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An Assessment on Declining Ground Water Quality and Water Quality Index in Bengaluru, South India

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Abstract

Groundwater is a vital and important reliable natural resource for our life support system. The quality of water is worsening in the Bengaluru city due to geogenic and anthropogenic activities and it has drawn great attention, as it is the major alternate source of domestic and drinking water supply. In the southern region of India, particularly a city like Bengaluru, studying the water quality is very important due to the abnormal increase in the population and industrial development. The study of underground contamination will be an immense help for environmental regulators to initiate regulative measures. In the present study, an assessment of groundwater quality in different zones of Bengaluru was carried out and a total of 18 sites were identified from 4 different zones throughout the city i.e. North, South, East and West. The water samples were analyzed as per the drinking water standards of IS 10500 for major physicochemical parameters, heavy metals etc, and Water Quality Index (WQI) was calculated for evaluating overall quality of groundwater.

Introduction

Water is an important reserve for the survival of any living entity. Availability and quality of water is gaining very much importance in metropolitan/cosmopolitan cities like Bengaluru. More people depend on ground water for their domestic requirements in rural areas even though there is water supply from Akravathi and Cauvery river Basins and Lakes. Ground water is also being exploited for construction purposes. Bore wells are being drilled all over the city without the approval of Central Government water board and supplying water through tankers. Due to the rapid urbanization, drying of lakes, excessive usage of groundwater for consumption and industrial purposes are collectively making the city dry and the natural water resources highly polluted (Reddy, 2003).

Bengaluru is one of the cities, which may run out of groundwater by 2020 as reported in Niti Ayog Study 2018. Loss in tree cover, multiple scarce rainfall events, doubling-up of population and built up area at the expense of open areas in the last 25 years, are some of factors that have made the city on edge of a water crisis (Sahana, 2018). Water contamination because of infective agents, chemicals, heavy metals, pesticides, water disinfectants and their by-products as an effect of industrial and agricultural activities, leaching from soil, rocks and atmospheric deposition and other human activities has also become an environmental risk leading to hazard of human health in several regions of the city (Khayum *et al*., 2011). From the total solid waste generated in the city, only 30-40% is collected and sent to composting units by municipality directly and the 70% of municipal solid waste is collected and transported through contractors. Due to several issues properly operating landfills are less in number. Some are either closed or badly managed. Much of municipal solid waste gets dumped in the open dumps, posing health risks to residents in their neighborhood. This causes high risk of contamination of ground water/surface water, soil and air (Naveen and Sivapullaiah, 2016). The city suffers extensively with dust pollution, waste disposal, and unsystematic, unscientific waste retrievals.

The chemistry of groundwater is not only associated with the lithology of the region and time the water is in touch with rock material, but also reflects inputs from the atmosphere, from soil and weathering as well as from pollutant sources such as mining, land clearance, salt interference, industrial and domestic wastes (Sarath Prashanth *et al*., 2012). The illegal dumping of waste mixed with mass untreated sewage, ground water extraction, seasonal fluctuations, and pesticides in India's Silicon Valley situated in Bengaluru is creating a water crisis which threatens residents' health. Heavy metals in the water and water bodies are getting into our body through the food chain (Hapke, 1996), not only through the consumption of water, but also through feeding on vegetables, fruits grown downstream of such polluted water bodies and soil. Water Quality Index is a broadly used technique for estimating the suitability of drinking water (Jena *et al*., 2013). This technique helps in representing the relative picture of water quality and enables further appraisal and improvement of the water issues for any area. Water quality index (WQI) can transform large quantities of water quality data into a single number, which represents the water quality level (Tyagi and Sarma, 2018). In fact, developing WQI in a region may be a basic method in the designing of land use and water resources management. The objective of the water quality index is to make number of complex water quality parameters into information that is understandable to the public (Venkateswarlu *et al*., 2017). In this scenario, the quality assessment of water is unavoidable and keeping the current scenario in view, a detailed study of groundwater quality assessment was planned. For this purpose, Bengaluru city was divided into four different zones and under each zone four/five locations were identified as a) North Zone –Yeshwanthpur, Kalyannagar, Nagavara, and Ramamurthy Nagar, b) South Zone – Kumaraswamy Layout, Hanumanth Nagar, J.P. Nagar and Ejipura), c) East Zone – Krishnarajapuram, Whitefield, Bellandur, Varthur and Jeevanbheemanagar), d) West Zone – Vijay Nagar, Kengeri, Nagarbhavi, Basaveshwar Nagar and Rajajinagar. The samples were collected and analyzed for various physico-chemical parameters and heavy metals. A comparative study was done on the water quality/contamination using water quality index. Parameter selection in calculating WQI has a great importance and consideration of too many parameters might unwiden the quality index.

