Assessment of Supply Water Quality Using GIS Tool for Selected Locations in Delhi—A Case Study

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Assessment of Supply Water Quality Using GIS Tool for Selected Locations in Delhi—A Case Study

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ABSTRACT: The importance of water quality is well understood, and it becomes even more critical when is use for drinking purposes. A case study was carried out to know the applicability of GIS tool for determining the quality of supply water. Water samples from 21 houses at different locations of Delhi were collected. Sample analysis was done for physicochemical parameters viz., pH, EC, TDS, Total Hardness, Total Alkalinity, Chloride, Fluoride, and Nitrate. The water quality data from these selected locations was analyzed using Geographical Information System (GIS) Technique. GIS software did interpolation through the inverse distance weighted (IDW) method to know the water quality (WQ) in different part of the city for various parameters mentioned above and prepare thematic maps from the analysis of water quality data as a database. These thematic maps show the distribution of different water quality parameters. Using Weighted Arithmetic Index (WAI) method, Water Quality Index is calculated. After that, the Drinking Water Quality Index (DWQI) map was generated using thematic layer, reclassification, and weight value assigned in weighted overlay tools in GIS software. Five categories viz., excellent, good, satisfactory, poor, and very poor is assign to describe DWQI. Out of all the selected locations, DWQI was good only at two locations, whereas, at the remaining sites, the DWQI was found satisfactory. However, the overall water quality was found suitable for human consumption. The analysis outcome was represented as maps that will be advantageous to know the water quality status for the area under study. The spatial database established can be a reliable technique for monitoring and managing water quality in the water supply system.

KEYWORDS: Water Quality, spatial interpolation, IDW, DWQI and GIS

Introduction

Developing countries usually face water accessibility as one of the significant challenges. The impacts of water scarcity are well visible in these countries. To make availability of better-quality sources of drinking water for the population, is one of the development goals. Water is the most valuable and vital resource for the sustainability of life and various developmental activities (Sunitha et al., 2012). Hour demands to use water resources systematically, judiciously, and consistently on a real-time basis to meet the ever-rising requirements. With the increase in the population, provision increased, so water has become scarce in many parts of the world. Water pollution has further aggravated the situation. In India, improper management of water resources and environmental degradation are leading to a fresh water crisis. In many parts of India, fresh water crisis is prevailing. Although, its scale and intensity vary with the time of year. Therefore, a check is necessary on the supply of water to maintain its quality.

Geographical Information System (GIS) helps to determine the water quality of an area. It can be a powerful tool to develop solutions related to water resources problems on a local (Hossen et al., 2018) or regional scale (Rahmati et al., 2015; Youssef et al., 2011). The primary purpose of the present study is to estimate the water quality in the study area and thematically represent the water quality status. Geo-informatics technology has played a critical role inability to understand the present scenario at a glance. The use of water is extensive in the domestic, industrial, and agriculture sector. Analysis of water quality in a particular area is of prime importance that requires monitoring and assessment to formulate preventive measures against health hazards. Variation of water quality in a location is a function of physicochemical parameters (Manual on Water Supply and Treatment, 1999). Water Quality Index (WQI) as a single number expressed water quality at a particular location. WQI is generated based on numerous parameters for water quality that communicate information on the overall quality status of water from different sources (Kannel et al., 2007).

Delhi being one the most populated metro city, has a dense network of water supply pipeline. Further, the most of the areas in Delhi are densely populated. To determine the water quality is such areas physically in almost an impossible task. The present study was planned to know the applicability of GIS techniques to determine water quality in such dense supply system.

Methodology

Area of study

A small area in Delhi, the capital of India, is selected for the study. A buffer of 15 km radius is created from NEERI Delhi Centre (Lat. 28°29′54.26″ to 28°46′8.73″ N and Long. 76°58′54.22″–77°17′18.4″E), which cover 706.85 km² area and 11 districts in the Delhi region. Out of 11 district 7 were partially covered whereas 4 districts are almost completely covered. (Figure 1). All the locations that lies within the buffer zone were used for the generation of spatial distribution maps, whereas the location outside the buffer area were not included for study.

Figure 1. Study area map.

