ASSESSMENT OF DRINKING WATER QUALITY USING QGIS FOR BHOPAL CITY IN MADHYA PRADESH

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ABSTRACT

The water quality management is of great importance due to the increasing demand for water in urban areas. This study was conducted to find out the application of GIS tools to determine the quality of water supply in the city of Bhopal. In this study, water quality data at 76 sampling points from different wards were collected from the Nagar Nigam Laboratory, Arera Hills, Bhopal. Different physiochemical parameters are analysed, such as pH, total hardness, Ca hardness, Mg hardness, alkalinity, EC, TDS, chloride, sulphate, and iron. Interpolation techniques were used to analyse the collected data on water quality, and spatial distribution maps were created that show variations in water quality parameters in the city. The inverse distance weighted (IDW) technique of interpolation was used to determine values for the unknown points based on the values of the surrounding data points, and finally, the spatial distribution map was prepared using QGIS Desktop 3.22.16. The weighted arithmetic index (WAI) method was used to calculate the water quality index (WQI), and based on the WQI value, water is categorised into different categories. The spatial distribution map helps to identify the source of pollution, and proper operation and management for the required remedial measures for a specific area.

***Keywords**: GIS, water quality, supply water, interpolation, WQI*

INTRODUCTION

In recent decades, with rapid industrialisation and social development, nonpoint source pollution has become a significant problem for sustainable management. In developing countries, the availability of clean water is a significant challenge, and water scarcity is a visible problem. With population growth and increasing demand for water, many parts of the world are facing a shortage of water resources. In India, improper management of water resources and environmental degradation are leading to a freshwater crisis [1]. Water pollution is one of the most significant problems caused by anthropogenic activities, which poses a significant threat to human health. Many rivers and water bodies in developing countries are heavily polluted due to anthropogonic activities [2]. Reliable quantitative information on water quality parameters is necessary for appropriate water quality management. According to the World Health Organization (WHO 2017), about 80 % of all human diseases are related to water quality [3].

For predicting water quality parameters, geographical information system (GIS) technology can be a useful tool for detecting problems with drinking water resources, at a local or regional level. GIS-based mapping of supply water quality is a vital component of a supply water planning strategy that identifies potentially contaminated zones and indicates the suitability of water for drinking. This study aims to assess the quality of supply water in 85 wards of Bhopal using GIS techniques. The IDW technique of interpolation was used to estimate values for the unknown points based on the values of surrounding data points, and finally a spatial distribution map was prepared using QGIS Desktop 3.22.16.

The WAI method is a commonly used approach in the calculation of the WQI [1]. The WQI is an indicator of water quality that considers various physical, chemical, and biological parameters. The WAI method assigns a weight to each parameter based on its relative importance in determining water quality and calculates the average of the weighted values to obtain an overall water quality score. By assigning weights to different parameters based on their importance, the WAI method provides a comprehensive and customized measure of water quality that can form decisions about water use and conservation.

STUDY AREA

Bhopal, the capital city of the Indian state of Madhya Pradesh, was selected as the study area for this research. It is located in central India in Madhya Pradesh and is bounded by Guna district to the north, Vidisha district to the northeast, Raisin district to the east, Sehore district to the southwest, and Rajgarh district to the west. The study area covers northern latitudes 23°11'10'' N to 23°18'32'' N and eastern longitudes 77°19'52'' E to 77°32'32'' E, covering a total area of approximately 285 km^2, as shown in Figure 1. According to the 2011 census of India, the city of Bhopal had a population of 2371061. About 75 % of the district is covered with black cotton soil, while the rest is covered with yellowish-red mixed soil [4]. Bhopal is also known as the "City of Lakes" due to the abundance of natural and artificial lakes. Upper Lake, also known as "Bhojtal", is one of the oldest and largest artificial lakes in India. It was made in the 11th century by king Bhoj of the Paramara dynasty to provide water to the nearby city of Bhopal and for irrigation purposes. Two important rivers, Betwa and Narmada, flow through Bhopal. The Survey of India Topo Sheet shows that Bhopal lies in sheet No. 55 E. The district has an average annual rainfall of 1126.7 mm.

