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Using Quantum GIS for Real-Time Monitoring of Groundwater Quality: A Case Study of Gorakhpur City, India

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Abstract

Objective: This study involves application of Geographic Information System (GIS) technique for assessment of the groundwater quality using the features and working of the GIS software for plotting the geospatial data which is very useful in monitoring the groundwater quality for effective management. The groundwater quality in the Gorakhpur district has special significance and needs great attention of all concerned because it is the only source of water for industrial, domestic and irrigation water supply. **Method**: The groundwater samples were collected manually from the available water sources from 150 locations distributed in Gorakhpur city. Quantum GIS was used for WQI & spatial-distribution data maps of 150 Samples. WQI and weighted overlay maps were produced, which provide a better understanding of the existing water Quality Scenario of Gorakhpur City. WQI classifies water into five categories that are Excellent, Good, Poor, Very Poor & Water unsuitable for drinking purposes. The weighted overlay maps were created in the study area from the spatial distribution of seven water quality parameters. **Finding:** Quality analysis of the drinking water such as spatial distribution maps of individual water quality parameters, Water Quality Index was found and various stress zones in Gorakhpur City were identified. According to WQI, out of 150 samples, only 3 samples were found of Poor Ground Water for drinking purposes sampled inwards Purdilpur (Ward 42), Dilejakpur (Ward 38) and Alhadadpur (Ward 55) with WQI of 103.54, 100.17 and 100.11, respectively. The best water sample is that whose WQI is the least. Shaktinagar (Ward 37) was found to have the best results with a WQI of 59.05 i.e., good water. None of the samples were found as 'Excellent'. **Novelty:** This study proposed a concept of assessment and categorization of the groundwater quality based on WQI, which took 7 parameters into consideration so that proper steps of monitoring, and management can be done to stop the deterioration of the quality of water.

Keywords: Ground water; Water Quality Index (WQI); Weighted Overlay; GIS; IDW Surface Interpolation; Spatial Distribution

1 Introduction

Groundwater quality is governed by Chemical, biological and physical parameters. It is less prone to biological pollution than surface water which is always in contact with soil, rocks and foreign materials. But freedom from biological pollution itself does not make it eligible for drinking purposes. Various materials and minerals could be present in it either in the dissolved or dispersed form. These materials and minerals are very hard to detect from the naked eyes and most of it doesn't affect the human body are even beneficial up to some extent. But some of them are highly toxic and if taken in higher concentration could be fatal for the living being.

Groundwater is susceptible to soil properties and aquifer level. The property of groundwater is dependent on depth of the water into the ground and surrounding soil strata [(1)]. Also, the water quality of groundwater depends on the rainfall, as after every rainfall the percolation through the soil layers from pores and cracks occurs causing the change in water quality as percolation of water takes the contaminants and soil pollutants along with it.

IS code 10500:2012- "Drinking water specification" provides acceptable and permissible values of various water quality parameters for drinking purposes. The electrical conductivity does not affect the drinking water quality but is used for irrigation purposes. BIS have mentioned irrigation standards for electrical conductivity, which have been used in this paper [(2)]. The water having the quality parameters under acceptable levels is the best for drinking purposes. In the absence of other sources, the water source containing parameters within permissible limits is accepted as water sources for drinking purposes. Water having quality parameters crossing permissible values are not chosen for drinking purposes.

In a research by Central Ground Water Board, 2013, it has been mentioned that all the values of water are under the permissible limit and the Gorakhpur city, which is very prone to flood and water logging during the monsoon season, the quality parameters are susceptible to change since past 6 years. The growing population and industries have increased the water consumption, generation of wastewater and effluent to rivers that have become the source of contamination for the groundwater. Therefore, to determine the quality of groundwater from India Mark II pumps and pumps at shallow depth of less than 50 m, it was found that the pumps at shallow depth had 25% more total dissolved solid (TDS) and hardness [(3)]. This study was done in an urban area of Gorakhpur and a semi-urban area of Khorabar. In the same year i.e., 2014, the water quality index (WQI) was too calculated for different locations of the Gorakhpur City to compare the quality of the water by standard methods as it is the best tool to classify the different areas according to their water qualities [(2)]. Earlier, WQI and weighted overlay analysis were used as imperative tools for classifying the Lucknow sector into regions of safe and unsafe water thus, [(2)].

