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PHYSICOCHEMICAL ANALYSIS OF GROUND WATER POLLUTION IN BHOPAL CITY

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ABSTRACT

Groundwater is a crucial natural resource that plays an important role in supporting human life. Groundwater pollution has emerged as a critical environmental challenge, particularly in urban and semi-urban areas where dependency is very high. This study aimed at evaluating the condition of ground water pollution in Bhopal City of Madhya Pradesh, India. Twenty-one samples were collected from different locations within the city and analysed for their physio-chemical properties by standard methods of American Public Health Association APHA (2005). The findings obtained here were compared against the guidelines set by World Health Organisation (WHO) and Bureau of Indian Standards (BIS). The assessment indicated that some of the vital parameters, viz., TDS, TH,Total Alkalinity exceeded the acceptable limit and parameters like pH, Mg^{+2}, and Ca^{+2} etc, exceeded the permissible limit according to WHO and BIS standards. Hence, it appears that direct consumption of water from these sources can have potential health hazards. Water quality index (WQI) values as calculated for the study area came in the range of Excellent to unfit, which again proves the quality of groundwater in Bhopal City to be very inappropriate for drinking purposes.

KEY WORDS : Ground Water Pollution, Bhopal City, Physicochemical Parameters, Water Quality Index.

INTRODUCTION

Groundwater is one of the most important resources of water for cities, especially in countries like India which is in their developing phase, because it serves as the primary source of drinking water and other activities. Groundwater is a vital source for Bhopal, the capital city of the state of Madhya Pradesh, to cater the demand of ever-increasing population and economic activities in the city. However, the quality of this resource is continually threatened by the growing pollution, rapid urbanization and industrial activities.

The quality of groundwater concerns its physical, chemical, and biological characteristics with respect to the specific intended uses of water. Human activities are the major threats to groundwater quality; however, there are times when harmful substances are introduced naturally (Talabi and Kayode, 2019).

Urbanization, especially in developing nations such as India, has adversely affected the availability and quality of groundwater in terms of over exploitation. Once groundwater is contaminated, the quality cannot be restored by stopping the pollutants from the source (Balan *et al*., 2012).

Ground water can be contaminated in a number of ways, including through the use of fertilizers in farms and seepage from effluent bearing water bodies. Most of the industries discharge without proper treatment effluent into nearby open pits or through unlined channels whereby, ground water gets contaminated (Reza and Singh, 2009).

Groundwater in Bhopal city is contaminated, mainly because of the industrial sector. The disastrous Bhopal Gas Tragedy of 1984 had left a

chemical residue on the soil and aquifers, infiltration of harmful substances into the ground water due to poor sewerage management and unplanned disposal of municipal waste can make situation worst. Poor drinking water quality as a result of contamination of groundwater usually causes health problems such as dental fluorosis and chronic kidney disease (Lila *et al.*, 2024). The rising levels of pollution pose severe threats to human health, including waterborne diseases and long-term toxicity, as well as the sustainability of this vital resource.

Study Area: Bhopal city is located between N-latitude 23°07' & 23° 20' and E- longitude 77° 19' & 77°31'from the equator and maximum height of 505 meters above sea level and minimum 180 meters. The climate of city is healthy and sweet. This district comes in the dry part of India, the total annual average rain fall of Bhopal is 1260.2 mm. During the southwest monsoon, about 92 % of the rain falls during the monsoon sky period. About 39% of it usually can be found within the month of July CGWB (2013).

According to Bhopal Municipal Corporation, the city has been the capital of the state of Bhopal in British India and now the state capital of Madhya Pradesh. Situated in central India, the city makes a geographical part of the Bhopal district having an extended planning area from 296 square kilometres to 463 square kilometres, Bhopal stands as one of the 15 largest cities in India. There are 85 municipal wards in the city BMC (2023).

According to the census of India, population of Bhopal has increased from 1,85,000 in year 1961 to 2371061 in year 2011. out of the total Bhopal population for 2011, 80.85 percent live in urban regions of district. In total 18,86,100 people lives in urban areas. Although Bhopal city has population of 1,798,218.