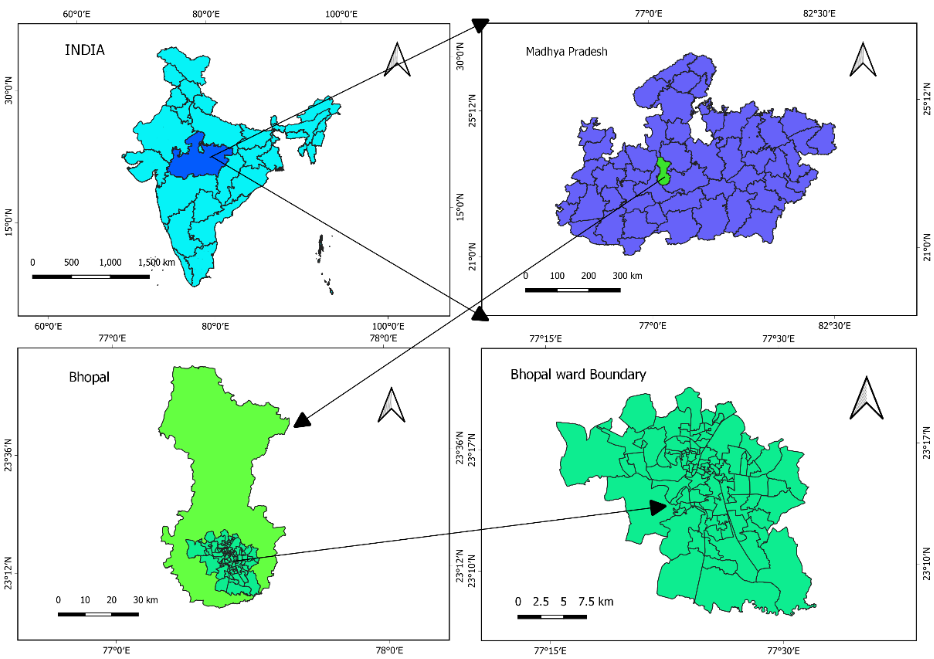

Figure 1. Location map of the study area

METHODOLOGY

The methodology includes collection and analysis of the data on physiochemical quality of water supply, preparation of spatial distribution maps followed by WQI to assess overall water supply quality in 85 wards of the Bhopal city and finally statistical analysis of the physiochemical parameters. The process is explained in the following sections.

Data collection

Water data from 85 wards (76 sample) were collected from Nagar Nigam laboratory, Arera Hills, Bhopal. Various physiochemical parameters considered for the analysis of water quality include pH, turbidity, TDS (total dissolved solids), EC (electrical conductivity), alkalinity, total hardness, chloride, Ca^{+2} hardness, Mg^{+2} hardness, sulphate, and iron. The shapefile of India, Madhya Pradesh and Bhopal is obtained from the official website of Survey of India. The shapefile of Bhopal city is obtained from the geoportal of Madhya Pradesh, and consists of administrative ward boundaries, ward number and the name of respective wards. This ward map was used to show the variations of different physiochemical parameters in the study area.

Preparation of spatial distribution map

Spatial distribution map was generated for all the above-mentioned parameters using GIS (QGIS Desktop 3.22.16). The map shows the spatial variation of a certain variable or attribute across different wards of the city. The map was created in accordance with established cartographic principles and guidelines, ensuring the accuracy and clarity of the information presented. The spatial distribution maps provide a comprehensive visual representation of the overall water quality conditions, enabling decision-makers to identify areas of concern and prioritize targeted management actions to improve water quality. The spatial distribution map is prepared using interpolation (interpolation is a technique used to estimate values for a location based on the values of surrounding locations [5]). In this study, inverse distance weighted (IDW) interpolation was used to prepare a spatial distribution map.

