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ORIGINAL ARTICLE

Groundwater vulnerability assessment of Hoshangabad and Budni industrial area, Madhya Pradesh, India, using geospatial techniques

Rakesh Ahirwar[1,2] · **Mohammad Subzar Malik**[2] · **Jai Prakash Shukla**[1,2]

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Abstract

The quality of groundwater can be determined by hydrogeological formations which vary geographically. Subsurface geology has significant role in governing the movement and quality of groundwater. The present study aims assessment of groundwater contamination vulnerability in Hoshangabad and Budni industrial area using the DRASTIC model approach. The model is hybridization of the seven parameters that provides input to the model. In the model, rating and weightage to each parameter were assigned as per the relative significance of the parameter in groundwater contamination. Groundwater contamination vulnerability index (GWVI) has been computed by integrating of these data layers in ArcGIS environment. The obtained GWVI in the area varies from 66 to 170, which was further divided into five zones, i.e. (1) very low GW contamination zone, (2) low GW contamination zone, (3) moderate GW contamination zone, (4) high GW contamination zone and (5) very high GW contamination zone. Further, the model has been validated by analysing the sulphide concentration in groundwater of the delineated GW contamination vulnerable zones. The model has been found effective for the prevailing hydrogeological settings of the area. The model can serve as an effective tool for the concerned authority, social workers and government/non-organizations for the management of groundwater resources in the area. Further, application of the GIS technique has been found useful in preparing the database of each variable of the model.

Keywords DRASTIC model · Groundwater contamination vulnerability index · Geological setting · ArcGIS · Hoshangabad and Budni industrial area

Introduction

Groundwater is an indispensable substance to humankind for the sustenance of life on the earth (Gordon et al. 2008) that should be managed properly (Samake et al. 2011; Gupta 2014) by employing new scientific methods. The presence and quality of water depends upon geographical location. Our globe contains total 1400 million cubic kilometre area, out of which 97% is covered by oceans as saline water, 2% is present in the form of solid (locked in ice caps and glaciers) and the remaining 1% fresh water flows in lakes, rivers, ponds, wells, etc. Half part of the fresh water is stored as groundwater (Balasubramanian 2015). The term groundwater vulnerability is related to the groundwater contamination process and its harmful factors (Qian et al. 2012). Groundwater vulnerability to contamination term was first coined by Margat (1968). Groundwater vulnerability to contamination concept depends on the assumption where physical, environmental and human activities are against to groundwater (Prasad and Shukla 2014). Groundwater hazard evaluation can be described as calculation capacity of the area to the contamination from the nearby surface up to the groundwater (Rebolledo et al. 2016). It is the very helpful factor for the proper land use and sustainable natural management (Ghosh et al. 2015).

Maps of aquifer contamination vulnerability are in high demand and serve as useful tool because groundwater is the main source of drinking water in many parts of the globe (Neshat et al. 2014a, b; Shrestha et al. 2016). The high rate of groundwater consumption in different sectors, e.g. domestic, industrial and agricultural, became the potential cause of decline in water table as well as sources of groundwater

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✉ Rakesh Ahirwar
gis07rakesh@gmail.com

[1] Academy of Scientific and Innovative Research (AcSIR), CSIR-Advanced Materials and Processes Research Institute (CSIR-AMPRI) Campus, Bhopal, Madhya Pradesh 462026, India

