

# Chapter 8

## Groundwater Vulnerability Assessment Using Drastic Method: A Case Study of Bhilwara District, Rajasthan



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**Abstract** Globally, groundwater (GW) is a significant source of fresh water utilized in home, commercial, industrial, and other applications, as well as in ecosystem support. As a result, Rajasthan, a desert state in India, has experienced groundwater quality issues caused by both man-made contaminants and naturally occurring hazardous minerals. With a land size of 10,445.1 square kilometers, the Bhilwara district is situated in southern Rajasthan. Since groundwater contamination will directly influence human health, it is important to evaluate how it is affected by the availability of minerals, the rise in anthropogenic activities, and the number of mining companies. The DRASTIC model, based on a geographic information system (GIS), was used in this study to create a susceptibility vulnerability map of the groundwater system. Adding Land Use (LU) maps from the research area has further upgraded the DRASTIC maps. Using a technique called hotspot mapping, it is possible to forecast how many significant hotspots will be present in the area under study and to find the sources of contamination. The water quality index and overlay approach were also used to understand the state of vulnerability better. The results showed that the index value has seven subclasses and spans from 100 to 205. The DRASTIC and DRASTIC–LU maps were linked with the nitrate concentration map for validation. It was discovered that the Sahara, Mandal, and Raipur blocks are particularly susceptible to the rapid increase in nitrate concentration. The highest percentages of TA, TDS, and  $\text{NO}_3^-$  (100%) are found in the entire dataset.

**Keywords** Groundwater vulnerability · DRASTIC · Rajasthan · Land use

### 8.1 Introduction

To raise awareness of the condition of groundwater, the word vulnerability was first used in France in 1960 (Vrba and Zoporozec 1994). Across several segments of the globe, groundwater is an important resource of drinking water. A significant health

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risk will result from GW becoming polluted. All around the world, especially in rural areas, emerging nations, numerous megacities, and industrialized regions, it is a vital source of water supply. Through farming, industrialization, garbage disposal, sewage, and the leaching of pesticides and fertilizers, it has succeeded in getting more and more contaminated every day. According to Rao and Mamatha (2004), biological, organic, and inorganic processes are responsible for contaminating 70% of the nation's surface water resources.

India has 3.287 million km<sup>2</sup> of land area and surpassed one billion people in population in 2000. The amount of precipitation that falls on average each year is roughly 4000 km<sup>3</sup>, of which 700 km<sup>3</sup> directly evaporates, 1150 km<sup>3</sup> flows by way of superficial water, and the residual 3000 km<sup>3</sup> infiltrates into the soil, of which 2150 km<sup>3</sup> is used to compensate for the soil's lack of moisture, 1650 km<sup>3</sup>. The other 500 km<sup>3</sup> is utilized only to fill the groundwater reservoir (Singh et al. 1997).

690 km<sup>3</sup> of India's yearly water resources are surface water, while the remaining 450 km<sup>3</sup> are groundwater. Together, these 1140 km<sup>3</sup> of water resources can be used annually. Approximately 84% of the overall water used in the nation is castoff for irrigation, followed by roughly 4.4% for drinking water and community use, 4% for commerce, 3.6% for the creation of new energy sources, and the remaining 4% for other services. By 2025, the country would require approximately 1050 km<sup>3</sup> of water yearly due to the rising demand for water needed to cultivate supplementary sustenance ounces for the expanding inhabitants, which is anticipated to grasp up to 1.25 billion people by that time. Year 2000 saw a 750 km<sup>3</sup> annual water requirement for India.

Ajmer, Rajsamand, Bundi, and Chittorgarh are to the north, west, east, and south, respectively, of Bhilwara, which has a population of 20,13,789 (Hydrogeological Atlas in Rajasthan, Bhilwara District 2001). Several mining companies are currently operating in the area, which has been reported to contain a range of minerals, including lead, zinc, soapstone, China clay, feldspar, quartz, garnet, silver, beryllium, mica, asbestos, barite, agate, and kyanite (district survey) disclosed in 2017. Since there are many minerals available and mining and anthropogenic activities are expanding daily, it is crucial to establish the impact on water quality because groundwater pollution directly affects human health. People should take precautions because, according to WHO (1998), water-borne diseases are the primary cause of most illnesses affecting humans. It is also impossible to exaggerate how crucial it is to safeguard water supplies and give people access to high-quality water that will meet their needs after seeing this scene. The appropriate steps must be taken in order to appropriately plan, develop, conserve, and manage the existing water resources.

### ***8.1.1 Scope of the Work***

According to earlier studies, the Bhilwara district has not yet had its risk assessed, despite the fact that the entire region is undergoing tremendous economic growth and advancement. Due to extensive urbanization and mining operations, the possibility

of groundwater contamination has dramatically increased in this region. The fact that the aquifer is the only substantial source of water supply for all kinds of needs in the examined area contributes to the development of a sufficient understanding of the aquifer's health and groundwater quality. With a focus on the DRASTIC model, the current work will review the methods already in use for assessing groundwater vulnerability before using them to determine the susceptibility of groundwater in the Bhilwara district.

### **8.1.2 Objectives**

The prime objective of current investigation is to evaluate the groundwater vulnerability of Bhilwara district, Rajasthan, India, using DRASTIC method. The specific objectives are as follows:

- To evaluate the susceptibility of groundwater to contamination using DRASTIC model for Bhilwara district.
- To explore comparison between DRASTIC and modified DRASTIC model after integrating Land Use attribute.
- To explore the water quality (WQ) status of the region by estimating the violations in standards and calculating WQ Index to interpret the pollution scenario of the region through overlaying of various thematic maps.

## **8.2 Study Area**

### **8.2.1 General Depiction**

Bhilwara, the southernmost district of Rajasthan, is encircled by other districts in all four directions. It has a topographical area of 10,445.1 km<sup>2</sup>, located between the latitudes of 25° 00' 38.87" and 25° 57' 53.70" N and 74° 00' 31.67" and 75° 27' 46.25" E. Overall, it has 11, 1753 towns and villages. With lows as low as 7.3 °C in January and highs as 46 °C in June, January is the district's coldest month. August has the greatest relative humidity of any month (79.30%). April has the lowest relative humidity of any month (18.71%). August is the month with the most days with rain (17.43 days). December had the fewest days with precipitation (0.57 days). The difference in precipitation between the wettest and the extremely dry month is 245 mm (10 in.).

### 8.2.2 Topography

This district is rectangular in shape with undulating plains where western portion is broader than the eastern one. The hills that are in the southeastern and western direction follow a trend from northeast to southwest. Banas River enters the Bhilwara district, flows from west to east, and exits from South West (SW) to North East (NE).

### 8.2.3 Geological Setup

Out of the four Supergroups, the Bhilwara Supergroup occupies the most land. Along the major boundary fault, a few conglomerates and shale, sandstone, and limestone make up the Vindhyan Supergroup. The Proterozoic-aged Delhi Supergroup comprises two groups, Gogunda (a larger group than Kumbhalgarh Group) and its equal, the Alwar Group. West of the district is where the Paleoproterozoic Aravalli Supergroup is exposed. It is represented by the Dovda Group and characterized by metamorphic rocks that underwent amphibolite metamorphism under the influence of greenschist facies. The Sandmata Complex, Hindoli Group, Mangalwar Group, Jahazpur Group, and Pur-Banera Group all comprise the Bhilwara Supergroup. The location map of study area is shown in Fig. 8.1.

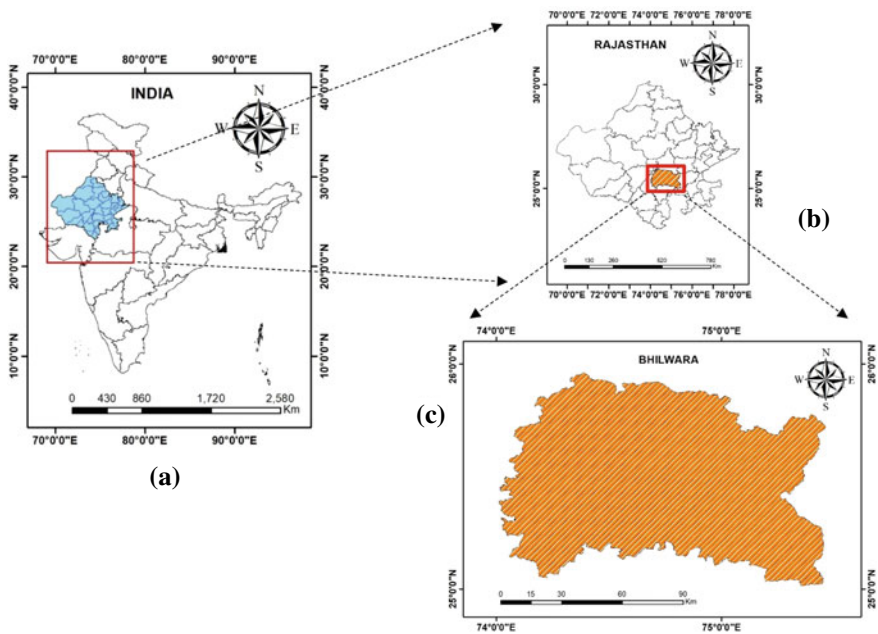


Fig. 8.1 Location map of study area: a India, b Rajasthan, and c Bhilwara

## 8.2.4 *Hydrogeology*

The literature of the Bhilwara region revealed the existence of two aquifer systems, the first phreatic in nature and the other non-homogeneous and distributed isostatically throughout the territory. Weathered gneisses make up the top layer of the substratum in the center. Most likely, the northernmost section is coated in weathered gneiss beneath a thin layer of alluvium. Major formations that include water include gneisses and schist. Muscovite schist develops foliation, and irregular joints are invaded by granite, pegmatite, and quartz veins due to temperature and pressure changes. The contact between these intrusive and schists creates a beneficial conduit for groundwater circulation.