IDW interpolation

Interpolation is a widely used technique in the GIS that allows estimation of values for unsampled locations based on the values measured at nearby sampled locations. In QGIS, there are several interpolation methods available that can be used to create continuous surface maps from point data. In this study, the IDW method is used to prepare a spatial distribution map of physiochemical parameters of water in the study area using QGIS Desktop 3.22.16. The IDW interpolation technique considers the distance-weighted average values of surrounding sampling points to estimate the values at the unsampled locations. This approach enabled the creation of continuous and spatially explicit maps that accurately depict the water quality variations in the study area.

Water quality index (WQI)

Considering the large amount of data related to water quality, a simplified approach was adopted to assess the overall quality of water, and a water quality index is calculated for this purpose. WQI is a single parameter used to classify water into different categories, i.e. excellent, good, poor, very poor, and unsuitable [6]. The WQI value was calculated using the following parameters: pH, turbidity, TDS, EC, alkalinity, total hardness, chloride, Ca^{+2} hardness, Mg^{+2} hardness, sulphate, and iron. WQI is a numerical value used to assess the overall quality of water based on multiple physicochemical and biological parameters. It provides a convenient way to summarize and communicate water quality information in a single value, making it easier to understand and compare water quality in different locations. In this study, the weighted arithmetic index method given by Brown et. al. (1997) was used.

First, the unit weighting factor for the selected water quality parameters is calculated using the equation below:

$$W_i = \frac{K}{S_i} \quad (1)$$

where is:

$$K = \frac{1}{\left(\frac{1}{S_1}\right)+\left(\frac{1}{S_2}\right)+\left(\frac{1}{S_3}\right)+\ldots+\left(\frac{1}{S_n}\right)} = \frac{1}{\sum\left(\frac{1}{S_i}\right)} \quad (2)$$

S_i - standard desirable value of n-th parameter.

The sum of all the unit weighting factors for the selected parameters is 1, i.e. $\sum W_i = 1$. The next step after determining the unit weighting factor is to calculate the sub-index value or quality rating for each water quality parameter using the following equation:

$$Q_i = \frac{\{(V_{actual} - V_{ideal})\}}{\{(S_{standard} - V_{ideal})\}} \quad (3)$$

where is: V_{actual} - observed/test value of the i-th parameter, $S_{standard}$ - standard allowed value of the i-th parameter (according to IS 10500 - 2012), V_{ideal} - ideal value of the i-th parameter in pure water.

The ideal value for all parameters is assumed to be zero, except for pH and dissolved oxygen. The ideal value of pH is 7, and 14.6 mg/l for oxygen. Finally, the water quality index is calculated using the following equation:

$$WQI = \frac{\sum W_i \cdot Q_i}{\sum W_i} \quad (4)$$

RESULTS AND DISCUSSION

The analysed physiochemical parameters include physical parameters (pH, TDS, electrical conductivity, and turbidity, shown in Figures 2 to 5) and chemical parameters (alkalinity, total hardness, Ca^{+2} hardness, Mg^{+2} hardness, chloride, sulphate, and iron, shown in Figures 6 to 12). The statistical analysis of physiochemical parameters and values according to BIS standard (IS 10500-2012) are presented in Table 1, which also shows the range of different physicochemical parameters and their deviation from mean values.

Physical parameters - The spatial distribution maps of four physical parameters i.e., pH, turbidity, EC, and TDS were generated, and the variations of these parameters are shown in Figures 2 to 5.

The pH of water can be defined as the concentration of the hydrogen ions (H^+) or hydronium ions (H_3O^+) in a solution. The pH of the water sample varies from 6.86 to 8.1, and the prescribed range according to IS 10500-2012 is 6.5 to 8.5. The variations of pH are shown in Figure 2.

