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Assessment of Groundwater Quality for Potability in Southwest Karnataka, India

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ABSTRACT

Urbanization results in increased pressure on the availability of groundwater and reduce the water quality index (WQI) and its usefulness owing to various kinds of pollution. The current study assessed the physicochemical and biological qualities of selected groundwater in southwest India. The region selected is undergoing rapid urbanization, the development of educational institutions, hospitals, shopping complexes and small-scale industries. The population of the area has increased by 2-3 folds compared to the past two decades. Temperature, conductivity, alkalinity, turbidity, total hardness, total dissolved solids (TDS), chemical oxygen demand (COD), Cu, Cr, Na, K and Cl^- in groundwater studied were within the permissible limits throughout the year. The electrical conductivity (EC) exceeded the permissible limit. The Fe content in pre-monsoon was high, but diluted during monsoon season and reduced drastically in the post-monsoon season. The total coliforms showed a direct correlation with Fe content by increased most probable number (MPN). The pH, Fe and MPN values were not satisfied the yardsticks of the Bureau of Indian Standards (BIS). The F^-, As and Pb levels were high during the post-monsoon season. The groundwater needs stringent purification for potability owing to coliforms, however, this water could be used for agricultural purposes.

Keywords: Coliforms, Drinking water, Most probable number, Physicochemical features, Pollution, Water quality index

1. INTRODUCTION

Groundwater is one of the precious natural resources that cater the domestic as well as irrigation requirements and becoming one of the limited resources (Varol et al. 2012). Relatively, the groundwater is less polluted compared to the surface waters depending on various conditions especially precipitation, soil strata, the extent of urbanization and waste dumps. The quality generally deteriorates due to saltwater intrusion, industrial effluents and agricultural runoff. If the catchment areas and surface waters are abused by human interference, the groundwater succumbs to contamination by hazardous chemicals as well as harmful microbes. Moreover, owing to widespread agricultural activities, improper waste management and urbanization, the groundwater qualities are deteriorating beyond control. If the groundwater is polluted, its quality cannot be reinstated so easily. According to Akoteyon et al. (2011), up to 1.8 million people (especially children) die every day in developing countries owing to drinking contaminated groundwater.

Groundwater being the most valuable source of drinking water, its periodical monitoring its physicochemical features, biological qualities and risk assessments are of critical importance (Yan et al. 2015). Water quality monitoring and assessment are the major yardsticks for water quality management, hence there is an increasing demand for such accomplishments, especially for the rivers and groundwater on regular intervals to forecast the adequacy or inadequacy of the water quality index (WQI) (Hirsch et al. 1991). Various methods and approaches have been adapted to evaluate groundwater pollution, especially the single factor pollution index (SFPI) as well as the comprehensive pollution index (CPI) (Yan et al. 2015). Chemistry has also been employed as a potential tool to predict water quality for various purposes (Edmunds et al. 2010). Besides, geo-statistical as well as Geographical Information systems (GIS) were adapted to forecast and label the extent of pollution and unsafe sources. The success of the methodology of groundwater assessment depends on pinpointing the vulnerable regions of groundwater as well as identifying the source of its contamination.