## 8.3 *Methodology*

### 8.3.1 *Introduction*

The assumptions on which the DRASTIC method is based are:

1. GW pollution follows at the surface of the ground.
2. Contaminants are brought into groundwater by rainwater.
3. It has the freedom of movement to water.
4. The mapping zone assessed by means of DRASTIC should be 0.4 km<sup>2</sup> or more than this (Aller et al. 1987).

### 8.3.2 *Procedure*

- The final vulnerability map, which is known as a DRASTIC map, is the combinations of initial letters of all seven parameters that have been created in different steps of the procedure given below:
- The extent to the hydrological parameters such as water table, recharge, and type of aquifer media, soil type, local topography, rainfall statistics, and hydraulic conductivity are taken into account while making a map for each attribute. Combining these parameters in the spatial database will produce the DRASTIC INDEX map. Further reclassification of the DRASTIC INDEX map will have the vulnerability map of the area. Arc GIS 10.1 software creates these single maps and the overall vulnerability map.
- DRASTIC index number is determined by augmenting every single constraint rating by its assigned weightage and then combining it together, which is ranked on a scale of 1–10. The highest number, like 10, indicates an increased rating of contamination potential of the constraint.

- DRASTIC vulnerability index is calculated by a linear sequence of each parameter with a specific symbol for each, which is shown below.
- DRASTIC vulnerability index (VI), Eq. (8.1):

$$DVI = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w \quad (8.1)$$

- $D_r$  Ratings to the depth to water table,
- $D_w$  Weights given to the depth to water table,
- $R_r$  Ratings for scales of aquifer recharge,
- $R_w$  Weights for aquifer recharge,
- $A_r$  Ratings designated to aquifer media,
- $A_w$  Weights designated to aquifer media,
- $S_r$  Ratings for the soil media,
- $S_w$  Weights for the soil media,
- $T_r$  Ratings for topography,
- $T_w$  Weights designated to topography,
- $I_r$  Ratings assigned to vadose zone,
- $I_w$  Weights allotted to vadose zone,
- $C_r$  Ratings for rates of hydraulic conductivity,
- $C_w$  Weights given to hydraulic conductivity.

- Using original DRASTIC parameters with their rating and assigned weight, the DI equation to calculate DRASTIC Index will become Eq. (8.2):

$$D_I = D_r * 5 + R_r * 4 + A_r * 3 + S_r * 2 + T_r * 1 + I_r * 5 + C_r * 3 \quad (8.2)$$

- Finally, the DRASTIC vulnerability map is categorized as per the area prone to contaminant. Now, the extension of the DRASTIC vulnerability map is DRASTIC—LU map in which all the previous parameters used in DRASTIC map will be same; only the new parameter Land Use will be added to the modified DRASTIC map ( $D + R + A + S + T + I + C + LU$ ).
- Now the modified equation will become to calculate DRASTIC—LU Index is: DI Eq. (8.3)

$$-LU = D_r * 5 + R_r * 4 + A_r * 3 + S_r * 2 + T_r * 1 + I_r * 5 + C_r * 3 + LU * 5 \quad (8.3)$$

The overall summary of methodology is shown in Fig. 8.2

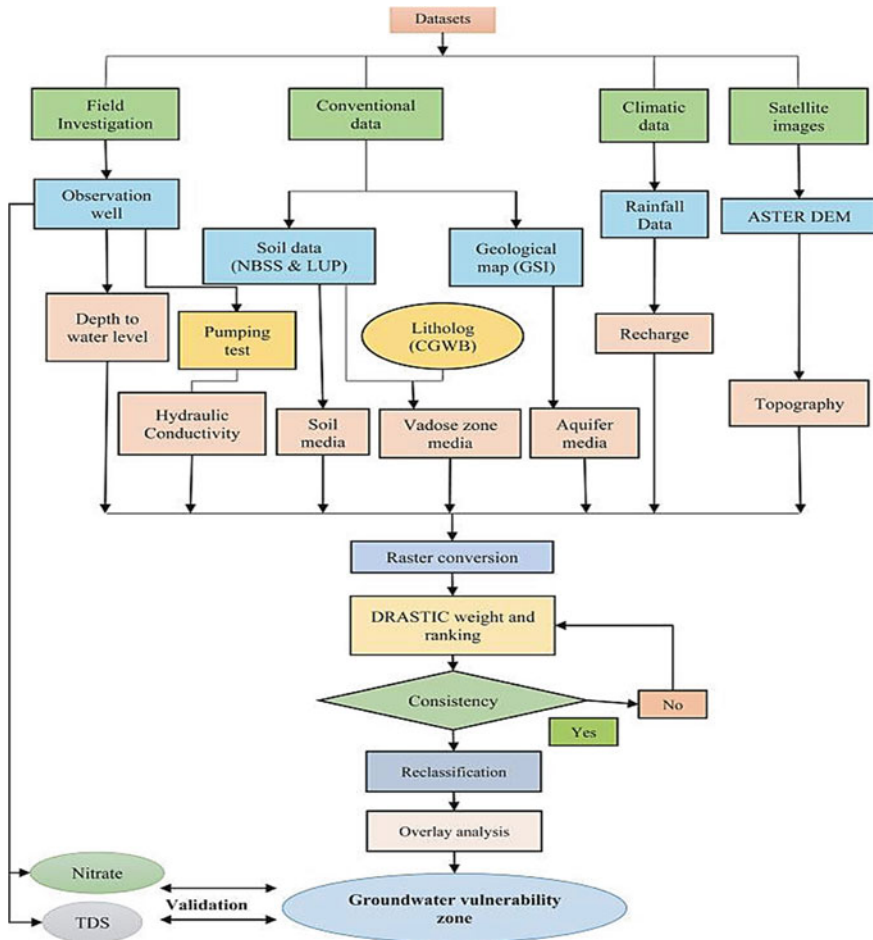


Fig. 8.2 Flowchart representing the methodology

### 8.3.3 Preparing Layer Maps

#### 8.3.3.1 Depth to Water Table

It displays the distance among the ground surface to the water table. There is a decreasing likelihood of contamination with depth. Nearly 80 wells were sampled to gauge the groundwater level. The groundwater table stretches between 1 and 350 m below the surface. The data has been tabulated using depth and location as input parameters in the ArcGIS 10.1 spatial analyst tool to interpolate using an IDW approach and reclassify it according to the reclassified algorithm.

### **8.3.3.2 Net Recharge**

There are some parameters that can be used to test a vulnerability, such as net recharge. To test the vulnerability, knowing how much water runs deep down into the ground during a rain event is necessary. As a result, more precipitation will cause a higher net recharge. A key parameter in determining recharge is rainfall. Data for the year 2019 has been taken from IMD for the Bhilwara district with five rainfall gauge stations. The amount of rain from these gauges has been used to calculate net recharge with interpolation using IDW in ArcGIS 10.1.

### **8.3.3.3 Aquifer Media**

The capacity of an aquifer's formations to store water is indicated by their degree of consolidation or consolidation. The aquifer with the largest water storage capacity will be the best one. When creating the aquifer media map, the inputs utilized to reclassify the map include the study area's lithology (Aller et al. 1987).

### **8.3.3.4 Soil Media**

The amount of water infiltration that occurs below the unsaturated layer is determined by the soil media. Many organic materials are found in soil, which increases the likelihood of biological activity there. Data from the National Bureau of Soil Survey and Land Use Planning was utilized to create this map, which was then divided into three groups using digital technology (loamy, clay loamy, and loamy).

### **8.3.3.5 Topography**

The study area topography depicts the slope variance. Along with flow rate, steep slope, gentle slope, heavy runoff, and low runoff are also impacted. An elevation map has been produced using ASTER DEM as an input parameter. Aquifer media have been divided into four classes by examining the local lithology and utilizing the reclassification tool in Arc GIS.

### **8.3.3.6 Impact of Vadose Zone**

The vadose zone is the region from the ground surface to the upper part of the water table and lies in the unsaturation zone through which water percolates into the water table. The material permeability substantially impacts the vadose area recharge rate and pollutant migration.



### **8.3.4 Violation**

A cumulative density graph between concentration and %file was created. A cumulative density graph of water quality parameters was plotted between concentration and percentage. The values that were discovered following the crossing must be deducted from one hundred ( $X - 100$ ), and the outcome reveals that values over the standard are %age violations. When creating a thematic map to illustrate which area has been exhibited more % violation and which area has less, the value of each parameter's station was entered into the formula below. The greater the %age of parameters that are violated, the more clearly those parameters are over their normal range and have an adverse effect on human health.

$$\text{Violation} = \{(\text{Parameter value} - \text{Standard value}) / \text{Parameter value}\} * 100$$

### **8.3.5 Mapping of Hotspots**

The hotspot map indicates that how much a source of contamination is present in this area. This map is prepared using the input data from Google Earth, CGWB report, and state pollution control board (SPCB).

### **8.3.6 Overlay Analysis**

#### **8.3.6.1 Overlay of Vulnerability Map with % Violation Parameter Map**

To compare the vulnerability map with individual %age violation parameter, overlay method was used where %age violation parameter was overlaid over vulnerability map in Arc GIS.

#### **8.3.6.2 Overlay of Hotspot Map with % Violation Parameter Map**

In order to compare the hotspot map with the % violation parameter, an overlay method was used. To do this, the hotspot map and vulnerability map were both added to Arc GIS. Reducing the transparency helped to make both maps transparent, which led to sharpening the features of the overlaid map and making the features of both maps visible together.

