Chapter 15
GIS-Based Assessment of Urban Groundwater Pollution Potential Using Water Quality Indices

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15.1 Introduction

The interaction of urbanization and water quality is considerably controlled by the city's land use structure as different types of land use labor various sources of contaminants and hazards which influence both water quality and quantity (Baier et al. 2014, 2015; Pande and Moharir 2018). Urbanization refers to a process in which an increasing proportion of an entire population lives in cities and the suburbs of cities and change of land use from agriculture to human settlements, commercial sectors, and industries (Putra and Baier 2008). The growing human population and development activities, increased human access to environmental resources, and the

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C. B. Pande, K. N. Moharir (eds.), *Groundwater Resources Development and Planning in the Semi-Arid Region*, https://doi.org/10.1007/978-3-030-68124-1_15

exploitation of renewable or nonrenewable resources of land have led to changes in water quality (Ghorbani et al. 2014). The issue of water contamination and wastewater disposal is an intense problem in cities of developing countries where, generally, densely populated and inadequate managed sewer drains areas created by high rates of population migration into cities (Sinha et al. 2019a, b). These areas are unplanned and located in the outskirts of the cities forming shanty towns (typically between 30% and 60% of the overall urban population) where pit latrines or septic tanks are common. In some cities, septic tanks and pit latrines are the only way to dispose of sewage (Putra and Baier 2008). The consumption of these different contaminants through biodegradation or toxicity resistance to these pollutants by the microbial communities can provide information about pollutant exposure, metabolic diversity and the potential source of contamination and the potential for the ecosystem natural attenuation, thus may be a practical indicator of the water quality (Karbassi et al. 2011; Pande et al. 2018).

Water quality index was first introduced in 1848 about 168 years ago in Germany where the presence or absence of certain organism in water was used as fitness indicator of a water source. The use of numerical scale to represent gradation in water quality levels is a recent phenomenon, beginning with Horton index in 1965 (Mustapha and Aris 2011; Moharir et al. 2019). The concept also aims at eliminating the subjective assessment of water quality and the individual biases of water resource managers (Sarkar and Abbasi 2006). Water quality is the function of anything and everything the water might have picked up during its journey to the water body in dissolved, colloidal and suspended form. Water quality may be assessed in terms of: Quality for life (e.g., the quality of water needed for human consumption), Quality for food (e.g., the quality of water needed to sustain agricultural activities), Quality for nature (e.g., the quality of water needed to support a thriving and diverse fauna and flora in a region), and the selection of parameters used to assess the quality of water depends largely on the intended use of the body of water (Poonam et al. 2013; Nikoo et al. 2011; Khadri et al. 2013; Khadri and Pande 2015a, b).

15.2 Study Area

Raipur city is located between 21°12′N–21°18′N latitude and 81°33′–81°41′E longitude depicted in Fig. 15.1. The climate of the study area is subtropical with three different seasons. Temperature is moderate and May is the hottest month and December is the coldest month. The Kharun River flows to the west of the city of Raipur, which is also a source of domestic water supply to the city (RMC 2010; Sinha et al. 2016). The city has a population of 11,46,383 and experienced a growth rate of 51.06% during decade 2001–2011. Present study is focused on the groundwater condition in the municipal boundaries of Raipur City, Chhattisgarh, India (Sinha et al. 2019a, b). The sanitation ratings conducted as per national urban sanitation policy, Raipur ranked 274 out of 423 cities with a score of 30.8/100 and

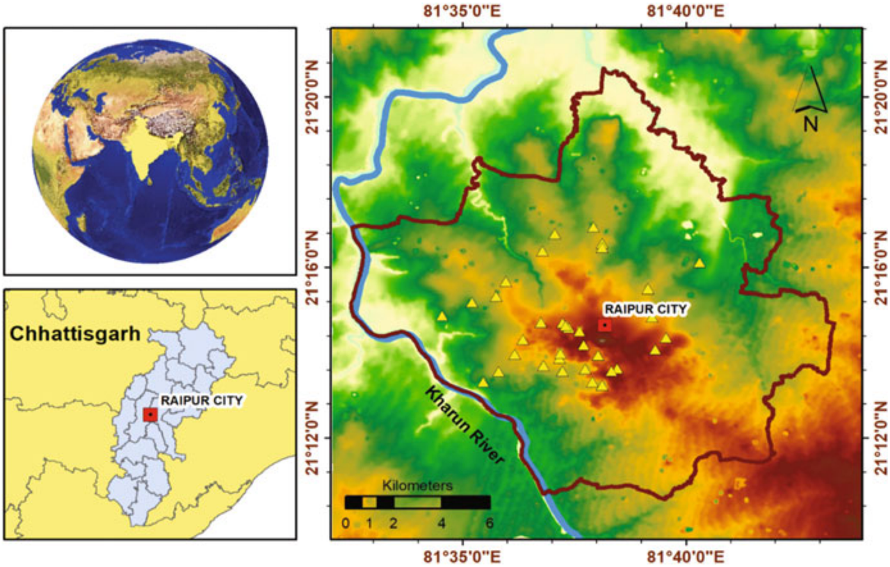

Fig. 15.1 Location map of the study area

falls in the red category. Raipur was blessed with 154 Talabs, which had either been built by nature or by human intervention, has presently only 85 Talabs survived. These 85 surface water bodies of varying sizes (2800–402,000 m^2) occupying a total surface area of 2.83 km^2, which is about 2% of the city's area. These lakes were one of most prominent sources to recharge the groundwater in Raipur, as the aquifer is shallow in the region. Due to human interference since long back the lakes were severely contaminated, which was also connected to groundwater and open wells. Thus, the pollutants get easily transferred from surface water to groundwater. Thirty-four prominent open wells near to lakes were selected for groundwater quality assessments (GIZ 2010, 2011).