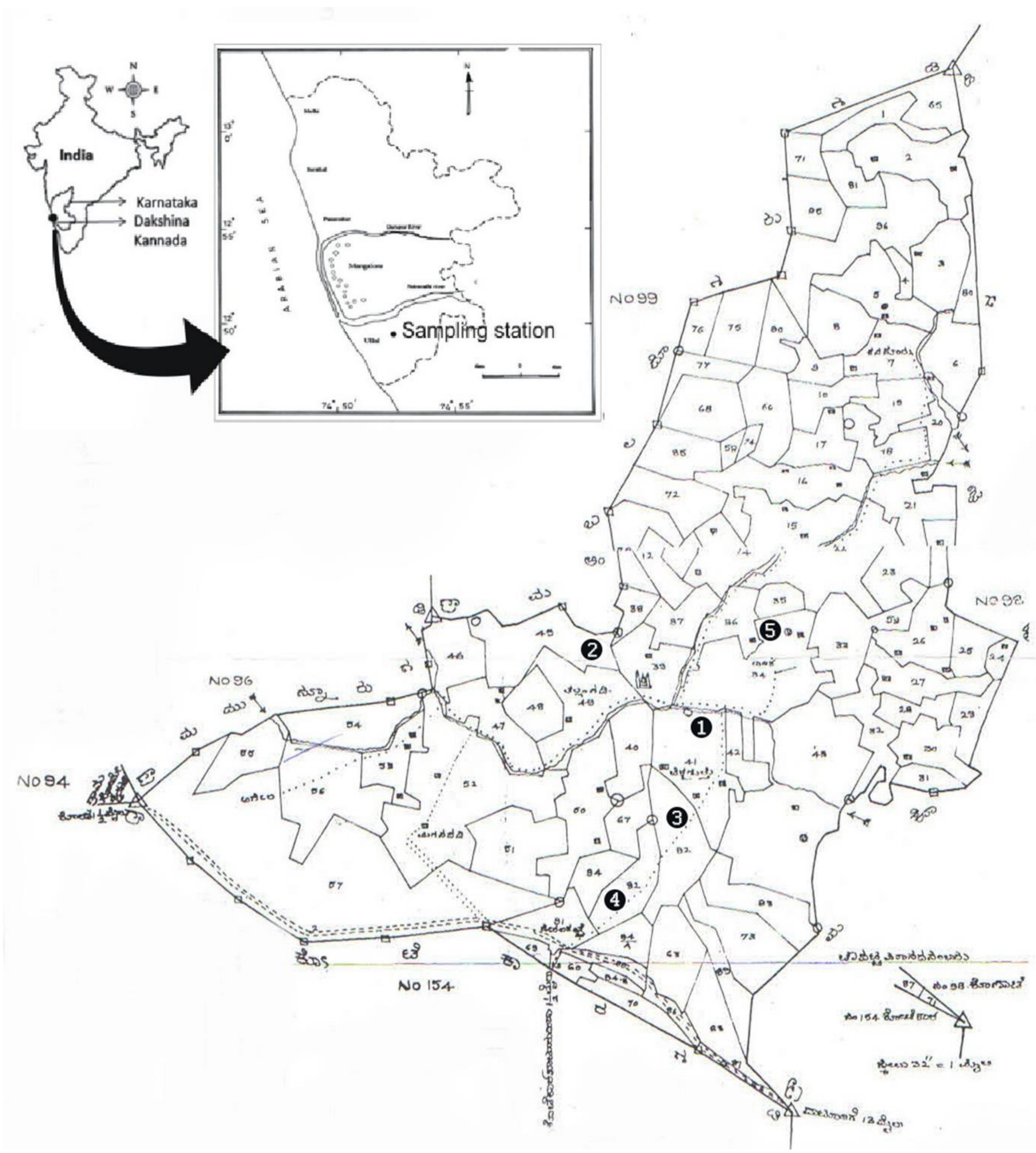

Fig. 1. Sampling stations (1-5) of groundwater studied for the water quality index (WQI) in southwest India.

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A few studies are available on the assessment of water qualities of surface or groundwater and sewage outbreaks in and around Mangalore (e.g. Madhyastha et al. 1988; Narayana and Suresh 1989; Balakrishna et al. 2007; Ramprasad et al. 2007; Avvannavar and Shrihari 2008; Dhanraj and Rajesha 2017). There seem to be no studies on seasonal water quality assessment of groundwater in and around Mangalore. The perspective of the current study is to assess the quality of groundwater in one of the areas roofed under the greenbelt of Mangalore City in southwestern India during post-monsoon, summer and monsoon seasons. Population in this semi-urban area mainly depends on groundwater for drinking, domestic and irrigation purposes. The area under study is rapidly growing the educational institutes, hospitals and small-scale industries. The groundwater qualities have been assessed by physical, chemical and biological parameters to develop baseline information for future water quality assessments.