### 8.3.7 Calculation of Water Quality Index

The assessed rates of the physicochemical constraints have been used to create the WQI. Ten variables were chosen because of their significance to water quality. pH, TDS, TH, Ca, Mg, Na, K, Cl, NO<sub>2</sub>, HCO<sub>3</sub>, and SO<sub>4</sub> were among them. The Guidelines BIS: 10,500 Indian standards for drinking water were the drinking water standard used in this investigation.

**There are four steps in calculating the water quality: -**

- All of the ten constraints have been given a weight ( $w_i$ ), which ranges from 1 to 5, based on its significance in the overall characteristic of the water. The most significant weight was 5.00, and the least effective was 2. Due to their considerable importance in determining water quality, calcium, magnesium, and total hardness were given the highest weight of 5, and potassium and sulfate were given the minimum weight of 2. Additional constraints for instance pH, TDS, HCO<sub>3</sub>, Na, and Cl were given weights ranging from 1 to 5.
- The relative weight ( $W_i$ ) of the chemical constraints was computed by applying the subsequent equivalence.

$$W_i = w_i / \sum W_i$$

- In accordance with the recommendations of the World Health Organization, a quality rating scale ( $Q_i$ ) for each constraint is calculated by dividing its concentration in each water sample by its equivalent standard. The Indian Standard BIS (2012) is used if the WHO standard is unavailable, and the result is augmented by 100.

$$Q_i = (\text{Concentration}/\text{standard}) * 100$$

- Next, the sub-indices (SI) have been computed to calculate the WQI: SI = Relative weight ( $W_i$ ) \* Quality rating scale  $Q_i$

$$WQI = \sum SI$$

## 8.4 Results and Discussions

### 8.4.1 Evaluation of Vulnerability

#### 8.4.1.1 DRASTIC Model

DRASTIC parameter input data was entered in vector form in Arc GIS 10.1 software. The map was prepared and modified by assigned ratings and weights to all seven constraints extending from 1 to 10 (Aller et al. 1987).

#### 8.4.1.2 Depth to the Water Table

The distance from the surface to the water table is the primary component of what is known as the depth to the water table. In addition, it is involved in a wide variety of chemical and biological processes, which in turn have an impact on the amount of time it takes for contamination to reach the groundwater table (leaching, oxidation, and sorption). If the water table is located very close to the earth's surface, then the likelihood of it being contaminated is increased. Final map generated (Fig. 8.6a) according to (Aller et al. 1987) assign highest weight "5" to depth to water table and rating was classified into seven classes (1, 2, 3, 5, 7, 9, 10) to determine vulnerability by using DRASTIC model generally shallowest water table remark in southern, northern, and western while deepest water observed in eastern part of Bhilwara district generally shallowest water table remark in eastern part of Bhilwara district generally shallowest water table remark.

#### 8.4.1.3 Net Recharge

The precipitation is a highly essential source for groundwater recharge because it enables polluted water to rise precipitously to the water level and then move straight to reach the aquifer. As a result, the possibility of contaminants reaching the water table increases proportionately with the magnitude of the recharge. The net recharge value was computed using the average annual rainfall that was collected from seven rain gauge stations in the Bhilwara district. These stations were located in Bhilwara, Asind, Jahazpur, Kotri, Mandalgarh, and Raipura. The yearly rainfall averaged between 430 and 730 mm. The second final layer was produced after net recharging was given a weight of 4, divided into five groups based on rating (1, 3, 6, 8, 9), and class, respectively (Fig. 8.6b). The region to the southeast and northeast had the lowest rating ranking, which encompassed five blocks: Shahpura, Jahazpur, Kotri, Mandalgarh, and Beejoliya blocks. The region to the southwest had the highest rating, which was noticed in the smaller area that covered the Raipur block.

#### 8.4.1.4 Aquifer Media

The aquifer media deal with the geology and lithology of the research area; corresponding to Aller et al. in 1987, the aquifer media are assigned weight “3” in the DRASTIC model. The likelihood of contamination increases when pre-existing rocks possess high permeability and porosity. In this location, different aquifer formations were documented. Sand and gravel, which have high porosity and high permeability and are more susceptible to contamination, were assigned an “8” rating (Aller et al. 1987) and covered the majority of the Raipur, Sahara, Mandalgarh, Kotri, and Banera blocks, followed by sandstone, which covered a portion of the Beejoliya block, and Dolomite bearing aquifer, which was observed in the Mandalgarh block. Moreover, schist and gneiss are less susceptible to contamination; they were rated “3” due to their low permeability and porosity; they covered most of the study region and generated the final third parameter layer (Fig. 8.6c).

#### 8.4.1.5 Soil Media

The soil medium is responsible for a significant amount of the movement of water deep within aquifers where it is found. In the DRASTIC model, which was developed in 1987 by Aller et al., the weight “2” was given to the soil medium. In addition, the attenuation activities of percolation, biodegradation, sorption, and volatilization may be particularly substantial in regions of the soil when the soil zone is quite thick. The soil media organization has separated soil into two categories, namely loamy and clay loamy, and it was given ratings of five and three for both of these categories (Aller et al. 1987). The majority of the research area is comprised of loamy soil. However, the part that is situated in the north-northeast corner of the study area was composed of clay loam (Fig. 8.6d). To put it another way, loamy soil is more prone to contamination, whereas clay loam is the soil type least prone to contamination.

#### 8.4.1.6 Topography

Topography implies to the slope of the area, how gentle and steep it is. If the site is gentle, then the water will stagnate there for a long time; the chances of pollutant infiltration will be more, and it will be more vulnerable to contamination while in mountainous region because of steep slope where the water does not stop for long, more runoff generation thus reported to less susceptible to contamination. The topography was assigned weight “1” in DRASTIC model according to Aller et al. in 1987. It reflects topography does not play a significant character to assess the vulnerability of any area and it was categorized accordingly into five classes based on rating (10, 9, 5, 3, 1); therefore, the highest rating “10” covered maximum blocks of the study zone while moderate and lowest rating covered some minor area in southeastern and northeastern direction (Fig. 8.6e).

#### 8.4.1.7 Impact of Vadose Zone

Vadose zone always rests above the water table. The below lying formation affects water percolation reaches the aquifer and it has assigned weightage “5” while rating (Aller et al. 1987) accordingly in three classes (3, 4, 6). The material below the normal soil horizon and above the water table attenuates differently depending on the kind of vadose zone media. According to geological profile of this area, vadose zone consists of amphibolite, sandstone, shale, granite, dolomite, gneiss, quartzite, phyllite, schist, and calc-silicates. Formation like sandstone and dolomite was assigned highest rating “6,” and it has more vulnerable to contamination and majorly covered three blocks of southwestern part (Sahara, Mandal, and Raipur); subsequently, the metamorphic rocks were assigned rating “4” and it covers maximum blocks (Beejoliya, Mandalgarh, Jahazpur, Kotri, Shahpura, Bhilwara, Banera, Hurda, Asind) of the study area while Shales has lowest rating and covered minor area of Hurda, Shahpura, Banera, Kotri, and Jahazpur block which indicates the low tendency to retain water inside and become less vulnerable to contamination (Fig. 8.6f).

#### 8.4.1.8 Hydraulic Conductivity

Hydraulic conductivity concerns with the ease with which the water transmitted. The groundwater flow affects the flow of contaminants (Aller et al. in 1987) which weight assigned “3” to this parameter in DRASTIC model. It reclassifies rating into three classes: (a) “1” ( $<0.002$ ), (b) “1” lies in range between 0.2 and 0.5, and (c) “2” lies in range between 0.5 and 2.0. Highest rating display in the maximum portion of the study zone shielded Sahara, Raipur, Bhilwara, Mandal, Asind, Banera, Beejoliya, Mandalgarh, and Kotri, whereas lowest rating “1” assigned to some part of northeastern region covered majorly three blocks (Sahara, Jahazpur, and Kotri) and has low hydraulic conductivity, which means the area is less prone to pollution while the rest area has high value of hydraulic conductivity which is more vulnerable to contamination (Fig. 8.6g).

#### 8.4.1.9 DRASTIC Index

DRASTIC map was created by integrating seven different raster maps together. The finished product is referred to as the vulnerability map. According to the findings, the value can range anywhere from 100 to 205, and it is broken down into seven different subclasses: low vulnerability zone, moderate vulnerability zone, moderate to elevated vulnerability zone (VZ), high VZ, very VZ, and completely VZ. The map that was constructed using color codes can be found in Table 8.2, and it reveals that the majority of the Beejoliya block and a small portion of the Jahazpur block are located in a low vulnerability zone (100–119). This indicates that the location in question is located in a region that has a high slope, hilly terrain, non-porous and non-permeable soil, limited infiltration of water, and an impervious surface. The blocks

**Table 8.1** Color codes  
DRASTIC index

Classes	Index ranges	Color codes
1	Less than 79	Violet
2	80–99	Indigo
3	100–119	Blue
4	120–139	Dark green
5	140–159	Light green
6	160–179	Yellow
7	180–199	Orange
8	200 and above	Red

Source Aller et al. (1987)

**Table 8.2** WQI scales

Water quality	WQI Ramakrishnaiah (2009)	WQI Mohanty (2004)
Excellent	<50	<50
Good	50–100	50–100
Poor	100–200	100–200
Very poor	200–300	200–300
Unsuitable	>300	>300

of Asind, Hurda, Banera, Shahpura, Kotri, Mandalgarh, and Jahazpur are located in an area with a moderate to high vulnerability; the value of this zone ranges from 120 to 179. Very high vulnerability zones include Mandal, Bhilwara, and a portion of Raipur and Sahara; their values range from 180 to 199. Completely vulnerable zones include the majority of the Raipur block and a little sector of Sahara; their values range from 180 to 199 (200 and above), as shown in Table 8.1. It is a sign that the location is located in a region with a gentle slope and a plain terrain, maximum opportunities for water infiltration, porous rock and soil with high permeability and porosity, and a surface that is pervious (Fig. 8.6h).