15.3 Materials and Methods

The procedure adopted in this study was graphically shown in Fig. 15.2. This study aims to assess the groundwater quality of the Raipur city. The most prominent locations were selected on the basis of susceptibility toward polluted recharging zone in the city area to check the samples of groundwater. The distribution of selected parameters is geostatistical interpolated over the Raipur city area. These thematic maps of all the selected parameters are used for the spatial computation of National Sanitation Foundation Water Quality Index (NSFWQI). The resultant NSFWQI Map demarcates the safe groundwater withdrawal zone in the city area. Apart from that on the other hand Canadian Council of Ministers of the Environment

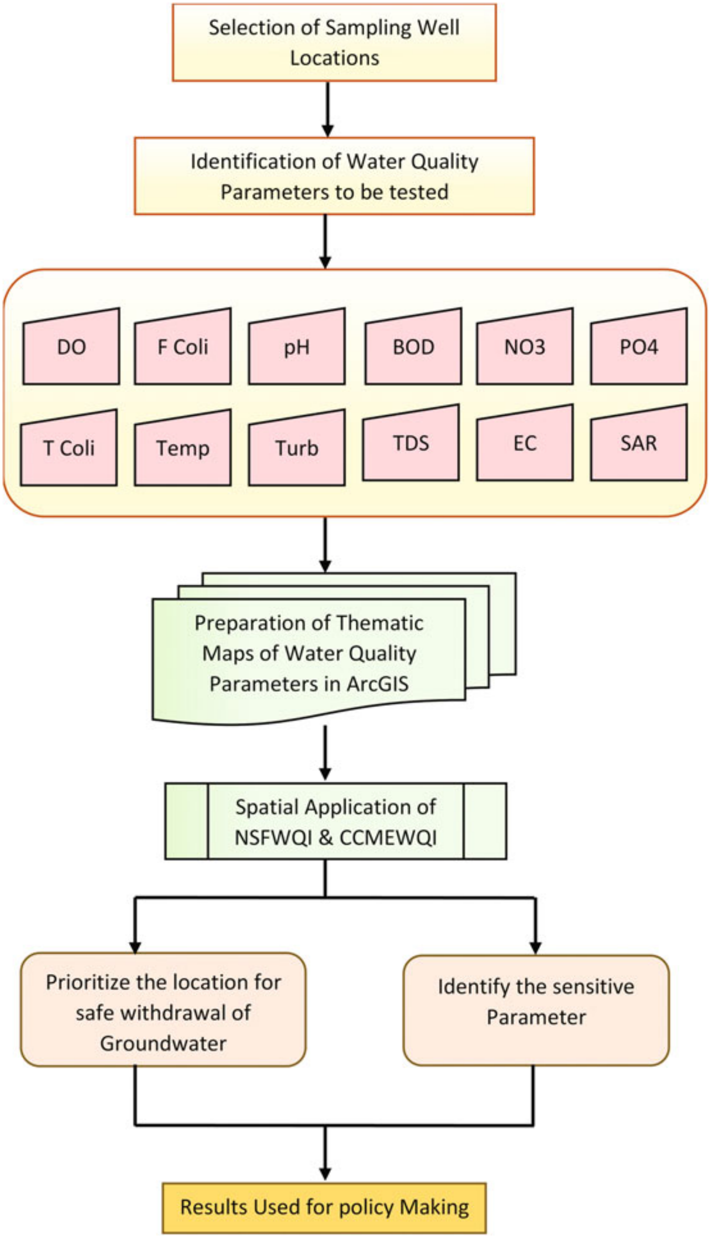

Fig. 15.2 Flow diagram of working procedure

Water quality Index (CCMEWQI) were computed over all 34 sampling locations and the most sensitive parameter affected due to urban pollution was identified. On the basis of these outcomes, groundwater use policy was suggested for the Raipur city.

15.3.1 Selection of Water Quality Parameters and Laboratory Analysis

Water quality parameters dissolved oxygen (DO), biochemical oxygen demand (BOD), electrical conductivity (EC), pH, sodium adsorption ratio (SAR), total coliforms (Tcoli), total hardness (TH), total dissolved solids (TDS), temperature (Temp), phosphate (PO_4), nitrate (NO_3), and turbidity (Turb) were selected to identify the most affected parameter due to pollution load on the water body. The statistical behavior of these parameters was shown in Fig. 15.3. And its statistical properties were listed in Table 15.1. These parameters were selected on the basis of:

- How strong is the influence of urban area on the parameter?
- Do the data values show anomalies as compared to expected values?
- Pollution intimation property for the different types of uses of groundwater.

Groundwater samples were collected in the second week of every 3 months gap from July 2018 to April 2019 at selected sites. The water samples were analyzed to study the physiochemical parameters by following the standard methods of American Public Health Association (Apha 2005; RMC 2011; Pande et al. 2019). The physical parameters were examined at the spot, and chemical parameters like DO were also carried out near the spot. Other chemical parameters like BOD, NO_3, PO_4, and TH were analyzed at the laboratory. The pH and DO of water samples were measured immediately after sampling at the field itself. Samples were subjected to filtration before chemical analysis. The determination of TDS was done by gravimetric process while the TH was carried out by EDTA complex metric titration method. The Winkler's alkali iodide-azide method was followed for the estimation of DO and BOD. NO_3 was determined colorimetric procedure. Fecal coliform population was analyzed by MPN/100 ml method by growing on M-FC medium at temperature 44.5 °C and counted after 48 h.

15.3.2 National Sanitation Foundation Water Quality Index

Brown, McClelland (Brown et al. 1970) developed a common scale and assigning weights to the selected parameters for which elaborate Delphic exercises were performed. The field data is transformed into *Q*-value which is nothing but the rating curve or sub-indices. Sub-indices transform to nondimensional scale values from the