[2] CSIR-AMPRI, Bhopal, Madhya Pradesh 462026, India

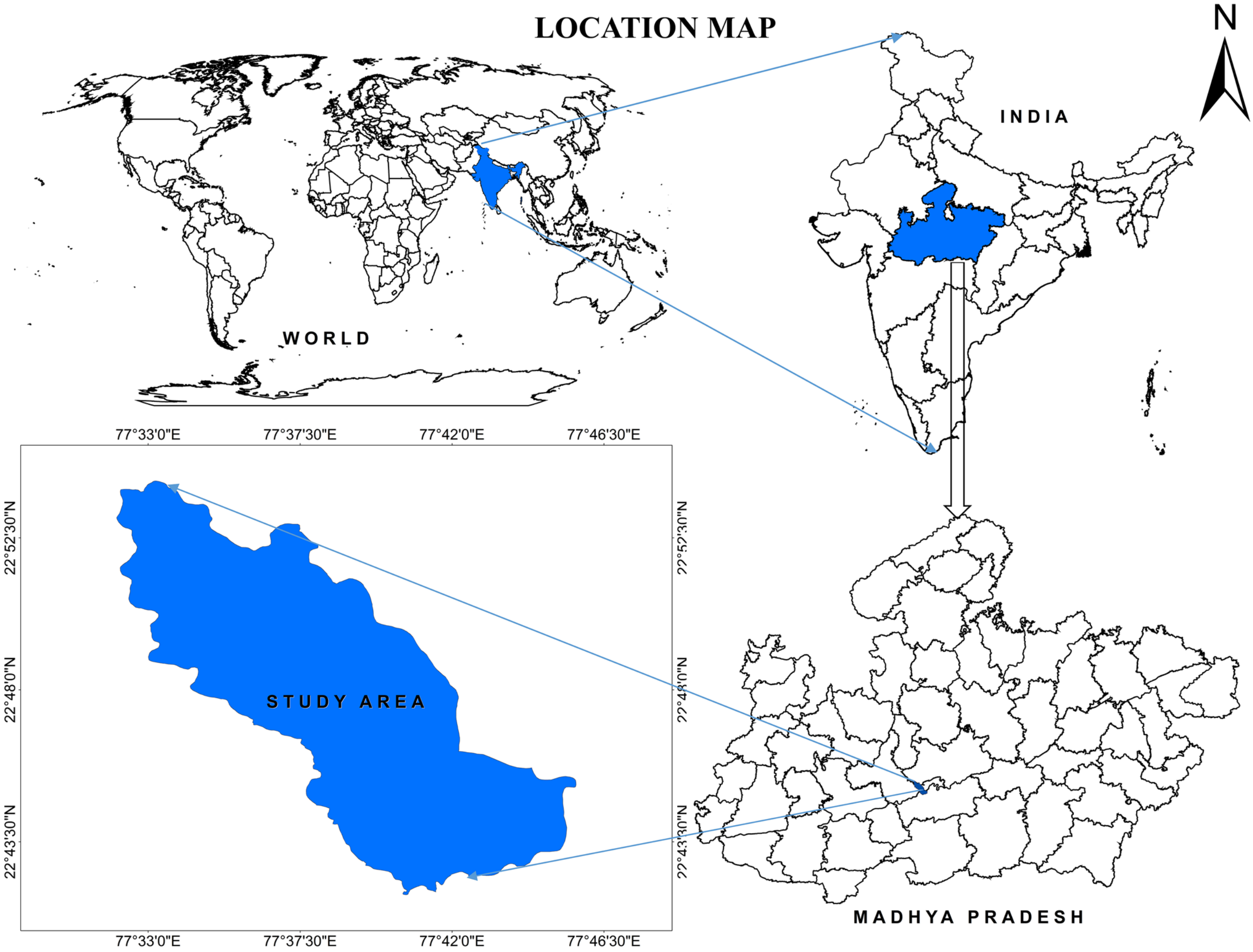

Fig. 1 Location map

contamination. The contamination of aquifers due to human or natural interferences is one of the emerging and biggest environmental concerns in both urban and industrial areas (Aller et al. 1984; Harlow and Lecain 1993; Alwathaf and El Mansouri 2011; Tirkey et al. 2013). Therefore, there is keen requirement to conduct scientific research studies to tackle this growing environmental challenge (Rahman 2008). DRASTIC model approach which works on the hydrogeological settings of an area gives some advantages between these studies (Huang et al. 2018; Ahirwar and Shukla 2018; Malik and Shukla 2019). The model uses the hydrogeological parameters such as depth to water, net recharge, aquifer media, soil media, topography, impact of vadose zone and hydraulic conductivity as input parameters of the model in order to compute the groundwater vulnerability index (Aller et al. 1987; Rosen 1994; Baalousha 2006; Sener et al. 2009; Mogaji et al. 2014; Chandrasekar et al. 2014).