#### 8.4.1.10 DRASTIC–Land Use (LU) Model

Integrating the LU map into the DRASTIC map resulted in certain changes being made to it. Natural Breaks (Jenks) categorization strategies were evaluated by Ersoy and Gultekin (2013) and determined to be appropriate for use in dividing the ranges for the DRASTIC–LU model. The index value can range from 100 to 250 and is divided into five different classes. The areas of Bhilwara, Asind, and a portion of Banera are classified as belonging to a very high vulnerability zone, with an index value that ranges from 163 to 214. On the other hand, the majority of Asind, Banera, Shahpura, Kotri, and Jahazpur are classified as belonging to a high vulnerability zone (144–163). The plain terrain and mild slope in that location, both of which have

maximum potential for seepage of water inside the aquifer, as well as the rocks that are present in the research area, are two of the possible reasons why extremely high vulnerability to high vulnerability exists in the area. It has the ability to hold onto water, in contrast to loamy soil, which helps more contaminants to become ingrained in the ground. It is clear from examining the similarities and differences between the DRASTIC model and the DRASTIC–LU model that the DRASTIC–LU model is superior to the DRASTIC model. This is because there are more anthropogenic activities being included as a parameter, each of which plays an essential part in the poisoning of groundwater. Regarding the land use category, agriculture was carried out across the entirety of the research region. When compared with the DRASTIC map, which reveals the high vulnerability formed in the southwestern portion of the region, the DRASTIC–LU map shows that the impact of agricultural operations can be seen quite clearly (Fig. 8.6j).

## 8.4.2 Validation

### 8.4.2.1 Drastic

In order to validate the DRASTIC map, it was combined with the nitrate concentration map. It was discovered that nine water samples fall into the low to moderate vulnerability zone, with concentrations ranging from 1.69 to 70 mg/L encompassing the eastern portion of the district. Eight samples of water with a medium concentration of nitrate (70–120 mg/L) fall in a zone of high vulnerability, covering Kotri, Banera, and Hurda, while eight samples of water with a high concentration of nitrate (120–283 mg/L) fall in a zone of extreme vulnerability, covering Raipur block and a portion of the Sahara block (Fig. 8.3).

### 8.4.2.2 DRASTIC–LU

The nitrate values in the study area vary from 1.69 and 283 mg/L, respectively, and it can be seen from the spatial distribution of the parameters when DRASTIC–LU map integrated with nitrate concentration map; Raipur, Sahara, and some part of Mandal are completely vulnerable area in which concentration of nitrate is getting very high (120–283 mg/L). The agricultural contaminants mix up with the recharge water and further contaminate the groundwater. The nine lowest nitrate concentration samples generally fall in the eastern part of the district which belongs low to moderate vulnerability zone, and chance of contamination was less likely (Fig. 8.4).

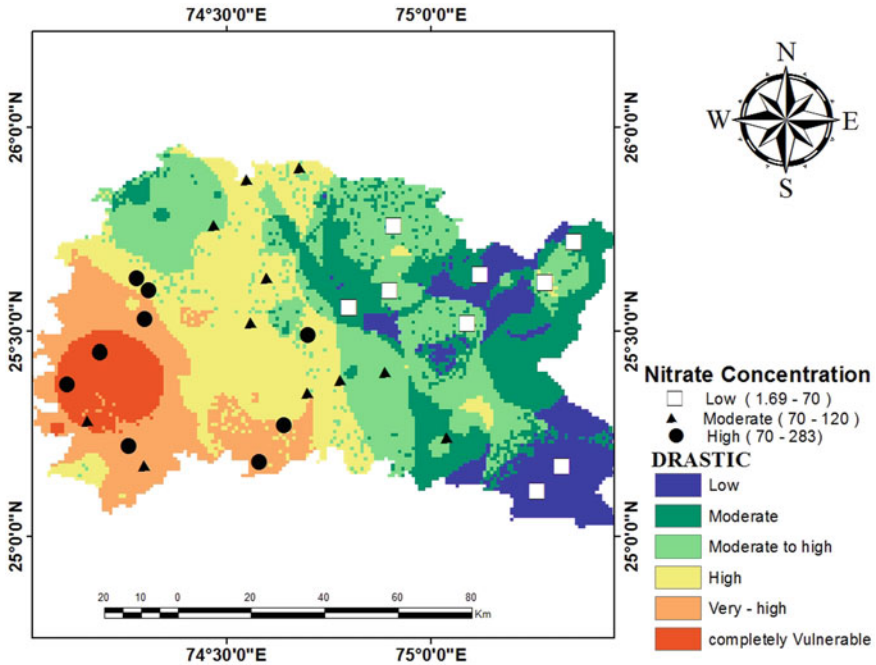


Fig. 8.3 Nitrate distribution over DRASTIC vulnerability map

### 8.4.3 Evaluation of %Age Violation W.R.T Drinking Water Standard

#### 8.4.3.1 % Violation on the Basis of the Overall Dataset

Percentage violation is generated for those stations whose value is above its standard.  $\text{NO}_3^-$ , TA, and TDS show that 100% violation which means 100% values are above than its standard. TDS % and  $\text{NO}_3^-$  % violation evidently draw attention to the impact of anthropogenetic undertakings in the groundwater quality. The value that was found after the calcium intersection shows that 78% values are less than standard and 22% value is higher than standard because of some geochemical process like dissolution, leaching, and precipitation of calcium bearing rocks and mineral (sandstone, limestone, calcite, and dolomite) which further help to uplift the calcium concentration and responsible for causing hardness in groundwater. Magnesium graph shows 20% values are less than standard and 80% values lie above standard, it shows highest %age violation, and along with hardness, its deficiency also causes loss of appetite, fatigue, and weakness while its exorbitance causes gastrointestinal problems, such as diarrhea, nausea, or cramping. Sodium %age violation graph is taken out; it shows 40% values lie below standard and 60% lies above while chloride shows 55% values lie below standard and 45% lies above standard; it shows no harmful effect on human



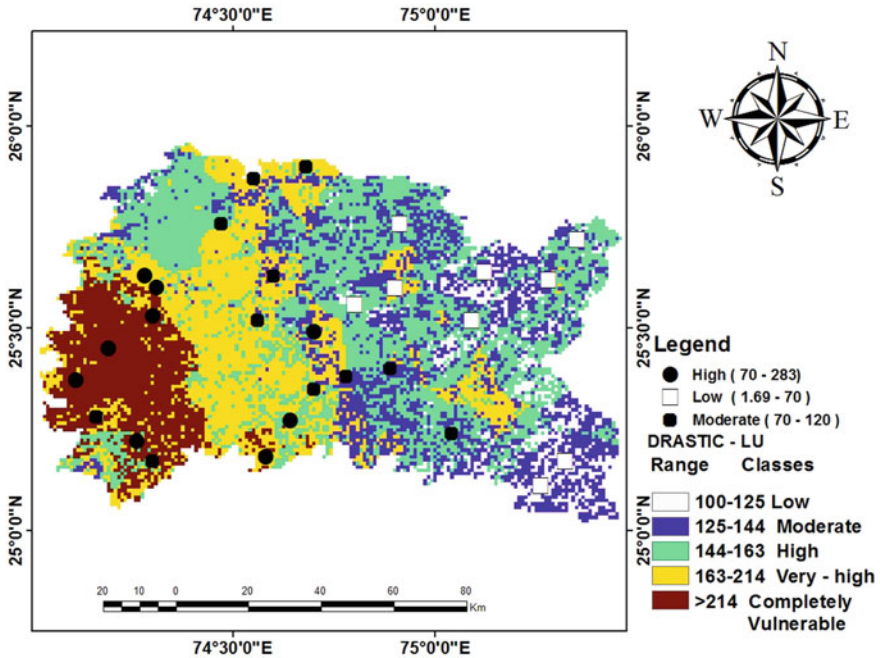


Fig. 8.4 Nitrate distribution over DRASTIC–LU vulnerability map

but causes salty taste if present in high quantity; sulfate shows 62% values are less than standard and 38% values lie above standard; its concentration increases due to leaching Glauber’s salt or Epson salt; and its high concentration causes objectionable taste and causing unwanted laxative effect. The high concentration of iron is very toxic; its %age violation value is 42%. Industrial activities happening in the surrounding region were the reason of having such high value of violation while TH shows 56% %age violation.

**8.4.3.2 Spatial Representation of % Violation**

The violation %ages are calculated for every station, and the spatial representations are made using the kriging method in ArcGIS 10.1, suggesting that the highest violation is found in this location, while the lowest violation is located in this location. Moreover, the TDS, Cl (chloride), NO<sub>3</sub> (nitrate), and SO<sub>4</sub> (sulfate) parameters play an important role from the viewpoint of anthropogenic activities, where TDS and sulfate (Fig. 8.7b, c) are generally higher in Sahara, Bhilwara, and Jahazpur which indicates a greater level of anthropogenic activities. The highest %age violation of chloride has been observed in the northeastern and southwestern directions, mainly in the Shahpura, Jahazpur, Bhilwara, Sahara, and Raipur blocks; therefore, Beejoliya, Banera, Asind, and Hurda areas have a much lower %age violation, indicating that

these areas are less affected by anthropogenic activity. Figure 8.7d shows moderate to high %age violations in the southern direction, covering Bhilwara, Sahara, Raipur, Mandal, Asind, and some parts of Banera. A geological activity has caused the presence of  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ ,  $\text{Na}^+$ , TH,  $\text{Fe}^{++}$ , and TA in groundwater. Calcium shows (Fig. 8.7i) the highest %age in eastern part of the area and covered Jahazpur, Shahpura, and Bhilwara blocks, while Magnesium shows (Fig. 8.7f) the lowest value of %age violation in Mandal, Asind, and Hurda blocks. Sodium and TH show the high value of %age violation in such areas, viz. Bhilwara, Kotri, Shahpura, and Jahazpur. In the district, only Shahpura, Kotri, and Jahazpur showed more than 1% violation in iron, while TA showed % violation in just three places (Shahpura, Kotri, and Jahazpur).