Table 1. Statistics of the observed data and WQI

Parameter	IS 10500-2012	min.	max.	mean	SD
pH	6.5 - 8.5	6.86	8.1	7.44	0.27
EC		54.6	221.2	158.59	32.95
TDS (mg/l)	500 - 2000	39	158	113.28	23.53
Turbidity (NTU)	1.0 - 5.0	0.3	6.4	1.825	1.42
Alkalinity (mg/l)	200 - 600	36	136	96.05	24.51
Hardness (mg/l)	200 - 600	48	134	103.82	17.77
Ca hardness (mg/l)	75 - 200	12	32.8	25.26	4.25
Mg hardness (mg/l)	30 - 100	4.32	13	9.05	2.18
Chloride (mg/l)	250 - 1000	11	178	19.57	18.88
Sulphate (mg/l)	200 - 400	10	21	14.35	2.04
Iron (mg/l)	0.3	0.01	0.5	0.046	0.09
WQI		11.52	71.71	26.48	13.96

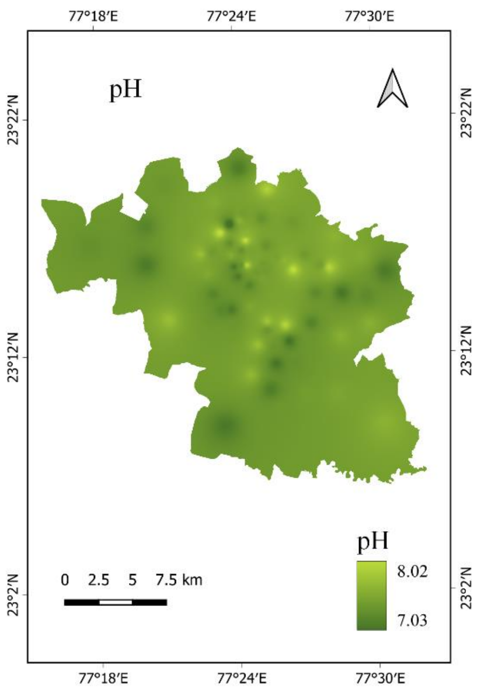

Figure 2. Variations of pH

The electrical conductivity is defined as the ability to conduct the electric current through a solution and is an indicator of dissolved minerals in the water sample. The electrical conductivity varies from 54.6 µS/cm to 221.2 µS/cm, as shown in Figure 3.

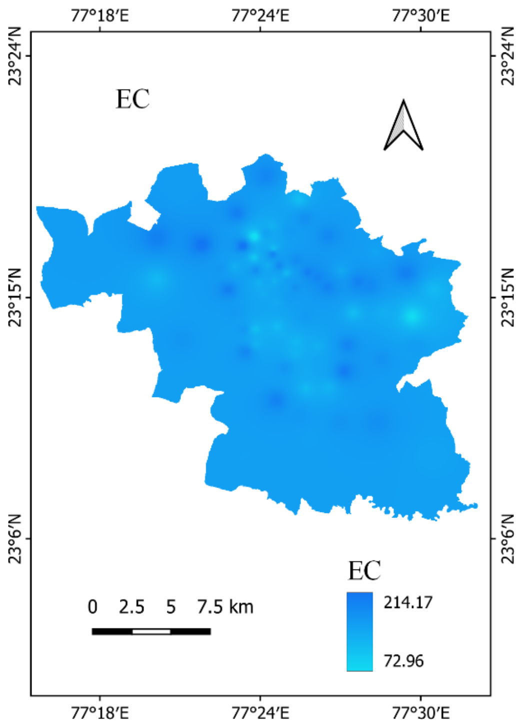

Figure 3. Variations of EC

Total dissolved solid represents the concentration of all organic and inorganic substances present in water. It varies from 39 mg/l to 158 mg/l, and the prescribed range according to IS 10500-2012 is 500 mg/l to 2000 mg/l. The variations of TDS are shown in Figure 4.