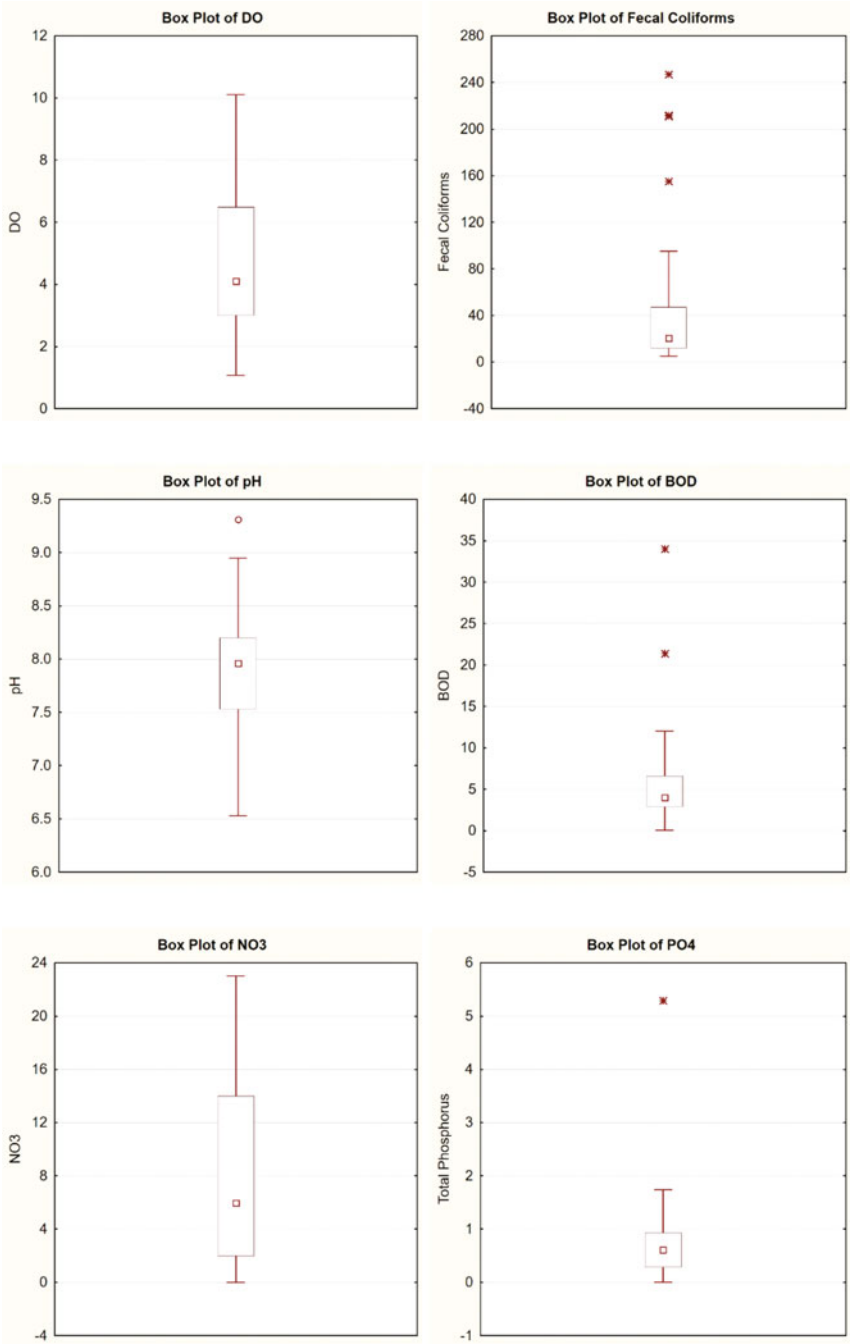

Fig. 15.3 Box plots of water quality parameters used to calculate water quality index

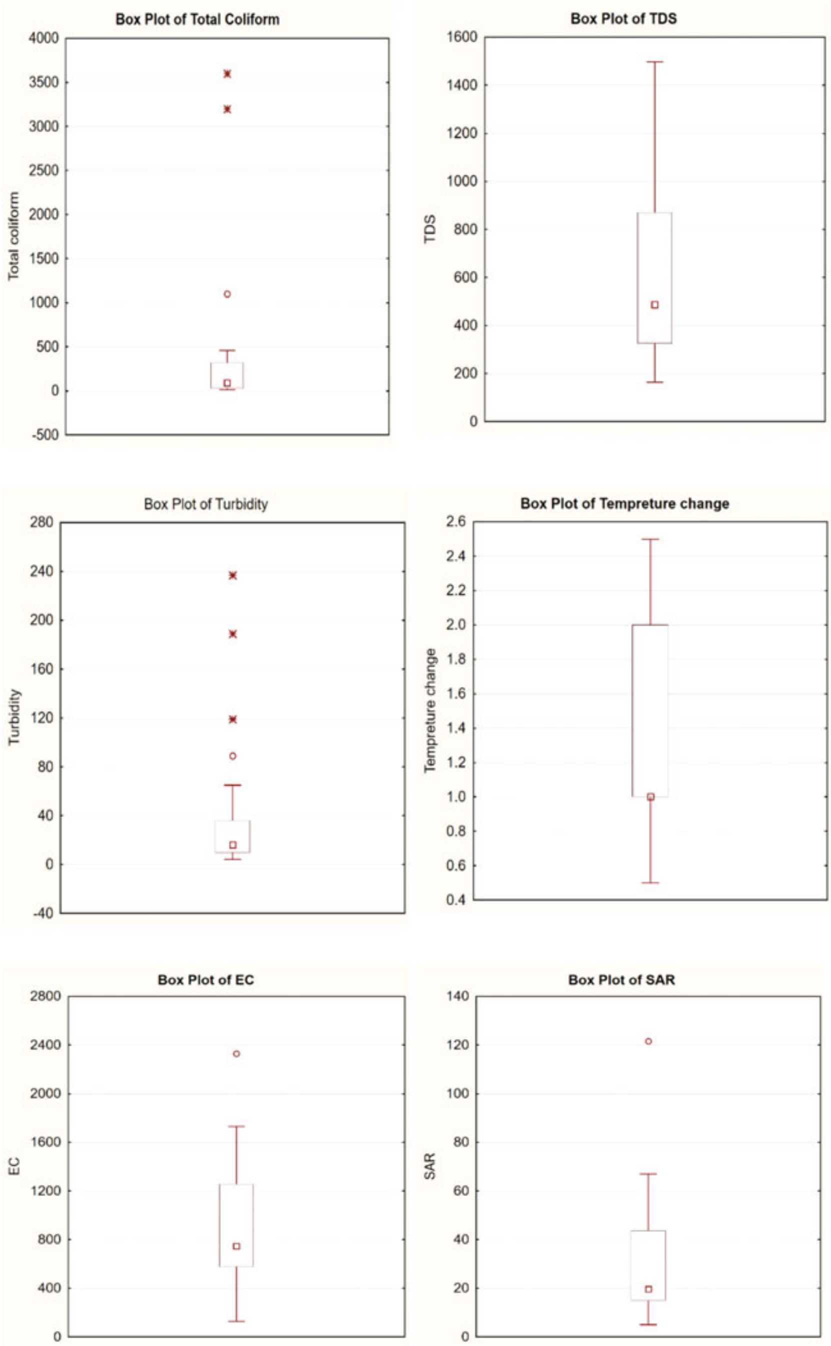

Fig. 15.3 (continued)

Table 15.1 Statistics of groundwater quality parameters used in the study

Parameters	Median	Outlier		Non-outlier range	
		25%	75%	Lowest	Highest
pH	7.96	7.53	8.2	6.53	8.95
EC	747	578	1255	130	1732
TDS	487	326	870	164	149
Turb	16.27	9.9	36	4.23	65
NO_3	5.95	2	14	0	23
PO_4	0.61	0.29	0.93	0.005	1.74
DO	4.1	3.01	6.49	1.07	10.11
BOD	4.005	2.89	6.6	0.05	12
T.coli.	93	28	320	15	320
F.coli.	20.5	12	47	5	95
SAR	19.64	14.96	43.56	5.04	66.97
Temp	1	1	2	0.5	2.5

Table 15.2 Categorical ranking of CCMEWQI and NSFWQI used after Poonam et al. (2013)

Category	NSFWQI	CCMEWQI	Description
Excellent	91–100	95–100	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels
Good	71–90	80–94	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels
Medium	51–70	65–79	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels
Bad	26–50	45–64	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels
Very bad	0–25	0–44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels

variables of its different units and weighting factor W sets the relative importance of a particular parameter to overall water quality. The standard weight for the water quality parameters is DO (0.17), FColi (0.16), pH (0.11), BOD (0.11), NO_3 (0.1), PO_4 (0.1), Temp (0.1), Turb (0.08), and TDS (0.07). The standard formula to calculate water quality index is:

$$\mathrm{WQI} = \sum\nolimits_0^X W \times Q$$

Based upon the weight factor and Q-values the water quality rankings for NSFWQI are tabulated in Table 15.2.