## 8.4.4 Overlay

### 8.4.4.1 LU Map and DRASTIC Map Overlay with Hotspot Map

Even less experienced users may understand the idea of overlaying data layers. Additionally, as the majority of data currently comes in a digital format, the data need might be seen as modest. Information on hydrogeology is either already known or might be inferred using pertinent data. Consequently, these approaches produce generally accurate answers for vast regions with a complicated geological structure. Finally, water resource managers may quickly understand the outcome of this strategy and use it to inform their decision-making. Important contamination hotspots may be seen on the vulnerability map even with only a cursory visual examination. The inherent subjectivity in determining the rating scales and the weighting factors is perhaps the most significant and evident drawback of these systems noted by scientists and professionals.

When the LU and DRASTIC maps are superimposed on top of the hotspot map (Fig. 8.5), it can be seen that the western segment of the region is home to the majority of the region mining and agricultural activity. This is one of the primary contributors to the district's high level of vulnerability. It has been observed that the maximum number of hotspots can be found in the Bhilwara block and the Hurda block, both located close to vulnerable districts. As a result, there is a possibility that the water in this region will be exposed to a higher level of danger and will be more likely to become polluted. The Bhilwara block has the highest rate of urbanization, which has a variety of negative effects on the urban settlement and takes the lead to an expansion in the amount of surface water and groundwater that is polluted. As a result of the fact that groundwater can be a source of contamination, these locations must be inspected regularly.

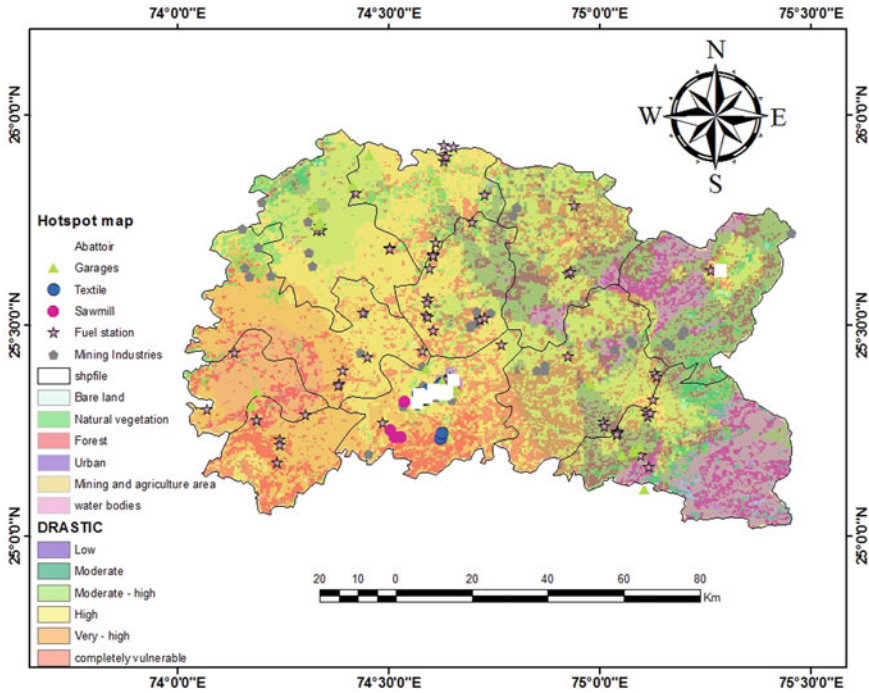
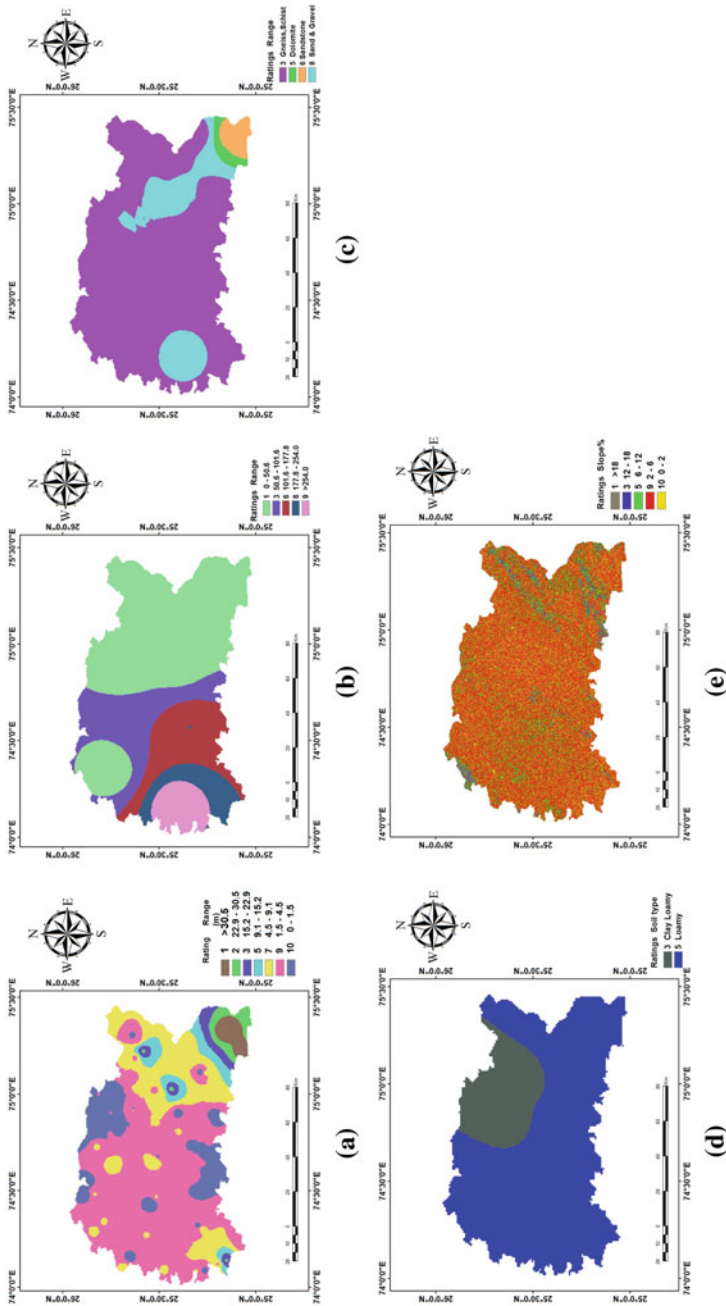


Fig. 8.5 DRASTIC, LU, and hotspot overlay map

### 8.4.4.2 Overlay Violation Parameter with DRASTIC Vulnerability Map

Sub-regional and regional size vulnerability maps are often used. They are often not used for assessments that are site-specific, especially zones that are less than a few tens of square kilometers. To accurately determine groundwater susceptibility, several methods have been devised. The majority of these methods rely on analytical tools to link land use with groundwater pollution. Process-based simulations, statistical techniques, and overlay and index approaches are the three different categories of assessment methodologies. Numerical modeling is a component of process-based techniques, which are helpful at the local level but not the regional one. Statistical methods demand a considerable amount of site-specific data and entail linking real water quality data to geographical characteristics. By assigning a numerical index, overlay and index methods stress the inclusion of different zonal maps. In the GIS, both processes are easy to apply, particularly when using a zonal measure. As a result, these techniques are the most often used for vulnerability estimates.

A process typically changes in many directions is known as percentage violation. Based on the analysis of the collected data, it was discovered that the value of TA and TDS indicates the highest value of % violation. In contrast, the value of pH shows the lowest value of % violation. When the vulnerability map was overlaid



**Fig. 8.6** Input maps for DRASTIC MODEL **a** Depth to water table **b** Recharge **c** Aquifer media **d** Soil Media **e** Topography **f** Impact of vadose zone **g** Hydraulic Conductivity **h** DRASTIC Vulnerability map **i** LU map **j** DRASTIC—LU map

