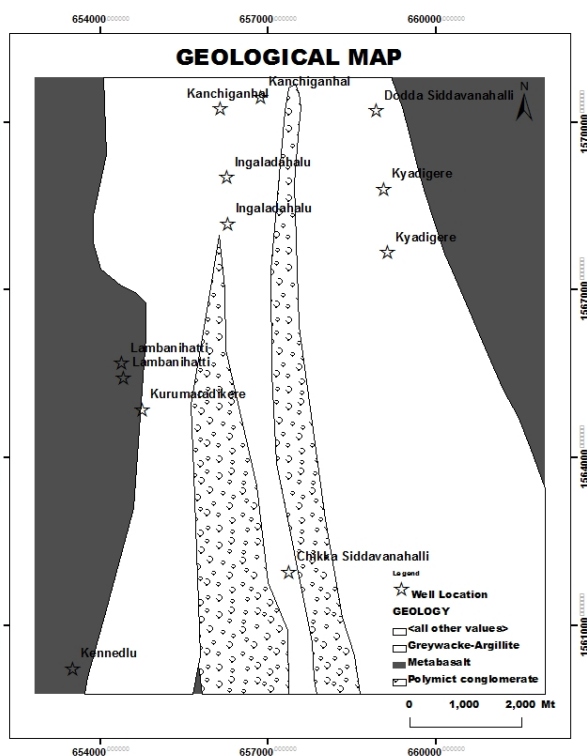


Fig. 2: Geological map of the study area (After NRDMS Chitradurga 2008).

water bodies in the study region. The entire population of the village makes use of groundwater for drinking, domestic and irrigation purposes. At present, groundwater is drawn from a depth varying from 47 to 54 m.

Table 1: Fourteen major parameters obtained from 12 groundwater samples.

Well No	ID Sample	EC	TDS	TH	pH	Ca ²⁺	Mg ²⁺	K ⁺	Na ⁺	SO ₄ ²⁻	Cl ⁻	CO ₃ ⁻	HCO ₃ ⁻	NO ₃ ⁻	F ⁻
W1	KUNGW-1	1080	668	510	8.16	67	82	14	90	68	77	0	529	42	1.430
W2	SCKGW-1	1100	684	410	7.97	83	49	9	64	82	133	0	417	22	0.882
W3	INGGW-1	2600	1600	1400	8.01	114	250	6	38	286	469	0	480	162	0.882
W4	INGGW-2	950	594	420	8.01	61	55	12	54	72	63	0	441	45	0.809
W5	LHGW-1	1410	897	600	7.78	117	74	16	88	80	133	0	574	102	0.716
W6	LHGW-2	1650	1045	700	7.78	150	78	15	95	114	196	0	534	128	0.563
W7	KUMGW-1	1950	1240	730	7.86	75	130	28	172	168	259	0	695	58	0.663
W8	KNDGW-1	1700	1065	640	7.61	139	70	24	116	108	231	0	485	130	0.527
W9	CHSGW-1	1580	982	730	7.92	69	134	12	82	208	245	0	431	14	0.451
W10	KYDGW-1	2000	1273	510	8.1	59	87	40	248	216	301	0	539	50	0.903
W11	KYDGW-2	1900	1195	530	8.34	59	92	34	214	196	224	29	519	85	0.802
W12	DSHGW-1	3120	1913	960	7.74	93	175	58	290	276	623	0	539	126	0.929

Where, All parameters in mg/L and EC in $\mu\text{S}/\text{cm}$

Table 2: Classification of groundwater based on TDS.

Concentration in mg/L	Significance
<1000	Freshwater type
1000-10000	Brackish water type
10000-100000	Saline water type
>100000	Brine water type

Table 3: Groundwater classification based on TH.

Concentration in mg/L	Significance
0-75	Soft
75- 150	Moderately Hard
150-300	Hard
>300	Very Hard

Table 4: The effect of fluoride on human health.

Concentration in mg/L	Effects
< 1.0	Safe Limit
1.0-3.0	Dental fluorosis (discoloration, mottling and pitting of teeth)
3.0-4.0	Stiffened and brittle bones and joints
4.0-6.0 and above	Deformities in knee and hip bones and finally leads to paralysis. Crippling fluorosis.

Hydrogen ion concentration (pH): pH indicates the ionic concentration of hydrogen, based on which the acidic or basic nature of the groundwater is decided. pH reflects the availability of carbonate in the host area (Moore et al. 2011). The value of pH in the study area ranges from 7.61-8.34 (Table 1). As conforming to the drinking water standards (WHO 2011, US-EPA 2002, ISIRI 2010), pH values are within the permissible limit.