Approach of study

The flow chart in Figure 2 represents the methodology adopted during the study. Followed by physicochemical analysis of collected samples, the water quality prediction in areas was determined using interpolation by a geostatistical tool. After that, spatial distribution maps of all parameters were generated using GIS software (ArcGIS Desktop 10.8, Vers: 10.7.0.10450). The reclassification process was done as per the Bureau of Indian Standard (BIS, I.S. 10500:2012, 2012) drinking water standards to generate a WQI map. Accordingly, for each parameter, weights were calculated (equation 2) and assigned. After that drinking water quality index was developed for the study area, using reclassified parameters and their assigned weight as inputs in the weighted overlay tool in GIS software. The data were converted from raster to vector format using the conversion tool (raster to vector). The categories were assigned based on a reclassification of WQI value to generate the final Water Quality Index (WQI) map.

GIS–modeling (IDW technique)

GIS techniques simplify integrating and analyzing many variable data of spatial and non-spatial types within the exact
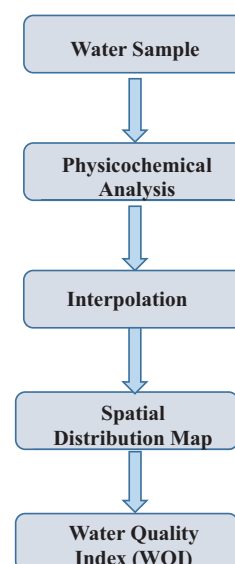
Figure 2. Methodology flow chart.

location. In GIS, interpolation of the water quality parameter at an unknown location from known values is allowed, which gives an idea about the water quality of the study area. GIS has emerged as a powerful tool for creating spatial distribution

maps. This technique helps to conclude several areas, including environmental and engineering fields, by storing, displaying, and analyzing spatial data. Spatial distribution maps illustrated the variation in concentrations of the different chemical parameters through spatial distribution maps. In GIS software, the inverse distance weighted (IDW) raster interpolation technique of the spatial analyst module is used to prepare spatial distribution maps (Nelly & Mutua, 2016).

IDW interpolation explicitly assumes that things farther apart are more different than those close to one another. The predicted value is more influenced by the measured values closest to the prediction point than those farther away. IDW uses the measured values surrounding the prediction location to predict a value for any unmeasured location (Rao et al., 2016).

It is assumed in IDW that the local influence of each measured point diminishes with distance. In IDW, assign more weight to the point nearer to the prediction location. The reduction in weightage is a function of distance—assigned weights to the data points.

The general formula for the IDW interpolation method is:–

$$Z(So) = \sum_{i=1}^{N} \lambda i. Z(Si)$$

Where,

$Z(So)$ = predicted value for So,

N = Total number of measured sample points around the prediction location,

λi = assigned weights to each measured point that we are using here, these weights will diminish with distance;

$Z(Si)$ = observed value at the location Si.

In comparing several interpolation techniques, more consistent results are obtained in the study through IDW with a squared distance term.

Determination of WQI

The water quality index (WQI) converts complex water quality data into more understandable and usable information for the public. It proves to be a valuable and effective method to indicate the quality of drinking water. In the study, Weighted Arithmetic Index Method is used to calculate WQI (Cude, 2001). The weighting factor is multiplied by water quality components followed by an aggregate of simple arithmetic mean. The quality rating scale (Qi) for each parameter is estimated using equation 1 to assess water quality in the study area (Singha et al., 2015).

$$Qi = \left\{ \left[\frac{V\,actual - V\,ideal}{V\,standard - V\,ideal} \right] \times 100 \right\} \tag{1}$$

Where,

Qi = Quality rating of ith parameter for a total of n water quality parameters

V actual = Laboratory test value

Table 1. Standard for Water Quality Parameters.

PARAMETER	STANDARD (IS 10500:2012)
pH	7.5
EC, µS/m	300
TDS, mg/L	500
Total hardness, mg/L	200
Calcium, mg/L	75
Alkalinity, mg/L	200
Chloride, mg/L	250
Sulfate, mg/L	200
Fluoride, mg/L	1
Nitrate, mg/L	45

V ideal = Value of water quality parameter as obtained from standard table

V ideal for pH = 7 and 0 for other selected parameters.

V standard = BIS values for water quality parameter (2012) and shown in Table 1.