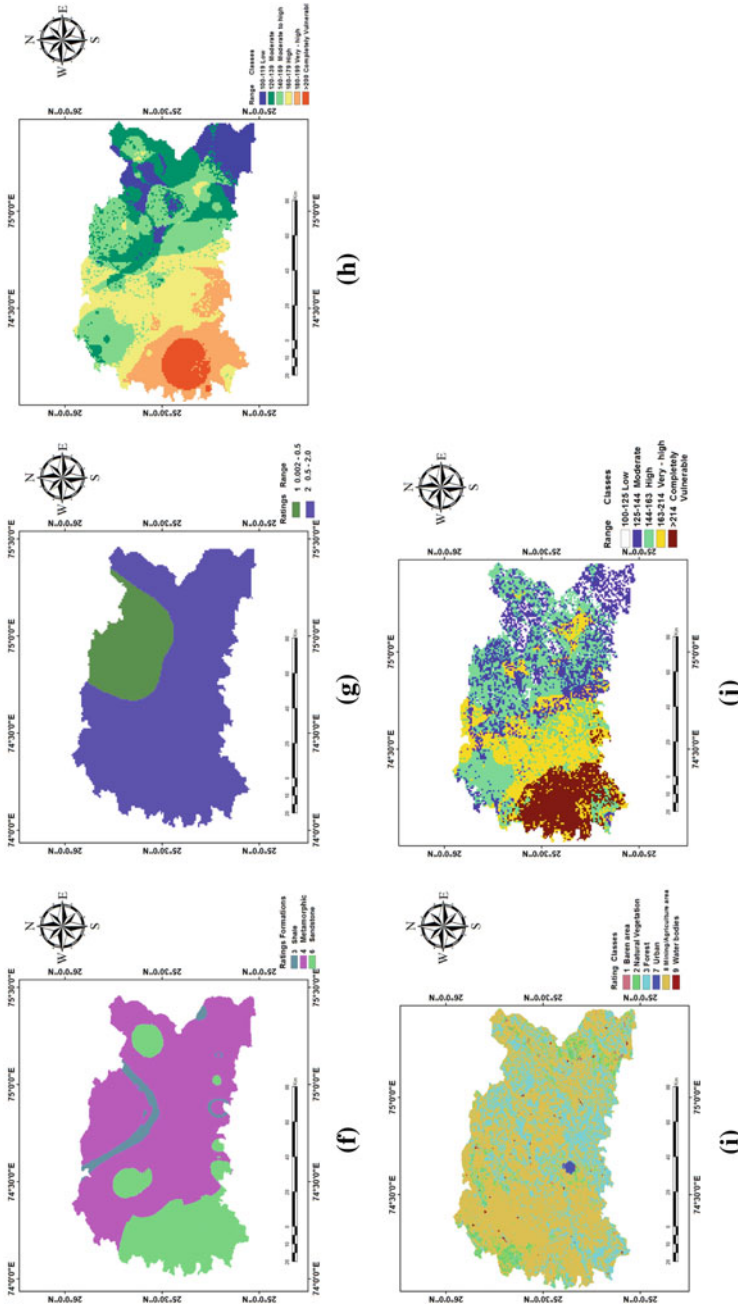
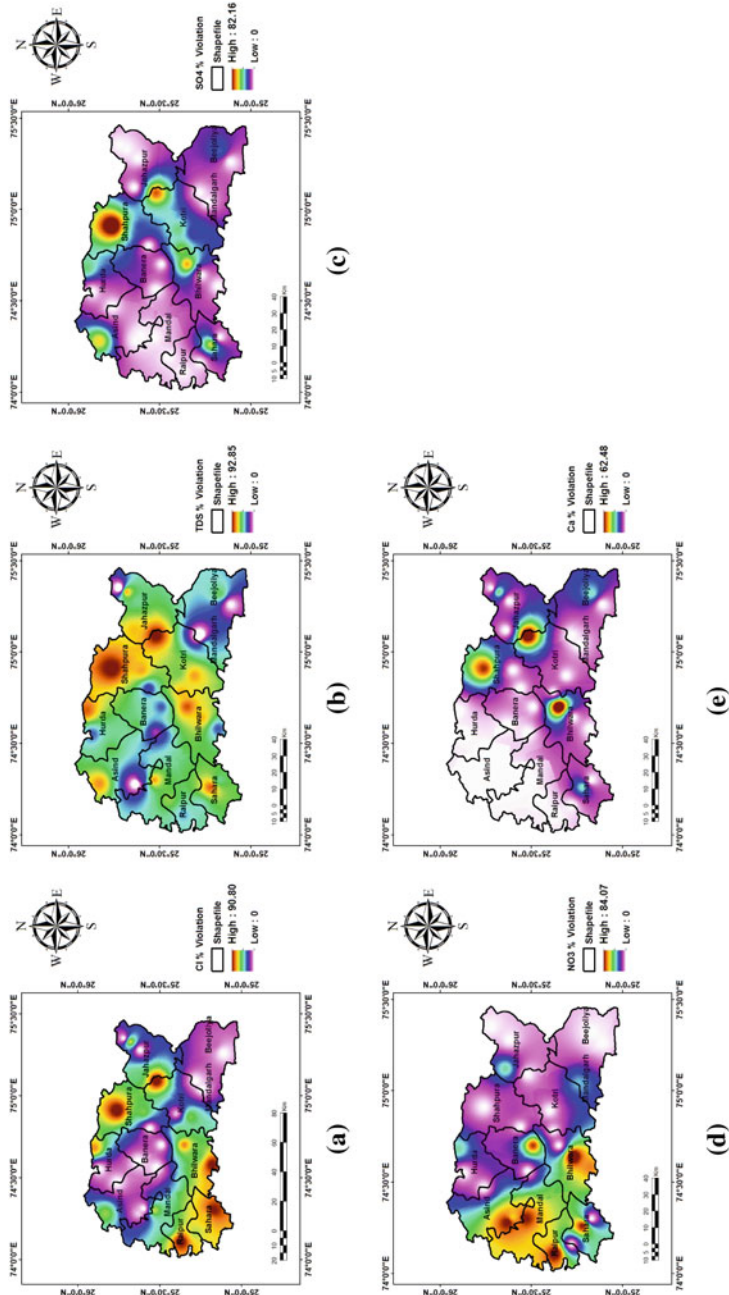


Fig. 8.6 (continued)



**Fig. 8.7** % Violation maps of **a** Cl<sup>-</sup> **b** TDS **c** SO<sub>4</sub><sup>2-</sup> **d** NO<sub>3</sub><sup>-</sup> **e** Ca<sup>++</sup> **f** Mg<sup>++</sup> **g** Na<sup>+</sup> **h** Fe<sup>++</sup> **i** TA **j** TH

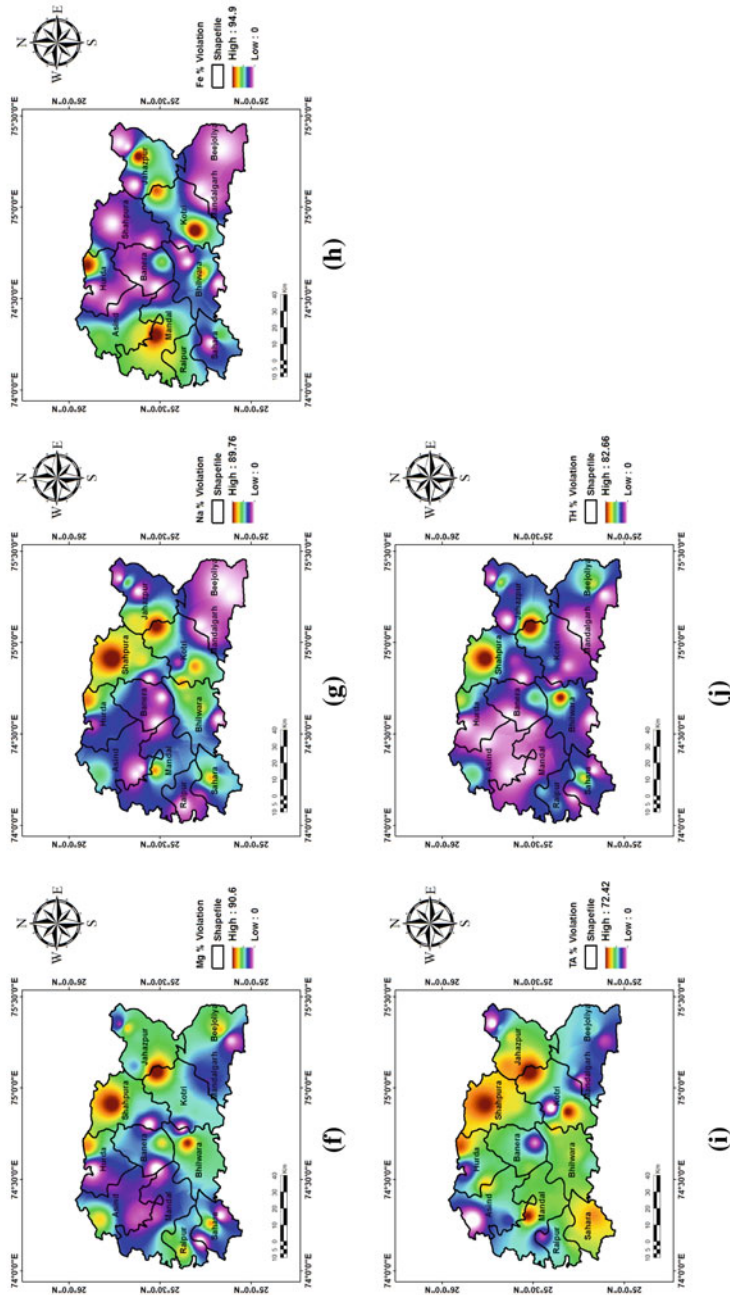


Fig. 8.7 (continued)

with each violating parameter individually, it was discovered that the Ca % violation (Fig. 8.6a) was greater in the northeastern part, which covered Jahazpur, Shahpura, and Bhilwara, all of which belong to the moderate vulnerability zone. Likewise, the Mg % violation was greater in the east and the west, with high concentrations being observed in Bhilwara, Banera, Beejoliya, Kotri, and Jahazpur; it was discovered that the district as a whole had a greater %age of violations. It was observed from the layered map that the violation % of Na (Fig. 8.6c) was higher toward the southern and northern parts of the Bhilwara area, whereas the Cl concentration elevated in the northeastern and southwestern parts, which resulted in the water having a salty taste in that particular region. A higher %age of total alkalinity being violated was discovered in zones rated as moderately vulnerable to extremely highly vulnerable or entirely vulnerable, indicating that these zones are very susceptible to industrial and chemical contamination. Similarly, TDS exhibits the highest trend toward northern, southern, covered Sahara, and Raipur blocks. Higher violations were recorded in the corners in all four directions for Fe. However, the SO<sub>4</sub> overlaid map with vulnerability represented the relatively small area coverage of the northeastern region and the Bhilwara block. Nitrate concentrations are rising in the southwest region, which is classified as extremely sensitive to vulnerable. The zone of moderate to high vulnerability contains the whole hardness value at its highest.