The major requirement of drinking water supply in Bhopal city is met from surface water sources, namely Upper Lake and Kolar reservoir and the Narmada River (Kumar and Verma, 2024). The unaccounted privately owned dug wells and bore wells also cater the requirement of individual households, industries, business complexes, private and government colonies developed in the out skirts of the Bhopal city (CGWB, 2013).

METHODOLOGY

This study is based on primary data.Total twenty-one zone wise locations were selected as sampling points for ground water monitoring. Samples are collected during month of November post monsoon season. Details of all monitoring locations are depicted in Table 1 and Figure 1. Base map of Madhya Pradesh and Bhopal district (Survey of India) is shown in Fig 1

During sample collection, (handling and

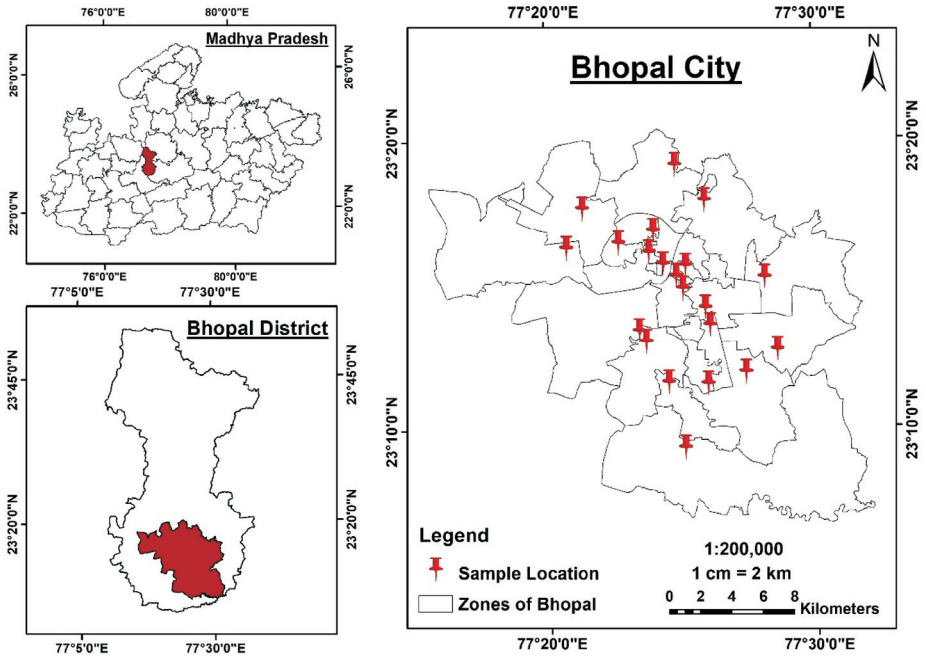

Fig. 1. Bhopal City Map

Table 1. Sample code, their location and source type

Sample Code	Zone of Bhopal	Source Type	Sample Code	Zone of Bhopal	Source Type
B1	1	HANDPUMP	B11	11	BOREWELL
B2	2	HANDPUMP	B12	12	BOREWELL
B3	3	HANDPUMP	B13	13	BOREWELL
B4	4	HANDPUMP	B14	14	DUGWELL
B5	5	HANDPUMP	B15	15	BOREWELL
B6	6	BOREWELL	B16	16	BOREWELL
B7	7	HANDPUMP	B17	17	BOREWELL
B8	8	BOREWELL	B18	18	BOREWELL
B9	9	BOREWELL	B19	19	BOREWELL
B10	10	BOREWELL	B20	20	BOREWELL
-	-	-	B21	21	BOREWELL

preservation) standard procedures recommended by APHA (2005) and guidelines as followed by Central Pollution Control Board CPCB (2007). Water samples were collected during the post monsoon season for this study from bore wells, hand pumps and dug well. High-density polyethylene (HDPE) bottles were used for sample collection. Samples were filled to up to the brim and immediately sealed to prevent exposure to air and systematically labelled. The labelled samples were analysed in the laboratory for various physicochemical parameters according to standard methods prescribed by BIS. All the results were compared with the standard limits along with that of drinking water BIS (2012).