15.3.3 Canadian Council of Ministers of the Environment Water Quality Index

Water quality parameters are compared to water quality guidelines or site-specific objectives. The index is based on three attributes of water quality that relate to water quality objectives: Scope F1—How many? The number of water quality variables that do not meet objectives in at least one sample during the time period under consideration, relative to the total number of variables measured. Frequency F2—How often? The number of individual measurements that do not meet objectives, relative to the total number of measurements made in all samples for the time period of interest. Amplitude F3—How much? The amount by which measurements which did not meet the objectives depart from those objectives.

$$\text{CCMEWQI} = 100 - [(F_1{}^2 + F_2{}^2 + F_3{}^2)/1.732]^{1/2}.$$

The constant, 1.732, is a scaling factor (square root of three) to ensure the index varies between 0 and 100. The result is further simplified by assigning it to a descriptive category. Table 15.2 describes the assigned category.

15.4 Results and Discussion

The pollution load on the groundwater has been analyzed by calculating two water quality indices namely NSFWQI and CCMEWQI. To protect the groundwater by degradation and maintain its respective uses water quality index calculated for the standards of the parameters provided by the Central pollution control board (Govt. of India). The spatial variation of water quality parameters was by the geostatistical interpolation technique in GIS platform as depicted in Fig. 15.4, 15.5, 15.6, 15.7, and 15.8. There are many water quality parameters that indicate the pollution by their aberrant concentration. According to the computation of NSFWQI Table 15.3 reveals the present condition of groundwater in the selected location. Figure 15.9 shows the NSFWQI Map of Raipur city. After analysis of the data it is found that according to BIS (ISO: 10500) desirable limits of drinking water for the parameters chosen in NSFWQI computation deviate from its standard. In any of the 34 locations turbidity and fecal coliform does not meet the drinking water quality standard. Also, there are some locations at which pH, DO, BOD, PO4 and TDS violates the objective. It is revealed that only the NO_3 is in under desirable limit of 45 mg/l. The collective effect of these parameters by the NSFWQI computation represents that six sampling locations (W12L02, W14L01, W62L03, W65L03, W65L04, W68L01) are in BAD condition and only one sampling location (W16L04) is in GOOD condition. The remaining 28 sampling locations are in MEDIUM condition.

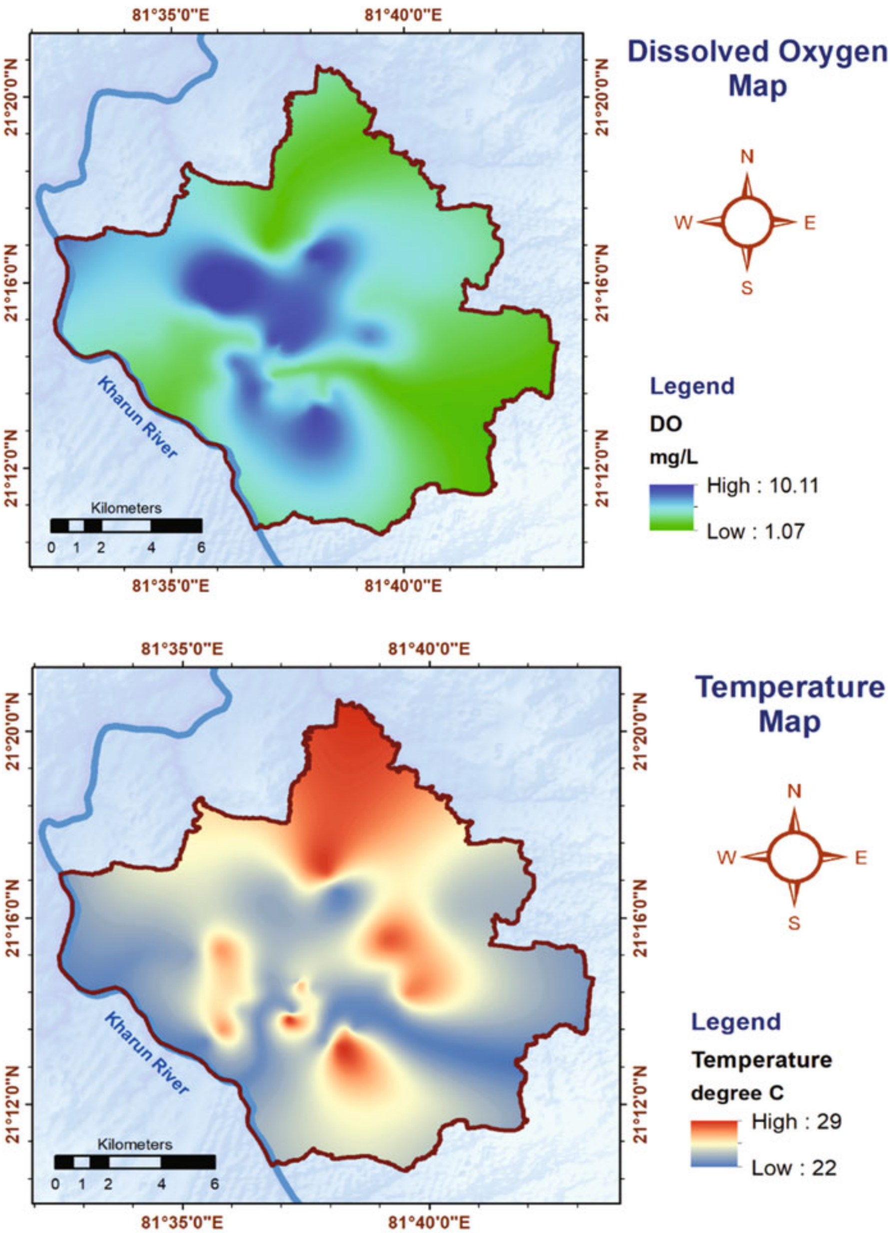

Fig. 15.4 Spatial distribution of dissolved oxygen and temperature in the study area