#### **8.4.4.3 Overlay Violation Parameter with Hotspot Map**

The soil medium is responsible for a significant amount of the movement of water deep within aquifers, where it is found. In the DRASTIC model, which was developed in 1987 by Aller et al., the weight “2” was given to the soil medium. In addition, the mitigation practices of percolation, biodegradation, sorption, and volatilization may be particularly significant in regions of the soil when the soil zone is quite thick. The soil media organization has separated soil into two categories, namely loamy and clay loamy, and it was given ratings of five and three for both of these categories (Aller et al. 1987). The majority of the research area is comprised of loamy soil, but the part that is located in the north-northeast corner of the study area was comprised of clay loam (Fig. 8.6d). To put it another way, loamy soil is more prone to contamination, whereas clay loam is the soil type that is least prone to contamination. The findings are shown in Figs. 8.9 and 8.10.

#### **8.4.5 Water Quality Index (WQI)**

The weighted arithmetic WQI approach that was established for groundwater constraints characterizes the overall excellence of water depending on the extent of purity for any deliberate purpose. This approach was established for the purpose of groundwater parameters. This approach was developed specifically for analyzing groundwater properties. The values of the individual samples for the water quality

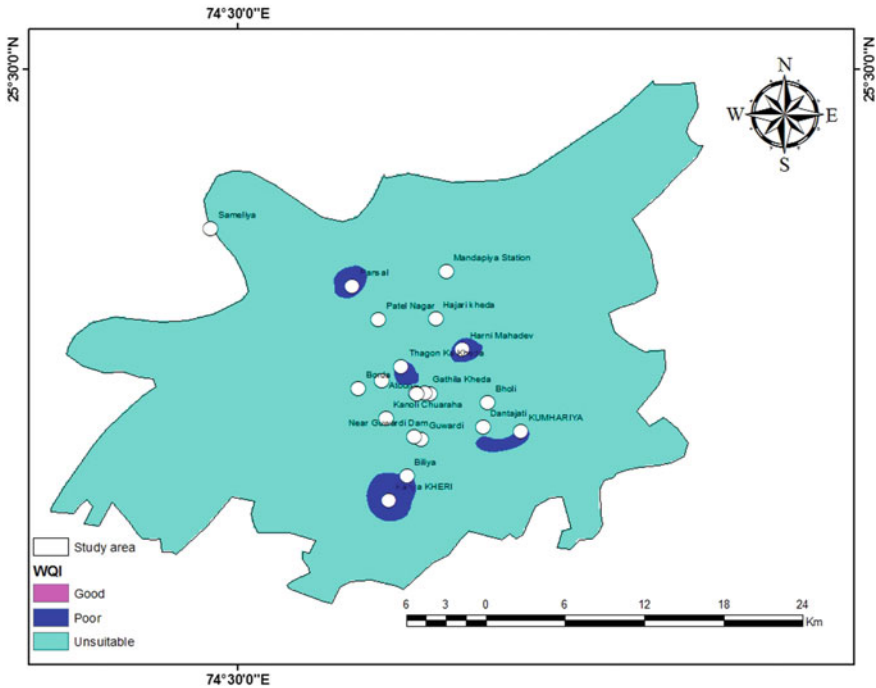


index as well as the types of water that are contained in each sample are documented in Table 8.3, which can be located further down the page. It is a mathematical equation that summarizes a set of data relevant to water quality into language that can be understood by the average person (excellent, good, poor, etc.) The WQI for the Bhilwara district extends from 92 to 791, which shows that the water quality in this region is both poor and unsuitable for consumption or use. The quality of the groundwater samples was evaluated as follows: Ten % were classified as “good,” eighteen % were rated as “poor,” and seventy-two % were assessed as “unsuitable.”

You can view the work that was completed in the past for certain aspects of the water quality index on this page (Saini et al. 2020, Multivariant Statistical Analysis of Bhilwara, Bhilwara district, Rajasthan; Internship report). Corresponding to the extent that was developed by Ramakrishnaiah et al. (2009) and Mohanty (2004), the following is how the water quality index value is broken down: According to this classification, the vast majority of the water quality tests that were taken in the Bhilwara region fall under the category of improper water type. Near Guwardi Dam, the readings on the water quality index are among their highest, followed by Bholi.

**Table 8.3** Water quality classification

Location	WQI	Type
Sharda dream city colony	341.82	Unsuitable
Gathila Kheda	198.18	Poor
Sangam University	245.58	Unsuitable
Patel Nagar	595.72	Unsuitable
Dantajati	236.81	Unsuitable
Pansal	340	Unsuitable
Sangam University	264.00	Unsuitable
Kanoli Chuaraha	277.83	Unsuitable
Atoon	251.13	Unsuitable
Sameliya	555.00	Unsuitable
Thagon Ka Kheda	160.74	Poor
Harni Mahadev	92.06	Good
Kumhariya	177.98	Poor
Bholi	791.89	Unsuitable
Hajari Kheda	550.98	Unsuitable
Mandapiya Station	398.56	Unsuitable
Borda	274.20	Unsuitable
Biliya	183.77	Poor
Guwardi	527.79	Unsuitable
Swarup Ganj	446.79	Unsuitable
Kanya Kheri	93.78	Good
Near Guwardi Dam	638.00	Unsuitable