Materials and Methods

Study Area

Bangalore https://en.wikipedia.org/wiki/Bangalore, officially called Bengaluru, is situated in the southeast of Karnataka. It is situated at 12.97° N 77.56° E and covers a vicinity of 2,190 square kilometres (850 sq mi) and is located in the heart of the Mysore Plateau (a region of the larger Deccan Plateau) at an average altitude of 920 metres (3,020 ft). The city had pleasant and equable climate throughout the year. However, due to deforestation, it is becoming warmer. The average temperature will be 23.60C and annual rainfall of 970 mm in a year. Soils of Bangalore consist of red laterite and red, fine loamy to clayey soil. Bengaluru has district borders with Kolar and Chikkaballapur in the northeast, Tumkur in the northwest, Mandya and Ramanagaram in the southeast and Mysore. It is the second fastest growing metropolis of India and Fourth highest GDP Contributor after cities like Mumbai, Delhi, and Chennai. It is popularly known as Silicon Valley of India as it is a major IT hub of the nation. It has a population of over 10 million, making it a megacity and 24th most populous city in the world and the fastest-growing Indian metropolis behind New Delhi. (Bangalore Population, 2019). The city was categorized into four different zones like north, south, east and west and four to five locations were identified from each zone (Figure 1) and the coordinates of each location has been located.

Data Collection and Methodology

As described earlier, the groundwater samples majorly consumed for the drinking and domestic purposes were collected in the month of August 2018 from 18 different locations distributed over four different zones of Bengaluru and were analyzed for physicochemical parameters.The sampling locations were selected with a view to cover whole of the city and to achieve a good sampling illustration over the study area. All the water samples were collected into one litre sterilised plastic bottles. The bottles were sterilised by washing with 5% nitric acid, and then rinsing several times with distilled water to avoid all kinds of contaminants. The samples were then kept in an ice box and transferred to the water quality analysis laboratory.