The water quality index (WQI) is a good tool which can show lots of data in a single value and make easy understanding of information (Ketata *et al.*, 2012). The weighted arithmetic water quality index method classified the water quality depending on degrees of purity by using readily measurable water quality variables, and calculation of the WQI was made Brown *et al.* (1972) by the following equation:

$$WQI = \Sigma QnWn/\Sigma Wn$$

Each parameter's quality rating scale (Qi) is Computed by this Formula:

$$Qn = 100[(Vn - Vo/Sn - Vo)]$$

Here, Vn is estimated concentration of ith parameter in the analysed water

Vo is denoted the ideal value of parameter in pure water

Vo = 0 (except pH =7.0)

Sn is recommended standard value of ith parameter

Each water quality parameter's unit weight (Wi) is calculated by using this expression:

$$Wn = K/Sn$$

K= proportional constant.

The calculated WQI values are categorized into five categories from "excellent water" to "water, unfit for drinking". The maps are prepared by using inverse distance weighted (IDW) interpolation in Qgis softwere.

Table 2. Standard Water quality index level and its status.

Water quality index level	Water quality status
0–25	Excellent
25–50	Good
50–75	Poor
76–100	Very poor
>100	Unfit for drinking

Source: Brown *et al.* (1972); Kumar and Verma (2024)

RESULTS AND DISCUSSION

The respective groundwater samples were analysed for pH, Turbidity, Electrical conductivity, TDS, Total hardness, Calcium, Magnesium, Fluoride, Chloride, Nitrate, Sulphate and Iron. Their analytical results are denoted in Table 3 and the status of water quality of such ground water sources are included in Table 4.

Colour: The acceptable and permissible of Colour are 5 Hazen unit and 15 Hazen Unit respectively. In the study area Colour ranges from 1 Hazen unit to 14 Hazen unit. only 9 samples come under acceptable limit and rest 12 samples come under permissible limit in the study region.

pH: pH is the measure of hydrogen ion concentration value in water which indicates whether a solution is acidic, neutral or basic. If pH value is less than 7 it indicates acidity, a pH value of

Table 3. The physico-chemical concentrations of collected groundwater samples

S. No.	Parameters (unit)	BIS*	WHO**	Min.	Max.	Average	Standard deviation
1.	pH	6.50 - 8.50	7.0 - 8.0	6.43	7.83	7.2486	0.4982
2.	TDS (mg/l)	500 - 2000	600 - 1000	112	977	492.9048	225.9741
3.	Turbidity (NTU)	1.0 - 5.0	1.0 - 5.0	0.02	3.8	1.0124	1.2539
4.	EC (µS/cm)	750 - 3000	500 - 1000	220	1640	887.1429	0.3651
5.	Total Alkalinity (mg/l)	200 - 600	_	198	319	287.3095	93.7063
6.	Total Hardness (mg/l)	200 - 600	200	105.04	436.96	220.2724	88.9003
7.	Ca^{+2} (mg/l)	75 - 200	100 - 300	34.66	213.09	87.9305	40.6311
8.	Mg^{+2} (mg/l)	30 - 100	_	2.53	147.98	43.9990	37.0616
9.	Cl-(mg/l)	250 - 1000	250	7.81	281.4	89.3786	66.9474
10.	F- (mg/l)	1 - 1.5	1.5	0.25	0.75	0.393	0.1650
11.	Fe (mg/l)	0.3	0.3	0.0002	0.038	0.0076	0.0094
12.	SO_4 (mg/l)	200 - 400	250	0.39	1.72	1.8162	1.8681
13.	NO_3 (mg/l)	45	50	1	3.87	2.406	0.7398

Source: - Primary Data based on laboratory testing, * BIS (2012), EC value of BIS from Kumar and Verma (2024), ** WHO (2011), EC value of WHO, 2022 from (Lila *et al.*, 2024).