It has been found that the increment in the level of physical and chemical parameters of the groundwater raises significantly in the urban areas. In a study TDS, turbidity, alkalinity and hardness exceeded the acceptable limits but were below the permissible limits [(4)].

Observing the role and significance of WQI in assessing the water quality, we determined the groundwater quality of Gorakhpur city was by calculating WQI for respective locations. We used this water quality data for creating and publishing the spatial distribution maps. The determined water quality data was compared with the guidelines for drinking water provided by BIS (IS: 10500-2012).

2 Study Area and physiographic characteristics

Gorakhpur city is situated along the bank of Rapti river in the eastern part of the state of Uttar Pradesh, India and near the border with Nepal [(5)] [(6)]. The Gorakhpur City occupies the extreme North-Eastern part of Uttar Pradesh and lies between $26^0$70' and $26^0$83' North latitudes and $83^0$32' and $83^0$44' East longitudes. The geographical area of Gorakhpur District is 141.02 km^2. Gorakhpur City is the headquarters of its district. The district is in the Central Ganges Plain (Plate-I). Gorakhpur Municipal Corporation (GMC) with a population of about 6.7 Lac is the Gorakhpur City's only municipal corporation. Population density of the city is 4776 persons per km^2. There are a total of 70 wards in the city [(7)] (supplementary table 1). Figure 1 presents the physical map of the Gorakhpur city depicting all the 70 wards.

The normal rainfall is tuned to 733.4 mm. The most rainfall in the area occurs during the south-west monsoon during mid-June to September. In the rest of the year, the rainfall is sporadic and scanty. The drainage system of the district represents a part of the Ganges basin and Ghaghara sub-basin. The main river system is controlled by the Rapti River it's affluent in the city. The Gorakhpur City's geology is a primarily river born alluvium. Few mineral products are mined here with the most common being a nodular limestone conglomerate known as canker and saltpeter.

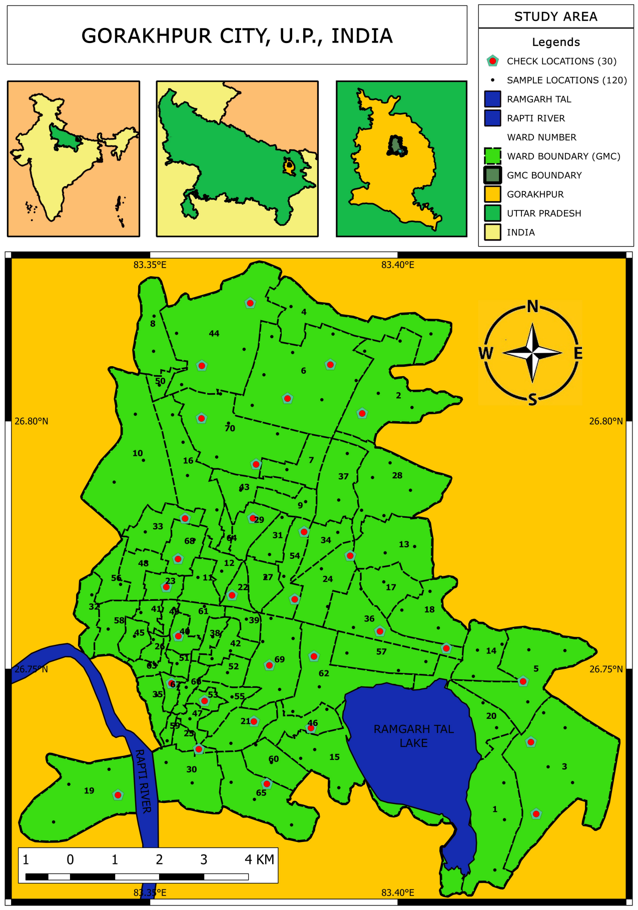

Fig 1. Ward list of area

3 Water Supply System

The existing source of water supply in the city is groundwater. Presently, there are 108 tube wells and 37 Mini tube-wells working in the city. The average discharge of water from these tube-wells is 0.71MLD, which makes a total of 102.8 MLD. The total length of water supply distribution lines is 908.73 km. There is no source of surface water in the Gorakhpur City, but the city proposes for surface water supply for which survey is going by U.P. Jal Nigam. The per capita water supply in the city is 135 LPCD. The quality of the water supply is 95% (Ministry of Urban Development). There are 126735 households in GMC out of which 76060 households (60%) have tap water connections. Remaining 50675 households directly depend on groundwater [8].