Groundwater vulnerability assessment plays a vital role in the utilization and aegis of groundwater resources (Antonakos and Lambrakis 2007; Meng et al. 2011). DRASTIC model working in association with GIS has become a widely acceptable method for impressive management and planning of groundwater resources (Secunda et al. 1998; Sinha et al. 2016). DRASTIC model is used for detailed groundwater contamination vulnerability mapping while assigning rating to each parameter multiplying with the given weightage in ArcGIS (Al-Rawabdeh et al. 2014; Al-Zabet 2002; Jaseela et al. 2016). The model included the use of statistical and geo-statistical method for the amendment of the parameter ratings and weightage of each DRASTIC parameter in a GIS environment (Panagopoulos et al. 2006). Groundwater contamination vulnerability maps generated by DRASTIC model are helpful in monitoring of groundwater quality, identification of the areas that require more care to prevent them from contamination, aquifer management and land use planning (Jasrotia and Singh 2005; Bojórquez-Tapia et al. 2009; Baalousha 2016). DRASTIC model provides us the information about the area which is prone to

Table 1 Data source and format of data

S. no.	Parameters	Sources	Format of data
1.	Groundwater level	Primary data (through well inventory)	Map
2.	Net recharge	Secondary data LISS III Image	Map
3.	Lithology map	Secondary data (District Resource Map Published by GSI, 2003)	Map
4.	Soil map	Secondary data (National Bureau of Soil Survey and Land use Planning, ICAR) (NBSS Publ.59)	Map
5.	Slop map	Secondary data SRTM satellite data	Map
6.	Impact of vadose zone	Secondary data (District Resource Map Published by GSI, 2003)	Map
7.	Conductivity	Secondary data (District Resource Map Published by GSI, 2003)	Map

