

# Rock-Water Interaction and Chemical Quality Analysis of Groundwater in Hard Rock Terrain of Chamrajanagara District, Karnataka, India Using Geoinformatics

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## Abstract

Groundwater is one of the main natural resources having its application in various fields which affects its quantity. Groundwater pollution occurs when used water is returned to the hydrological cycle. The present study aims to assess the spatial variations of groundwater quality parameters in Southern tip of Karnataka using Geoinformatics technique. Efforts have been made to evaluate a total number of 46 representative groundwater samples (C1 to C46) from different parts of the study area during pre-monsoon period (April-May 2005) to assess its parameters such as F<sup>-</sup>, NO<sub>3</sub><sup>-</sup>, CO<sub>3</sub><sup>2-</sup>, Cl<sup>-</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup>, SO<sub>4</sub><sup>2-</sup>, Fe, K<sup>+</sup>, pH and EC. Groundwater quality is found to be more controlled by rock-water interaction and residence time of water in aquifers and affected more by anthropogenic factors at many locations. Each Land Use/Land Cover (LU/LC) patterns and major lineaments are mapped and digitized using Sol topomap of 1:50,000 scale and IRS-1D, PAN+LISS-III satellite data through GIS software's. Wide applications of chemicals, pesticides, fertilizers, herbicides in large agricultural and vegetative lands; mining activities are the major factors that are contaminating the soil and leaching through seepage, fractures, faults and joints (lineaments) into the groundwater. The study reveals the potentiality of Geoinformatics application in preparation of more consistent and accurate baseline information predicting the groundwater quality in Precambrian hard rock terrain of the study area.

**Keywords:** Groundwater quality analysis; Precambrian rocks of Chamrajanagar district; Geoinformatics

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## Introduction

Water is the main source for domestic, engineering, industrial, agricultural and multipurpose uses which affects its supply and demand due to rapid rise in population. Occurrence and movement of groundwater are controlled by the degree of weathering, fracturing, the geomorphological set up and precipitation [1,2] Scarcity of potable drinking water is one of the major development issues in parts of many states [3] Groundwater is contaminated more by anthropogenic activities reducing its supply in the study area and posing threats to water developmental programmes. Intensive application of fertilizers, agrochemicals, sewage/drain water leakage and mining activities

are noticed on major lineaments and observed to be serious threats to groundwater quality [4] The quality of groundwater is governed by the mineralogical composition of the rocks [2] Several groundwater related studies have been reported all over the world on groundwater evaluation [5,6] and groundwater quality mapping [7,8] using GIS. The geochemical characterization of groundwater in SE and NE parts of India reveals deterioration of water quality due to over-exploitation. Most of the cases, groundwater is contaminated by nitrate due to agricultural activities [9] and soil contamination due to irrigation water [10]. Mani [11] discussed about groundwater conditions in hard rock areas of Madhya Pradesh, Karnataka and Rajasthan. Analysis of

harvested rainwater quality is assessed for both domestic and drinking purposes in northern area of Kefalonia Island in Greece using 3 year surveillance factors [12,13] proposed a GIS integrated technique to evaluate the quality of irrigation water based on the potential soil and crop problems in Western Anatolia, Turkey; revealing the fairly good groundwater quality found to be mostly suitable for irrigation purpose. Groundwater resource is under threat from pollution either from human life style manifested by the low level of hygiene practiced in the developing nations [14].

## Location

Study area lies in between 11°40'58" to 12°06'32" N latitude and 76°24'14" and 77°46'55" E longitude with an aerial extent of 5,685 Km<sup>2</sup> falling under Southern dry zone. It includes four taluks namely Chamarajanagara, Gundlupete, Kollegala and Yelanduru [15-17] (Figure 1). The district may be classified as partly maidan and general tableland with plain, undulating and lofty mountain ranges covered with thick forests are noticed with N-S trending hill ranges. The southern and eastern parts in the district converge into group of hills with general elevation ranging from 600 to 1,000 m above MSL. Dense forest covers are noticed in the Southern and Southwestern parts of all 4 taluks. Cauvery, Kabini, Gundal and Suvarnavathi are the major rivers that drain most part of the district.

## Rainfall and Climate

The climate is quite moderate throughout the year with fairly hot summer and cold winter periods. Average annual rainfall recorded is 811 mm in 2008. Temperature ranges from 16.4°C to 34°C. During October and November, some of the depressions and cyclonic storms originates in Bay of Bengal passing through the district, causes wide spread of heavy rainfall and high winds. Relative humidity ranges from 69 to 85% in the morning and 21%

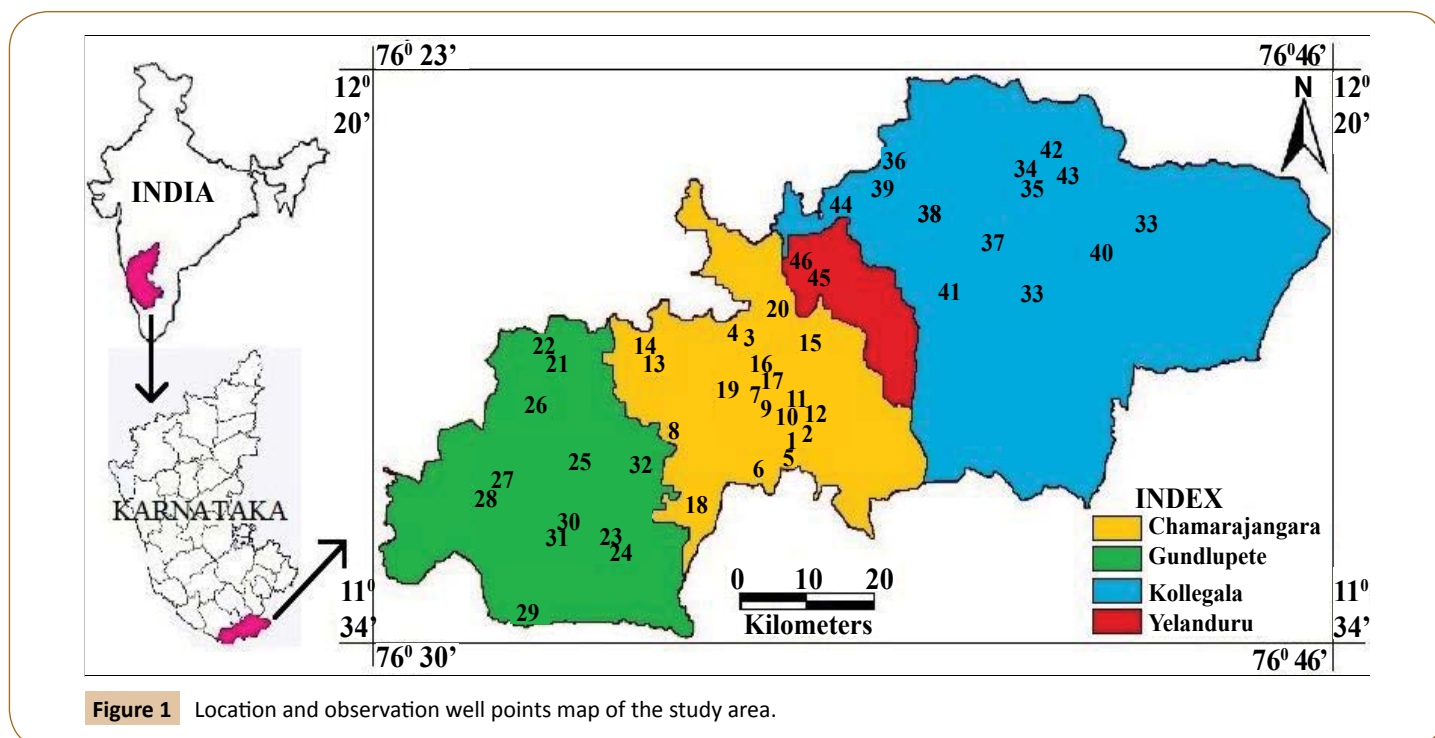
to 70% during evening time [18]. Wind speed varies from 8.4 to 14.1 Kmph. Overall on an average, there are 67 normal rainy days which records minimum at Yelanduru taluk (63 days) and maximum at Gundlupete taluk (73 rainy days) [15,17].