2. MATERIALS AND METHODS

2.1 Study Site

The study was performed in the Belma village Panchayat (12°49ˈN, 74°56ˈE; 24 m asl) located about 15 km from the Mangalore City (Fig. 1). Belma Village Panchayat has 13 sub-villages with an area of 363 ha and a population of about 6,452. This area has more open wells than bore wells and 17 bore wells and four open wells are used to cater to the needs of drinking and domestic purposes. The average depth of the bore-wells ranges between 125 and 200 m. The area under investigation experiences hot summer (March-May) (~38°C), while during winter the temperature dips ~20°C. The rainfall in this area fluctuates between 350 and 400 cm per annum. The geology of the area has major rocks like granite gneiss, iron laterite and charnockite. The study area is covered with iron laterite and is highly porous with undulating topography (Dhanraj and Rajesha 2017). The Belma Taluk is fast growing with many educational institutions, hospitals, shopping centers and business enterprises. Assessment of groundwater qualities has been carried out three seasons in a sub-village Derlakatte of Belma panchayat.

2.2 Collection of Water Samples

Groundwater samples from five randomly selected bore wells were collected for analysis of physical, chemical and biological characteristics. Multiple samples (2 l each) were collected in clean glass bottles on each occasion as per standard protocol for the analysis of 23 physicochemical and 3 biological parameters (APHA, 1998; Rank, 2003). Water samples were collected during summer (April 2018), monsoon (July 2018) and post-monsoon (October 2018) to follow seasonal variations in water quality.

2.3 Analysis of Water Samples

Analysis of the groundwater samples was performed in accordance with the standard analytical procedures (APHA 1998). Parameters assessed include color, odor, pH, conductivity, temperature, total dissolved solids (TDS), turbidity, alkalinity, total hardness, chemical oxygen demand (COD), chloride, phosphate, nitrate, sodium, potassium, calcium, magnesium, copper, chromium, iron, fluoride, lead and arsenic (APHA 1998), total coliforms and *Escherichia coli* (Cruickshank et al. 1975).

The use of plant test systems to study the toxicity of environmental pollutants is widely accepted. *Allium cepa* (onion) root test is one of the sensitive, cost-effective and reliable assays to evaluate the genotoxicity of pollutants in waters. The mitotic index of genotoxicity of groundwater using *A. cepa* root tips by chromosome aberration assay (Rank 2003). The cytological parameters include aberrant cells in metaphase and anaphase, index of appearance of micronuclei and prevention of cell division. The Mitotic Index (MI) was evaluated by examining the number of dividing cells among the total number of cells. The MI serves as a measure of the state of proliferation of a cell population. It is the ratio of the numbers of cells with mitosis vs. the total number of assessed cells. Chromosomal Aberration (CA) is abnormalities in the number as well as structure of chromosomes.

Some of the parameters were assessed on the spot, while the rest were assessed or initiated in the laboratory within 1-2 hr and stored in a cooler till the completion of analysis. Mean and standard deviations were calculated for three replicate samples. Water quality results were compared with the Indian and International drinking water standards (BIS 2003; WHO 2004).

3. RESULTS

Physicochemical and biological parameters of groundwater assessed have been compared with WHO (2004) as well as the Indian standards (BIS 2003) (Table 1). The color of groundwater (score # 1) in all seasons, while the groundwater was devoid of odor. The water temperature of the samples ranged between 29.1°C (monsoon) and 33.5°C (summer). The pH was acidic and ranged between 6.6, 6.7 and 6.8 during monsoon, summer and post-monsoon, respectively. The Electrical conductivity (EC) ranged from 547-609 µS/cm, it was higher and almost similar during monsoon and summer seasons.

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Table 1. Physicochemical and biological parameters of groundwater samples of Belma village, southwest Karnataka state, India (*BIS 2003, Bureau of Indian Standards: desirable limit; **WHO 2004, maximum allowed concentration; BDL, below detectable limit)