7 indicates neutrality and the pH value of greater than 7 indicates basicity Lila *et al.* (2024). The pH required has to be in the range of 6.5-8.5 for the drinking purpose BIS (2012). The observed value of pH in 21 water samples is between 6.43 and 7.83. only 2 samples have value lower than 6.5 in the study region rest 19 sample have value under acceptable limit as recommended by BIS (2012). Sample B14 and B21 shows acidic nature as shown in Figure 2B.

Total Alkalinity (TA): Alkalinity is a measure of the capacity of water to resist variations in its pH due to acidification Sahoo *et al.* (2016). The acceptable and permissible of Total Alkalinity are 200 mg/l and 600 mg/l respectively. In the study area TA concentration ranges from 71.50 mg/l to 561 mg/l. only 3 samples come under acceptable limit, 18 samples come under permissible limit in the study region set down by BIS, 2012. The distribution of Total alkalinity is shown in Figure 2C.

Turbidity: Turbidity is a measure of the clarity of water. High turbidity causes the water to appear cloudy or muddy. Turbidity can then be defined as the density of light being scattered or perceived with respect to suspended particles in water (Kumar and Verma, 2024). Groundwater sources contain turbidity due to a combination of inert clay, chalk particles, precipitation of nonsalable reduced iron and other oxides when water is pumped from anaerobic waters. Turbidity is produced either by inorganic or organic substances or both. Microorganisms are generally attached to the particulates e.g. bacteria, viruses, and protozoa that can cause unsafe water WHO (2011).

The acceptable and permissible range of turbidity are 1 NTU and 5 NTU respectively. The observed value of turbidity in 21 water samples is between 0.020 and 3.80 only 13 samples come under acceptable limit and rest 8 samples come under permissible range limit in the study specified by BIS

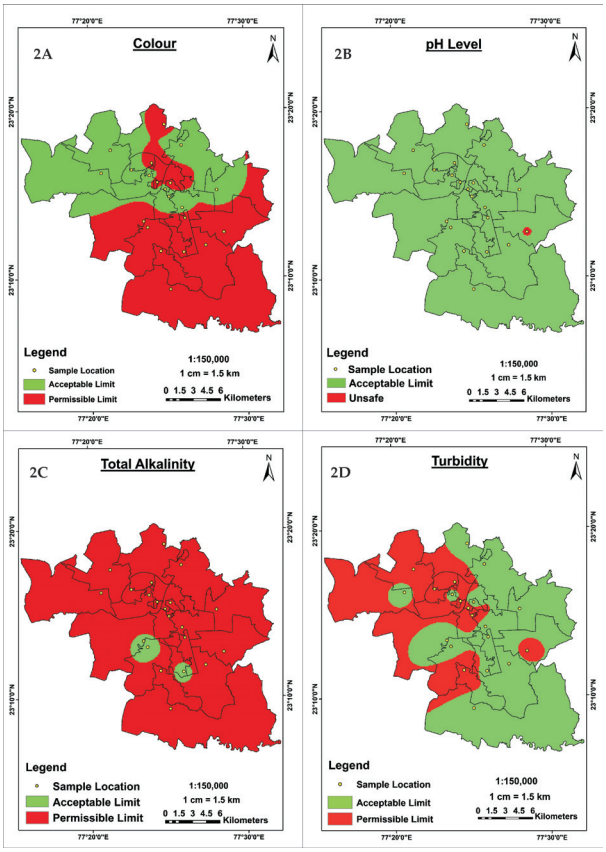

Fig. 2. Distribution of Physico-chemical in Bhopal City (From 2A to 2D)

(2012) as indicated in Figure 2D.