## Materials and Methods

About 46 groundwater samples are collected (32-borewells and 14-dug wells) during pre-monsoon period (April-May 2005) to assess its parameters such as Fluoride (F<sup>-</sup>), Nitrate (NO<sub>3</sub><sup>-</sup>), Carbonate (CO<sub>3</sub><sup>2-</sup>), Chloride (Cl<sup>-</sup>), Calcium (Ca<sup>2+</sup>), Magnesium (Mg<sup>2+</sup>), Sodium (Na<sup>+</sup>), Sulphate (SO<sub>4</sub><sup>2-</sup>), Iron (Fe), Potassium (K<sup>+</sup>), Potential of Hydrogen (pH) and Electrical Conductivity (EC). Survey of India (Sol) Toposheet no's such as 57H/3, 57H/4, 57H/7, 57H/8, 57H/12, 57H/16, 57D/12, 57D/16, 57A/5, 57A/6, 57A/9, 57A/10, 57A/13, 57A/14, 57E/1, 57E/2, 57E/5, 57E/9 of 1:50,000 scale (considered as base maps) which are geo-rectified and each LU/LC patterns are digitized and updated using Satellite Image. Lithological map is digitized based on each lithological units encountered during field visits and key elements interpretation on Satellite images; Lineament overlaid on LU/LC map and Spatial distribution maps of groundwater parameters are well digitized using ArcGIS v10. IRS (Indian Remote Sensing)-1D, LISS-III (Resolution: 24 m, year: 2010-11), PAN (year: 2005-06, Resolution: 5.8 m); PAN+LISS-III (2.3 m resolution) Satellite images are acquired and digitized the linear features/ faults/ fractures by Visual Image Interpretation Techniques (VIIT) and overlaid on LU/LC map. Arc GIS v10 and Erdas Imagine v2013 are the GIS's software applied to generate different thematic layers in the present study. A handheld GPS (Garmin-12) is used during the field visits to record the exact locations of Groundwater bore/ dug well points in the study area.

## Soil

Soil forms the basic geological structure derived from underlying parent materials. Leachate/ heavy metal migration forms through



the soil causes major contamination of groundwater particularly around industrial/ mining activities. Major portions of the district are covered by red soil derived from gneisses, charnockite, granulites, granites, amphibolites, banded magnetite quartzite and manganese horizons. The soils of the district are derived from Granitic gneisses and Charnockite rocks. Red soils are present in upland areas and also noticed at the contact of granites and amphibolites. These soils are admixture of sand and silt. Organic matters in these soils are low and respond well for irrigation menning and other management practices [16]. The thickness of the soil varies from less than a meter to 6.5 meters. Black soils are clayey, mostly of transported in origin, occurring along depressions where regular irrigation practices are in progress. Mixed type of soils localized at places along the contact of schist and other intrusions. These are medium to fine grained and moderately permeable shows high moisture content. The thickness varies from 1 m to 16.5 m [4,17].

### Lithology and Structure

The study area is broadly described under the dominating Archaean Granulite facies rocks generally termed as Charnockites occur extensively towards southern margins of the Dharwar Craton [19-23]. Lithological map is derived from published Geological map of 1:250,000 scale [24] and updated using IRS 1D PAN+LISS-III geocoded standard FCC (False Colour Composite) Satellite image using key interpretation elements (Figure 2). The contacts of litho units can be accurately marked and extended by using the tonal characteristics of satellite imagery with limited ground checks. The structures like dykes, faults, their trend and extensions are mapped based on synoptic viewing and discontinued with black signature. Encountered district litho units noticed as Gneisses, Charnockites, Pyroxene granulites, Ultramafic rocks, Amphibolites, Banded magnetite quartzite, Quartzites and Manganese horizons, Meta-hornblendite, Granites, Pink granitoid, Dolerites and Migmatites [17,25,26] (Figure 3). Structural investigation in the study area; mainly in Biligiri-Rangan Granulites (BRG) has shown at least three deformational events viz., D1, D2, D3 [19,26-28]. A major portion of Chamarajanagar district forms hilly and undulating terrain. The Kollegal Shear Zone (KSZ) [19,21,29] which trends N10°E to S10°W where retrograde metamorphic alteration is observed and demarcates the boundary between the gneisses and Biligiri-Rangan [29,30]. The Malai Mahadeshwara hills are defined by the NNE-SSW oriented Hogenakal and Mettur fault planes [20].