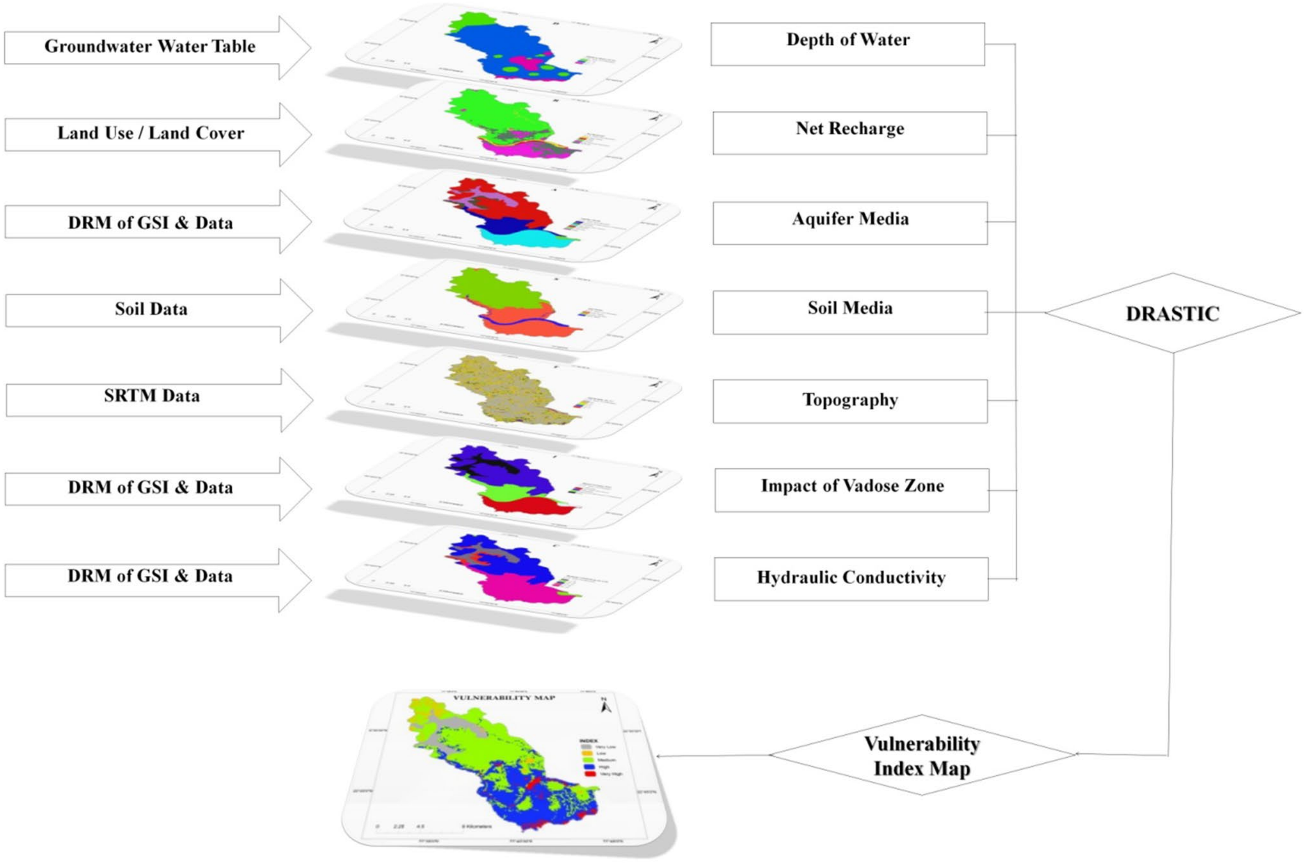

Fig. 2 Methodology flow chart

groundwater contamination by classifying them into low, moderate and high contamination zones (Leone et al. 2009). All these classes describe the probability of groundwater contamination potential in the area (Al-Rawabdeh et al. 2013; Kumar et al. 2016). The weightage and rating of each parameter comprise a GIS map layer. All the map layers were integrated to demarcate the final output, i.e. groundwater contamination vulnerability map (Fritch et al. 2000; Yin et al. 2013; Albinet 1970; Bai et al. 2012; Hamza et al. 2007).

Geospatial technology is an emerging technology in the field of hydrological sciences which helps in assessing, monitoring and managing of groundwater resources on large scale (Kaliraj et al. 2015; Kanade and Bhattacharya 2016). Groundwater being a limited resource is going exploited at rapid pace due to its maximum consumption in various sectors over years that leads to decrease its potentiality (Prasad et al. 2011). Currently, the contamination of groundwater is a big environmental concern resulted due to the rapid expansion of urbanization, industrialization, improper

Table 2 Assigned rating and weightage to DRASTIC parameters

DRASTIC parameters	Range	Rating	Weight	Index
Depth of water (D)	05–10	7	5	35
	10–15	5		25
	> 15	3		15
Net recharge (R)	Built-up	1	4	4
	Agriculture (including crop and fallow land)	3		12
	Forest	4		16
	Water body	8		32