After that, the Relative weight (Wn) was estimated by a value inversely proportional to the recommended standard (Sn) for the respective parameter using equation 2. Table 2 shows the relative weight values assigned to all parameters;

$$Wn = K / Sn \tag{2}$$

Where, Wn = Relative weight of nth parameter

Sn = Standard permissible value of the nth parameter

K = Proportionality Constant

The overall WQI is determined by aggregating the quality rating with the relative weight linearly, using equation 3

$$WQI = \frac{\sum QiWn}{\sum Wi} \tag{3}$$

wi = unit weight of ith parameter

The study mainly focused on the WQI for drinking water, Based on WQI values, the water quality is classified as excellent, good, satisfactory, poor, and very poor, as shown in Table 3.

Results and Discussion

Spatial distribution of water quality parameters

Thematic layers. The importance of water quality maps lies in assessing the usability, mainly for drinking water. The thematic maps generated using GIS, present various chemical parameters spatial distribution (Physical and Chemical Figures 3a–d, and 4a–g). These study areas lie within a 15 km buffer area from NEERI, Delhi Centre. The variations in physicochemical parameters (water quality) are as below.

Table 2. Relative Weight and Weight Percentage for Water Quality Parameter.

PARAMETER	STANDARD IS 10500:2012 (SN)	1/SN	K	WN (WEIGHT)	WEIGHT %
pH	7.5	0.133	0.838	0.1117	11.17
EC	300	0.003	0.838	0.0028	0.28
TDS	500	0.002	0.838	0.0017	0.17
Total Hardness	200	0.005	0.838	0.0042	0.42
Calcium	75	0.013	0.838	0.0112	1.12
Alkalinity	200	0.005	0.838	0.0042	0.42
Chloride	250	0.004	0.838	0.0033	0.34
Sulfate	200	0.005	0.838	0.0042	0.42
Fluoride	1	1	0.838	0.8381	83.81
Nitrate	45	0.022	0.838	0.0186	1.86

Table 3. Classification of WQI.

WATER QUALITY INDEX	DESCRIPTION
<50	Excellent
50–100	Good
100–200	Satisfactory
200–300	Poor
>300	Very poor

Physical parameter. The generated thematic map determined four parameters viz., pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), and Turbidity. The pH value of water indicates the logarithm of reciprocal hydrogen ion concentration present in the water. pH is one of the most vital water quality parameters. The optimum pH required falls in the range of 6.5 to 8.5. The values of pH in the water samples collected vary from 6.8 to 8.6. The water quality in the study area is within the desirable limit of pH except for one that is slightly below the desired value (Figure 3a).

The electrical conductivity of water is a measure of water's ability to conduct electricity. Pure water is a poor conductor of electricity, but it shows significant conductivity called the specific conductivity or the specific conductance of water; therefore, it approximately measures the total dissolved solids. In the study area, Electrical Conductivity (EC) varies from 182 to 10,720 μS/cm. The EC comes out to be high in the southwest part of the study area. The areas at Dwarka have higher Electrical Conductivity exceeding 2,000 μS/cm (Figure 3b).

Similarly, Total Dissolved Solids were calculated through EC by multiplying it by a conversion factor, called the conductivity factor. This factor depends on the chemical composition of the TDS as per IS 10500:2012, the desirable limit for TDS is 500 mg/L. The cause of excess TDS in water was mainly because of sewage, urban runoff, and industrial wastes, which may cause gastrointestinal irritation. It ranges from 177 to 2,068 mg/L. TDS was high in the south west parts of the study area (Figure 3c).

As shown in the Figure 3d, spatial distribution of turbidity in most of the study area are within the range. The turbidity values ranged from 0.1 to 4.1 NTU, in the selected locations. Since the acceptable limit of turbidity is 1 NTU and permissible limit is 5 NTU, in few locations the value is very close to permissible limit. Therefore it is essential to take care of water disinfection before supply to the public.

Chemical parameter. We have selected seven chemical parameters to determine water quality in the study zone. The parameters were Total Hardness (TH), Calcium, Alkalinity, Chloride, Sulfate, Fluoride, and Nitrate. The BIS acceptable limit for the total hardness and calcium in drinking water is 200 and 75 mg/l. The hardness in water is mainly because of calcium and magnesium salts of carbonates and bicarbonates and rarely due to sulfates, chlorides, and nitrates of calcium and magnesium. The spatial distribution of the total hardness in the study area varies from 62 to 668 mg/L (Figure 4a). Calcium is an essential element for a human being (~ 2 g daily) and plant growth. In the study area, the calcium hardness concentration ranges from 58 to 340 mg/L, this is more than the recommended standard limit of BIS. Higher values of hardness and calcium in the center of the study area is due to the natural salt accumulation (Figure 4b).