### Hydrogeology

The district is made up of hard rock terrain comprising peninsular gneiss, charnockites and limited extent of alluvium noticed on either side of major river courses. Gneisses are the wide spread and charnockitic formations are observed in few taluks. Alluvium aquifers are encountered up to the depth of 9.00 m bgl forming a good shallow aquifer system along the river courses. The weathered zone is up to 4.00 mbgl to 22.00 mbgl [18]. Groundwater occurs under water table conditions in weathered and fractured crystalline gneisses and charnockites and semi-confined conditions in deep-seated fractures [2]. Spatio-temporal variation in groundwater composition depends mainly on

rainwater, soil and aquifer materials [31]. Groundwater quality differs mainly due to rock-water interaction, oxidation-reduction processes and leaching of salts (especially landfill areas or metal plating industries) during the percolation of water through [32-36].

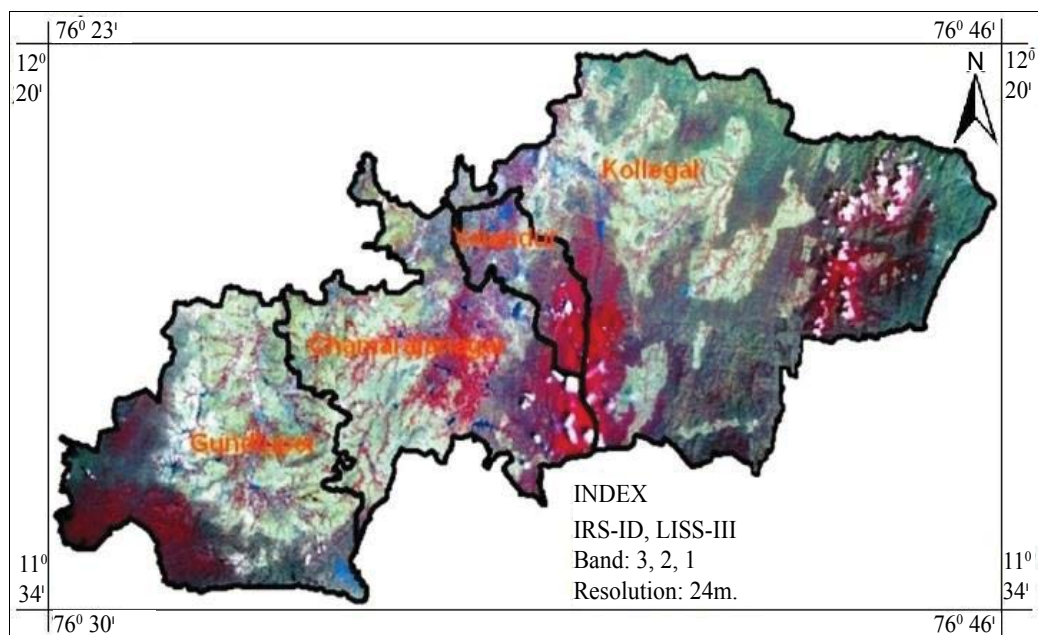
### Lineaments overlaid on land use/land cover patterns

Identification and analysis of underground fractures and concealed lineaments are crucial in hard rock terrains [37] ranging from ten to hundreds of Kilometers. Fractures, rock cleavages, joint systems and fault/thrust play a vital role in affecting the surface storage, groundwater recharge and movement [38] which depends on secondary porosity of lithological and structural aspects such as lithological contact, unconformities, folds, faults, bedding planes, fracture, joints, dykes, shear zones, etc. Lineaments are derived from IRS-1D, PAN+LISS III satellite images and the prominent linear structures are trend towards NE, NW and NE-SW [23] (Figure 4). Lineaments noticed on pediplain, alluvium plain, valley and valley fill areas depicts very good groundwater storage and movement. LU/LC pattern of a region reveals of both natural and socio-economic factors and their utilization by man in time and space. Deriving information on LU/LC is helpful in suitable planning and implementation to provide the increasing demands for basic human needs [23]. LU/LC map is digitized using satellite images overlaid on Sol topomap on 1:50,000 scale in conjunction with conventional Ground Truth Check (GTC) [38-41]. Permanent features such as National and State Highways, Temples, Tanks, Power lines, Hills and other features in categorization of LU/LC patterns [41] are digitized. Land use/land cover classes of the study area are noticed as agricultural land (2419.52 Km<sup>2</sup>) built-up land (57.21 Km<sup>2</sup>), forest (2688.08 Km<sup>2</sup>), wastelands (283.68 Km<sup>2</sup>), water bodies (119.56 Km<sup>2</sup>) and others (100.87 Km<sup>2</sup>) [16,23] (Figure 4). Lineament overlaid on LU/LC map highlights the seepage, fractures, joints, dykes, faults, shear zones on different land patterns providing the major sources of contaminating the groundwater quality and to take measures in future plans.