Electric conductivity (EC) or specific conductance: EC is the measure of ionic activity and is directly related to ionic

concentration in waters. The large variation in EC is mainly attributed to distinct processes such as saline sources, mineral dissolution and influx of pollutants from anthropogenic activities. EC is related to total dissolved solids (TDS). The importance of EC and TDS lies in their effect on the corrosivity of a water sample and on the solubility of slightly soluble compounds such as CaCO_3 (Nas et al. 2010). In the study area, EC ranges from $950\mu\text{S}/\text{cm}$ to $3120\mu\text{S}/\text{cm}$ with an average of $1753.33\mu\text{S}/\text{cm}$. The samples, except W1, W2 and W4 have high EC, which exceeds the permissible limit stated by WHO (2011). Permissible values of EC ($<1400\mu\text{S}/\text{cm}$ as per WHO 2011) are found only in small portions of NE parts of the study area [Fig. 3(a)] and in most part of the study area, the samples show higher values of EC ($>1400\mu\text{S}/\text{cm}$) for drinking needs.

Total dissolved solids (TDS): Inorganic salts like Ca, Mg, K, Na, HCO_3 , Cl and SO_4 and some inorganic matter that are dissolved in water comprises TDS. The concentration of TDS in water varies considerably in different geological regions owing to differences in the solubility of minerals (WHO 2004). According to Freeze & Cherry (1979) waters can be classified as given in Table 2.

The TDS varies in the area from $594\text{mg}/\text{L}$ - $1913\text{mg}/\text{L}$. $\text{TDS}<1000\text{mg}/\text{L}$ is freshwater and $\text{TDS}>1000\text{mg}/\text{L}$ is brackish water. Based on this, the samples W1, W2, W4, W5 and W9 are freshwater and all others belong to brackish water type. The highest concentration of TDS is observed at Doddasiddavvana Halli, having sample id DSHGW-1. Fig. 3(b) shows the spatial distribution of the TDS in the study area. NE and SW parts of the study area belong to freshwater type and in the rest of the study area, water is not permissible for drinking purpose.

Total hardness (TH): Sawyer & Mc Carthy (1967) classified groundwater (based on TH as CaCO_3) as given in Table 3. Hardness of water affects its reaction with soap and

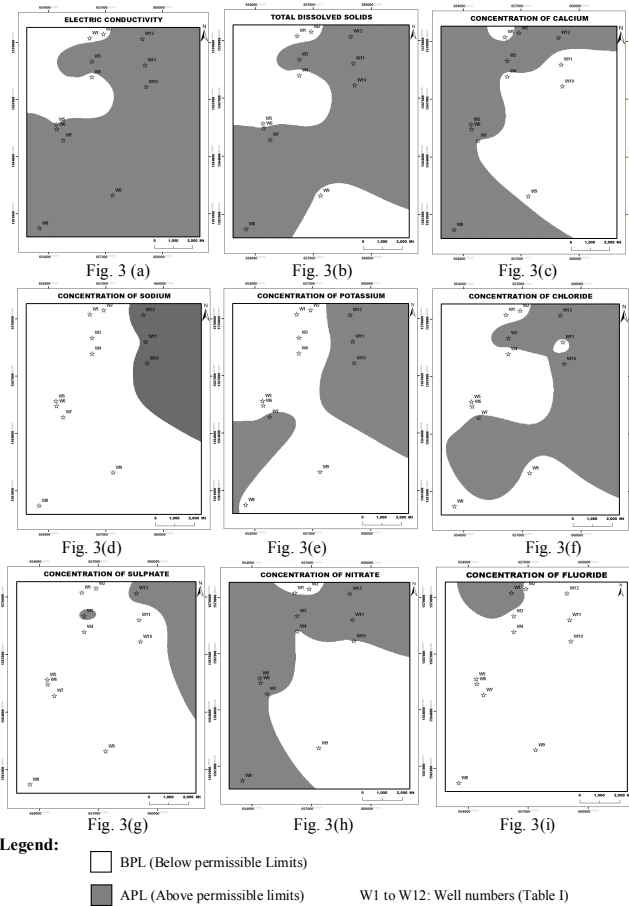


Fig. 3: Zonation maps of Ec (3a), TDS (3b), Calcium (3c), Sodium (3d), Potassium (3e), Chloride (3f), Sulphate (3g), Nitrate (3h) and Fluoride (3i).

causes scale and incrustation accumulation in containers and conduits where the water is heated or transported. According to the classification given by Sawyer & McCarthy (1967), the water is very hard and unfit for drinking purpose.