Total Dissolved Solids (TDS)

TDS is the concentration of total salts (inorganic salts + organic salts) present in the water. It is an essential physio-chemical parameter to examine the water quality.The acceptable and permissible limits of TDS are 500 mg/l and 2000 mg/l respectively. The observed value of TDS in 21 water samples is between 112 mg/l and 977 mg/l. only 12 samples come under acceptable limit and rest 9 samples come under permissible limit in the study region as directed by BIS (2012) and as appeared in Figure 2E.

Electrical conductivity (EC): Electrical conductivity refers to the ability or ease by which electric current can pass through water. The degree of conductivity in any body of water is affected by dissolved inorganic solids such as chlorides, nitrates, sulphates and phosphates which are known to form anions. The other main reason that ground water conductivity is different would be primarily based on the geology of the area in which the aquifer is located (Lila *et al*., 2024). The desirable limit of EC in drinking water is between 500 µS/cm to 1000 µS/cm (WHO, 2022 Lila *et al*. ,2024). The acceptable and permissible of EC are 750 µS/cm and 3000 µS/cm respectively prescribed by BIS (Kumar and Verma 2024). The observed value of EC in water samples is between 220 µS/cm and 1640 µS/cm. 05 samples have value come under acceptable limit 16 samples come under permissible limit of BIS. Two samples have value come under acceptable limit 14 samples come under permissible limit of WHO. five samples have value higher than 1000 µS/cm in the study region.

Total Hardness (TH): Hardness is mainly due to the presence of Calcium and Magnesium Bicarbonate, Sulphate, and Chloride ions. Permanent hardness in water caused by Calcium and Magnesium, Sulphate and Chloride can be removed by Ion exchange CGWB (2022). Total hardness is one of the most important parameters in water quality assessment. The acceptable and permissible limit of TH are 200 mg/l and 600 mg/l respectively. The observed value of total hardness in 21 water samples is between 105.04 mg/l to 436.96 mg/l. only 12 samples come under acceptable limit and rest 9 samples come under permissible limit in the study region as dictated by BIS, 2012 exhibited in Figure 2F.

The presence of calcium in ground water is attributed to minerals with certain rocks occurring in the area like $CaCO_3$, $CaSO_4$, Ca, Mg $(CO_3)_2$, etc. The source of magnesium may also be the same as that of calcium in ground water. Low amounts of calcium content in drinking water may lead to Rickets and over-excessive amounts result in kidney stones or sometimes stone in the bladder (Vohra *et al.*, 2023).

Magnesium: The acceptable and permissible limit of Magnesium are 30 mg/l and 100 mg/l respectively. In the study area Magnesium concentration ranges from 2.53 mg/l to 147.98 mg/l. only 9 samples come under acceptable limit, 10 samples come under permissible limit and 2 samples Specifically B13 and B17 are found above permissible limit in the study region prescribed by BIS (2012) as demonstrated in figure 2G.

Calcium: The acceptable and permissible limit of Calcium are 75 mg/l and 200 mg/l respectively. In the study area calcium concentration ranges from 34.66 mg/l to 213.09 mg/l. only 9 samples come under acceptable limit, 11 samples come under permissible limit and 1 sample B14 is found above permissible limit in the study region prescribed by BIS (2012) as mentioned in Figure 2H.