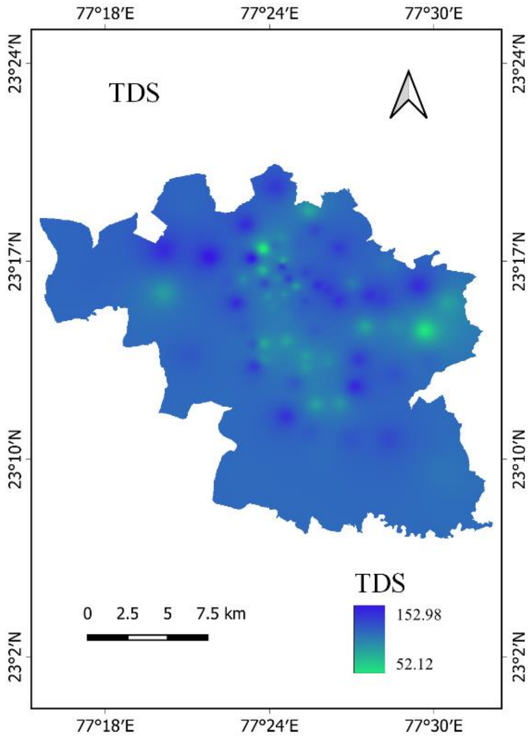

Figure 4. Variations of TDS

Turbidity is defined as the extent to which light is either scattered or observed due to the presence of organic and inorganic suspended matters. Turbidity varies from 0.3 NTU to 6.4 NTU which exceeds the prescribed range according to IS 10500-2012 (1 NTU to 5 NTU). The variations of turbidity are shown in Figure 5. Turbidity exceeds the permissible limit in ward number 5, 17, 27, 28, and 63, and this may be result of the rusting of distribution pipes or algae growth in the distribution system.

Chemical parameters - The spatial distribution maps of seven chemical parameters i.e., total hardness, Ca^{+2} hardness, Mg^{+2} hardness, alkalinity, sulphate, chloride, and iron were prepared, and the variations of these parameters are shown in Figures 6 to 12.

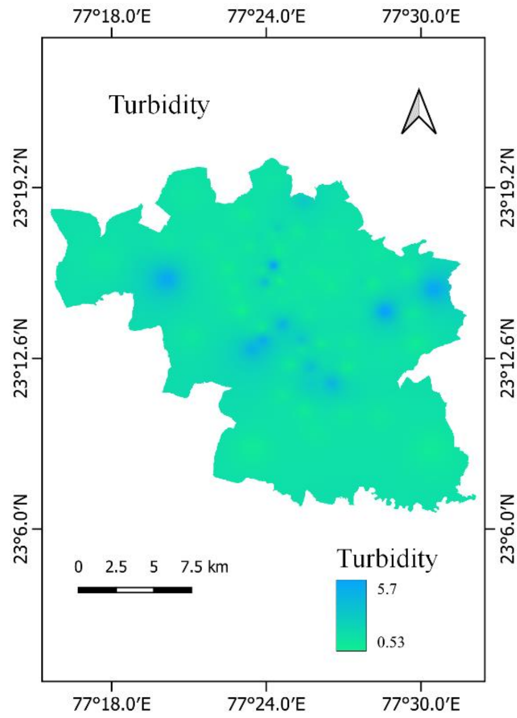

Figure 5. Variations of turbidity

The ability of water to neutralize H^+ ion or acidity is called alkalinity. The main ions that cause alkalinity in water are CO_3^{-2}, HCO_3^-, and OH^-. Alkalinity varies from 36 mg/l to 136 mg/l, and the prescribed range according to IS 10500-2012 is 200 mg/l to 600 mg/l. The variations of alkalinity are shown in Figure 6.