Similarly, the alkalinity of water is due to the presence of carbonate and hydroxide ions. Figure 4c shows the distribution of Total Alkalinity in water in the study area, and its value varies from 68 to 4,520 mg/L. Most of the locations indicate higher alkalinity.
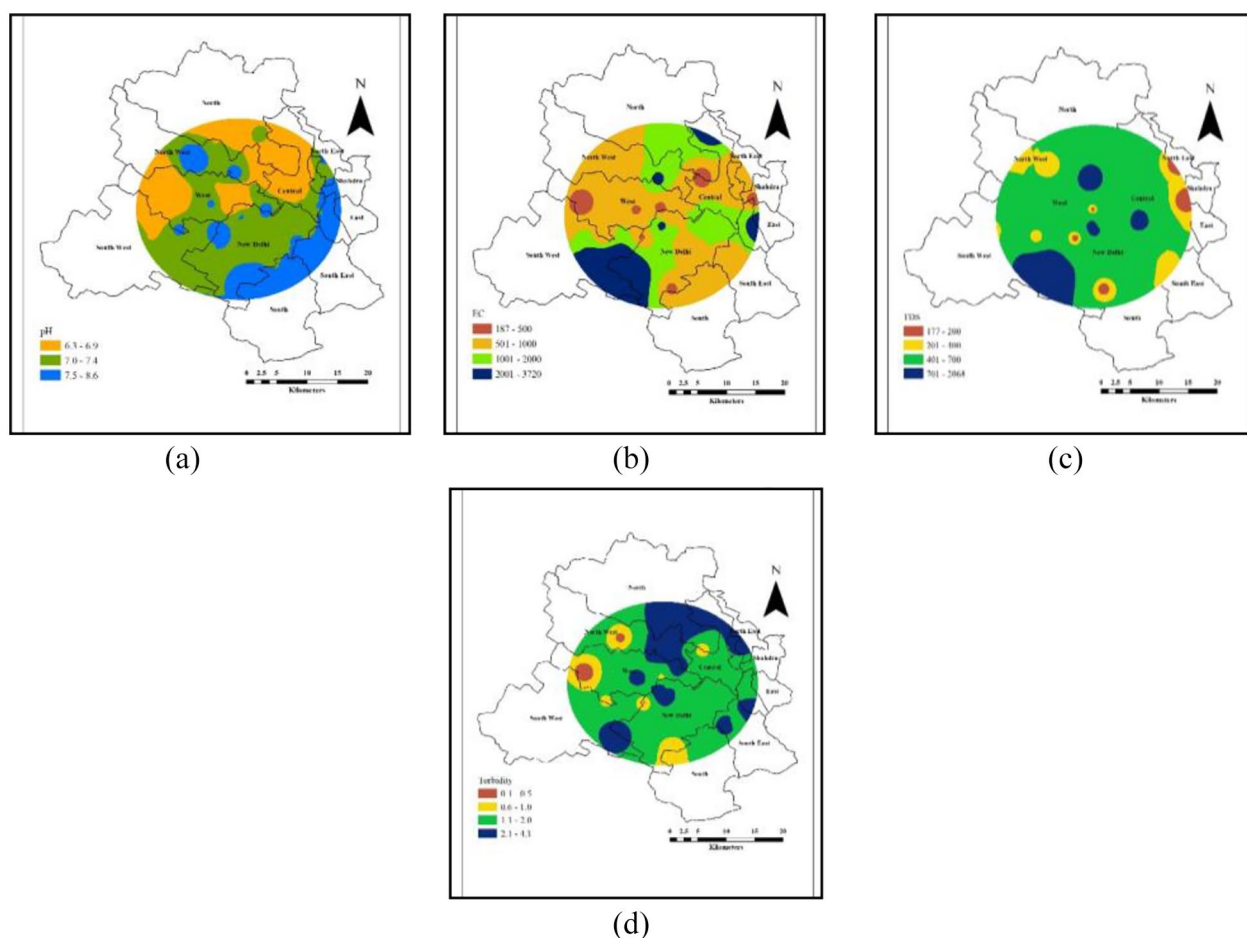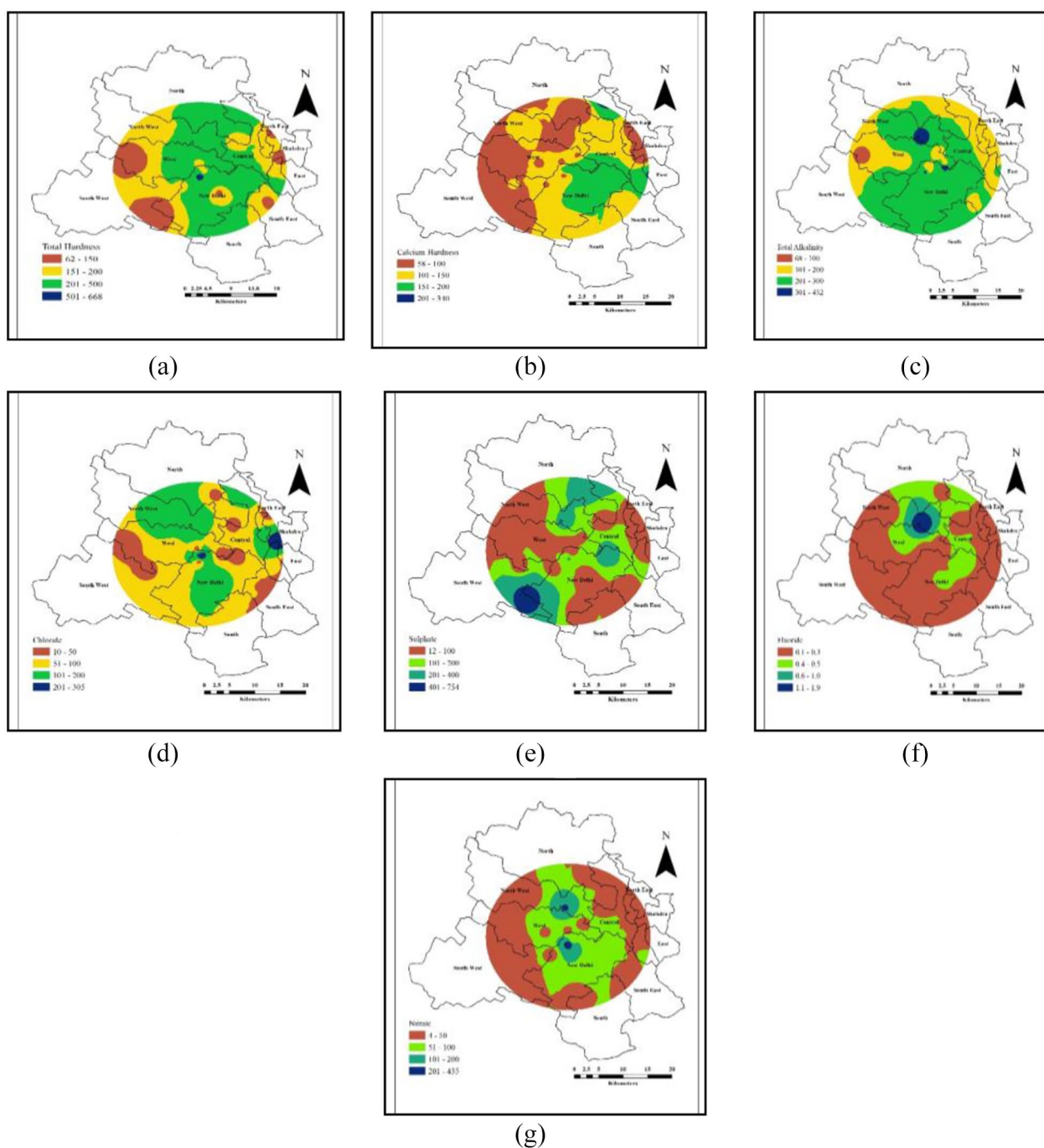
Figure 3. Spatial maps for physical parameters.
(a) pH
(b) Electrical Conductivity
(c) Total Dissolved Solids
(d) Turbidity