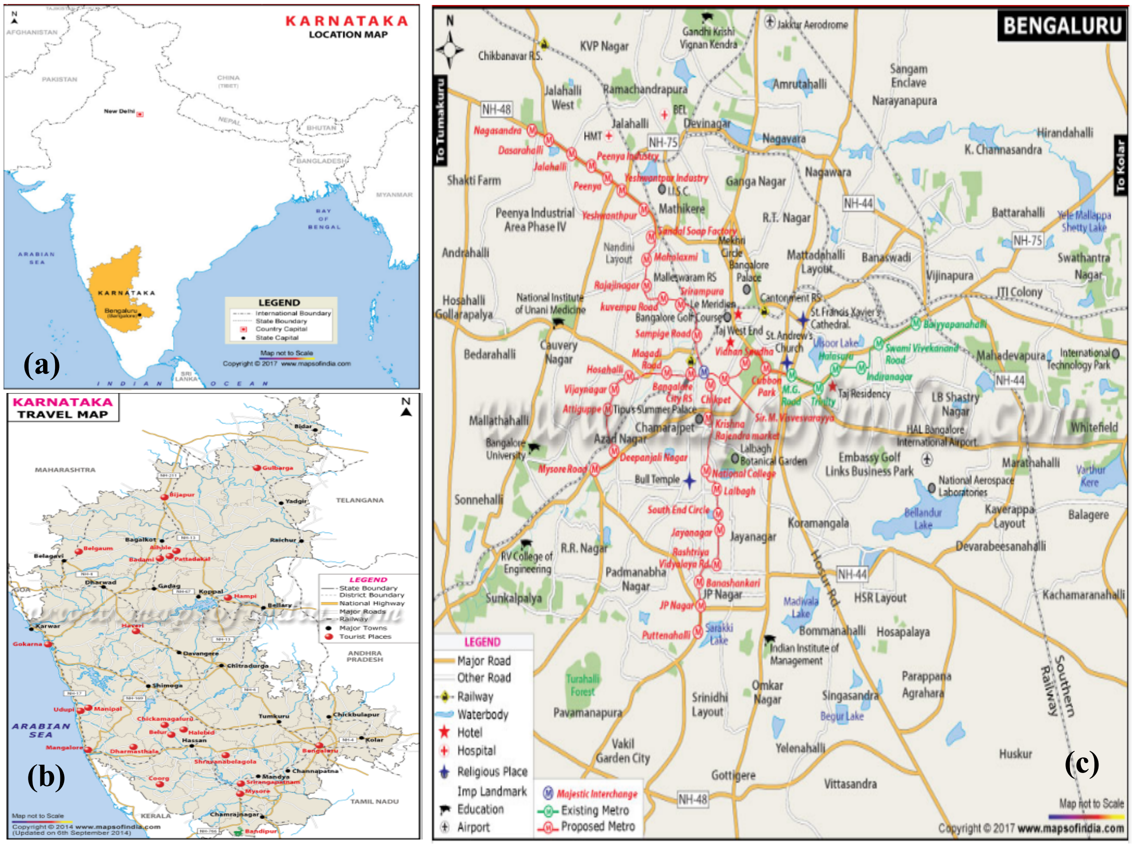

Figure: 1 a, b, c. Location map of Study Area (Source: Maps of India)

The parameters for study include pH, Turbidity, TDS, Electrical Conductivity, Total Hardness, Calcium, Magnesium, Total Alkalinity, Chloride, Nitrate, Sulphate, Fluoride and Heavy metals which were performed as per the Standard protocol (APHA, 2017). For heavy metal analysis, samples were collected in pre-washed and rinsed with 10% HNO_3 acidified polyethylene bottle and preserved with HNO_3 to maintain pH below 2. For determination of heavy metals, samples were digested with 10 ml conc. HNO_3 and filtered using Whatman No. 42 filter paper. The heavy metals viz., Fe, Zn, Mn, Cu and Cd were analyzed by using atomic absorption spectrophotometer (Varian). All the methods applied were standardized and parameters were analyzed and average values were reported as per relevant standards.

Water Quality Index Calculation

In this study the W.Q.I has been calculated for chosen 16 parameters by using the Indian standards (BIS, 2012) of drinking water quality. The weighted arithmetic index method has been used for the calculation of W.Q.I. (Satish Chandra *et al*., 2017) (Tyagi *et al*., 2013).

Table 1: Sampling Locations and their Coordinates

Sl No.	Locations	Sampling Areas	Coordinates	
			Longitude	Latitude
1	N1	Yeshwanthpur	77.5409° E	13.0280° N
2	N2	Kalyannagar	77.6400° E	13.0280° N
3	N3	Nagavara	77.6136° E	13.0423° N
4	N4	RammurthyNagar	77.6737° E	13.0085° N
5	S1	KumaraswamyLayout	77.5618° E	12.9038° N
6	S2	Hanumanth Nagar	77.5626° E	12.9425° N
7	S3	J.P.Nagar	77.5857° E	12.9105° N
8	S4	Ejipura	77.6308° E	12.9385° N
9	E1	Bellandur	77.6762° E	12.9260° N
10	E2	K.R.Puram	77.6878° E	13.0040° N
11	E3	Varthur	77.7412° E	12.9389° N
12	E4	Whitefield	77.7499° E	12.9698° N
13	E5	Jeevanbheemanagar	77.6595° E	12.9629° N
14	W1	Basaveshwarnagar	77.5383° E	12.9886° N
15	W2	Kengeri	77.4827° E	12.8996° N
16	W3	Nagarbhavi	77.5083° E	12.9599° N
17	W4	Vijayanagar	77.5299° E	12.9719° N
18	W5	Rajajinagar	77.5525° E	12.9901° N