	Sand	7		28
Aquifer media (A)	Alluvium	5	3	15
	Calcareous sand, gravel, conglomerate	9		27
	Sandstone	6		18
	Shale	2		6
	Silt, sand, clay, gravel	7		21
	Limestone	8		24
Soil media (S)	Fine loamy	2	2	4
	Loamy skeletal	5		10
Topography (T)	0–2	10	1	10
	2–6	9		9
	6–12	5		5
	12–18	3		3
	18+	1		1
Impact of vadose zone (I)	Alluvium	8	5	40
	Calcareous sand, gravel, conglomerate	5		25
	Sandstone	6		30
	Shale	3		15
	Silt, sand, clay, gravel	7		35
	Limestone	6		30
Hydraulic conductivity (C)	> 20	3	3	9
	20–40	4		12
	40–60	7		21
	60–80	8		24
	80–100	10		30

disposal of municipal and domestic waste, untreated waste and the uncontrolled growth of population. In rural areas, the application of fertilizers, pesticides, farm waste, etc., are the continuous sources of groundwater pollution (Kim and Hamm 1999). The vulnerability assessments of groundwater provide a scale of sensitivity of groundwater quality to an imposed contaminant and are globally accepted as a necessary element of aquifer management and protection (Ckakraborty et al. 2007; Brindha and Elango 2015). GIS practices have delivered a capable tool for evaluating and analysing the groundwater contamination potential of an area (Hasiniaina et al. 2010). The present study recommends that the model can be used as an effective tool for the management of this precious natural resource (Hamza et al. 2015; Barroso et al. 2015) and increases the sustainability of this everlasting natural source of water.