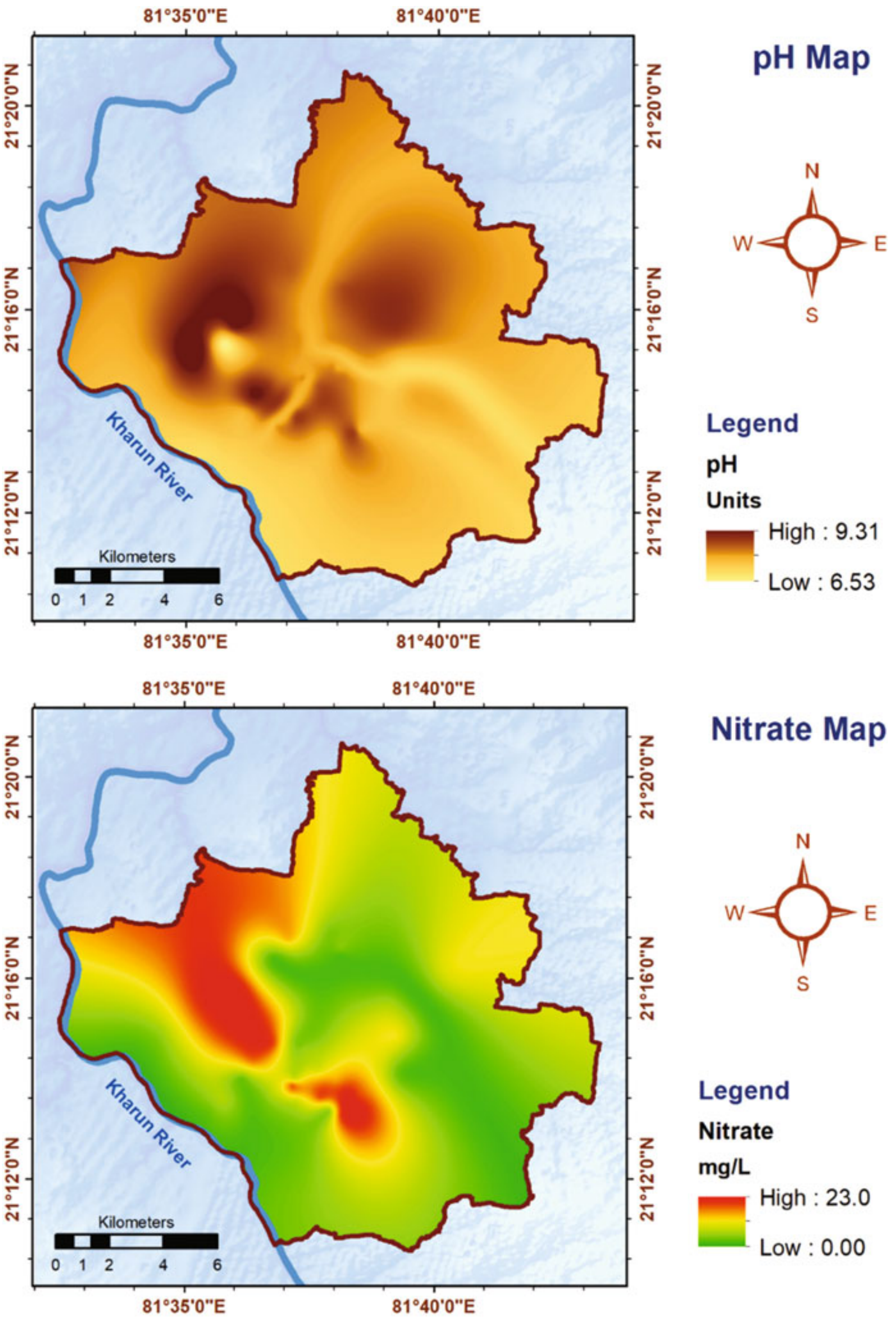

Fig. 15.5 Spatial distribution of pH and nitrate in the study area

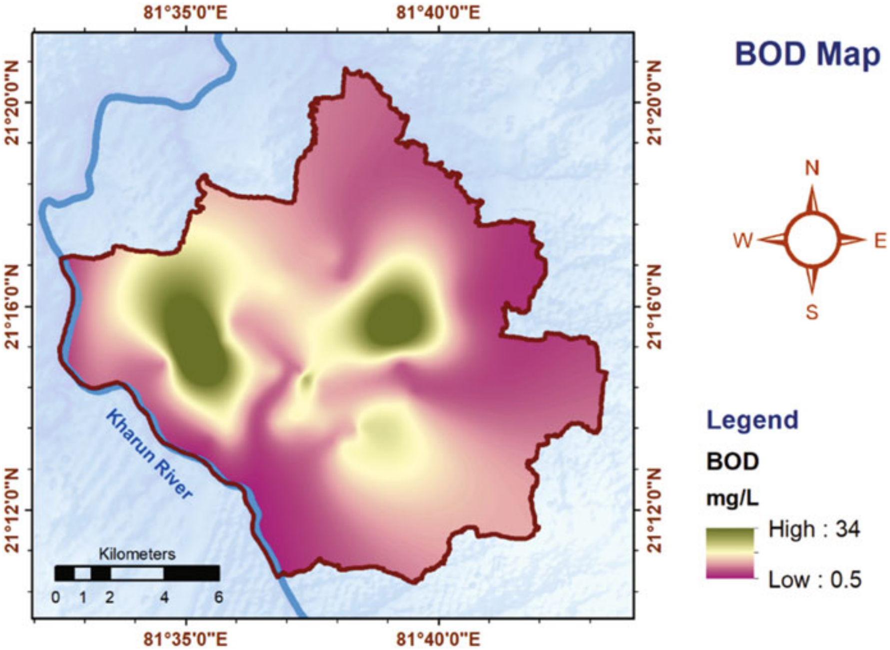

Fig. 15.6 Spatial distribution of BOD in the study area

15.4.1 NSFWQI Result

The spatial variation NSFWQI around the Raipur municipal boundary is shown in Fig. 15.9. Results of NSFWQI map reveals that the 79.41% of area of groundwater comes under the medium quality and 17.64% of area showing bed groundwater quality status. The only 2.94% is safe and suggest the good groundwater quality which can be used for drinking directly without any water treatment. A matrix of linear regression analysis has been drawn for all the parameters used in computation of NSFWQI. The linear regression between the parameters for the sample set is shown in Fig. 15.10. On the observation it is clear that there is strong positive correlation exist between BOD and pH, NO_3 and pH, PO4 and TDS, PO4 and DO, TDS and BOD. And on the other hand, strong negation correlation between, PO4 and pH, TDS and pH, TDS and NO_3, FColi and NO_3, DO and BOD, and NSFWQI and NO_3. The existence of these correlation matches well with the physical correlation of the parameters.