4 Materials and Methods

The groundwater samples were collected manually from the available water sources (Domestic Hand Pumps/ India Mark 2 Hand Pump) of 150 locations, which are approximately equally distributed in the Gorakhpur city. The parameters analyzed to determine water quality are pH, turbidity, chloride, electrical conductivity, total alkalinity, total hardness, and total dissolved solids. All the 150 samples were tested in a laboratory in two phases. In the first phase, 120 sample data were tested, and the result was used for spatial distribution and weighted overlay analysis and mapping using Quantum GIS (QGIS) software. In the second phase, water quality data of the remaining 30 points were tested and matched with the parameter values derived from the plotted maps using QGIS software. A plug-in known as 'Point Sampling Tool' was used for determination of the attribute data at any unknown point on the map. After that, the error analysis was done for these 30 points. Following activities were performed step by step to achieve the aim and Figure 2 presents the flowchart of the methodology adopted in the present study.

- Identification of 150 water samples uniformly distributed over the study area

- Collection of groundwater samples from hand pumps of 150 locations in Polyethylene bottles. The bottles used were clean and neat and as per IS: 3025 (Part-1) (1987).
- Collection of GPS coordinates of the collection sites and plotting of points using QGIS Software.
- All the samples were tested in a laboratory for quality parameters and designated by a sample number (SMN). The laboratory facility was provided by the Public Health Engineering Laboratory of Madan Mohan Malviya University of Technology, Gorakhpur.
- WQI was calculated for the comparison of groundwater quality between different locations of the city.
- Based on the spatial distribution maps, safe and unsafe zones of water quality were demarcated by taking in account water quality parameter and water quality index

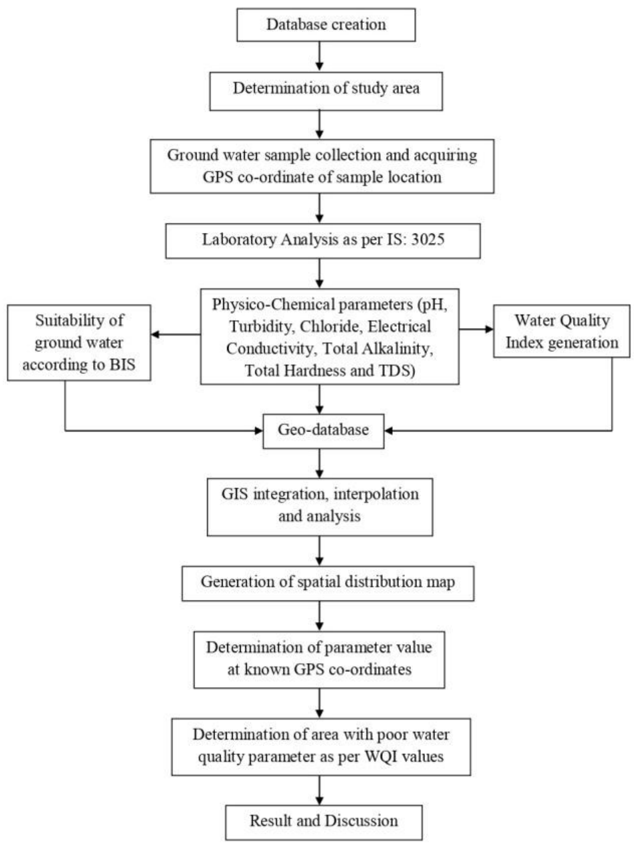

Fig 2. Flow chart of methodology

5 Parameters studied

There are large numbers of physical and chemical parameters of water, which need to be observed while determining the water quality and classifying water into the different categories like drinking purposes, irrigation etc. In the study, the seven physical and chemical parameters were tested, Table 1 shows the list of parameters used in studying the water quality with information on testing methods adopted according to the reference Additionally, Table 2 shows the water quality specification for different physical and chemical parameters of water with information on acceptable limit, permissible limit according to the reference.