Study area

The study area covers parts of Hoshangabad and Sehore districts of Madhya Pradesh, India. The study area has occupied total geographical area 217.13 km^2. The area falls in survey of India toposheet no's 55 F/9, 55 F/10 and 55 F/13, located between 22° 42′ 30″ N–22° 53′ 30″ N latitude and 77° 31′ 00″–77° 47′ 30″ E longitude. In the area, three large industries, viz Security Paper Mill (SPM), Abhishek and Vardhman Fabrics textile, are functioning from which huge amount of industrial waste and effluents comes out on daily basis. The industrial wastewater draining from these factories contains a number of harmful chemicals and salts which inflow through the soil and added directly

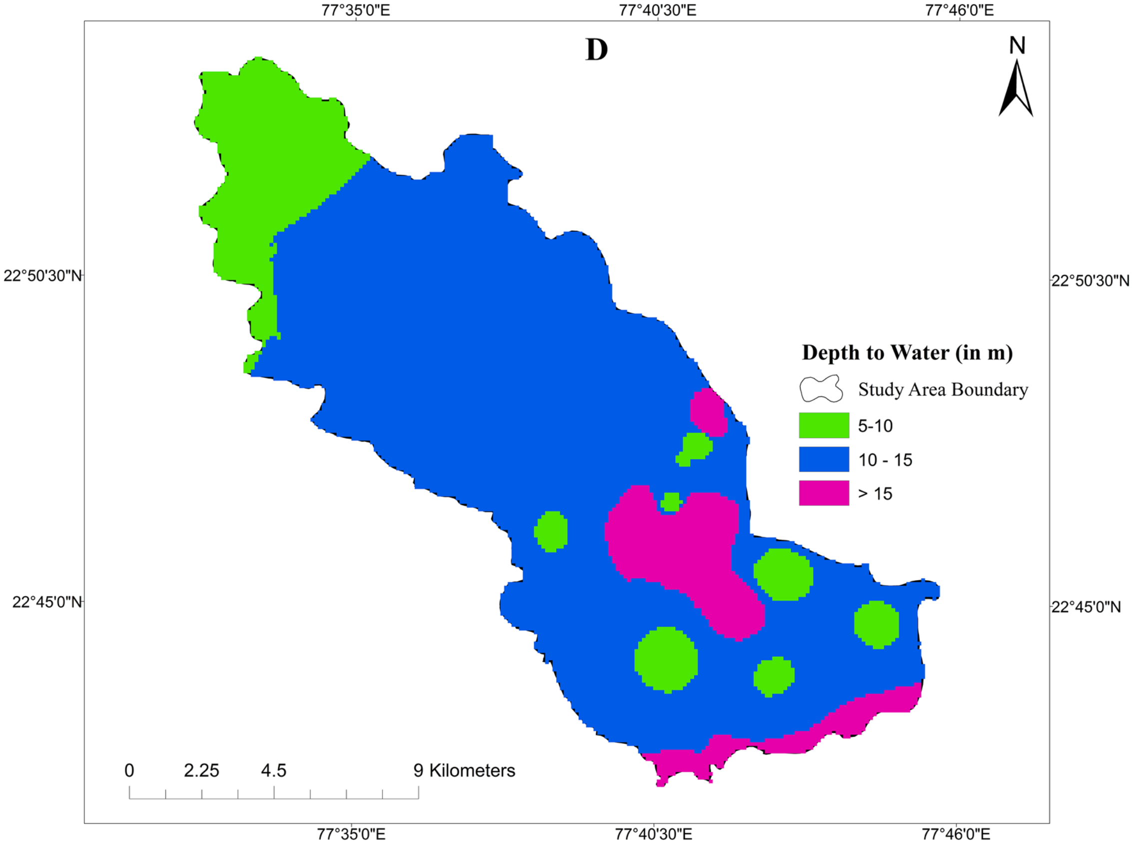

Fig. 3 Depths to water level

or indirectly into the groundwater. Thus, the study has found the scope of groundwater contamination probability in the area (Thukral and Rahman 2017; Census of India, Hoshangabad district 2011). Therefore, DRASTIC model approach has been employed which works for aquifer contamination vulnerability assessment by evaluating the hydrological and topographical conditions of the area. The location map of the area is presented Fig. 1.

Materials and method

DRASTIC modelling

In the study, DRASTIC model in association with geographical information system (GIS) has been used to assess the aquifer pollution potential in Hoshangabad and Budni industrial area. The model has been developed by US Environmental Protection Agency (EPA) with aim to determine the pollution potential of aquifers in the USA (Aller et al. 1987). Currently, this is the most widely used method for the assessment of aquifer contamination vulnerability. The model is formed by combination of seven hydrogeological parameters, viz D = depth of water table, R = net recharge, A = aquifer media, S = soil media, T = topography, I = impact of vadose zone and C = hydraulic conductivity which are working in coordination to assess the aquifer pollution potential (Al Hallaq and Elaish 2012; Ghazavi and Ebrahimi 2015). In the present study, data of each model parameter have been collected from various sources. Depth to water level has been collected from well-inventory data (bore/tub well) during field survey. Net recharge has been computed from land use/land cover, and aquifer media has been extracted from lithology of the area, which has been derived by processing of the District Resource Map (DRM), GSI 2002. Soil media data have been taken from soils of Madhya Pradesh map, National Bureau of soil survey and land use planning (NBSS and LUP 1996). Slope has been extracted by processing of Shuttle Radar Topography Mission (SRTM) imagery in ArcGIS. Impact of vadose zone has been studied from the lithological cross section (rock type), and hydraulic conductivity has been taken from the given values for the different rock/soil materials of (Rahman 2008) Table 2. Rating and weightage to each variable has been assigned as per their relative susceptibility to groundwater contamination. Weightage to each