Cation chemistry: The abundance of cations in the groundwater of the study area is in the following order: $Mg^{2+} > Na^+ > Ca^{2+} > K^+$. The major cation concentration in most of the groundwater samples is above the permissible limits set by various agencies [WHO (2004 & 2011), US-EPA (2002), ISIRI (2010)] for drinking purpose.

Calcium: The acceptable limit for Ca^{2+} is 75 and allowable limit is 200mg/L (WHO 2004) for drinking water purpose. The samples W2, W3, W5, W6, W7, W8 and W12 fall within the allowable limit of drinking water standards stated by WHO (2004) and the rest of the samples viz., W1, W4, W9 and W11 fall within the acceptable limits (Table 1). The spatial distribution of Ca in groundwater samples of the study area is shown in Fig. 3(c).

Magnesium: Magnesium is the main dominant cation in the groundwater samples of the study area. The ion exchange of mineral by groundwater within the rock and soil is believed to be the main source of Mg^{2+} in the groundwater. In the study area all samples exceed the desirable Mg^{2+} concentrations as per ISIRI (2010).

Sodium and potassium: In the groundwater samples of the study area, Na^+ concentration ranges from 38mg/L to 290mg/L and K^+ ranges from 6mg/L to 58mg/L. Desirable limit of Na^+ is 20mg/L and for K^+ is 30mg/L. The main sources for the Na and K in groundwater are plagioclase and potash feldspars, the weathering of which release the soluble products. In the spatial distribution maps of groundwater [Fig. 3(d) and Fig. 3(e)], the NE parts of the study area is found to have higher concentrations of Na+K, above the permissible limit.

Anion chemistry: The groundwater shows the following characteristics $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- > CO_3^{2-} > F^-$. Major anions of groundwater in the study area show concentrations above the permissible limits for drinking water standards set by various agencies.

Bicarbonates and carbonates: In groundwater, weathering and dissolution are the major sources of carbonate and bicarbonate concentration. The values of bicarbonate in the groundwater of the study area range from 417mg/L to 574 mg/L. 60mg/L is the permissible limit for drinking water as specified by US-EPA (2002). In the study area, all groundwater samples exceed the specified limit for drinking purpose. Carbonate concentration in the study area varies from 0mg/L to 29mg/L with a mean of 2.42mg/L. Carbonate is found only in the water sample of Kyadigere location i.e., well number W11.

Chloride: Chloride showed much variation and is found in the concentration ranging from 63mg/L to 623mg/L (Table 1). The lowest is at the location W4 and highest is at the well number W12. For drinking purpose, the permissible limit of chloride is 250mg/L (WHO 2011). The groundwater samples W3, W7, W10 and W12 are above the permissible limits. The spatial distribution map of chloride is given in Fig. 3(f). The natural processes such as weathering, incursion of seawater and irrigation drainage return flow are possibly responsible for chloride content in groundwater (Khairy et al. 2012).

Sulphate: The highest level of sulphate in groundwater is from natural sources like igneous, sedimentary and metamorphic rocks such as metallic sulphides. In the presence of aerated water, sulphur weathers to sulphate. Presence of sulphate in drinking water can cause a noticeable taste and very high levels might cause a laxative effect in unaccustomed consumers (Nas et al. 2010). Present study area demarcates

Table 5: The suitability of the groundwater for drinking purpose.

Parameter	Min	Max	Average	Sample numbers exceeding permissible limit of					
				WHO(2011)		US-EPA (2002)		ISIRI (2010)	
Ca ₂ ⁺	59	150	90.5	75-200	-	75-200	-	300	-
Mg ₂ ⁺	49	250	106.33	50	All, except w2	50-150	w2, w3, w12,	30	All
Na ⁺	38	290	129.25	200	w10, w11, w12	200	w10, w11, w12	200	w10, w11, w12
K ⁺	6	58	22.33	12	w1, w4, w5, w6, w7, w8, w9, w10, w11, w12	25	w7, w10, w11, w12	-	-
HCO ₃ ⁻	417	574	515.25	-	-	60	All	-	-
SO ₄ ²⁻	68	286	156	250	w12	400	Nil	250-400	Nil
Cl ⁻	63	623	246.17	250	w3, w7, w10, w12	250	w3, w7, w10, w12	400	w3, w12
CO ₃ ⁻	0	29	2.41	NGL	-	NGL	-	NGL	-
NO ₃ ⁻	14	162	80.33	50	w3, w5, w6, w7, w8, w10, w11, w12	50	w3, w5, w6, w7, w8, w10, w11, w12	50	w3, w5, w6, w7, w8, w10, w11, w12
F ⁻	0.45	1.43	0.8	1.5	Nil	-	-	-	-
pH	7.61	8.34	7.94	6.5-8.5	Nil	6.5-9.2	Nil	6.5-9	Nil
TDS	594	1913	1096.33	1000	w3, w6, w7, w8, w10, w11, w12	1500	w3	1500	w3
TH	410	1400	678.33	500	w1, w3, w5, w6, w7, w8, w9, w10, w11, w12	-	-	500	w1, w3, w5, w6, w7, w8, w9, w10, w11, w12
EC	950	3120	1753.33	1400	w3, w5, w6, w7, w8, w9, w10, w11, w12	-	-	-	-