Quality rating or sub index (*Qn*) was calculated using the following expression-

$$Qn = 100 \times [Vn-Vo] / [Sn-Vo] \qquad \text{Equation.1}$$

Where, Qn = Quality rating for the nth water quality parameter.
Vn = Estimated value of the nth parameter at a given sampling station.
Sn = Standard permissible value of the nth parameter.
Vo = Ideal value of nth parameter in a pure water.
Unit weight was calculated by a value inversely proportional to the recommended standard values Sn of the corresponding parameters.

$$Wn=(K/Sn). \qquad \text{Equation.2}$$

Where, Wn = Unit weight for the nth parameter.
Sn = Standard value for nth parameter.
K = Constant for proportionality

$$K = 1/\Sigma(1/Sn) \qquad \text{Equation.3}$$

The overall Water Quality Index (*W.Q.I*) was calculated by aggregating the quality rating with the unit weight linearly.

$$WQI = \Sigma Q_n W_n / \Sigma W_n \quad \text{Equation.4}$$

Water Quality Rating as per Weight Arithmetic Water Quality Index Method is mentioned in Table 2.

Table 2 Water Quality Index Rating

WQI Value	Rating of Water Quality	Grading
0-25	Excellent	A
26-50	Good	B
51-75	Poor	C
76-100	Very poor	D
Above 100	Unsuitable for Drinking Purpose	E

Results and Discussion

The hysico-chemical parameters have been found that some of the parameters are not meeting the limit of the IS standards and results are discussed below (Table 3). The physico-chemical characteristics and heavy metal concentrations of all samples are shown in the Table 4.

Table 3 Physicochemical parameters and limits as per IS 10500 for drinking water

Sl No.	Parameters	Units	IS Standards(IS 10500:2012)	
			Acceptable Limits	Permissible Limits
1	pH		6.5	8.5
2	Electrical Conductivity	µS/cm	...	....
3	Total Dissolved Solids	mg/L	500	2000
4	Turbidity	NTU	1	5
5	Total Hardness, as $CaCO_3$	mg/L	200	600
6	Calcium, as Ca	mg/L	75	200
7	Magnesium, as Mg	mg/L	30	100
8	Total Alkalinity, as $CaCO_3$	mg/L	200	600
9	Chloride, as Cl	mg/L	250	1000
10	Sulphate, as SO_4	mg/L	200	400
11	Nitrate , NO_3	mg/L	45	No relaxation
12	Fluoride, as F	mg/L	1	1.5
13	Iron, as Fe	mg/L	0.3	No relaxation
14	Zinc, as Zn	mg/L	5	15
15	Manganese, as Mn	mg/L	0.1	0.3
16	Copper, as Cu	mg/L	0.05	1.5
17	Cadmium as Cd	mg/L	0.003	No relaxation

Physico-Chemical Analysis

pH is an indicator of the acidity or alkalinity of the solution and the concentration of hydrogen ion concentration. It has no direct undesirable effects on health; however, higher values of pH accelerate the scale formation in water heating apparatus and also reduce germicidal potential of chloride. High pH also induces the formation of tri halo methane in chlorinated drinking water, which is toxic (Jena, *et al*., 2013). In the present survey, pH remains slightly alkaline in nature with no marked deviation and is recorded within the desirable limit of pH 6.5-8.5 as mentioned in IS 10500-2012.