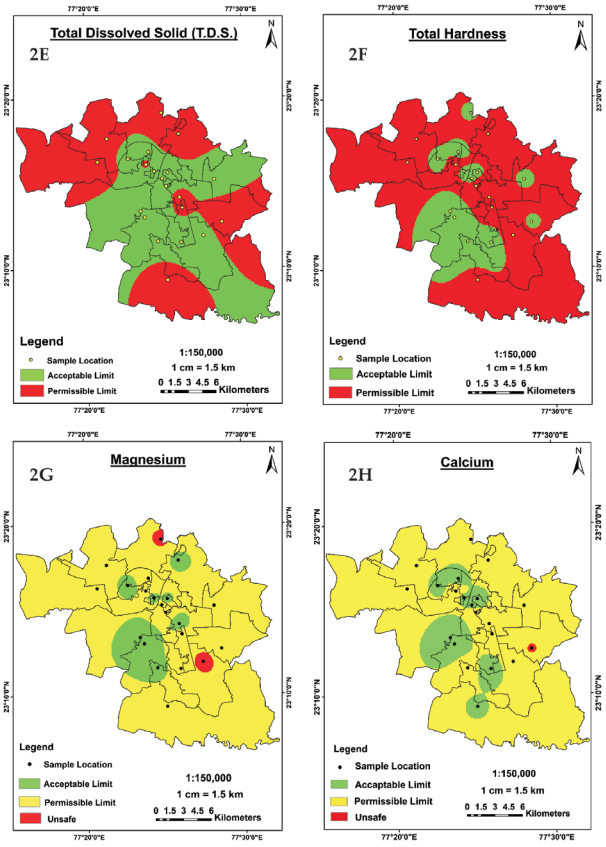

Fig. 2. Distribution of Physico-chemical parameters in Bhopal city (From 2E to 2H)

Chloride (Cl): Chlorides in another psychochemical parameter to evaluate the quality of groundwater. Higher content of chloride makes water flavour saline. its monitoring is important because in high concentration it can cause a possible health consequence (Mishra *et al.*, 2023). Excessive consumption of ground water with higher concentration of chloride can give rise to indigestion in the human body. It may further cause high blood pressure and other heart and kidney related complications (Vohra *et al.*, 2023).

The acceptable and permissible limit of chloride are 250 mg/l and 600 mg/l respectively. In the study area chloride concentration ranges from 7.81 mg/l to 281.40 mg/l. only 20 samples come under acceptable limit and rest 1 samples namely B21 come under permissible limit in the study region prescribed by BIS (2012) as presented in Figure 2J.

Fluoride (F): Groundwater fluorides have a great importance to human health. It is usually found in very low concentrations in both surface and groundwater concerning the intake levels a few amounts of it is enough to prevent dental carries, within Acceptable limit of 1.0 mg/l. However, the fluoride concentration above the permissible limit of 1.5 mg/l BIS (2012) in drinking water becomes a potential toxic hazard upon human exposure, which leads to mottled teeth and skeletal fluorosis CGWB (2022).

Beyond that, accumulation may lead to higher levels within the skeletal system and incapacitating adverse health effects (Dar *et al.*, 2010). However, Fluoride at low concentrations has a beneficial effect on teeth by preventing and reducing the risk of tooth decay (Kundu *et al.* ,2001). In the study area Floride concentration ranges from 0.250 mg/l to 0.750 mg/l. All 21 samples come under acceptable limit in the study region mentioned by BIS (2012) as shown in Fig. 2K.

Nitrate: The main source of nitrate concentration in drinking water is anthropogenic activity. Sewage and animal waste contain considerable amount of Nitrate and its discharge on land and subsequent leaching by rainfall causes enrichment of Nitrate in ground water CGWB (2022). The standard acceptable limit Nitrate concentration is 45 mg/l (BIS, 2012), above this can causes methemoglobinemia (blue baby syndrome), gastric cancer, thyroid disease and diabetes (Kumar *et al.*, 2014). Hence, increasing nitrate contamination seriously threatens public drinking water supply and human health. Nitrate concentration ranges from 1 mg/l to 3.87 mg/l in the study area. All sampling points the study area is falling under the acceptable limit prescribed by BIS (2012) indicated in Figure 2L.