6 Quantum GIS and its application

Quantum GIS also known as **QGIS**) is a free & open-source, cross-platform desktop GIS software. It supports viewing, editing, and analysis of geospatial data. It provides many the plug-in that increases the functionality of QGIS software. Like other GIS software, It is a system designed for capturing, storing, analyzing, managing data and attributes associated, which are spatially referenced to the Earth. GIS software is great for creating solutions for water resources, like water quality assessment and management of water resources on a local or regional scale. Many

Table 1. Water quality tests and references

SN	Parameter	Testing Method/ Instrument	Reference
1	pH	Colorimetric method	IS:3025 (11)-1983
2	Turbidity	Nephelometric method	IS:3025 (10)-1984
3	Chloride	Argentometric method	IS:3025 (32)-1988
4	Electrical Conductivity (EC)	Conductivity Meter	IS:3025 (14)-1984
5	Total Alkalinity (TA)	Indicator method	IS:3025 (23)-1986
6	Total Hardness (TH)	EDTA method	IS:3025 (21)-2009
7	Total Dissolved Solid (TDS)	Gravimetric method	IS:3025 (16)-1984

Table 2. Water quality specifications

SN	Parameter	Acceptable limit	Permissible limit	Reference
1	pH	6.5-8.5	No relaxation	IS:10500- 2012
2	Turbidity, NTU, max	1	5	IS:10500- 2012
3	Chloride, mg/l	250	1000	IS:10500- 2012
4	EC, μS/cm	2000	Not Specified	BIS (2)
5	TA, mg/l (as CaCO3), max	200	600	IS:10500- 2012
6	TH, mg/l (as CaCO3), max	200	600	IS:10500- 2012
7	TDS, mg/l, max	500	2000	IS:10500- 2012

hydrologists use GIS technology for integration of various data applications into one and manageable system [9]. QGIS too includes a function to interpolate the data and find out the value of any parameter at any GPS coordinate. We used QGIS for creating and publishing the spatial distribution and weighted overlay map of the water quality variables. Figure 2: Flowchart of the methodology for determining water quality and classifying areas from excellent to unsuitable for drinking.

7 Tools for data analysis

For analysis of the collected data and to achieve results, we used certain tools to analyze, store, arrange and get to a reliable number which could represent the water quality of groundwater. For such purposes, the WQI is considered as the best tool for analyzing many parameters by a single number. For The interpolation of data, between two points was performed to create the colour-coded spatial distribution maps. The colour intensity in the spatial distribution map was depicted in gradient way from low to high and it decreases when we move away from points and increases while we move towards the point.

8 Calculation of WQI and classification

WQI indicates the overall water quality at a certain point and time in a single-digit number based on the value analysis of various water quality parameters. The main aim of finding the WQI is to convert the complex water quality data into meaningful information, which could be easily understood and used for other purposes such as planning and decision making. For this, the groundwater samples which were collected manually from the hand pumps and Mark 2 are the main source of drinking water for the people living in those areas of the Gorakhpur city.

For computing the water quality index, the following three steps were adopted.

Step 1: Each physical and chemical parameter of water was acknowledged with a weight W_i according to its relative importance in the overall water for drinking purposes. Table 3 presents the details on the weight and relative weight of each parameter.

Step 2: Relative weights were for each parameter was computed using the following equation,

$$\mathbf{Wir} = \mathbf{Wi} / \sum \mathbf{n_{i=1}}\ \mathbf{Wi}$$

Where, relative weight is denoted by W_{ir},

Weight of each parameter is denoted by W_i and the number of parameters is represented by n.

Step 3: For each parameter, qi, a rating scale representing quality is assigned by the following equation

$$\mathbf{q_i} = (\mathbf{C_i}/\mathbf{S_i}) \times \mathbf{100}$$

Table 3. Relative weight of quality parameters

SN	Parameter	Wi (Weight)	Wir (Relative Weight)
1	pH	5	0.208
2	Turbidity	2	0.083
3	Chloride	4	0.167
4	EC	3	0.125
5	TA	3	0.125
6	TH	3	0.125
7	TDS	4	0.167
		Σ Wi = 24	Σ Wir =1.0

where quality rating is denoted by qi, Ci represents concentration of each parameter in water sample in mg/l, Si is the acceptable value for the chemical parameter in sample of water represented by Si in mg/l according to guidelines of IS: 10500-2012 (Indian drinking water standards).