All values in mg/L except EC (μ S/cm).

sulphate concentration range from 68mg/L to 286mg/L, with an average of 156.17mg/L. WHO (2004) and US-EPA (2002) indicates a maximum contaminant level of 250mg/L sulphate for drinking purpose. According to the above standards, groundwater well numbers W3 and W12 were found to contain elevated concentration of sulphate and thus not fit for drinking purpose. Fig. 3(g) depicts the spatial distribution of sulphate in the groundwater of the study area.

Nitrate: The nitrate concentration in groundwater and surface water is normally low, but can reach high levels as a result of leaching or runoff from agriculture land or contamination from human or animal wastes as a result of oxidation of ammonia and similar sources (WHO 2004). The maximum concentration of nitrate in the water for drinking purpose is given as 50mg/L by WHO (2011), US-EPA (2002) and ISIRI (2010). Nitrate concentration varies from 14mg/L to 162mg/L, with an average of 80.33mg/L. Groundwater of the borewells W1, W2, W4, W9 and W10 are within a maximum contaminant level. The spatial distribution map also shows the same in the Fig. 3(h).

Fluoride: Weathering and runoff of fluoride containing rocks and soils and leaching down into the groundwater are the major source of fluoride in groundwater. Fluoride is one of

the natural contaminant found in groundwater. Fluoride beyond acceptable limit in potable water may lead to health associated problems (Table 4). In some regions of India, water contains fluoride up to 38mg/L, which is exceedingly high compared to the maximum permissible limit of 1mg/L set for India (Susheela 1999). In the study area, excepting Kunchiganhal wherein groundwater is having fluoride concentration of 1.43 mg/L, the rest falls within the safe zone Fig. 3(i).

The suitability of the groundwater of this area for drinking, based on the physico-chemical characteristics, is given in Table 5.

Hydrochemical characteristics of the groundwater of the study area were evaluated based on the region of plots of the epm percentages of cations and anions on Piper's trilinear diagram (Fig. 4) (Piper 1944). Hydrochemical data of the ground water of the study area plotted in the piper trilinear diagram reveals that in all the samples, alkaline earths exceed alkalis. In majority of the samples, weak acid and strong acids do not show any dominance. In three samples W3, W9 and W12 non-carbonate hardness exceed 50% and in another three samples W1, W4 and W5 carbonate hardness exceeds 50%. Cation facies-wise, nine samples are magnesium type

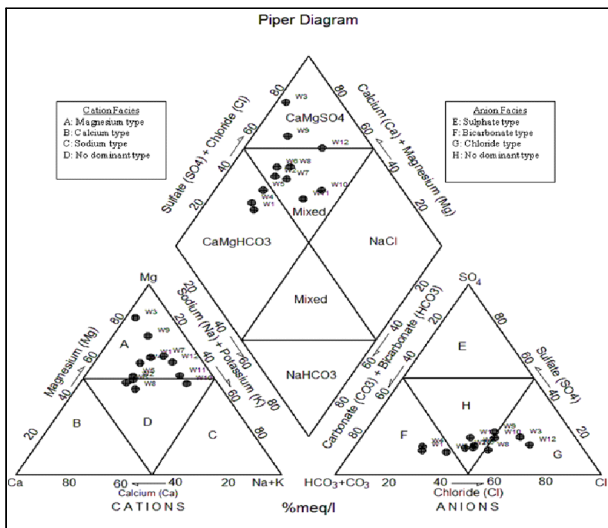


Fig. 4: Piper trilinear diagram.

and another three are no dominant type. Anions facies-wise, three are bicarbonate-carbonate type and four are chloride type and five are no dominant type. Groundwater from the study area consists of 3 hydrochemical facies types, viz., CaMgHCO_3 -type ($n=3$), CaMgSO_4 -type ($n=3$) and mixed-type ($n=6$).