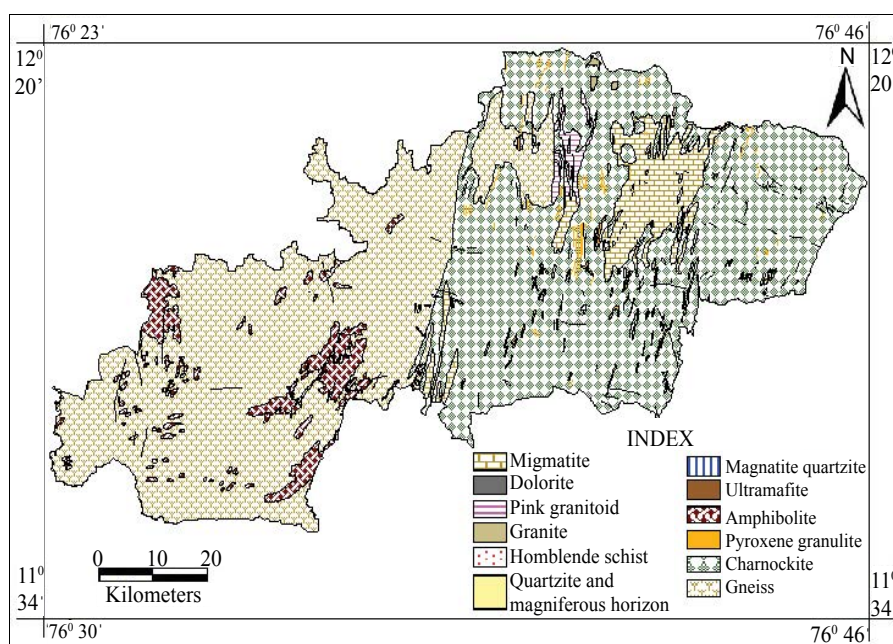
### Assessment of groundwater quality

Around 46 number of groundwater samples are collected from different parts of the study area during end period of pre-monsoon season (April-May) in 2005; out of which, 32 from bore wells and 14 from dug wells ranging from approximately 34 to 98 m bgl. The collected samples are analyzed for 12 groundwater quality parameters such as Fluoride (F<sup>-</sup>), Nitrate (NO<sub>3</sub><sup>-</sup>), Carbonate (CO<sub>3</sub><sup>-</sup>), Chloride (Cl<sup>-</sup>), Calcium (Ca<sup>2+</sup>), Magnesium (Mg<sup>2+</sup>), Sodium (Na<sup>+</sup>), Sulphate (SO<sub>4</sub><sup>2-</sup>), Iron (Fe), Potassium (K<sup>+</sup>), Potential of Hydrogen (pH) and Electrical Conductivity (EC) [1] (Tables 1 and 2).

**Fluoride:** Fluoride widely dispersed in the environment accounting for 0.38 g/kg of the earth's crust and varies in groundwater based on the geological settings. The fluoride level ranges from 0.3 to 1.8 mg/L in which 34% of total number of samples exceeds their permissible limits with reference to WHO and BIS standards with an average of 1.2 mg/L (Figure 5 and Table 2). Fluoride shows its presence in all the collected samples. Weathered product dissolve and leaches the fluoride bearing minerals (muscovite, biotite, fluorite, fluoro-apatite) which contributes most to the



**Figure 2** IRS-1D, LISS-III Satellite image of the study area.



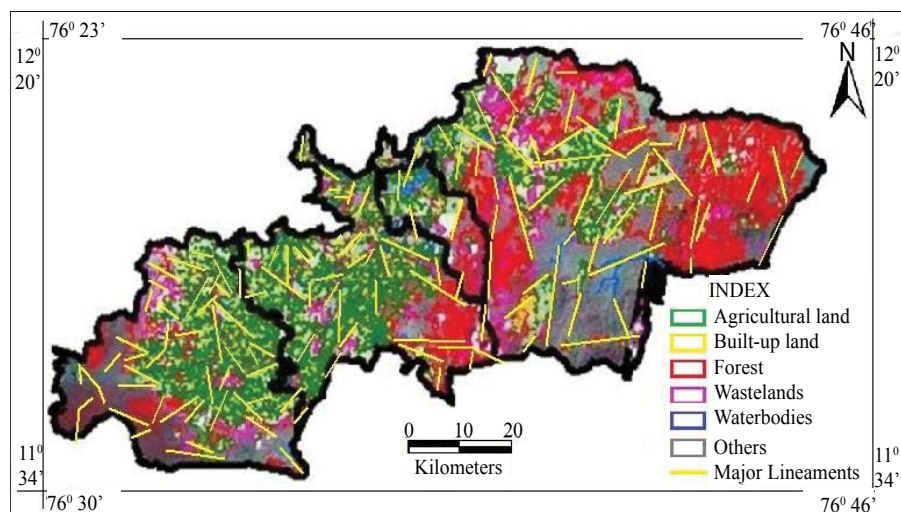
**Figure 3** Lithology map of the study area.

surface and subsurface water bodies during irrigation and groundwater exploration during groundwater movement/ storage and rock layers interaction. The fluoride concentration is found to be beyond permissible limit in western parts of Chamarajanagar taluk.

**Nitrate:** Nitrate varies from 0 to 5.03 mg/L with an average of 1.47 mg/L (**Table 2**). Natural concentrations of nitrate-nitrogen in groundwater originate from the atmosphere, living and decaying organisms [1]. All the collected samples show nitrate permissible limit of WHO and BIS Standards [42-45].

**Carbonate:** Carbonate varies from 0 to 3.3 mg/L with an average of 0.4 mg/L (**Table 2**). All the samples are within the permissible limit of WHO and BIS Standards.

**Chloride:** Chloride is associated with sodium observed in higher concentrations and varies by dissolution from minerals, industrial and domestic wastes [46]. Chloride is often an important dissolved constituent in groundwater contamination from sewage and various types of industrial wastes [47]. Chlorides in groundwater are originated from various sources including the dissolution of



**Figure 4** Lineament overlaid on LU/LC map.

**Table 1** Chemical analysis data of Groundwater samples of the study area (April and May-2005). Note: All parameters are in mg/L and Ec in  $\mu\text{s}/\text{cm}$  except  $\text{pH}$ .