To identify the prominent parameter that affected seriously by pollution, CCMEWQI applied location wise. Central pollution control board, Ministry of Environment and Forests (Govt. of India) guidelines are considered for maintaining the respective use without degrading its life span and quality. Table 15.4 reveals the CCMEWQI result. From the result BOD is that parameter which is particularly more affected by the urban pollution. It categorized under poor condition according to

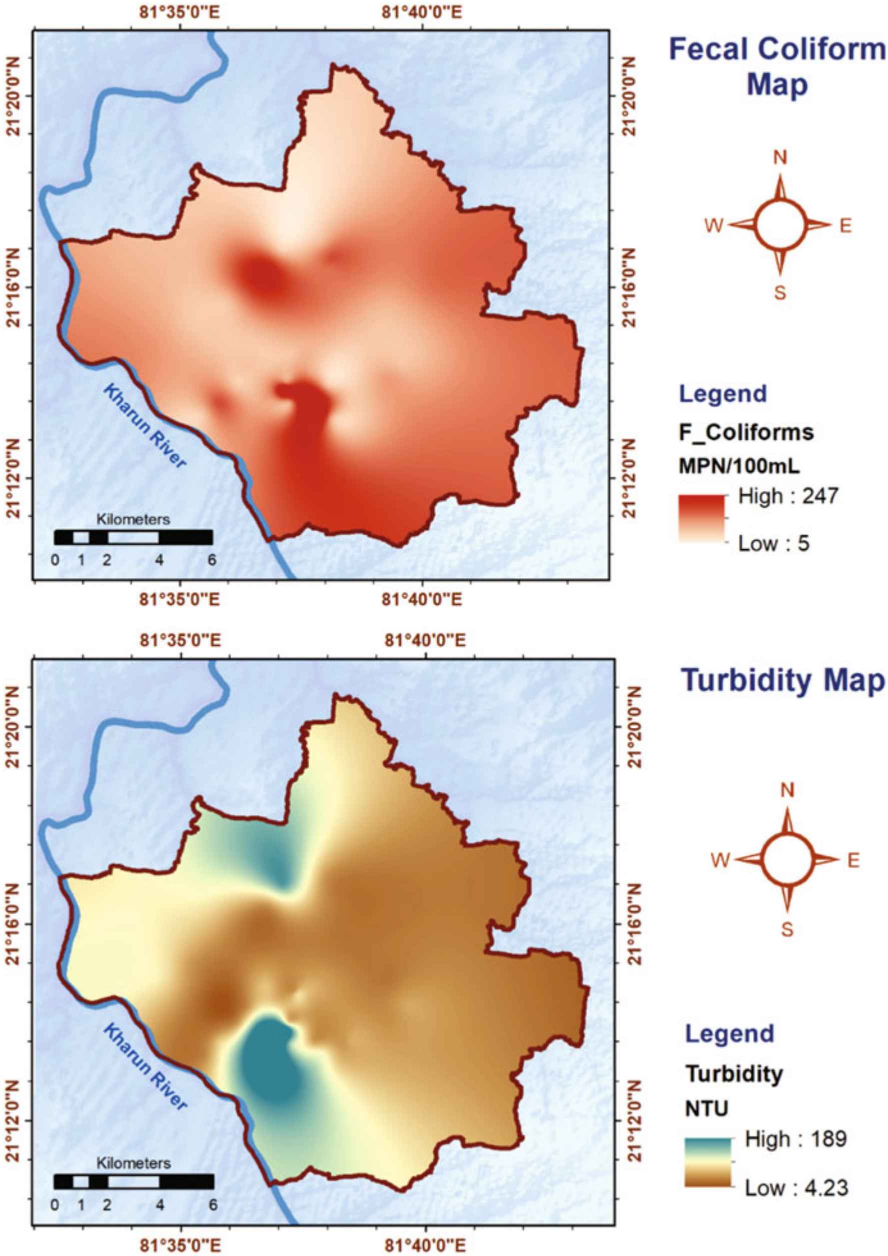

Fig. 15.7 Spatial distribution of fecal coliform and turbidity in the study area

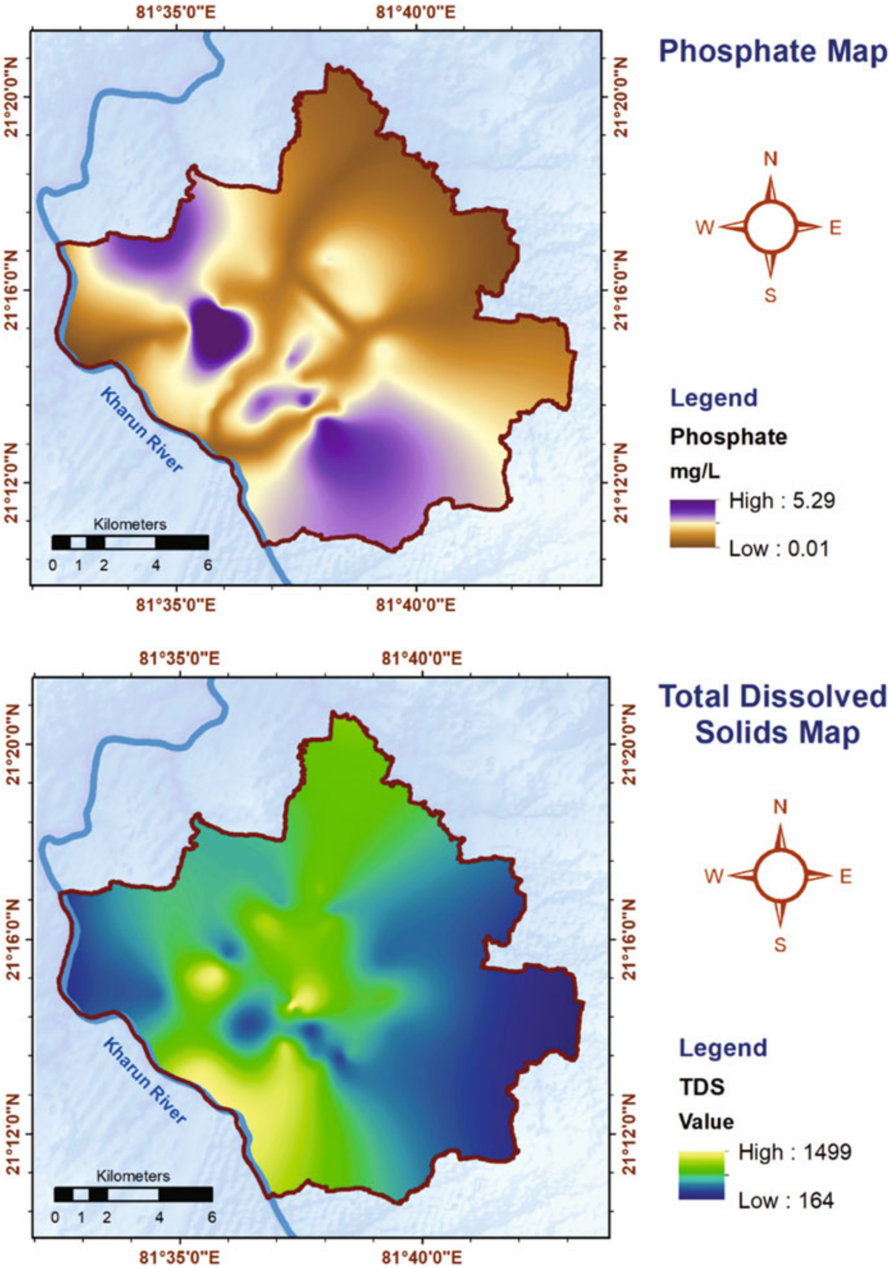

Fig. 15.8 Spatial distribution of total phosphate and TDS in the study area

Table 15.3 Water quality index and the parameters; violating standards based on present criteria