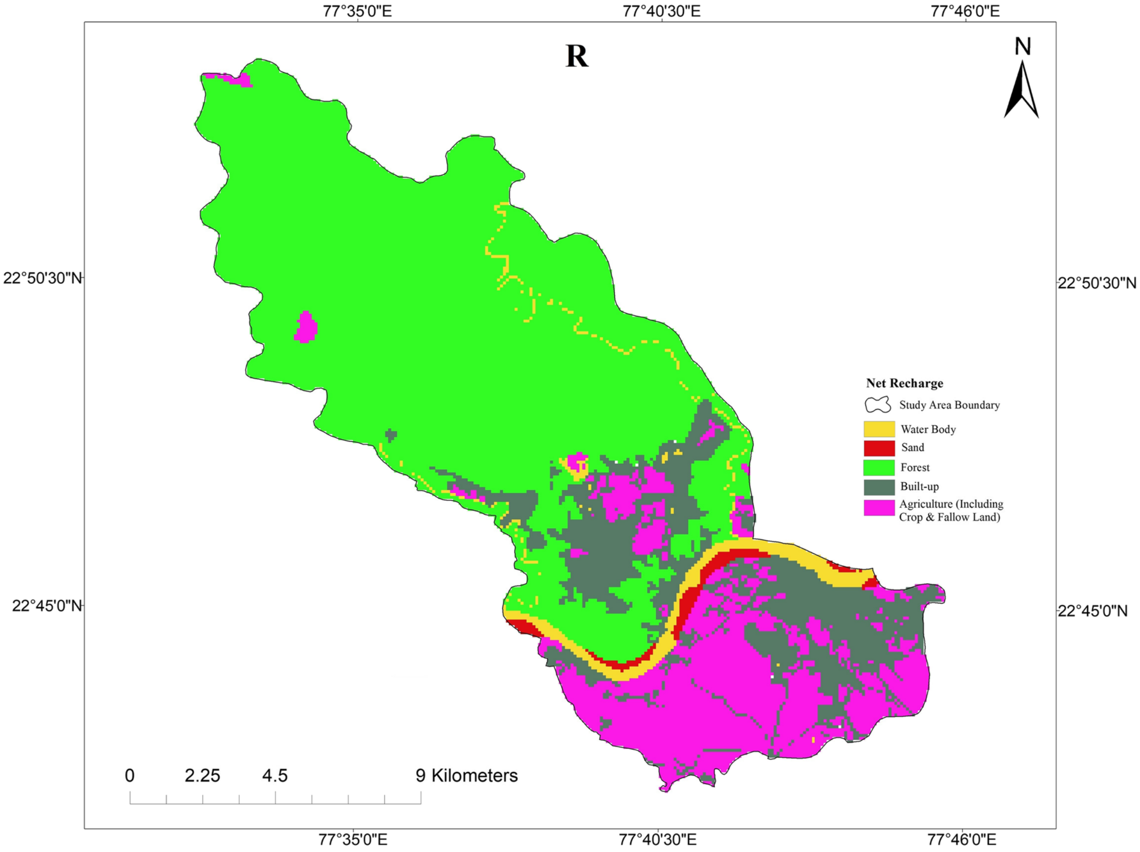

Fig. 4 Net recharge

parameter given varies from 1 (having least significance in GW contamination) to 5 (having well significance in GW contamination). Similarly, rating to each variable has been given which ranges from 1 (least significant) to 10 (most significant) (Aller et al. 1987; Kumar et al. 2015). Data collected from various sources are given in Table 1 and are presented in flow chart Fig. 2.

Finally, the output groundwater vulnerability to contamination map has been prepared by integrating all these variables by running the model using Eq. (1) as follows:

$$\mathrm{DI} = D_{\mathrm{r}}D_{\mathrm{w}} + R_{\mathrm{r}}R_{\mathrm{w}} + A_{\mathrm{r}}A_{\mathrm{w}} + S_{\mathrm{r}}S_{\mathrm{w}} + T_{\mathrm{r}}T_{\mathrm{w}} + I_{\mathrm{r}}I_{\mathrm{w}} + C_{\mathrm{r}}C_{\mathrm{w}} \tag{1}$$

where (r) is rating assigned to each parameter and (w) weightage assigned to each parameter of the model.

The systematic methodological approach with step-to-step process followed during the study is presented in Fig. 2.

Result and discussions

Depth to water

Depth to water represents the vertical distance from ground surfaces to the water table. It also marks the thickness of the media through which the infiltrated water has to travel to reach to the water table (Rahman 2008). Generally, the contamination chances of the groundwater become less with the extending of water table depth. In DRASTIC model, maximum weightage of 5 has been given to depth to water (Aller et al. 1987). In the study, depth to water level has been collected from the observation dug/bore wells during filed survey. Depth to water level has been measured in 26 observation wells. The minimum and maximum depth to water level recorded is 5 m and 15 m (bgl), respectively. The observed depth to water level has been further divided into three categories, i.e. 0–5 m, 5–10 m and > 15 m (bgl), respectively. Ratings were assigned to each class of depth to water level. The rating of 10 was given to shallow groundwater level depth and 5 to deep groundwater level depth. The