Sample no	Sample locations	Type of wells	Latitude	Longitude	$\text{CO}_3$	$\text{Cl}^-$	$\text{Ca}^{2+}$	$\text{Mg}^{2+}$	$\text{Na}^+$	$\text{SO}_4^{2-}$	$\text{NO}_3^-$	F-	Fe	$\text{K}^+$	pH	EC
<b>Chamarajanagara Taluk</b>																
1.	Attugulipura 1	Dug well	11.826	76.997	0.33	7.67	2.69	8.06	3.92	5.62	0.19	0.31	0.36	0.13	8.20	1500
2.	Attugulipura 2	Bore well	11.821	76.995	0.00	5.61	7.88	5.76	4.00	2.37	3.40	0.54	0.41	0.18	6.95	1780
3.	Bedarapura 1	Dug well	11.958	76.876	3.30	8.69	0.50	8.39	12.18	4.37	0.24	1.26	1.49	2.43	8.21	2235
4.	Bedarapura 2	Bore well	11.953	76.873	0.00	6.40	4.14	5.92	3.48	2.00	3.06	1.21	1.21	0.23	7.33	1433
5.	Bisalavady 1	Bore well	11.797	76.947	0.00	4.96	8.08	3.21	3.78	1.35	3.50	1.60	0.29	0.54	7.24	1559
6.	Bisalavady 2	Dug well	11.816	76.997	0.80	2.68	1.35	4.61	3.35	4.87	1.16	0.33	0.38	0.77	8.38	1145
7.	Chamarajanagara	Bore well	11.917	76.936	0.00	2.29	4.49	1.40	5.35	0.92	0.13	1.13	0.78	0.10	7.02	1134
8.	Devalapura	Dug well	11.848	76.817	0.00	0.08	2.30	1.97	1.78	0.06	0.24	1.24	0.54	0.10	7.15	616
9.	Haradanahalli 1	Bore well	11.877	76.956	0.63	12.47	3.04	7.57	9.92	2.50	0.85	1.23	0.53	0.41	8.35	230
10.	Haradanahalli 2	Bore well	11.875	76.952	0.00	6.32	1.20	4.94	13.49	1.67	1.29	1.03	0.69	0.13	7.82	1780
11.	Haradanahalli 3	Bore well	11.874	76.953	0.00	11.23	11.03	7.41	3.92	3.08	1	0.67	0.85	1.23	7.50	2358
12.	Haradanahalli 4	Bore well	11.871	76.955	0.00	1.89	5.19	4.44	4.79	1.81	0.39	0.39	0.61	0.15	7.20	1472
13.	Harave 1	Dug well	11.937	76.806	1.27	10.49	5.69	13.91	1.74	1.67	2.55	1.57	0.92	0.41	-	2500
14.	Harave 2	Bore well	11.935	76.805	0.00	4.96	3.74	8.89	3.83	2.17	1.85	1.59	0.50	0.43	6.98	1687
15.	Kagalavady	Bore well	11.958	77.017	0.00	2.54	1.05	4.77	6.39	2.10	0.06	0.49	0.81	0.26	7.73	1247
16.	Masagapura 1	Bore well	11.958	76.938	1.43	3.33	3.44	1.56	5.05	0.50	1.42	0.59	0.86	0.26	8.70	950
17.	Masagapura 2	Bore well	11.956	76.937	2.87	7.02	0.30	8.15	13.40	5.60	0.89	1.24	0.94	0.10	9	2085
18.	Yanaganahalli	Bore well	11.767	76.856	0.00	5.13	1.75	4.20	6.44	1.98	1.29	1.19	0.39	0.10	8.01	1282
19.	Yedapura	Bore well	11.907	76.907	0.00	1.75	2.40	5.68	4.05	1.25	0.58	0.67	0.55	0.08	7.36	1210
20.	Yediyur	Bore well	12.007	76.966	0.00	1.27	4.79	3.13	1.74	0.81	0.26	0.99	0.52	0.08	7.20	972
<b>Gundlupete Taluk</b>																
21.	Begur 1	Dug well	11.927	76.666	0.00	7.50	4.09	5.02	8.53	3.75	2.21	1.59	1.49	4.81	8.20	2243
22.	Begur 2	Bore well	11.925	76.664	0.00	0.76	3.64	1.56	1.52	0.65	0.34	0.35	1.64	0.15	7.40	687
23.	Bommalapura 1	Dug well	11.725	76.726	2.07	4.57	0.70	5.92	3.48	0.10	0.32	1.13	0.59	0	8.00	1005
24.	Bommalapura 2	Bore well	11.724	76.728	0.00	3.16	3.74	4.77	7.05	1.33	1.27	0.57	0.64	0.66	6.98	1621
25.	Gundlupet	Bore well	11.796	76.687	0.00	2.14	4.29	3.46	6.83	1.37	0.06	1.27	0.91	0.15	6.88	1473
26.	Hasaguli	Bore well	11.877	76.636	0.00	12.72	5.04	19.17	3.78	3.12	4.44	1.70	2.23	1.56	7.16	2958
27.	Kaggalahundi 1	Dug well	11.777	76.566	1.27	1.35	0.80	3.13	1.74	0.25	0.15	1.07	0.64	0.77	-	520
28.	Kaggalahundi 2	Bore well	11.767	76.566	0.00	6.23	10.63	4.11	1.83	1.87	2.50	1.63	0.78	0.15	7.41	1673
29.	Kekkanahalla	Dug well	11.616	76.606	0.00	1.58	4.79	1.81	3.18	1.52	0.05	0.95	0.23	0.46	7.61	1010
30.	Siddaianapura 1	Dug well	11.716	76.655	0.00	0.99	2.10	4.61	4.44	0	0	1.22	0.73	0.13	8.20	-
31.	Siddaianapura 2	Bore well	11.725	76.666	0.00	4.91	2.54	6.50	8.61	1.75	1.66	1.25	0.85	0.77	7.15	1840

32.	Terakanambi	Bore well	11.806	76.788	0.00	2.29	4.79	5.51	2.74	1.04	1.77	1.72	0.91	0.36	6.95	1328
<b>Kollegala taluk</b>																
33.	Ajjipura	Bore well	12.038	77.347	0.00	3.86	4.79	6.01	4.52	1.37	3.68	1.78	0.59	0.26	6.98	1557
34.	Bandalli 1	Dug well	12.169	77.357	1.60	1.81	2.99	2.47	1.96	0.50	0.85	1.56	2.48	0	8.59	900
35.	Bandalli 2	Bore well	12.159	77.347	0.00	1.89	4.14	6.09	2.65	1.31	2.03	1.66	2.12	0.05	7.02	1294
36.	Dhanagere	Dug well	12.209	77.146	0.00	1.41	2.40	3.04	1.61	0.81	0.21	0.55	0.63	0.03	7.58	708
37.	Hanur	Bore well	12.089	77.298	0.00	7.19	3.84	0.99	6.26	1.12	1.77	1.69	0.83	0.08	7.42	1941
38.	Kamagere	Bore well	12.128	77.217	0.00	10.58	7.58	15.80	8.35	3.75	4.42	1.58	0.94	0.20	7.39	3192
39.	Kollegal	Bore well	12.149	77.107	0.00	2.20	4.69	3.04	1.48	0.90	0.68	1.04	0.63	0.03	6.81	924
40.	Kowdalli	Bore well	12.069	77.437	0.00	6.63	1.45	10.12	6.57	3.44	4.05	1.75	0.51	0.31	7.89	1846
41.	Lokkanahalli	Bore well	12.017	77.247	0.00	5.33	7.49	9.96	2.83	1.08	5.03	1.56	0.49	0.05	6.83	2031
42.	Shagya 1	Dug well	12.209	77.377	2.40	2.06	2.35	8.81	2.18	0.75	1.84	1.76	0.32	0	8.55	1100
43.	Shagya 2	Bore well	12.209	77.398	0.33	1.38	1.40	5.27	1.35	1.08	2.02	1.63	0.89	0.28	8.50	828
44.	Uttamballi	Dug well	12.138	77.076	1.60	3.55	1	1.89	13.75	2.91	0.48	1.21	0.91	0.15	8.93	1677
<b>Yelanduru taluk</b>																
45.	Mellahalli	Bore well	12.049	77.027	0.00	4.18	3.29	5.92	5.22	1.67	0.53	0.93	0.51	0.05	7.59	1448
46.	Yelandur	Bore well	12.049	77.007	0.00	7.50	5.44	4.86	12.62	3.54	1.03	1.22	0.84	1.15	7.72	2400