	Summer	Monsoon	Post-monsoon	BIS* and WHO**
Colour (Hazen unit)	1	1	1	5*
Odour	Agreeable	Agreeable	Agreeable	–
Temperature (°C)	33.5±0.15	29.1±0.04	32.6±0.2	–
pH	6.7±0.27	6.6±0.32	6.8±0.22	6.5–8.5*
Conductivity (µS/cm)	607.6±158.3	608.8±273.8	547.1±216.1	400**
Turbidity (NTU)	0.3±0.42	0.2±0.42	0.3±0.4	5.0*
Total dissolved solids (mg/l)	423.3±113.2	407.7±206.7	386.1±151	500*
Alkalinity (mg/l)	141.9±16.9	104.9±27.4	112.9±28.9	200*
Total hardness (mg/l) (as $CaCO_3$)	133.3±35	92.1±73.65	92.9±9.02	300*
Chemical oxygen demand (ppm)	42.6±162	BDL	33.1±11.3	10**
Chlorides (mg/l) (as Cl^-)	62.6±65.9	95.9±117.3	41.5±52	250*
Nitrate (mg/l) (as NO_3^-)	BDL	BDL	BDL	45*
Phosphate (mg/l)	0.07±0.04	BDL	0.12±0.1	0.1**
Sodium (mg/l)	58.0±1.5	53.5±18.9	47.1±29.9	200**
Potassium (mg/l)	48.7±2	43.5±1.3	43.7±0.8	82**
Calcium (mg/l) (as Ca)	29.7±7	15.8±12	26.3±5.3	75*
Magnesium (mg/l)	14.3±4.4	12.8±12.7	6.6±4.9	30*
Copper (mg/l)	BDL	BDL	BDL	0.05*
Chromium (mg/l)	0.03±0.04	BDL	BDL	0.05*
Iron (mg/l)	1.6±0.93	0.9±1.2	0.3±0.3	0.3*
Fluoride (mg/l) (as F^-)	0.04±0.03	0.3±0.05	2.2±0.23	1.0*
Lead (mg/l)	BDL	BDL	0.05±0.06	0.05*
Arsenic (mg/l)	BDL	BDL	2.1±0	0.05*
Total coliforms (MPN/100 ml)	140	<1.8	<1.8	10*
Escherichia coli (MPN/100 ml)	140	<1.8	<1.8	10*
Mitotic index	16.3±4.5	17.1±3.4	15.9±3.2	–

The nephelometric turbidity units (NTU) in groundwater ranged between 0.2 and 0.3. The total dissolved solids (TDS) ranged from 386.1 mg/l (post-monsoon) to 423.3 mg/l (summer). The alkalinity of groundwater ranged between 105 (monsoon) and 142 mg/l (summer). The range of hardness in groundwater studied was between 92.1 mg/l (post-monsoon) and 133.28 mg/l (summer). The COD values of groundwater were between 33.1 (monsoon) and 42.6 (summer), while it was below detectable limits in monsoon samples.

Chloride values fluctuated between 41.5 mg/l (post-monsoon) and 95.9 mg/l (monsoon). The groundwater studied was devoid of nitrate in all seasons. Phosphate content ranged between 0.07 (summer) and 0.12 (post-monsoon), while monsoon samples were devoid of phosphate. Sodium content ranged from 47.1 mg/l (post-monsoon) to 58 mg/l (summer). The potassium content did not show a wide difference, however, it was highest during summer (48.7 mg/l), while it was almost similar in other seasons (43.5-43.7 mg/l). The calcium content in groundwater was highest during post-monsoon (26.3 mg/l), while it was least during monsoon (15.8 mg/l). Magnesium content ranged from 6.6 mg/l (post-monsoon), while it peaked during summer (14.3 mg/l). Copper content was below the detectable limit in groundwater, so also the chromium content (except for trace value during summer, 0.03 mg/l). Iron content ranged between 0.3 mg/l (post-monsoon) and 1.6 mg/l, (summer). Fluoride content was higher in post-monsoon (2.2 mg/l), while lower during summer (0.04 mg/l). Similarly, the lead content during the summer and monsoon seasons were below detectable levels, while during the post-monsoon season it was 0.05 mg/l. As seen in the lead, the arsenic content was below detectable levels during summer and monsoon, while it was up to 2.1 mg/l post-monsoon.

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The MPN of coliforms was below 1.8/100 ml during monsoon and post-monsoon, while it was as high as 140/100 ml during summer. The MPN of *E. coli* was also similar to that of coliform counts. Genotoxicity of groundwater by *Allium cepa* chromosomal aberration assay revealed the mitotic index (MI) in negative control as 13.07±0.38, while it was ranged between 15.9 (post-monsoon) and 17.1 (monsoon).