Turbidity is a measure of the cloudiness of water due to suspended particles and it affects the scattering of light and absorption properties in a water body (Mathew and Krishnamurthy, 2018). Turbidity in groundwater is mostly inorganic and caused by natural geological factors. The turbidity of only one area i.e., Kengeri (W2) was found to be out of maximum permissible limit and one from East was out of acceptable limit.

Electrical conductivity (EC) measures the water capacity to convey the electric current such that the higher EC shows enrichment of dissolved salts in the groundwater.Total dissolved solids (TDS) are a measure of the sum of dissolved ions in water. High TDS concentrations are due to the presence of bicarbonates, carbonates, sulphates, chlorides, calcium and magnesium which may originate from natural sources, sewage, urban runoff, and industrial wastewater. They can furthermore be derived from chemicals utilized in the water treatment practice and from pipes or other hardware used in the plumbing. The TDS can be removed by reverse osmosis, electrodialysis, exchange and solar distillation (Akhtar and Tang, 2013). TDS values are found to be on the higher side crossing the acceptable limit which is >500mg/L. Out of 18 locations, 5 are nearing to the maximum permissible limit and one from Whitefield area is above the permissible limit.

Total Alkalinity (TA) of groundwater rises due to presence of bicarbonate (HCO_3), carbonate (CO_3^{2-}) and hydroxide ions (OH^-) and forms the acid neutralizing capacity of the water (Saana *et al*., 2016). The desirable limit of alkalinity in water is 200 mg/L. The values of Total Alkalinity were greater than the desirable limit in all areas except 2 areas, but recorded within the permissible limit of 600 mg/L as $CaCO_3$ as per IS 10500-2012. The sources of chloride (Cl) include weathering, leaching from sedimentary rocks and soil, domestic and municipal effluents (Tyagi and Sarma, 2018). The inappropriate treatment of industrial effluents and the surplus usage of insecticides for agricultural activities have also contributed towards the increase in concentration of chlorides (Mathew and Krishnamurthy, 2018). In the study area, the chloride levels were highest at the Whitefield Area with 643 mg/L. Higher concentrations of Cl induce a salty taste in water. The value of Cl ranges with 70-643 mg/L and in which except two areas, for all other areas chloride is within the acceptable range of 250 mg/L.

Table 4: Statistical Analysis for Physicochemical Characteristics of Ground Water in Bengaluru