**Table 2** Comparison of observed values with Standard specifications for Groundwater as per WHO and Indian Standards.

S No	Parameter	Min	Max	Average	WHO (2004, 2011)		Bureau of Indian Standards (BIS) 10500-1991	
					Sample numbers exceeding permissible limit (1-46 is considered as C1-C46)			
1.	CO <sub>3</sub> <sup>-</sup> (mg/L)	0	3.3	0.4	-	-	-	-
2.	Ca <sup>2+</sup> (mg/L)	0.3	11	3.81	75-200	-Nil-	75-200	-Nil-
3.	Cl <sup>-</sup> (mg/L)	0.08	12.7	4.66	250	-Nil-	250-1000	-Nil-
4.	Mg <sup>2+</sup> (mg/L)	0.99	19.2	5.74	50	-Nil-	30-100	-Nil-
5.	Na <sup>+</sup> (mg/L)	1.35	13.8	5.17	200	-Nil-	200	-Nil-
6.	SO <sub>4</sub> <sup>2-</sup> (mg/L)	0	5.62	1.9	250	-Nil-	200-400	-Nil-
7.	NO <sub>3</sub> <sup>-</sup> (mg/L)	0	5.03	1.47	50	-Nil-	45-100	-Nil-
8.	F <sup>-</sup> (mg/L)	0.3	1.8	1.2	1.5	5,13,14,21,26,28,32,33,34,35,37,38,40,41,42,43	1-1.5	3,4,7,8,9,10,17,18,23,25,27,30,31,39,44,46,
9.	Fe (mg/L)	0.2	2.5	0.8	-	-	0.3-1	1,2,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,23,24,25,27,28,30,31,32,33,36,37,38,39,40,41,42,43,44,45,46
10.	K <sup>+</sup> (mg/L)	0	4.8	0.5	12	-Nil-	10	-Nil-
11.	pH	6.81	9.0	7.63	6.5-8.5	1,2,3,4,5,6,7,8,9,10,11,12,14,15,18,19,20,21,22,23,24,25,26,28,29,30,31,32,33,35,36,37,38,39,40,41,43,45,46	6.5-8.5	1,2,3,4,5,6,7,8,9,10,11,12,14,15,18,19,20,21,22,23,24,25,26,28,29,30,31,32,33,35,36,37,38,39,40,41,43,45,46
12.	EC	230	3192	1497.31	1400	1,2,3,4,5,10,11,12,13,14,17,21,24,25,26,28,31,33,37,38,40,41,44,45,46	3000	38

halite and related minerals, marine water entrapped in sediments and anthropogenic sources [1]. Chloride ranges from 0.08 to 12.7 mg/L with an average of 4.66 mg/L (Table 2). All the collected samples are within the chloride permissible limit of WHO and BIS Standards.

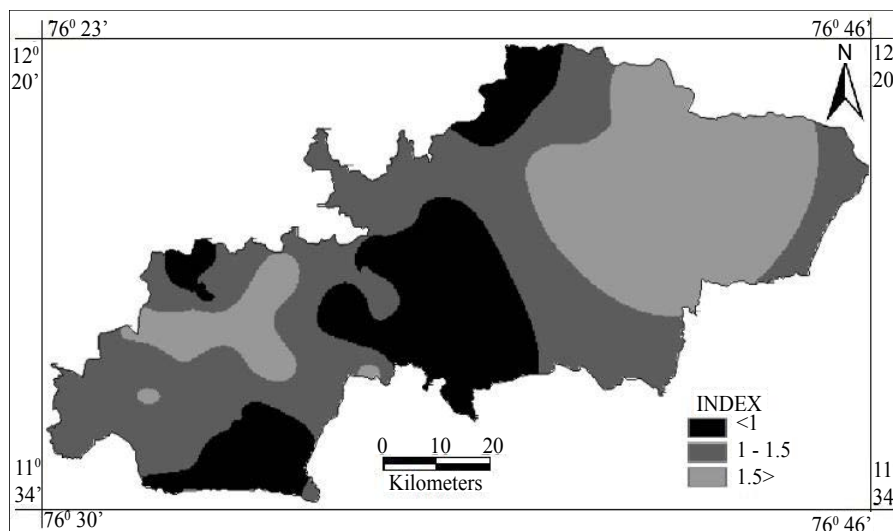
**Calcium:** Calcium is abundant in soils and rocks (limestone and dolomite) and calcite bearing minerals [46]. Calcium ranges from 0.3 to 11 mg/L with an average of 3.81 mg/L and all the collected samples show calcium permissible limit of WHO and BIS Standards (Table 2). Concentration of calcium varies based on the occurrence of sedimentary sandstone as well as aragonite bearing minerals in sedimentary rocks [48].

**Magnesium:** Main sources of rocks (dolomite) and minerals

(magnesite) [46]. Magnesium ranges from 0.99 to 19.2 mg/L with an average of 5.74 mg/L, in which all the collected samples are within the permissible limits with reference to WHO and BIS Standards (Table 2). Natural water contains magnesium and calcium which caused hardness of groundwater based on dissolved polyvalent metallic ions [1].

**Sodium:** It is derived geologically from leaching of surface and underground salt deposit and decomposition of various minerals [44]. Sodium varies from 1.35 to 13.8 mg/L with an average of 5.17 mg/L, in which all the samples are within the permissible limits with reference to WHO and BIS Standards (Table 2).

**Sulphate:** It enters to environment by mineral dissolution, salt water intrusion, domestic and industrial waste [44]. Sulphate



**Figure 5** Spatial distribution of Fluoride.

ranges from 0 to 5.62 mg/L with an average of 1.9 mg/L and all the samples are within the permissible limit of WHO and BIS Standards (**Table 2**). No abnormal sulphate concentration is reported in the entire district [18]. One of the important sources is the dissolution or weathering of sulfur which includes evaporite minerals, such as gypsum and anhydrite ( $\text{CaSO}_4$ ). Gypsum and anhydrite are the two calcium sulphate minerals that generally occur in nature.