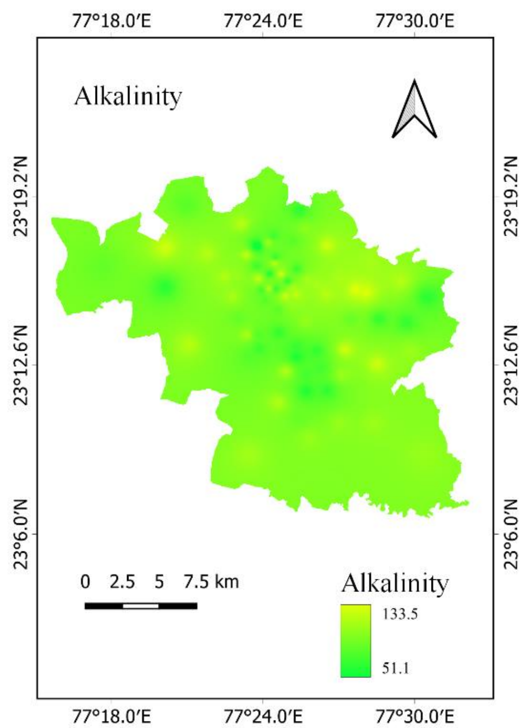

Figure 6. Variation of alkalinity

The hardness of the water is mainly caused by the presence of multivalent cations in the water. The total hardness varies from 48 mg/l to 134 mg/l, and the prescribed range according to IS 10500-2012 is 200 mg/l to 600 mg/l. The variations of hardness are shown in Figure 7.

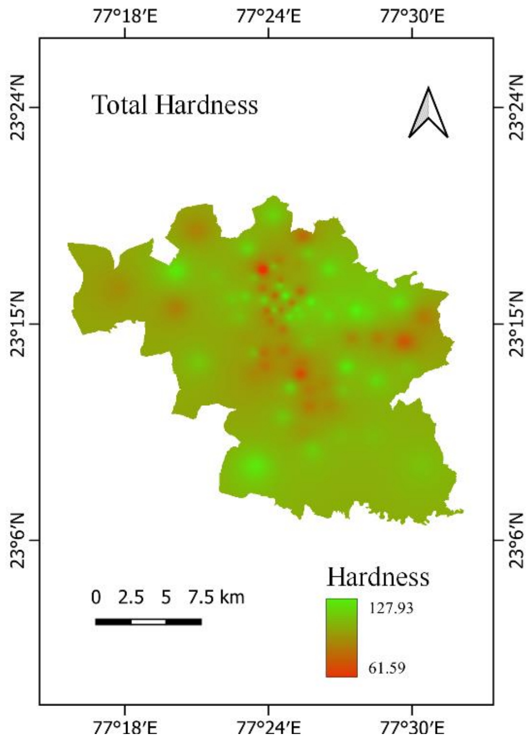

Figure 7. Variations of total hardness

Calcium hardness in water is primarily caused by the presence of Ca^{+2} ion. In the study area, the concentration of calcium ions varies from 12 mg/l to 32.8 mg/l, and the prescribed range according to IS 10500-2012 is 75 mg/l to 200 mg/l. The variations of Ca hardness are shown in Figure 8.

Magnesium hardness is primarily caused by the presence of Mg^{+2} cation. In the study area, magnesium hardness varies from 4.32 mg/l to 13 mg/l, and the prescribed range according to IS 10500-2012 is 30 mg/l to 100 mg/l. The variations of Mg hardness are shown in Figure 9.

In the study area, the chloride varies from 11 mg/l to 178 mg/l, sulphate varies from 10 mg/l to 21 mg/l, and iron concentration varies from 0.01 mg/l to 0.5 mg/l. The prescribed range according to IS 10500-2012 for chloride is 250 mg/l to 1000 mg/l, for sulphate is 200 mg/l to 400 mg/l and acceptable limit for iron is 0.3 mg/l. Variations of chloride, sulphate and iron are shown in Figures 10, 11 and 12. The variations of WQI in different wards are shown in Figure 13.