Sampling Zones	pH	Turbidity, NTU	TDS, mg/L	EC, µS/ cm	Total Hardness, mg/L	Ca, mg/L	Mg, mg/L	Total Alkalinity, mg/L	Cl mg/L	NO_3,mg/L	SO_4, mg/L	F, mg /L	Fe, mg /L	Mn, mg /L	Zn, mg/L	Cu, mg/L	Cd, mg/L
N1	7.3	0	619	1265	411	82	51	258	106	20	55	0.12	0.1	0	1.3	0	0
N2	7.3	1.1	548	1130	226	61	18	236	93	37	62	0.10	0.7	0.03	0.03	0.03	0
N3	7.1	0	587	1027	380	79	46	251	104	4	52	0.23	0.1	0	0.28	0	0
N4	6.6	0	955	1774	396	107	32	357	163	118	99	0.43	0.2	0	0.15	0.03	0
S1	6.6	1.2	584	1011	291	63	32	220	79	94	47	0.35	0.2	0	0.05	0.03	0
S2	7.2	0	365	650	189	44	19	122	70	51	32	0.11	0	0	0.03	0.03	0
S3	7.2	0	592	966	284	73	25	171	203	50	40	1.60	0.2	0	0.03	0.03	0
S4	6.7	0	728	1394	320	99	18	319	129	31	62	.09	0.1	0.03	0.08	0.03	0
E1	7.3	0	793	1379	388	109	26	342	159	2	80	0.46	0.1	0.03	0.03	0	0
E2	7.4	0	1061	1981	466	132	31	296	347	97	92	0.17	0.7	0.03	0.03	0	0
E3	6.9	0	951	1897	553	143	47	361	258	20	51	0.25	0.4	0.03	0	0	0
E4	7.1	0	1500	3010	1027	281	78	277	643	128	44	0.08	0.1	0.03	0.05	0.03	0
E5	7.3	2.4	681	1289	375	102	29	285	129	13	60	0.10	0.2	0	0.1	0.03	0
W1	7.2	0	457	831	291	61	35	194	68	22	34	0.32	0.8	0	0.4	0.03	0
W2	6.9	0	703	1315	386	93	37	319	111	27	57	0.16	0.1	0.8	0.43	0	0
W3	7.1	13.2	818	1521	484	101	56	388	165	2	21	0.10	2.1	0	0.03	0	0
W4	7.3	0	598	1036	318	59	42	281	75	28	53	0.36	0.1	0.03	0.20	0	0
W5	7.1	0	487	901	222	47	25	228	70	25	42	0.22	0.1	0.03	0	0	0
Min	6.6	650	365	0	189	44	18	122	68	2	21	0.08	0	0	0	0	0
Max	7.4	3010	1500	13.2	1027	281	78	388	643	128	99	1.6	2.1	0.8	1.3	0.03	0
Mean ± SD	7.09 ± 0.25	1354 ± 550.5	723.7 ± 266.4	0.99 ± 3.11	389.3 ± 185.3	96.4 ± 53.8	35.9 ± 15.5	272.5 ± 70.3	165.1 ± 139.8	42.7 ± 39.7	54.5 ± 19.9	0.29 ± 0.35	0. 34 ± 0.5	0.06 ± 0.19	0.18 ± 0.31	0.02 ± 0.02	0

The sources of chloride (Cl) include weathering, leaching from sedimentary rocks and soil, domestic and municipal effluents (Tyagi and Sarma, 2018). The inappropriate treatment of industrial effluents and the surplus usage of insecticides for agricultural activities have also contributed towards the increase in concentration of chlorides (Mathew and Krishnamurthy, 2018). In the study area, the chloride levels were highest at the Whitefield Area with 643 mg/L. Higher concentrations of Cl induce a salty taste in water. The value of Cl ranges with 70-643 mg/L and in which except two areas, for all other areas chloride is within the acceptable range of 250 mg/L.

Total Hardness (TH) of the groundwater is caused predominantly due to the presence of cations and anions. The highest value of hardness were recorded in the Whitefield area with a value of 1027 mg/L as $CaCO_3$ and it is exceeding the permissible limits of 600 mg/L due to the industrial wastes discharges. The values for other regions were also found out of the permissible limits except in Hanumanth Nagar. The presence of divalent cations such as Ca^{2+} and Mg^{2+} influence the hardness of drinking water (Tyagi and Sarma, 2018).The observed calcium and magnesium ion were ranging between 44-287 mg/L and 18-78 mg/L ,respectively, in which 11 out of 18 were found beyond the given acceptable limit of 75 mg/L and 30 mg/L, respectively. High concentration of these ions can lead to poor lathering and deterioration of the quality of clothes (Packialakshmi *et al*, 2015). Sulphate (SO_4^{2-}) concentrations greater than 400 mg/L leads to laxative effect on human organs. Use of large quantity of fertilizers and pesticides is the main source of non-point pollution which increases the concentration of sulphate (Jerome and Pius, 2010). The sulphate levels were found within the acceptable limits of 200 mg/L and vary from 21-92 mg/L.