No.	Location_ID	NSFWQI	Category	DO	BOD	SAR	Total coli	pH	EC
1	W02L06	69.40	Medium		•			•	
2	W03L01	62.34	Medium		•	•	•		
3	W04L03	50.29	Medium	•	•				
4	W04L05	56.20	Medium	•		•			
5	W07L01	68.19	Medium				•		
6	W07L02	68.42	Medium						
7	W12L02	47.99	Bad		•				
8	W14L01	42.88	Bad	•	•			•	
9	W15L02	52.33	Medium	•	•				
10	W16L02	55.39	Medium		•	•			
11	W16L03	61.39	Medium			•			•
12	W16L04	71.27	Good						
13	W24L01	65.90	Medium						
14	W25L02	51.12	Medium	•	•				
15	W26L12	64.01	Medium	•					
16	W38L02	57.55	Medium		•	•			
17	W42L01	54.34	Medium	•	•				
18	W43L01	63.55	Medium	•					
19	W49L03	53.10	Medium		•				
20	W49L04	53.73	Medium	•	•				
21	W54L01	57.23	Medium		•	•			
22	W56L01	53.45	Medium			•	•		
23	W57L01	53.06	Medium	•	•				
24	W58L01	55.90	Medium	•	•				
25	W62L03	49.87	Bad		•		•		
26	W64L04	50.64	Medium		•	•			
27	W65L03	41.08	Bad		•	•	•		
28	W65L04	49.53	Bad	•	•				
29	W66L01	54.58	Medium		•				
30	W68L01	48.06	Bad	•	•	•			
31	W68L04	61.23	Medium	•		•			
32	W69L01	63.79	Medium	•	•				
33	W69L02	61.23	Medium		•			•	
34	W70L01	56.23	Medium	•					

CCMEWQI criteria. DO is marginal and SAR and TColi is in fair condition. Table 15.3 displays the sampling location IDs that violates the standard based on present criteria of CCMEWQI.

It was observed in the Table 15.3 that there are 24 sampling locations in which BOD violates the standard of pollution control board. After that DO and SAR violates the standard at 16 and 11 locations respectively. TColi, pH, and EC are violating standard at 5, 3, and 1 location respectively. As all these parameters were

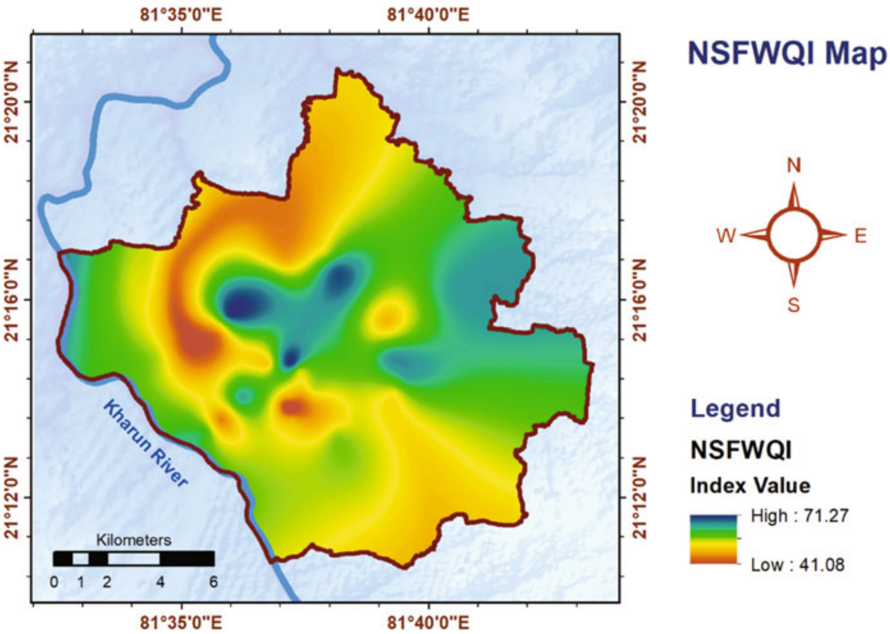

Fig. 15.9 Spatial variation of NSFWQI in Raipur City area

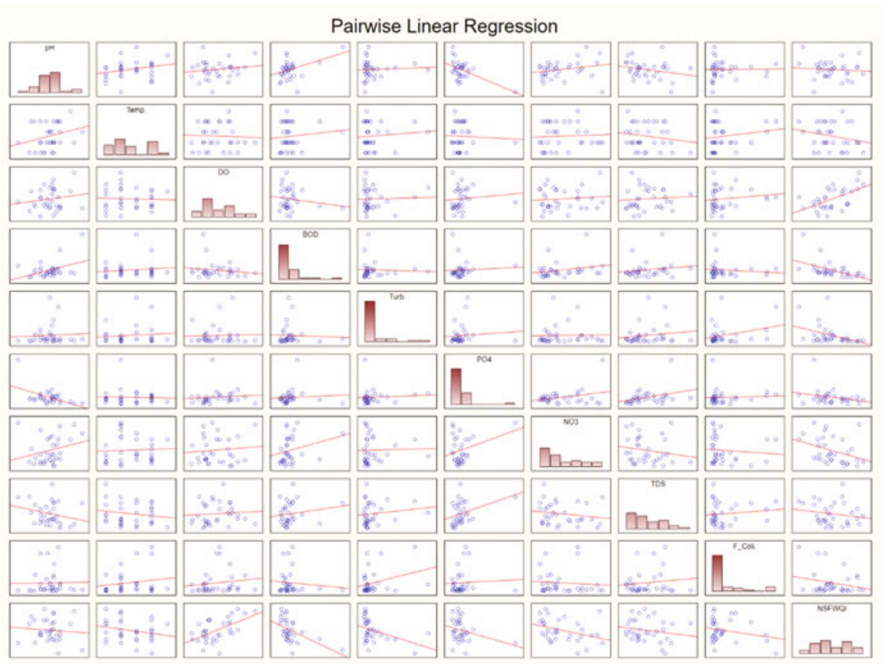

Fig. 15.10 Matrix plots of all water quality parameters used to calculate water quality index

Table 15.4 CCMEWQI analysis for 34 groundwater locations in Raipur city

Parameters	pH	EC	SAR	DO	BOD	Total coli.	NO_3
Total no. of locations	34	34	34	34	34	34	34
Number of failed locations	3	1	11	16	24	5	0
Total no. of tests	136	136	136	136	136	136	136
Number of failed tests	12	4	44	64	96	20	0
F1	8.82	2.94	32.35	47.06	70.59	14.71	0
F2	8.82	2.94	32.35	47.06	70.59	14.71	0
Excursion	0.18	0.04	11.51	10.37	35.25	19.40	0
Nse	0.01	0.00	0.34	0.31	1.04	0.57	0
F3	0.54	0.10	25.29	23.38	50.90	36.33	0
CWQI	92.79	97.60	69.82	59.27	35.30	66.27	100
Category	Good	Excellent	Medium	Bad	Very bad	Medium	Excellent

indicating their functions to make the water suitable for the use of humans, it's important to be on a prescribed limit.