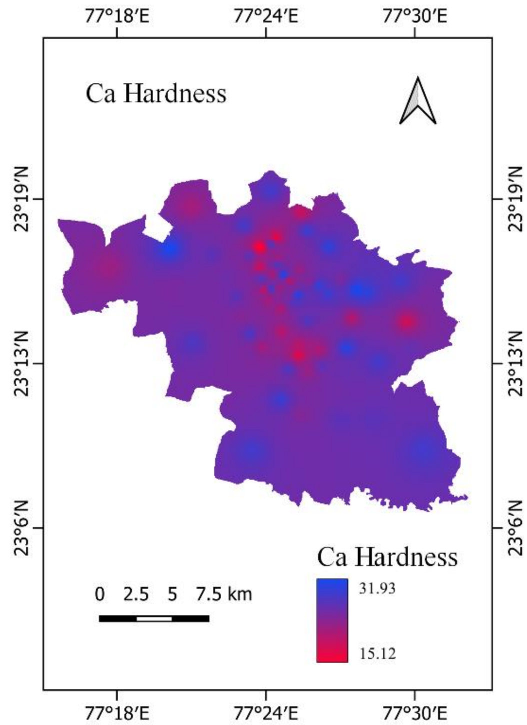

Figure 8. Variations of Ca hardness

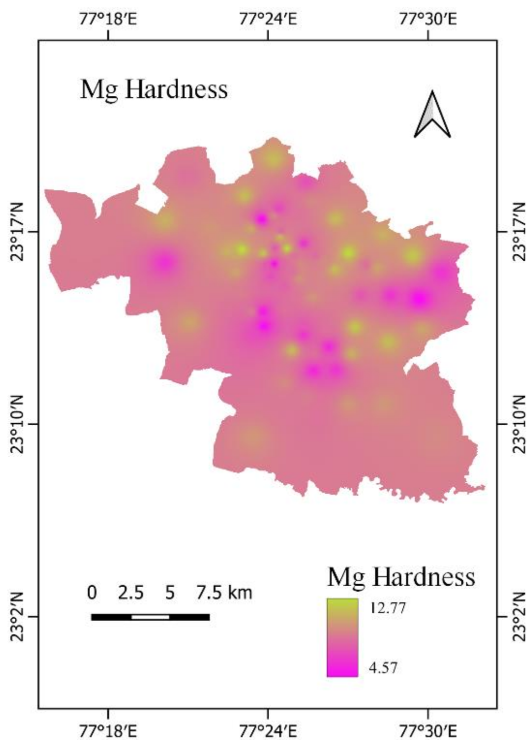

Figure 9. Variations of Mg hardness

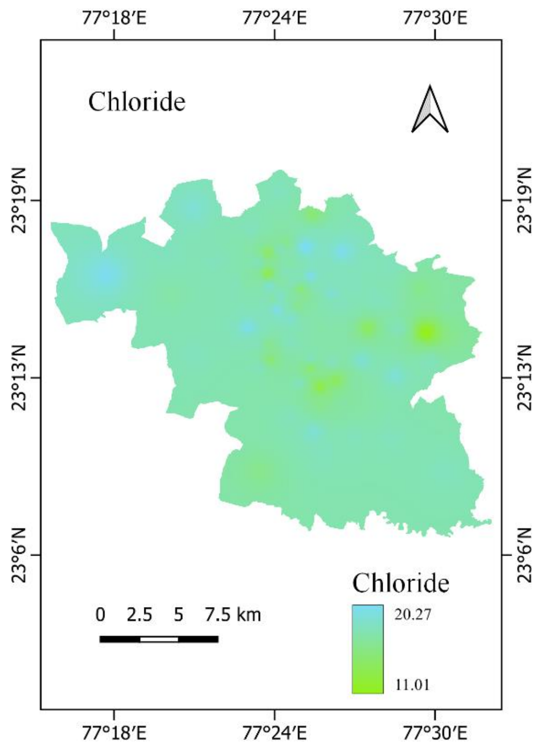

Figure 10. Variations of chloride

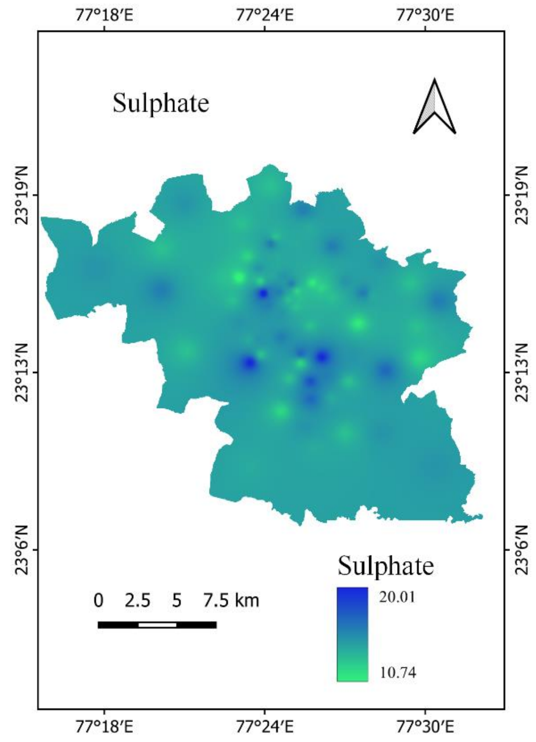

Figure 11. Variations of sulphate

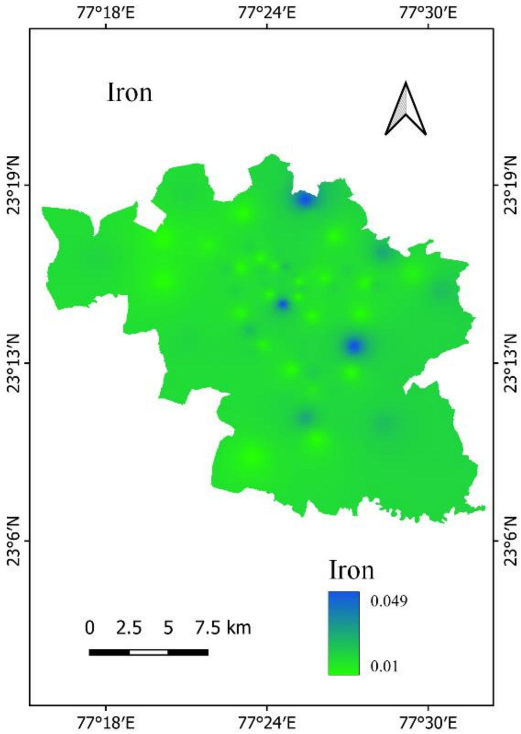

Figure 12. Variations of iron

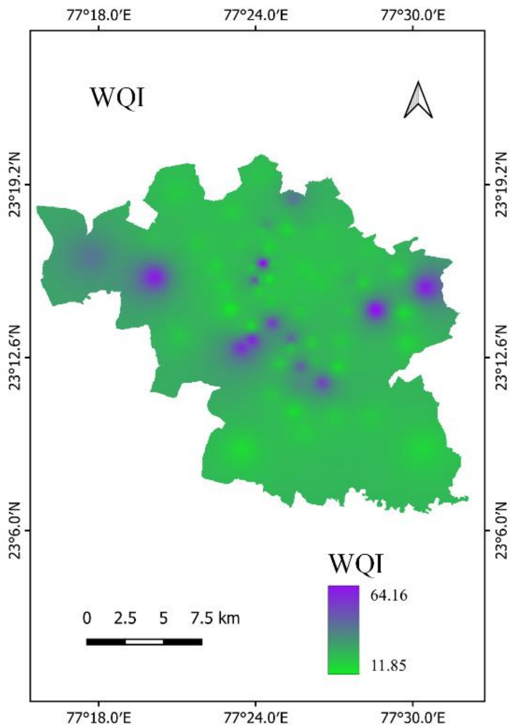

Figure 13. Variations of WQI

CONCLUSION

A study of the Bhopal city supply water shows that the water quality index varies from 11 to 71, which means that the water is very good and good quality. Almost all the monitored physiochemical parameters are within the permissible limits, except turbidity in certain wards. In certain wards, the turbidity is slightly higher than 5 NTU due to rusting and algae growth in the distribution pipes. This requires changing the pipes in that particular area, and it is necessary to prevent corrosion of other pipes. The prepared maps can help in identifying pollution sources, monitoring and surveillance, resource allocation, ecosystem and health management, etc.

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