The ratios between total cations to $\text{Na}+\text{K}$ and total cation to $\text{Ca}+\text{Mg}$ are 3.14 and 1.46 respectively. This observation showed the involvement of silicate weathering in the geochemical processes, which contribute mainly sodium, calcium and potassium ions to the groundwater (Stallard & Edmond 1983). Weathering of soda feldspar and potash feldspars, which are common in granites, gneiss and pegmatite occurring in this area, is greatly responsible for the contribution of Na^+ and K^+ ions to groundwater. Feldspars are more susceptible to weathering and alteration than quartz in silicate rocks. The regional geology also implies that the alkali earth silicates occur everywhere in the area.

CONCLUSIONS

Hydrochemical data of the groundwater of the Ingaldhal and surrounding areas of Chitradurga district of Karnataka state indicate elevated concentration of major ions in majority of the groundwater samples of the area. Groundwater drawn from 12 bore wells is characterized by $\text{Ca}^{2+} > \text{Na}^+ > \text{Mg}^{2+} > \text{K}^+$ and $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{NO}_3^-$, and hydrochemical facies-

wise belongs to CaMgHCO_3 -type ($n=3$), CaMgSO_4 -type ($n=3$) and mixed-types ($n=6$). In groundwater samples, the values of the molar ratios of $\text{Ca}^{2+}/\text{HCO}_3^-$, $\text{Ca}^{2+}/\text{SO}_4^{2-}$, $\text{Mg}^{2+}/\text{HCO}_3^-$, and $\text{Mg}^{2+}/\text{SO}_4^{2-}$ indicate that in all the samples, the cation content were derived from two processes namely weathering of silicate mineral and cation-anion exchange reaction.

ACKNOWLEDGEMENTS

This paper is a part of the work carried under the project entitled "The Abandonment of the Ingaldal Copper Mines, Karnataka State: Impacts of Sulphide Mineralization and Mining on Groundwater Quality" funded by UGC and is duly acknowledged by the second author.

REFERENCES

- American Public Health Association APHA 2005. Standard Methods for the Examination of Water and Wastewater, 21st edition, APHA, AWWA, WPCF, Washington DC, USA.
- Freeze, R.A. and Cherry, J.A. 1979. Groundwater. Eaglewood Cliffs: Prentice Hall Inc., 604.
- Farid Moore, Kobra Esmaili and Behnam Keshavarzi 2011. Assessment of heavy metals contamination in stream water and sediments affected by Sungun porphyry copper deposit, East Azerbaijan Province, Northwest Iran, Keshavarzi. Water Qual. Expo. Health, 3: 37-49.
- ISIRI, 2010. Drinking Water - Physical and Chemical Specifications. 5th ed., Institute of Standards and Industrial Research, Iran.
- Khairy Houshang, Janardhana, M. R. and Khademy, S. 2012. Hydrochemistry and quality of groundwater from two-tier aquifer system in parts of Amol-Ghaemshahr plain, Mazandaran province, N. Iran. J. of Appl. Geochemistry, 14(2): 194-216.
- Nas, B. and Berktaş, A. 2010. Groundwater quality mapping in urban groundwater using GIS. Environ. Monit. Assess., 160: 215-227.
- Piper, A.M. 1944. A graphical procedure in the chemical interpretation of groundwater analysis. Trans. Amer. Geophys. Union, 25: 914-928.
- Ramakrishnan, M. and Vaidyanadhan, R. 2010. Geology of India. Geological Society of India, Bangalore, 1:103-140.
- Sawyer, C.N. and McCarthy, D.L. 1967. Chemistry of Sanitary Engineers. 2nd edn., McGraw Hill, New York, pp. 518.
- Stallard, R. F. and Edmond, J. M. 1983. Geochemistry of the Amazon river-the influence of the geology and weathering environment on the dissolved load. Journal of Geophysical Research, 88: 9671-9688.
- Susheela, A. K. 1999. Dark side of fluoride. The Daily Star. February 20. Features 16, Col. No. 15.
- US-EPA 2002. Methods for Chemical Analysis of Water and Waste. EPA-600/4-79-020. US. Environ. Protection Agency, Cincinnati, Ohio, U.S.A.
- WHO 2004. Guidelines for Drinking Water Quality: Training Pack. WHO, Geneva.
- WHO 2011. Guidelines for Drinking Water Quality, 4th ed., Recommendations, WHO, Geneva, pp. 1-4.