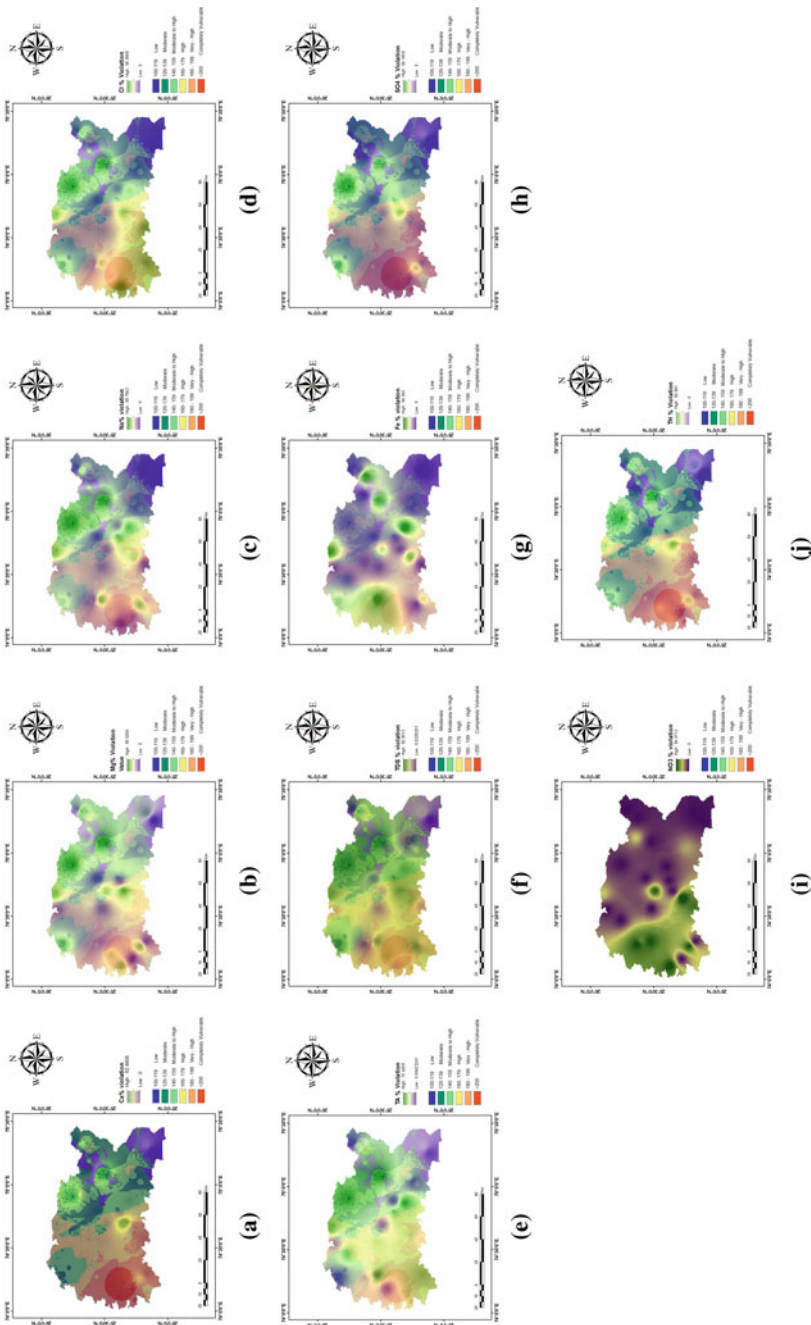


**Fig. 8.8** Spatial representation of WQI

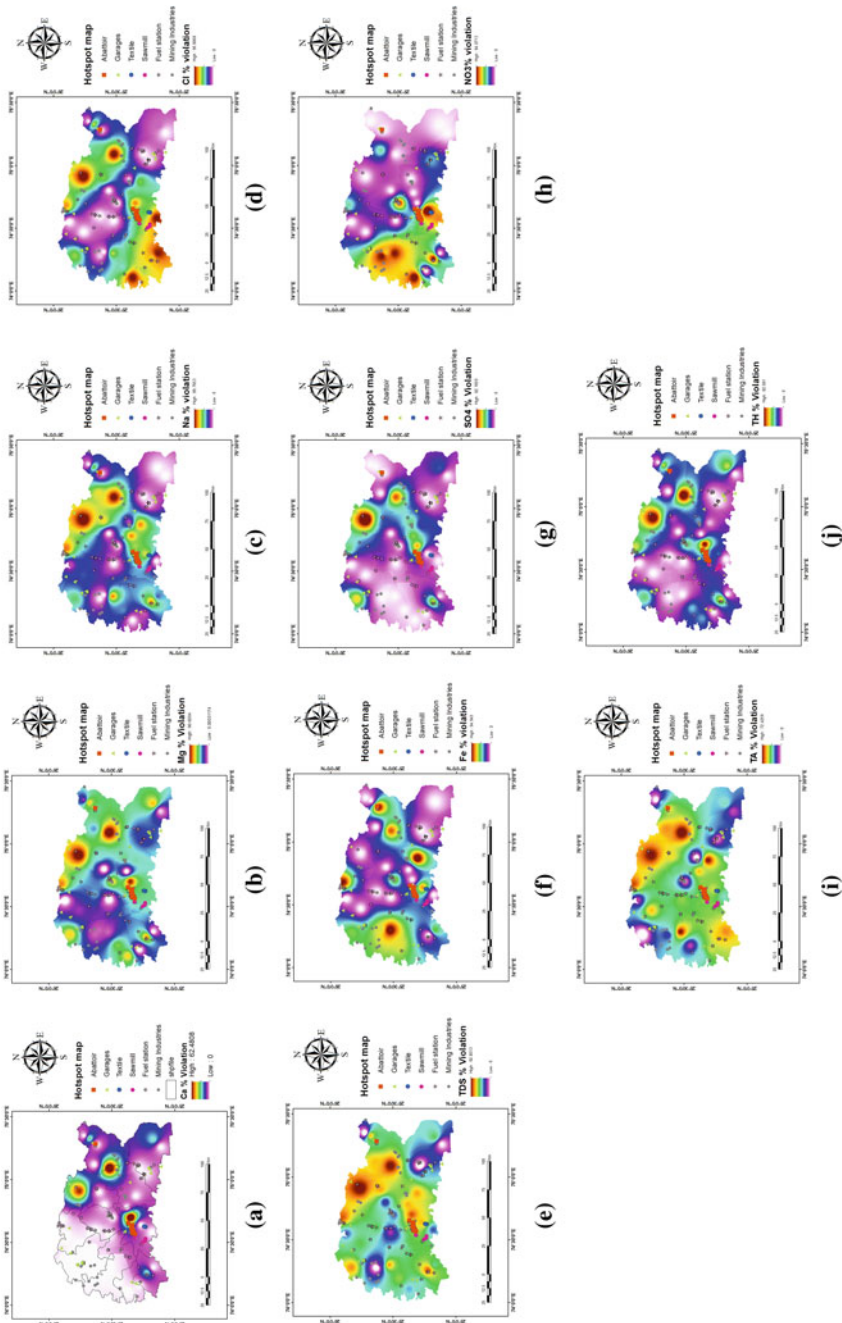
The values are at their absolute minimum close to Harni Mahadev. The high value of WQI in the region around Bholi and Guwardi Dam (Fig. 8.8) could be attributable to the presence of heavy metals (chromium, lead, zinc, and iron) in the open wells of the surrounding villages, or it could be the result of agricultural practices. Both of these explanations are plausible. When compared, the water at Harni Mahadev has a higher quality than the water at Kanya Kheri. In accordance with the findings, each and every well had a WQI that was higher than 90, and the results demonstrated that the water quality varied depending on the location of the wells. The quality of the water is established on the scale as suggested in Table 8.2.

## 8.5 Conclusions

In developing nations urban centers with fast population growth, the vulnerability assessment of the groundwater is an important area of research. Due to the declining groundwater level and rising pollution, which constitute a major danger to the ecosystem, groundwater vulnerability is a pressing problem everywhere in the globe. Numerous studies have been conducted to evaluate the groundwater sensitivity using various techniques in order to detect this risk. Process-based approaches, statistical



**Fig. 8.9** Overlay Vulnerability map with **a** Ca<sup>+</sup> % violation **b** Mg<sup>++</sup> % violation **c** Na<sup>+</sup> % violation **d** Cl<sup>-</sup> % violation **e** TA % violation **f** TDS % violation **g** Fe<sup>++</sup> % violation **h** % violation **i** SO<sub>4</sub><sup>--</sup> % violation **j** NO<sub>3</sub><sup>-</sup> % violation **h** TH % violation



**Fig. 8.10** Overlay Hotspot map with **a** Ca<sup>++</sup> % violation **b** Mg<sup>++</sup> % violation **c** Na<sup>+</sup> % violation **d** Cl<sup>-</sup> % violation **e** TDS % violation **f** Fe<sup>++</sup> % violation **g** SO<sub>4</sub><sup>--</sup> % violation **h** NO<sub>3</sub><sup>-</sup> % violation **i** TH % violation

methods, and overlay and index methods are often used in this context. One overlay and index approach for assessing vulnerability is the DRASTIC method. The goal of this research project was to develop the DRASTIC vulnerability map by thoroughly examining the depth to the water table, net recharge, aquifer types, soil profile, topography, and hydraulic conductivity. After analyzing the information from a rigorous field study, the following conclusions have been made:

1. According to the vulnerability map result, the value ranges from 100 to 205 and is classified into six subclasses. The resulted map revealed that the major northeastern and minor north-southern parts are in the low vulnerability zone (100–119), the moderate vulnerability zone (120–139), the moderate to high vulnerability zone (140–159), the high vulnerability zone (160–179), and the very high vulnerability zone (180–199), while the Raipur and Sahara are in the super vulnerable zone (>200).
2. The DRASTIC–LU map illustrates that 15–20% of the district area is in the southwestern part, which is a high vulnerability zone. Low vulnerability has been reported in the northeastern part of the district.
3. It was discovered when the DRASTIC–LU map was validated with the nitrate concentration map. Bhilwara, Sahara, and a portion of Raipur are completely vulnerable areas, with index values ranging from >214, while the majority of Mandal, Banera, and Hurda are in the high-vulnerable zone, with nitrate concentrations extending from 120 to 283 mg/L. Low to moderate vulnerability index values ranging from 100 to 144 reported in Shahpura, Beejoliya, Jahazpur, Mandalgarh, and Kotri in the Bhilwara district indicate low contamination, with nitrate concentrations ranging from 1.69 to 70 mg/L.
4. The Bhilwara block is the block with the most contamination sources out of the 12 blocks shown on the hotspot map. This block's water is highly vulnerable to contamination and at risk. Total soluble solids (TDS), chloride (Cl), nitrate (nitrate), and sulfate (SO<sub>4</sub>) characteristics all play a very important role from the perspective of anthropogenic activities. TDS and sulfate are typically more evident in Sahara, Bhilwara, and Jahazpur, signaling that more anthropogenic activities are actually happening in these blocks. Chloride exhibits the highest %age violation in the northeastern and southwestern directions, mostly covering the Shahpura, Jahazpur, Bhilwara, Sahara, and Raipur block. As a result, the low %age violation discovered in Beejoliya, Banera, Asind, and Hurda indicates that these areas are less impacted by anthropogenic activity. In the southern direction, which includes Bhilwara, Sahara, Raipur, Mandal, Asind, and a portion of Banera, nitrate displays moderate to high %age violations. Due to geogenic processes, groundwater contains Ca<sup>++</sup>, Mg<sup>++</sup>, Na<sup>+</sup>, TH, Fe<sup>++</sup>, and TA. Magnesium exhibits the lowest amount of %age violation, while calcium exhibits the greatest, covering the Jahazpur, Shahpura, and Bhilwara blocks in the eastern portion of the area. In certain locations, specifically Bhilwara, Kotri, Shahpura, and Jahazpur, sodium and TH exhibit a significant %age of violations. In such common blocks as Mandal, Bhilwara, Kotri, and Jahazpur, iron exhibits the maximum %age violation value.

5. Data analysis revealed that pH exhibits the least amount of % violation, while the values of TA and TDS show the highest %ages of violation. When the vulnerability map was overlaid with each violating parameter separately, it became clear that Ca% violation surpassed toward the northeastern half, covering Jahazpur, Shahpura, and Bhilwara, and Mg exceeds toward the east and west, with high concentrations found in Bhilwara, Banera, Beejoliya, Kotri, Jahazpur, and Shahpura. The overlaid map showed that the Na violation %age was higher in the southern and northern parts of the Bhilwara area, while the Cl concentration was higher in the northeastern and southwestern parts, causing the water in that area to have a salty taste. In zones that were moderately to extremely vulnerable or entirely vulnerable, there was a higher %age of total alkalinity violations, indicating that there was significant chemical and industrial pollution in these areas. Similar to TDS, the covered Sahara and Raipur blocks in the north and south exhibit the highest trends. While SO<sub>4</sub> overlaid map with vulnerability depicts the modest area coverage of the northeastern region and Bhilwara block, higher violation was recorded in the corners of all four directions for Fe. Nitrate concentration is rising in the southwest, a region that is extremely vulnerable to entirely vulnerable.
6. By overlaying the hotspot map with the violation parameter map, it was noticed that there were four similar blocks, namely Bhilwara, Sahara, Shahpura, and Jahazpura, where the concentration of each parameter was extremely high. Sahara is in a very high vulnerability zone, Shahpura is in a low vulnerability zone, Jahazpura is in a moderate vulnerability zone, and Bhilwara is one of the blocks in the Bhilwara district where the majority of the hotspots are located (Abattior, Garages, textile, sawmill, fuel station, mining industries).
7. The majority of Bhilwara water quality samples fell into the category of inappropriate water, according to the WQI. The greatest WQI values are found near Guwardi Dam, followed by Bholi, while the lowest values are found at Harni Mahadev. The presence of heavy metals (chromium, lead, zinc, and iron) in open wells in the villages or possible agricultural practices seem to be responsible for the high value of WQI near Bholi and Guwardi Dam. Water quality is best at Harni Mahadev and then at Kanya Kheri. The findings showed that all wells had WQI values above 90 and that water quality varied depending on where it was found. It is abundantly obvious that the water in this region is highly contaminated or dangerous because the value of % violation is similarly high and belongs to a high-vulnerable area. As a result, the region has to be examined, and the sources of contamination need to be addressed.

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