Sodium chloride (common salt) is the primary source of chlorides in the water. The variation of chloride contain in natural waters depends upon the chemical composition of the earth's crust (Geochemical). However, its concentrations increase due to sewage, industrial waste, leaching of saline residues in the soil and water. The presence of a high quantity of chloride in water may indicate water pollution due to sewage and other human or industrial waste. Any organic pollution in supply system is reflected by sudden increase in chloride concentration supply water, during regular analysis., The chloride concentration in the study area ranges between 10 and 305 mg/L. The DEC location shows a high chloride concentration of 305 mg/L (Figure 4d). Naturally increase in the concentration of sulfates in water is due to soil and rocks formations. As water percolates through the soil and rocks, sulfates get dissolved in water. In the study area, the sulfate concentration in the drinking water varies between 12 and 754 mg/L. In many places, the sulfate concentration was higher, above the permissible limit of 400 mg/L (Figure 4e).

Fluoride is one of the most common natural pollutants in water. Its high concentration may lead to diseases like dental fluorosis and skeletal fluorosis. The value of fluoride ranges from 0.1 to 1.9 mg/L. The fluoride concentration is below 1.0 mg/L in most of the areas that is well within the BIS limit. The CP location has the highest concentration of fluoride, that is, 1.9 mg/L. Figure 4f shows the spatial distribution of fluoride in the study area.

The presence of organic matter is the primary source of nitrogen in the water. According to World Health Organization (WHO, 2008), legumes, plant debris, animal excreta, and atmospheric gases are the primary source of nitrate in water. As the nitrate concentration increases beyond 100 mg/L, water taste gets bitter, leading to physiological distress in humans. The presence of too much nitrate in water may adversely affect the health of infants, causing a disease technically called "methemoglobinemia" (commonly called "blue baby syndrome"). At present, due to inadequate manure management practices, over-application of fertilizer, septic tank, sewage effluent, open dumpsites of solid wastes, etc., nitrogen content

Figure 4. Spatial maps for chemical parameters.
(a) Total Hardness
(b) Calcium Hardness
(c) Alkalinity
(d) Chloride
(e) Sulfate
(f) Fluoride
(g) Nitrate

in water is highly increased. In the entire study area, the nitrate concentration ranges from 4 to 455 mg/L. The degradation of organic material is responsible for a high concentration of nitrate. Nitrate concentration was higher in the center part of the study area (Figure 4g), where it was above the permissible limit..

Water quality index values. Table 4 and Figure 5 show the WQI for drinking water in the study area. In the study area, WQI ranges from 94.10 to 133.94. In some regions such as DB and SD location water quality was good. However, most of the locations have satisfactory water quality. In most areas, satisfactory water quality was mainly due to mismanagement

Table 4. Water Quality Status.

S. NO.	SAMPLE CODE	WQI	DESCRIPTION
1	PM	119	Satisfactory
2	SA	114	Satisfactory
3	MC	112	Satisfactory
4	AN	125	Satisfactory
5	SK	115	Satisfactory
6	SKG	109	Satisfactory
7	SAK	109	Satisfactory
8	GRS	104	Satisfactory
9	CP	109	Satisfactory
10	DEC	111	Satisfactory
11	DB	94	Good
12	MD	109	Satisfactory
13	SS	106	Satisfactory
14	SD	96	Good
15	MRB	116	Satisfactory
16	LEK	111	Satisfactory
17	RM	132	Satisfactory
18	TB	133	Satisfactory
19	RS	107	Satisfactory
20	AB	131	Satisfactory
21	SS	111	Satisfactory

of water supply and treatment, old distribution system, corrosion of pipeline and poor sewage infrastructure may be another cause of water contamination. Water contamination is the leading cause of affecting human health. The water in these areas has high electrical conductivity, TDS, and alkalinity that exceed their commended BIS values.

Conclusion

All the above results aim to monitor water quality status in the study area. The information so generated will help regulatory authorities to develop a water management plan. In this paper, the calculated WQI provides an easy understanding of the overall water quality. The GIS is of immense help in determining water quality for drinking purposes involving the integration of various thematic layers. The study area has WQI value ranging from 94 to 133. The spatial distribution map of WQI shows high values in all the locations under study, where WQI is in the satisfactory category, except for the low value of WQI at two locations

viz.; DB and SD where the water quality index is good. The highly affected parameters are pH, EC, Total hardness, and TDS. However, fluoride concentration is high only at one location (sample code CP) where it is above the permissible limit. At the same time, chloride concentration was within desirable limits except for the DEC sample. Except for four locations, most of the locations have nitrate well above the desirable limit.