WQI Equation: For each physical and chemical parameter, SI value was determined in mg/l, which was used to determine water quality index according to the equation given below:

$$SI_i = q_i \times W_{ir}$$

$$WQI = \sum SI_i$$

$$WQI = (q_{ipH} \times W_{irpH}) + (q_{iTurbidity} \times W_{irTurbidity}) + (q_{iChloride} \times W_{irChloride}) + (q_{iElctricalConductivity} \times W_{irElectricalConductivity}) + (q_{iTotalAlkalinity} \times W_{irTotalAlkalinity}) + (q_{iTotalHarness} \times W_{irTotalHardness}) + (q_{iTotalDissolvedSolid} \times W_{irTotalDissolvedSolid})$$

$SI_i = W_i{*}q_i$, $WQI = \sum SI_i$, SI_i represents sub-index of the ith parameter, ith parameter concentration denotes qi rating, the number of parameters is represented by n.

The computed water quality index values were classified into 5 types from "excellent water" to "water unsuitable for drinking" as depicted in Table 4.

Table 4. WQI Classification (2)

WQI Value	Water Quality (WQ)
<50	Excellent
50-100	Good water
100-200	Poor water
200-300	Very poor water
>300	Water unsuitable for drinking

9 Interpolation of the water quality data

Inverse Distance Weighted (IDW) method was used for interpolation of the data of water quality parameters to determine the values at unknown points, It is assumed that contribution of nearby values to the interpolated values is often more than the distant observations. In other words, an inverse relation exists between the influence due to a known data point and the distance from unknown location used for estimation. The advantage of IDW is that it is intuitive and efficient. Furthermore, uneven distribution of data clusters results in introduced errors.

In interpolation with the IDW method, a weight is assigned to the point to be measured. Amount of this weight depends on the distance between one point and another unknown point. These weights are controlled on the bases of power of 10. An increase in power of 10 causes a decrease in effect of the points which are far. Lesser power distributes the weights more uniformly between neighboring points. In this method, the distance between the points counts, so the points of equal distance have equal weights. The weight factor is calculated using the following equation.

$$\beta_i = (D_i^{-\alpha})/(\sum^n i = 1\, D_i^{-\alpha})$$

Where,

β_i = the weight of the ith point
D$_i$ = the distance between point i and the unknown point
$\alpha_{i\,=}$ the power ten of weight.
Water quality test data (data available as supplementary table)
Derived Data of 30 Locations from QGIS (data available as supplementary table)

10 Statistical Analysis of Result

The statistical analysis of the test data of 150 samples was done, Table 5 presents the descriptive statistics of each parameter with information on acceptable and permissible limits according to BIS below:

Table 5. Descriptive statistics and concentration standards and guidelines of groundwater quality parameters

Parameter	Standard Limit (BIS)			Max	Min	Mean	Mode	Median	S.D.
	Acceptable	Permissible							
pH	6.5-8.5	No Relaxation	150	8.0	6.0	7.25	7.5	7.5	0.404
TU (NTU)	1	5	150	0.5	0.1	0.11	0.1	0.1	0.05
CH (mg/l)	250	1000	150	204	45	110.53	138	104	41.96
EC (μS/cm)	2000	Not Specified	150	1342	478	848.5	856	856	136.46
TA (mg/l CaCO3)	200	600	150	259	90	184.16	198	186	35.14
TH (mg/l CaCO3)	200	600	150	315	80	193.49	205	190	46.85
TDS (mg/l)	500	2000	150	1007	359	636.38	642	642	102.34

Further, the statistical analysis of the errors associated with computed data of 30 samples was done and Table 6 shows the descriptive statistics of these samples for each parameter with information on error associated with each parameter.