**Iron:** Iron varies from 0.2 to 2.5 mg/L with an average of 0.8 mg/L, in which 80% of all the collected samples are above permissible limit with reference to BIS Standards only (**Figure 6** and **Table 2**). Many Banded Magnetitic Quartzites (BMQ) bearing isolated patches are encountered in northern parts of the district with higher Fe content. These range from 1 m to 10 m thickness in size. They are generally parallel to regional trend of  $\text{N}5^\circ\text{W}$ - $\text{S}15^\circ\text{E}$  with vertical dip. Magnetitic quartzites are seen in the charnockite gneiss as a mixed zone along the foliation of the country rocks. These are folded with alternate layers of magnetite rich bands noticed in the villages of Devarabetta and Tumbe betta. Manganiferous horizons are also encountered as very thin bands in Charnockite Gneiss mixed zone and well exposed in Hoonganur, Gumballi, Vadayarपालya area. Oxidation-reduction reactions constitute an important influence on concentrations of both iron and manganese [1,23]. High dissolved iron concentrations can occur in groundwater, when pyrite is exposed to oxygenated water/ ferric oxide/ hydroxide minerals are in contact with reducing substances.

**Potassium:** Main source of  $\text{K}^+$  in groundwater include weathering and erosion of K bearing minerals such as feldspar and leaching of fertilizers [44]. Potassium ranges from 0 to 4.8 mg/L with an average of 0.5 mg/L, in which all the collected samples are within the permissible limits of WHO and BIS Standards (**Table 2**).

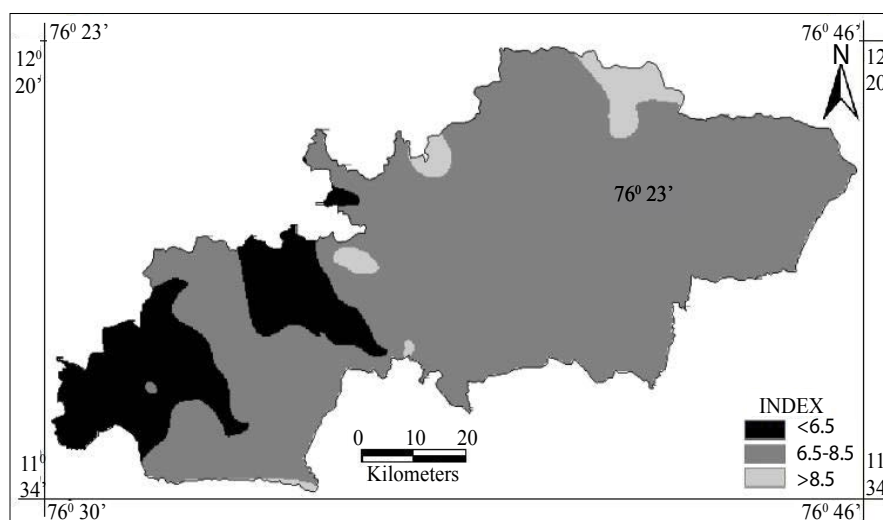
**Potential of hydrogen ( $\text{P}^{\text{H}}$ ):**  $\text{P}^{\text{H}}$  represents the numerical value indicating whether water is acidic and alkaline [46].  $\text{P}^{\text{H}}$  ranges from 6.81 to 9.0 mg/L with an average of 7.63 mg/L, in which 84% of the collected samples are above the permissible limits of

WHO and BIS Standards (**Figure 7** and **Table 2**). The alkalinity in most natural water is primarily due to the presence of dissolved carbon species, particularly bicarbonate and carbonate. Other constituents that may contribute minor amounts of alkalinity to water include silicate, hydroxide, borates and certain organic compounds. Carbonate contributors to alkalinity include atmospheric and biologically-produced carbon dioxide, carbonate minerals and sulfate reduction. Non-carbonate contributors to alkalinity include hydroxide, silicate, borate and organic compounds [1].

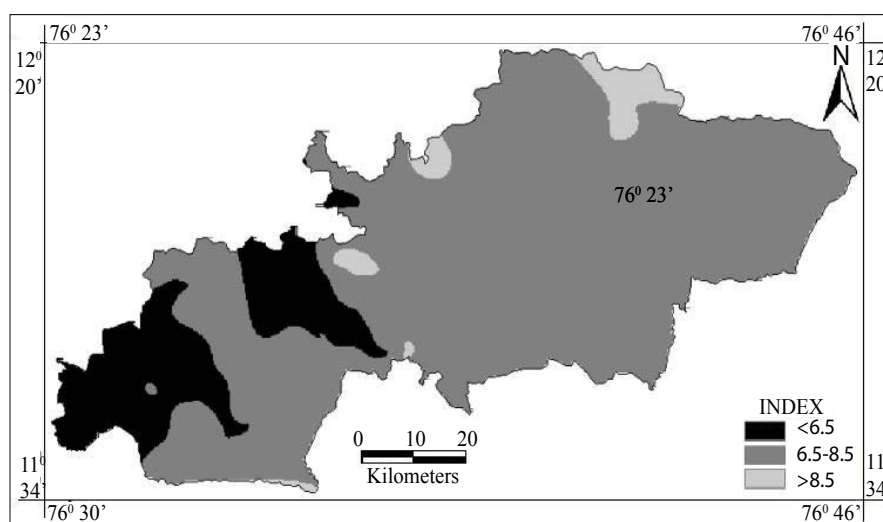
**Electrical conductivity (EC) or specific conductance:** Electrical Conductivity is a measure of the ability of water to pass electric current, is generally affected by the presence of inorganic solids such as,  $\text{Na}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$  etc. It is affected primarily by the geology of the local area that is in contact with water [44]. The large variation in EC is mainly attributed to distinct processes such as, saline sources, mineral dissolution and influx of pollutants from anthropogenic activities. In the study area, EC ranges from 230  $\mu\text{S}/\text{cm}$  to 3192  $\mu\text{S}/\text{cm}$  with an average of 1497.31, in which 54% of all the samples are above permissible limit with reference to WHO only (**Figure 8** and **Table 2**).