Iron: The iron occurs naturally in the aquifer levels in groundwater. The main source iron in ground water is soil, clay layer, rock mineral adjacent to the

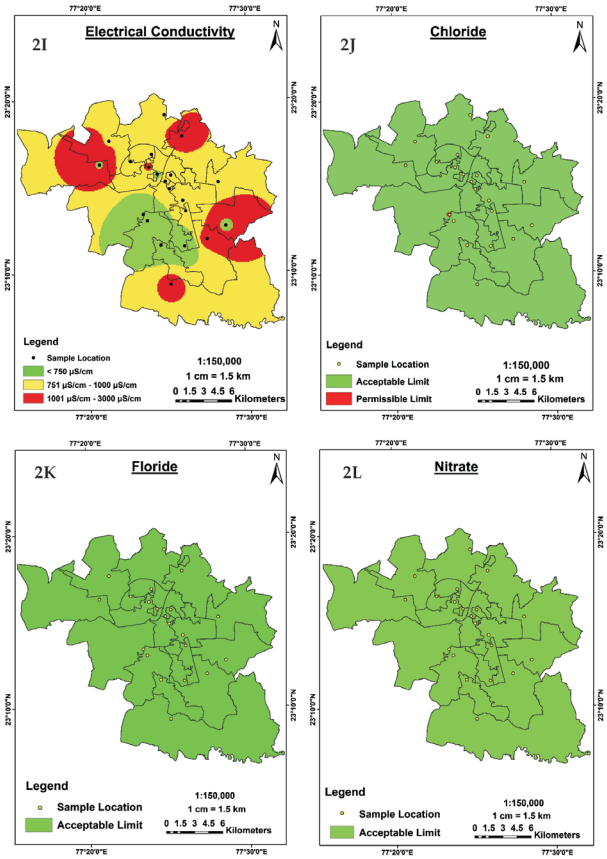

Fig. 2. Distribution of Physico-chemical parameters in Bhopal city (From 2I to 2L)

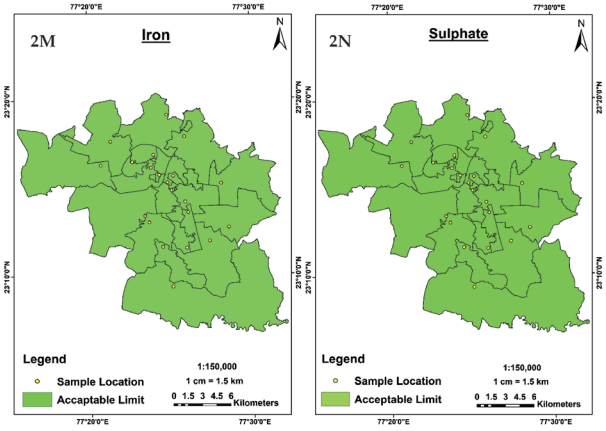

Fig. 2. Distribution of Physicochemical parameters in Bhopal city (From 2M to 2N)

aquifer. They are released through dissolution processes and available in varying oxidation states (Islam and Mostafa, 2024).

Iron can also be increased by dissolution of ferrous borehole pipe. Reservoirs of water can also get problems like "red water" due to excessive corrosion in iron pipes. The corrosion of iron is a very complex process which involves the oxidation of the metal, normally by dissolved oxygen (WHO ,2011). Trace metals like Iron are needed in very small quantity for body but excessive iron content in drinking ground water led to the hazardous and lethal effect on health (Vohra *et al.*, 2023). Iron values were found ranging between 0.0002 mg/l to 0.0380 mg/l can be seen in 2M. BIS standard acceptable limit for Iron for drinking water is <0.3mg/l as well as WHO (2011) has fixed it to be <0.3 mg/l.

Sulphate: Industrial activities and agriculture practices are the main cause of Sulphate contamination in ground water (Kumar and Verma ,2024). The acceptable and permissible limit of sulphate are 200 mg/l and 400 mg/l respectively. In the study area Calcium concentration ranges from 0.06 mg/l to 8.18 mg/l. All 21 samples come under acceptable limit in the study region prescribed by BIS (2012) as shown in Figure 2N.

Total coliform bacteria: The total coliform bacteria Should not be detectable in any 100 ml sample BIS (2012) but all 21 sample have some number of coliform bacteria from the range of 6 CFU/ml to 14 CFU/ml further test conducted to observe the presence of faecal coliform bacteria but all the sample show the absence of faecal coliform bacteria.