4. DISCUSSION

Colour of groundwater (Hazer unit, 1) meets the WHO requirement (Hazen unit, 5 or <5). The odor and taste of water are usually due to the presence of dissolved organic matter, in our study, the groundwater has no odor in all seasons indicating its good quality. The temperature of groundwaters (29.1-33.5°C) partially matches with earlier studies of groundwater in low-lying open wells of Belma village showed (28.3-29.5°C) (Ramprasad *et al*., 2007). The pH being an important indicator of water quality, it is within the permissible limits for drinking purposes (6.6-8.5 vs. 6.5-8.5). However, the pH of open wells of the waters of Belma village was alkaline (7.6-7.9) (Ramprasad et al. 2007). The acidic pH values of a recent study in groundwater of the Belma region during summer corroborates our study (Dhanraj and Rajesha 2017). The electrical conductivity (EC) serves as an indicator of the dissolved minerals in the water, in our study it exceeded the WHO standard (2004) (547-609 vs. 400 μS cm^{-1}). However, the EC was within the permissible limits in open wells as well as other groundwater of Belma (Ramprasad et al. 2007; Dhanraj and Rajesha 2017).

Turbidity denotes the number of suspended solids, which may be colloidal to coarse dispersion. As an indicator, turbidity correlates with sodium and TDS. The nephelometric turbidity units in groundwater is within the permissible limit across the seasons according to the Indian Standards (0.2-0.3 vs. 5). However, although the turbidity is within the permissible limits, it was at a higher range than other groundwater in Belma village during summer (Dhanraj and Rajesha 2017). The TDS denotes dissolved mineral content from various rock formations. The TDS consists of salts (bicarbonates, calcium, chlorides, magnesium, potassium, sodium and sulfates) and organic matter in a dissolved state in tiny proportion.

The TDS is not generally considered as harmful but entails many minerals that might be harmful in higher concentrations. In our study, the TDS ranged from 386.1 mg/l during the post-monsoon to 423.3 mg/l during the monsoon seasons, which is within the permissible limits of WHO standard (500 mg/l). However, a drastic variation in the TDS was seen in another groundwater study in Belma village (Dhanraj and Rajesha 2017). Alkalinity is influenced by various constituents in groundwater. Ions like bicarbonates, carbonates, hydroxides, phosphates, silicates and organic acids influence the alkalinity. In drinking waters, the preferred alkalinity range (105-142 vs. 200 mg/l) is within the limit in groundwater studied. Total hardness is mainly due to the presence of ions of calcium and magnesium. Depending on the bicarbonates or sulfates of the calcium and magnesium ions, the hardness has been divided into temporary hardness and permanent hardness. Hard water is not suitable for domestic purposes as it causes deposition of scales in plumbing, lowers the soap lather and reduces the efficiency of water heaters. The range of hardness in groundwater studied was between 92.1 mg/l and 133.28 mg/l, which is within the permissible limits (300 mg/l). The TDS, alkalinity and total hardness of open well waters in Belma village were below the quantities found in our study (Ramprasad et al. 2007). The COD indicates the amount of oxidizable organic matter, which reduces the dissolved oxygen (DO) levels. Such reduction of DO sets anaerobic conditions, which is dangerous to aquatic lives. The COD values of groundwater studied are within the permissible range in all seasons.

Chlorides are extensively distributed in nature as salts (calcium, sodium and potassium), which reach the soil and groundwater by leaching various rocks by weathering. High chloride content leads to corrosion of metals and affects the taste (e.g. salty) of water as well as the food products. Chloride values ranged between 62.6 mg/l and 95.9 mg/l, which is within the permissible limits (250 mg/l). However, drastic variation has been seen in chloride content in other Belma villages although within the permissible limits and one of them exceeded the permissible limits (e.g. Renjady, location # 2, 701-756 mg/l) (Dhanraj and Rajesha 2017). Nitrate is a naturally-occurring constituent of nitrogen found in soil, which is also the product of chemical fertilizers. The high nitrate levels in water cause methemoglobinemia in infants. The groundwater studied was devoid of nitrate in all seasons indicating its superior quality for drinking purposes. However, the open well waters in Belma village consist of nitrate in the permissible range of 0.04-0.3 mg/l (Ramprasad et al. 2007). In other groundwater in Belma, the nitrate level fluctuated drastically although it was within the permissible limits (Dhanraj and Rajesha 2017). Phosphorous is usually present in inorganic form, which was not present in the monsoon season, while in summer and post-monsoon seasons, its range was close to the maximum allowed limits (0.07-0.12 vs. 0.1 mg/l). Sodium content is within the WHO stipulated standards (47.1-58 vs. 200 mg/l). Potassium content is also within the acceptable limits. Similar to sodium, the calcium content, in groundwater is also they are within the standard limits (15.8-29.7 vs. 75 mg/l), so also the magnesium content (6.6-14.3 vs. 30 mg/l).