Nitrate (NO_3^-) contamination is a major problem in groundwater systems and higher concentrations likely to cause diseases such as methenoglobinemia, gastric cancer, thyroid disease and diabetes (Krishna Kumar *et al*., 2012). The values of nitrate in the groundwater vary from 2 to 128 mg/L out of which 6 locations are out of the permissible limits of 45 mg/L. The probable source of groundwater pollution in these areas with high content of nitrates will be due to leaky septic tanks and open disposal of garbage. Through the underlying soil horizons, nitrite goes through a sorbtion process. During seepage phosphorus and pathogens are removed along with all other septic tank matter. However nitrites (along with nitrate) typically fall through these zones and contaminate groundwater. Nitrate level in ground water is more than the contaminated surface water bodies due to longer residential time (ammonia available in surface water converted into nitrate) and sustained inflow of sewage concentrates nitrate levels in ground water. This highlights the need for immediate interventions in solid and liquid waste treatment to prevent further contamination of groundwater (Ramachandra and Kashyap, 2013).

Phosphate containing fertilizers will increase the fluoride content in soil and groundwater. Only one location from south side was found to have crossed the permissible limit; otherwise all others are in the acceptable limit. Fluoride (F^-) element required in trace amounts for the development of teeth and bones, however, exposure to higher values of F^-greater than 1.5 mg/L causes fluorosis. Skeletal fluorosis that causes weakness and bending of the bones results because of long term consumption of water containing high fluoride. Presence of low or high concentration of fluoride in groundwater is due to natural or anthropogenic causes or a combination of both (Karthikeyan and Lakshmanan, 2011).

Heavy metals analysis

Iron (Fe) is observed as the key metal in groundwater samples and the higher concentration of Fe was found in the east, west and north regions. Rusting of the pipes and/or hand pumps might contribute to presence of Fe in the groundwater (Saana *et al*., 2016).However, Fe is predominantly found as the natural element in the Earth surface and can be involved as the geogenic in the nature. The interaction of oxidized Fe bearing minerals and dissolution of Fe_2CO_3 might be the reason for iron contamination in the groundwater. About 22% of the groundwater samples were exceeding the permissible limit. The concentration of Manganese (Mn) is ranging from 0.03-0.8 mg/L. The highest value of was recorded at Kengeri which was exceeding the permissible limit of 0.3 mg/L and shows the proximity to major urban disposal sites as it is densely populated area. The heavy metal like copper (Cu) is as essential element required in trace amounts but in excess amounts, it leads to toxicity. However, Cu was found within their permissible limit of 1.5 mg/L. Cu values range from 0.0-0.03 mg/L and were within the safe limits of 0.5 mg/L. The mean concentrations of Zinc (Zn) in all the sites were found within the safe limits of 5 mg/L and the concentration of cadmium was found below the detection limit for all the areas.

Groundwater Quality Assessment using Water Quality Index

The groundwater quality was classified into excellent, good water, poor water, very poor and unfit for drinking categories based on the WQI values (Figure 2 and Table 5). Based on the classification, about 4 samples out of 18 groundwater samples were found unfit for drinking and overall groundwater quality is not potable. The study area of Bengaluru is immensely polluted from the industrial and rapid urbanization. Only 2 sites within selected sites showed good water, which could be the reason as no respective parameter, is exceeding the limits of IS 10500- 2012. These sites are also affected by the industrial effluent and wastes discharges from densely populated sites.