Water Quality: Out of 21 samples 9 samples show excellent water quality. 4 samples came under good category of water quality. 2 samples have poor quality while one sample have very poor status. 4 samples cross the bar of unfit water quality of the city. North and north western part of the city show the poor water quality specifically Sample B2 collected from Idgah hills shows unfit for drinking water quality. Some patches in the city like sample B18 collected from Trilanga Shahpura and sample B7 collected from Ravindranath Tagore ward show the unfit status. Sample B14 shows poor quality of

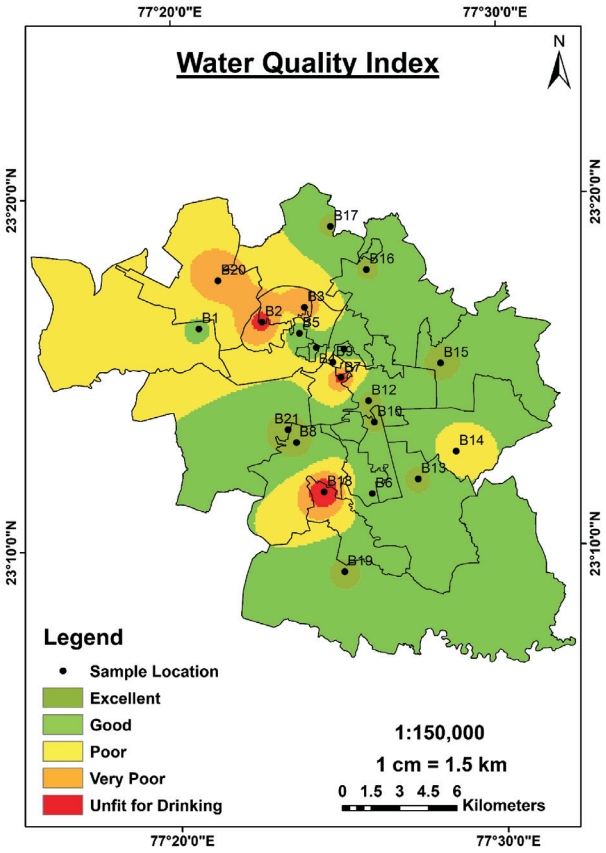

Fig. 3. Water Quality Index of Bhopal City

Table 4. The computed WQI values of samples and their status

Sample code	WQI	Status	Sample code	WQI	Status
B1	45.9311	Good	B11	20.9648	Excellent
B2	110.9049	Unfit	B12	13.5369	Excellent
B3	100.4815	Unfit	B13	18.0950	Excellent
B4	43.6744	Good	B14	68.0707	Poor
B5	31.2791	Good	B15	17.0071	Excellent
B6	29.8425	Good	B16	20.3782	Excellent
B7	112.7609	Unfit	B17	21.1773	Excellent
B8	11.8511	Excellent	B18	126.7949	Unfit
B9	62.5903	Poor	B19	20.0260	Excellent
B10	20.2204	Excellent	B20	92.0912	Very poor
-	-	-	B21	9.0565	Excellent

Source: - Calculation based on formula of WQI

water from Barkheda-Pathani. Maximum part of the city comes either in the excellent and the good water quality class of the water quality index as shown in the Figure 3.

CONCLUSION

From the analysis conducted, the quality of groundwater in the study area has given Insite that all values, except for those of a few parameters like Calcium and Magnesium values in some locations, are well within the ranges of both Acceptable and permissible limits for drinking water norms of BIS (2012). It is important to notice here that BIS recommends that the acceptable limit should be established. Values exceeding those mentioned under acceptable limit render the water unsuitable but may be tolerated in the absence of an alternative source, but only to the indicated limits as per permissible limit in the absence of alternate source. All the parameter except nitrate, fluoride, iron, sulphate exceeding the acceptable limit in several locations of the city. Considering the water quality index of the city north and north western part have poor water quality with some several locations like sample B18, B7 and B14 also show poor water quality.

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