## Results and Discussion

Average levels of all the selected wells ranges approximately from 34 to 98 m bgl [2]. The district falls in Cauvery River Basin (CRB) and drained by its tributaries such as Suvarnavathi and Chikkahole. About 80 to 90% of the groundwater in the district is utilized for irrigation and remaining 10% by bore wells/ dug wells/ open wells. The cultivable land measures about 209,009 ha; out of which only around 34,246 ha (16%) is irrigated [18]. The major crops grown are the cereals with an area 92,261 ha where Jowar, Maize and Ragi are the major cereals; where cash crops measures an area of 76,763 ha in which sugarcane and cotton are the major crops. Pulses measures an area of 39,699 ha and oilseeds, sunflower with an area of 33,069 [18]. These agricultural lands measures an area of 31.05% of total geographical study



**Figure 6** Spatial distribution of Iron.



**Figure 7** Spatial distribution of P<sup>H</sup>.

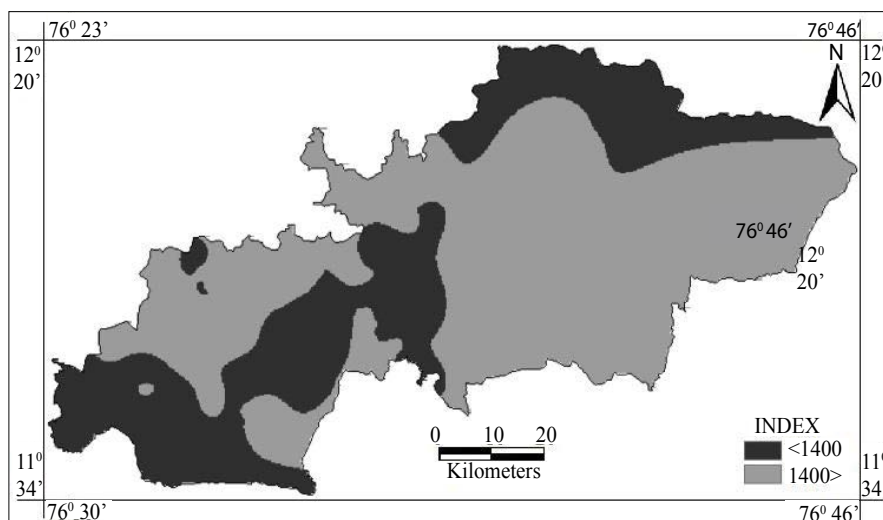
area which need a large amount of agrichemicals, fertilizers and pesticides which directly impacts the groundwater quality especially during monsoon season [17]. The main sources of anthropogenic activities noticed are the discharge of wastes such as treated sewage/solid waste, certain agricultural activities, mine activities and wastes dumping, industrial operations, urban runoff on particular catchment regions, seepage areas (lineaments) in the study [1,4,26,27] (Figure 4). 34% of fluoride and 84% of potential of Hydrogen contents show above the permissible limit of both WHO and BIS; while 54% of electrical conductivity and 80% of iron contents are observed to be above the permissible limit of WHO and BIS respectively. High fluoride concentration in groundwater appears to have been contributed more by geogenic activity (rock-water interaction) of the country rocks with the leaching of phosphatic fertilizers applied to large agricultural areas in the district [46]. Fluoride level in drinking water needs periodic monitoring and management [47-50]. Level of fluoride rises depending on the exposed inorganic fluoride

containing minerals such as the release of phosphate fertilizer from rock phosphates as byproduct (Figure 9).

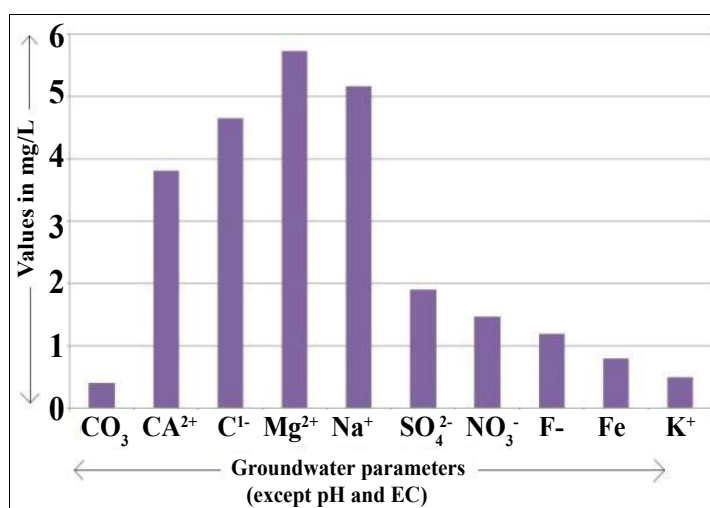
## Conclusions

Degradation of groundwater quality and quantity is a serious issue of societal and environmental concern playing a crucial role all over the world. The study area consists mainly of charnockites, granites and gneisses which are classified as crystalline formations in groundwater point of view. Fractures, fissure, seepages, recharge areas developed along with joints and faults (lineaments) traversing the rocks allow toxic elements and contaminating the groundwater circulation affecting the water quality. The chemistry of groundwater existing in hard rock terrain is mainly controlled by the rock-water interaction mainly of granitic composition and their derivatives. The results indicate that the water is alkaline in nature with average pH value of 7.63 showing maximum in Kollegala taluk. Similarly, Fluoride concentration is beyond 1.5 mg/L is observed in the eastern parts





**Figure 8** Spatial distribution of electrical conductivity.



**Figure 9** Column graph depicting the average observed values of groundwater parameters in the study area (Except pH and EC).

of Kollegala taluk mainly from the leaching of phosphatic fertilizers used in agricultural fields. Electrical conductance ranges from 230 to 3192 (average 1497.31  $\mu\text{s}/\text{cm}$ ), chloride is in the range of 0.08 to 12.7 mg/L (average 4.66) and sodium ranges from 1.35 mg/L to 13.8 mg/L (average 5.17) indicating low sodium type of groundwater and permissible limit for irrigational purposes. Irrigation is confined mainly to intermountain valleys resulting in densely spaced wells in particular areas of Kollegala taluk due to the uneven topography. Fluoride (F<sup>-</sup>), Iron (Fe), Potential of Hydrogen (P<sup>H</sup>) and Electrical Conductivity (EC) are above the permissible limits with 34%, 80%, 84% and 54% respectively with references to WHO and/or BIS Standards. High concentration of fluoride caused digestive disorders, skin diseases and increased risk of dental fluorosis noticed in few villages of Kollegala taluk. Chemical quality of groundwater is suitable for all purposes in major parts of the district with low sodium type except in few

pockets. Spatial variations of groundwater quality maps are effectively applicable in identifying locations that involve the possible threats at unmeasured locations through ArcGIS v10. Spatial distribution maps communicates the possible information of overall water quality distribution in the study area and being an effective technique in its monitoring, management and future modeling with the aid of GIS tool.

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