The present study illustrates the utility of GIS techniques as a practical and effective approach for analyzing water quality. However, the output value for a cell using inverse distance weighting (IDW) is limited to the range of the values used to interpolate. Further, the interpolation can easily affected by uneven distribution of observational data points. In order to get best results from IDW it is desirable that the sampling is sufficiently dense with regard to the local variation. With all this improvement in sampling the GIS will be helpful for decision-makers and planners to suggest the control of water quality in the supply system.
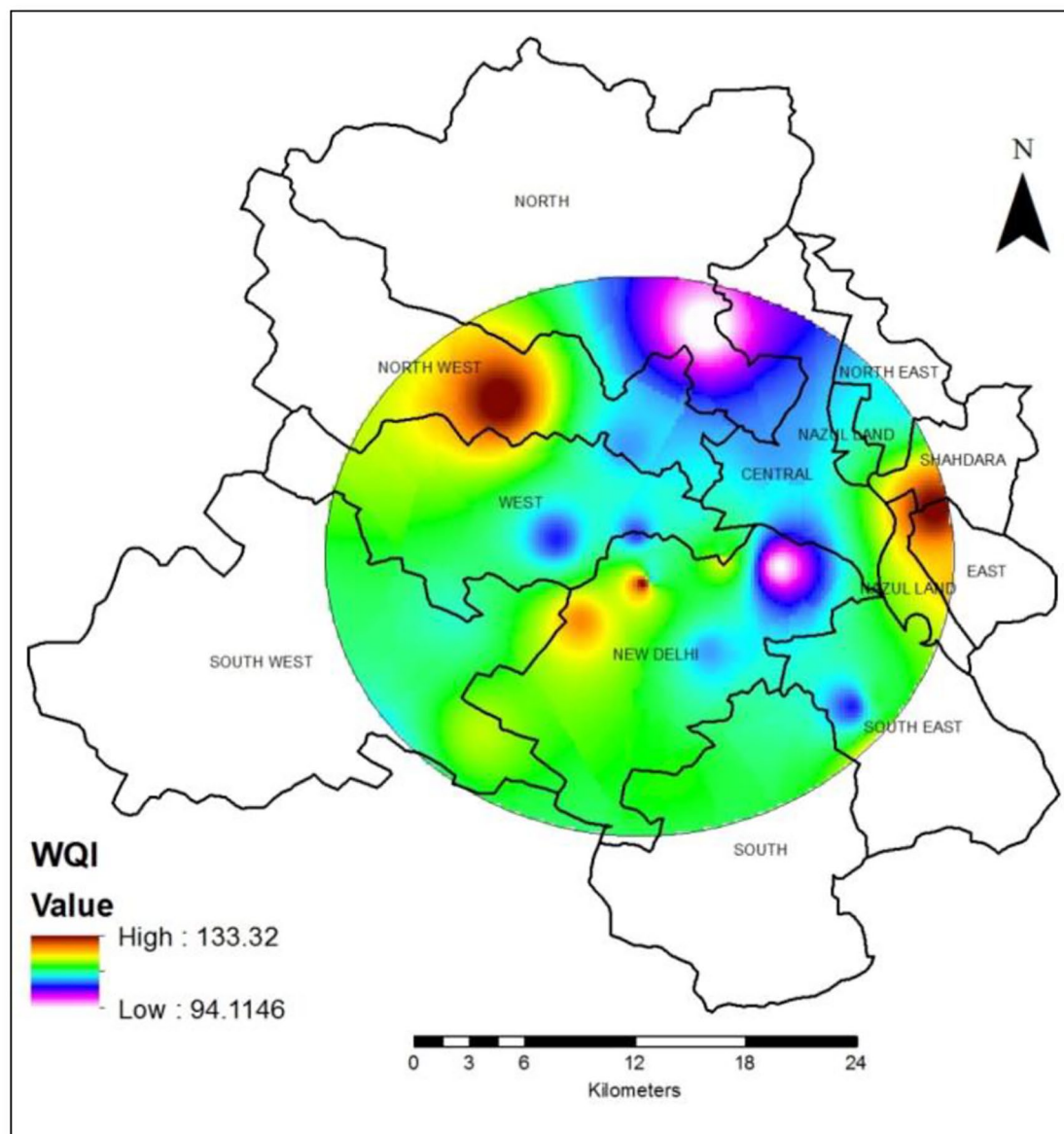
Figure 5. Water quality index map (WQI).

Availability of Data and Material (Data Transparency)

Data is available.

Code Availability

Not applicable.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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