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The copper content was below the detectable limit in groundwater, so also chromium (except for trace during summer, 0.03 mg/l). The iron content ranged between 0.3 and 1.6 mg/l, which is higher during the summer and monsoon seasons than the permissible limits (0.3/l). Five locations of Belma village, possess iron within the permissible limits, but additional five locations possess an excess of iron (Dhanraj and Rajesha 2017). Fluoride occurs as fluorite, phosphorite crystals, rock phosphate and triphite. High fluoride levels in drinking waters cause dental fluorosis. F*luorosis* is characterized by hypomineralization of tooth enamel by consumption of excess fluoride through drinking waters. Fluoride content in groundwater during summer and monsoon was within the limits (0.04-0.3 mg/l), while during post-monsoon, it exceeded the limits (2.2 vs. 1 mg/l). Similarly, the lead content during the summer and monsoon seasons were below detectable levels, while during the post-monsoon season it was equivalent to standard concentrations (0.05 mg/l). As seen in the lead, arsenic content was below detectable levels during summer and monsoon seasons, while it exceeded the permissible limits during the post-monsoon season (2.2 vs. 1 mg/l).

Total coliforms and the presence of *Escherichia coli* are the indicators of disease-causing microorganisms in drinking waters. High coliforms and *E. coli* count in groundwater studied show contamination from sewage or fecal material. The MPN of coliforms in open well waters in Belma is extremely high compared to the present study (110-1600 vs. <1.8-140/100 ml) (Ramprasad et al. 2007). Based on the WQI of River Nethravathi, Avvannavar and Shrihari (2007) indicated that the human interference is severe and which has resulted in deterioration of water quality especially the MPN of coliforms.

The genotoxicity of groundwater by *Allium cepa* chromosome aberration assay revealed the mitotic index (MI) in negative control as 13.07±0.38, while in the pre-monsoon, monsoon and post-monsoon, it was 16.3±4.5, 17.06±3.4 and 15.9±3.2, respectively. The MI of water samples was higher than the negative control as only normal dividing cells were found without any chromosomal aberrations in water samples indicating the least or no genotoxicity.

5. CONCLUSION

According to the WHO, up to 80% of all human diseases are caused by drinking water. In the present study, physicochemical and biological parameters of groundwater samples of southwest India showed their superiority in quality and it will serve as baseline data for future investigations. The suburb location of Mangalore City studied is currently in the greenbelt experiencing rapid urbanization (development of educational institutions, hospitals, shopping complexes and small-scale industries). The population of the area in 2001 was 4,963, which has been elevated to 6,452 according to the 2011 census. Hence, there will be a growing freshwater crisis to meet the basic domestic/drinking water requirements. On analysis of various parameters following conclusions were drawn: 1) Temperature, alkalinity, turbidity, conductivity, TDS, total hardness, COD, Cu, Cr, Na, K and Cl^- contents are within the permissible limits in the summer, monsoon and post-monsoon seasons; 2) The water samples possess acidic pH, but its range is within the safe limit; 3) Iron content in pre-monsoon is high, but gets diluted during monsoon and is completely reduced in post-monsoon season; 4) The MPN as well as coliforms counts, were higher than the safe standards; 5) The pH, conductivity and iron content did not satisfy the standard requirements; 6) Fluoride, arsenic and lead levels showed higher values during the post-monsoon season; 7) The water for potability needs disinfection (e.g. boiling, filtration and UV irradiation), however, groundwater could be used for domestic (cleaning and gardening) and agricultural purposes.

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Conflicts of interests

The authors declare that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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