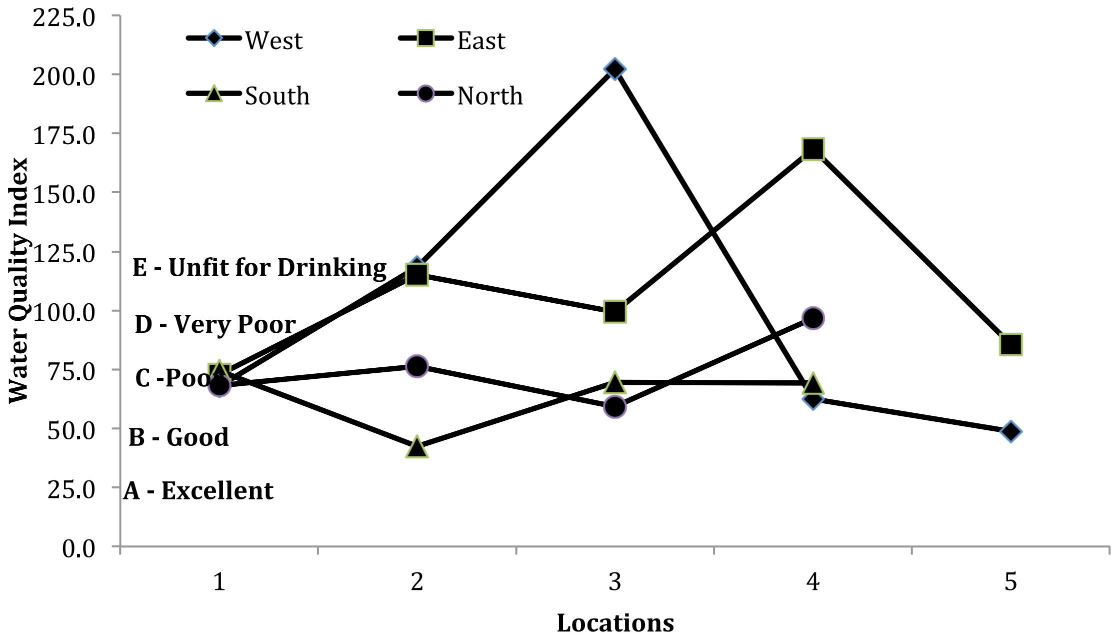

Figure 2: Water Quality Index

Table 5: Water Quality Index Value for Different Sampling Locations

Sl No.	Locations	Location Name	WQI Value	Quality
1.	N1	Yeshwanthpur	68.2	Poor Water Quality
2.	N2	Kalyannagar	76.2	Very Poor Water Quality
3.	N3	Nagavara	59.3	Poor Water Quality
4.	N4	RammurthyNagar	96.6	Very Poor Water Quality
5.	S1	KumaraswamyLayout	74.4	Very Poor Water Quality
6.	S2	Hanumanth Nagar	42.4	Good Water Quality
7.	S3	J.P.Nagar	69.5	Poor Water Quality
8.	S4	Ejipura	69.2	Poor Water Quality
9.	E1	Bellandur	72.8	Very Poor Water Quality
10.	E2	K.R.Puram	115.0	Unsuitable for drinking
11.	E3	Varthur	99.4	Very Poor Water Quality
12.	E4	Whitefield	168.2	Unsuitable for drinking
13.	E5	Jeevanbheemanagar	85.6	Very Poor Water Quality
14.	W1	Basaveshwarnagar	68.0	Poor Water Quality
15.	W2	Kengeri	118.4	Unsuitable for drinking
16.	W3	Nagarbhavi	202.3	Unsuitable for drinking
17.	W4	Vijayanagar	62.6	Poor Water Quality
18.	W5	Rajajinagar	48.8	Good Water Quality

Conclusion

The present study investigated the status of groundwater quality of different areas of Bengaluru. The higher concentrations of the major physicochemical parameters and heavy metals such as Electrical Conductivity, TDS, Total hardness, Nitrate, Chloride, Fluoride, Iron, and Manganese are degrading the quality of groundwater. The existing practice of waste discharge and disposal near water bodies are creating nuisance in the environment. High Nitrate levels show the impact of waste mismanagement in urban area. Water Quality index results revealed that about 88% of the samples were in the category of poor quality. An immediate attention should be given in order to reduce the contamination through Nitrate, Iron and Manganese by checking the land use activities, heavy metals and pesticides loading for the shallow and deep aquifer levels. The study also unveils that the groundwater of the city is under great threat which demands regular monitoring of groundwater quality, abolishment of unhealthy waste disposal practices, and introduction of new techniques for waste management and also requires a degree of treatment to some extent before consumption. If the present system continues, ground water may not be available at all in the near future.

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