Table 6. Descriptive statistics of errors b/w test data andderived data from QGIS

Parameter	N	Min	Max	Mean Absolute Error	Standard Deviation	Root Mean Square Error
pH	30	0.001	0.861	0.298	0.227	0.372
TU (NTU)	30	0.000	0.121	0.022	0.032	0.038
CH (mg/l)	30	0.07	79.04	29.118	20.968	35.677
EC (μS/cm)	30	3.27	258.90	99.604	80.211	127.045
TA (mg/l CaCO3)	30	1.17	54.61	24.204	14.699	28.190
TH (mg/l CaCO3)	30	3.05	70.23	27.979	18.052	33.134
TDS (mg/l)	30	1.25	194.77	75.067	60.105	95.537

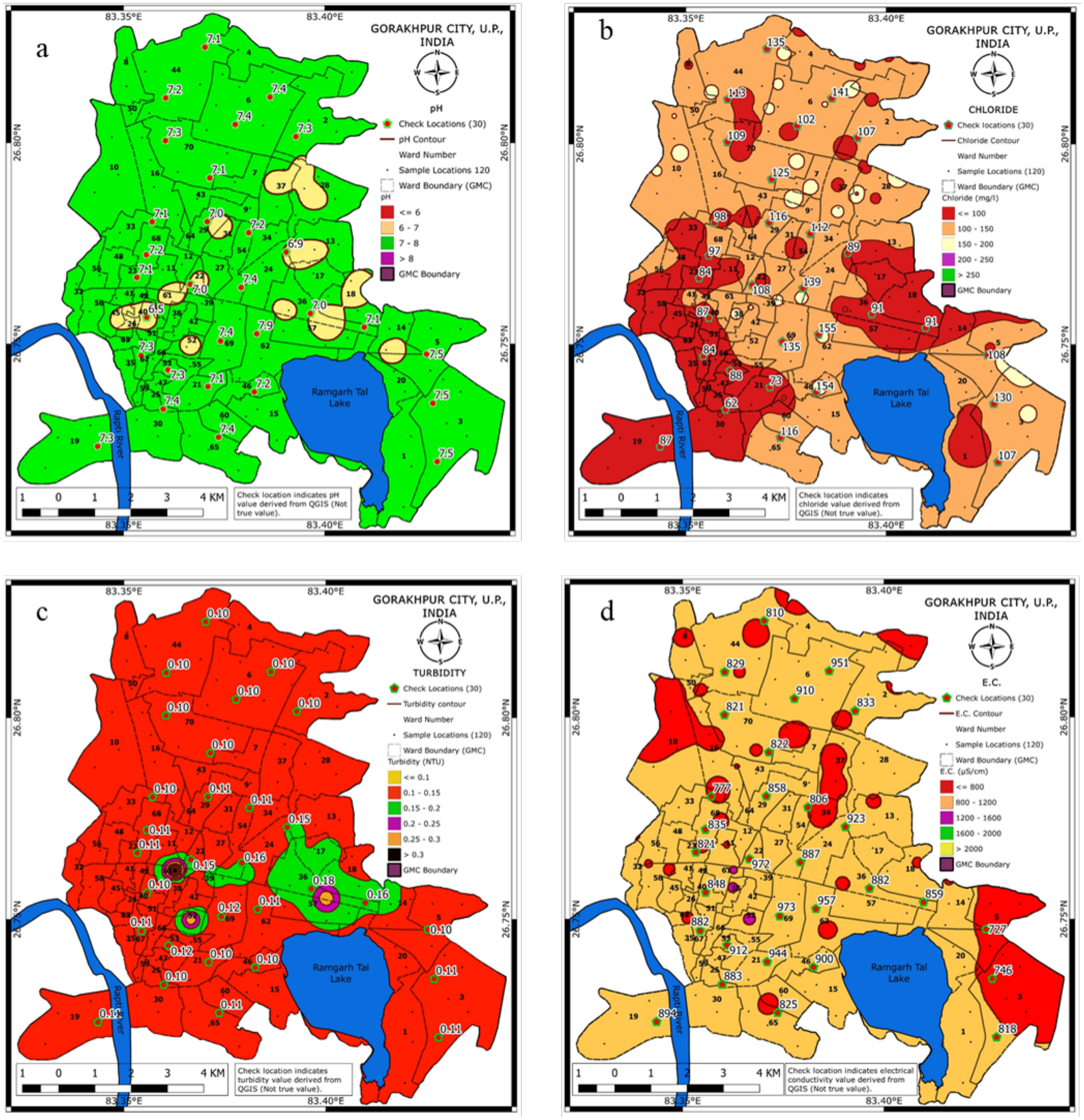

Fig 3. (a) Spatial Distribution Map for pH, (b) Spatial Distribution Map for Chloride, (c) Spatial Distribution Map for Turbidity, (d) Spatial Distribution Map for Electrical Conductivity