15.4.2 *Dissolve Oxygen (DO)*

An important variable that shows significant effect on the groundwater quality. DO concentration can be used for estimation of the valence state of trace metals. Dissolved oxygen stabilizes the biodegradable substances with the help of living organisms by which quantify the organic contamination in groundwater. In this study DO varies with minimum value of 1.07 mg/l to maximum value of 10.00 mg/l in Raipur city area.

15.4.3 *Temperature (Temp)*

It is required for the estimation of decay and growth rates. Therefore, it is necessary for water quality simulation, it also affects the solubility of DO and other parameters. Temperature is the parameter which affects the acceptability of inorganic and chemical contaminants in water. In this study its value varies from 22 °C to 29 °C. Temperature will alter the odor, color, and taste of water.

15.4.4 pH

The strength of acidity or alkalinity of any solution sample is represented by the pH. There is no health-based guideline for the pH value. It is required for evaluation of chemical and biological processes such as adsorption rate of heavy metals. It has range of 6.53–9.31.

15.4.5 Electrical Conductivity (EC)

It is directly related to TDS. Concentrations of TDS in water depend on different geological regions due to the differences in the solubilities of minerals. For domestic use it is recommended that water should have TDS less than 500 mg/l. If it is more than 1000 mg/l, it imparts unpleasant taste and makes inadequate for other uses. In this study area EC value varies with minimum of 130 to maximum of 1732μΩ/cm.

15.4.6 Nitrate Nitrogen (NO_3)

Naturally the nitrate concentration is low in groundwater but due to the humans it appears in the water body in considerable amount. Nitrate reaches the water body by leaching or runoff from agricultural land or contamination from human or animal wastes as a consequence of the oxidation of ammonia. As per WHO standard for drinking water it should not more than 10 mg/l. In this study nitrate varies from nil to 23 mg/l.

15.4.7 Biochemical Oxygen Demand (BOD)

An important variable which shows the immediate discharge of organic waste in the water. The landfill leachate is one of the major sources of contamination in groundwater. Organic matter mainly comes from the leachate in groundwater. But its composition depends on the age of landfill, composition of landfill waste, and climatic conditions. BOD value ranges from 0.5 to 34 mg/l over the Raipur city area.

15.4.8 Fecal Coliform (FColi)

The presence of fecal coliform indicates the pollution of animal or human waste as it is specifically found in these wastes only. It shows the recent pollution in groundwater system that may have other bacteria, viruses or disease-causing organisms. In this study its values vary from 5 MPN/100 ml to 247 MPN/100 ml.

15.4.9 Phosphate (PO_4)

It enters in the groundwater system from the industrial effluents, manure, laundry and human & animal waste (Khadri and Pande 2015a, b). Phosphate lowers down the DO concentration which causes increase in organic nutrients. It gets attached with the soil particle and thereby moves with groundwater. Phosphate is not toxic to humans or animals unless they are present in very high levels. Phosphate present in the range of 0.01–5.29 mg/l.

15.4.10 Turbidity (Turb)

It is caused due to the presence of suspended matters either chemical or biological, organic or inorganic particle. Turbidity does not cause any direct risk to public health. Sudden change in turbidity gives the idea of considerable pollution attack in the area. It varies from 4.23 to 189 NTU in Raipur city.

15.4.11 Total Dissolved Solid (TDS)

TDS involves both the inorganic salts as Cl, Mg, Na, HCO3, Ca, and S and some organic matter in dissolved state. The high value of TDS concentration does not indicate that the water is hazardous for consumption, but it indicates that the water has aesthetic problems. Groundwater contains mineral ions.

15.4.12 Total Coliform (TColi)

It represents the presence of bacteria. Groundwater mostly contaminated by bacterial load due to the runoff from forming fields, untreated sewage discharge and effluent from septic system. Well water supply affected due to deficit construction quality and maintenance practice. Infiltration of animal and house hold fecal matter increases the risk in the groundwater system. This study witnessed the value of 28 MPN/100 ml to 320 MPN/100 ml over the Raipur city area.

15.5 Conclusion

The contradictory research findings in relation to these measures clearly point to the significant role played by location specific factors influencing water quality rather than purely land use. The underlying processes and concepts relating to urban water quality are well known in a qualitative sense. However, their quantification has proved to be extremely difficult. Chemical processes exert a strong influence on urban storm water quality characteristics. Rainfall and the resulting surface runoff transport a variety of materials of chemical and biological origin to the nearest receiving water body and subsequently recharged to groundwater. This results in the groundwater fundamentally changed from its natural state. Urban expansion transforms local environments and can dramatically alter local conditions and in particular the rate of movement of pollutants into waterways, thereby adversely changing the quality of water. The primary sources include lawn fertilizer, sewer overflows, animal waste, vegetation debris, industrial activities, vehicle exhausts, power generation, and atmospheric dry and wet deposition. Some of the atmospheric pollutants in the solute or gaseous phases will undergo further synthesis due to physical or chemical processes. Results show that the organic load is more, which could be due to inadequate and deficiently designed, operated, and managed individual and community toilets in the urban poor areas resulting in open defection. This leads to pollution and sever health impacts. The sewage management system is deficient in city of Raipur which is evident from the fact that roughly 54% of the properties are connected to unscientifically designed septic tanks, part of which overflows into the open drains/areas ultimately draining into the natural water bodies. The outcomes of the study are required put in front of public, local administrator and government to aware them the condition of groundwater in their area. It is the need of the hour to work on a scientific and feasible planning for efficient groundwater quality management policy implementation.

Acknowledgments The authors would like to thank the Deutscher Akademischer Austauschdienst- German Academic Exchange Service (DAAD), as the research material is based upon work within the program “A New Passage to India”. One of the authors would like to acknowledge the help in field data collection provided by LIH workgroup.

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