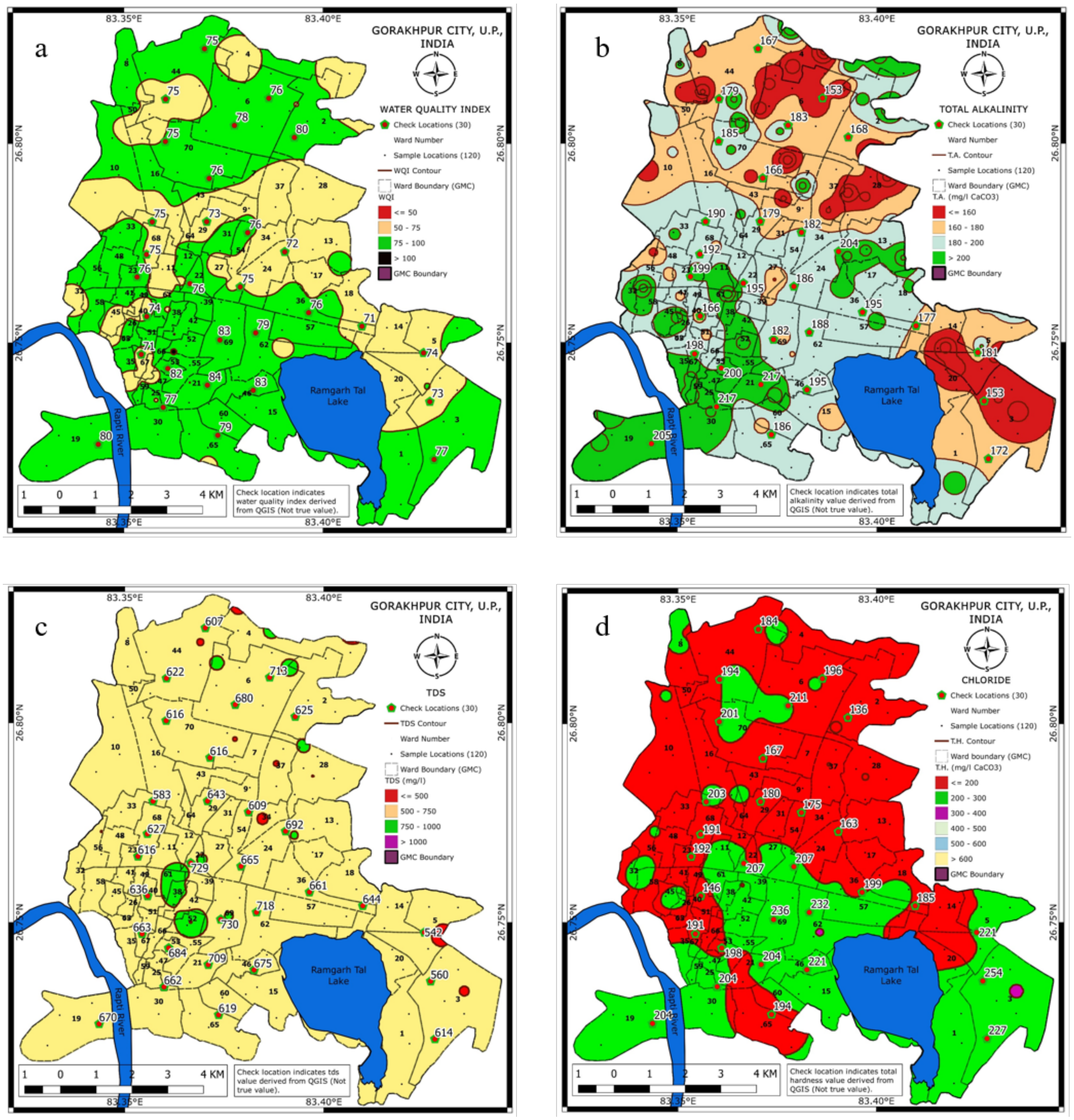

Fig 4. (a) Spatial Distribution Map of WQI, (b) Spatial Distribution Map of Total Alkalinity, (c) Spatial Distribution Map of TDS, (d) Spatial Distribution Map for Total Hardness

11 Discussion

1. PH
   The value of pH varied from 6.0 to 8.0 with the mean value of 7.25 ± 0.404. According to BIS (IS: 10500-2012), the acceptable and permissible limits for pH are '6.5-8.5' and 'no relaxation' respectively. The observed values are within the permissible limit, so the water quality is safe.

2. Turbidity
   The value of turbidity varied from 0.1 NTU to 0.5 NTU with the mean value of 0.11 ± 0.05 NTU. According to BIS (IS: 10500-2012), the acceptable and permissible limits for turbidity are 1 NTU and 5 NTU respectively. The observed values are within the permissible limit, so the water quality is safe.

3. Chloride
   Concentration of chloride mostly lied from 45 mg/l to 204 mg/l with the mean value of 110.53 ± 41.96 mg/l. According to BIS (IS: 10500-2012), the acceptable and permissible limits for chloride are 250mg/l and 1000mg/l respectively. The observed values are within the permissible limit, so the water quality is safe.

4. Electrical Conductivity
   The value of electrical conductivity varied from 478 μS/cm to 1342 μS/cm with the mean value of 848.5 ± 136.46 μS/cm. According to BIS (Irrigation Standard), the acceptable and permissible limits for electrical conductivity are 2000 mg/l and 'Not Specified' respectively. The observed values are within the permissible limit, so the water quality is safe.

5. Total Alkalinity
   The Concentration of total alkalinity varied from 90 mg/l to 259 mg/l as $CaCO_3$ with the mean value of 184.16 ± 35.14 mg/l as $CaCO_3$. According to BIS (IS: 10500-2012) the acceptable and permissible limit for total alkalinity are 200 mg/l and 600 mg/l as $CaCO_3$ respectively. The observed values are within the permissible limit, so the water quality is safe.

6. Total Hardness
   The value of total hardness varied from 80 mg/l to 315 mg/l as CaCO3 with the mean value of 193.49 ± 46.85 mg/l as CaCO3. According to BIS (IS: 10500-2012), the acceptable and permissible limit for total hardness is 200 mg/l and 600 mg/l as CaCO3 respectively. The observed values are within the permissible limits, so the water quality is safe.

7. Total Dissolved Solid
   Total dissolved solids varied from 359 mg/l to 1007 mg/l with the mean value of 636.38 ± 102.34 mg/l. According to BIS (IS: 10500-2012), the acceptable and permissible limits for total dissolved solid are 500 mg/l and 2000 mg/l respectively. The observed values are within the permissible limits, so the water quality is safe.

8. Water Quality Index
   After obtaining the test data for 150 samples, for each of the samples the water quality index has been calculated. As per the WQI classification of water, the wards with groundwater samples classified as 'Poor water' are Purdilpur (Ward 42), Dilejakpur (Ward 38) and Alhadadpur (Ward 55) with WQI of 103.54, 100.17 and 100.11 respectively. The best water sample is those whose WQI is the least. Shaktinagar (Ward 37) is found to have best results with a WQI of 59.05 i.e., Good water. None of the samples has been found as 'Excellent'. The mean value of WQI has been found 76.20 ± 6.239 for the study area. The overall water quality is found safe.

12 Conclusion

The present study assessed the Ground Water Quality of the Gorakhpur City by analyzing the 150 groundwater samples for which the tests were completed as per the guidelines laid down by BIS (IS: 3025). Out of 150 samples only one sample was found whose pH was of poor quality. The total alkalinity, total hardness and total dissolved solid of groundwater raised issues because about one-third of the samples crossed the acceptable limits, but not the permissible limits as per guidelines of BIS (IS: 10500-2012). The turbidity, chloride, and electrical conductivity of groundwater for all the samples were below the acceptable limit. As per WQI, out of 150 samples, only 3 samples were found showing Poor Groundwater for drinking purposes sampled inwards Purdilpur (Ward 42), Dilejakpur (Ward 38) and Alhadadpur (Ward 55) with WQI of 103.54, 100.17 and 100.11, respectively. The best water sample is that whose WQI is the least. Shaktinagar (Ward 37) is found to have best results with a WQI of 59.05 i.e., good water. None of the samples were found as 'Excellent'.

Hence the overall water quality of groundwater of Gorakhpur City is within permissible limits for all the measured seven parameters and the water quality is safe corresponding to these seven parameters.

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