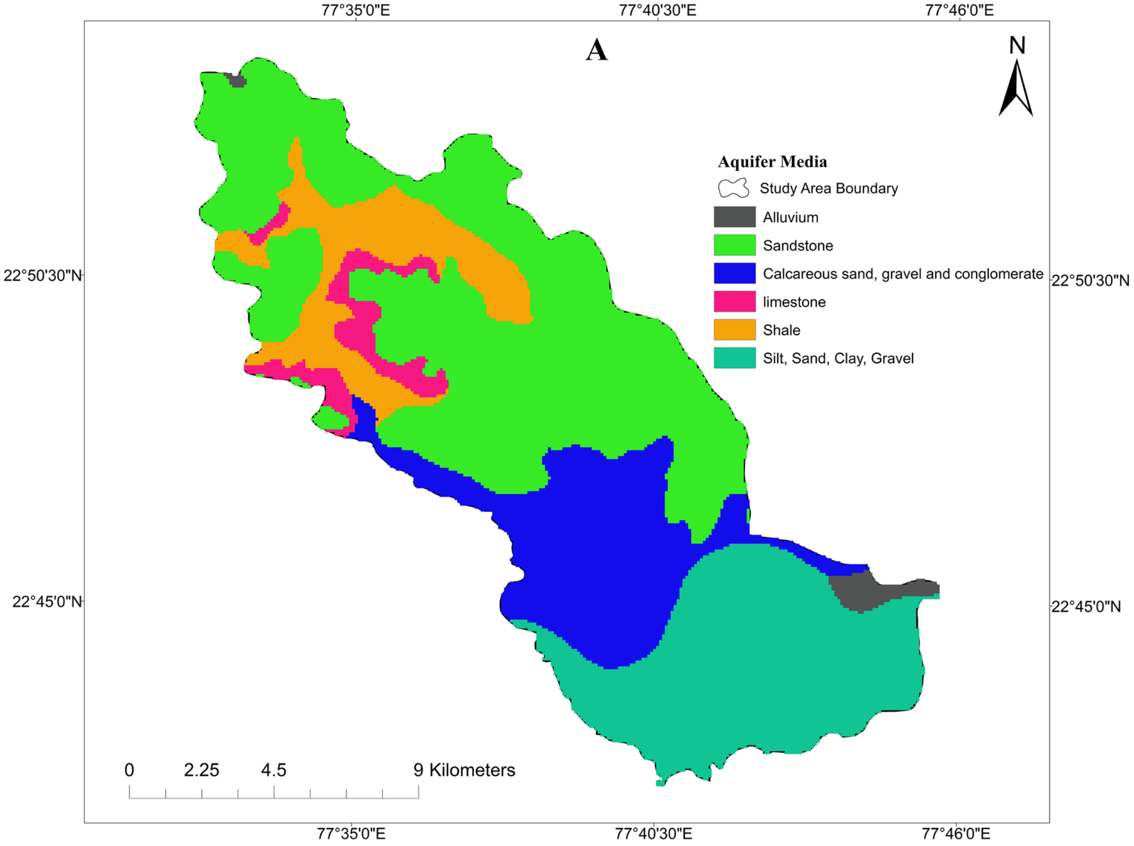

Fig. 5 Aquifer media

assigned rating, weightage and index of depth to water are given in Table 2. Depth to water level map is presented in Fig. 3.

Net recharge

The amount of water per unit area that percolates down to the groundwater on annual basis is called net recharge. Net recharge is a single medium of contaminant transporter from the ground surface through vadose zones to the water table (Yin et al. 2010). In the study, land use/land cover map has been taken in consideration for estimation of net recharge using the method suggested by (Rahman 2008). In land use/land cover analysis, five major land cover classes have been identified in the area, i.e. water body, sand, forest, agriculture (including crop and fallow land) and built-up (Fig. 4). An extensive sandy plain tract along the river valley where net recharge was found maximum has been given the rating of 7. The single water body present in the area has been assigned the highest rating of 8. Low ratings were given to built-up area, because it obstructs the infiltration of water to recharge groundwater. Thus, in the study rating of 1 has been given to less recharge area and 9 to maximum recharge area. The assigned rating, weightage and index to the net recharge are given in Table 2.

Aquifer media

The consolidated or unconsolidated rock or soil media which composes the aquifer refers to aquifer media. This media serves to an aquifer and controls the rate of contaminant movement down to the water table. In the study, aquifer media has been derived from the existing lithology of the area. Aquifer media derived is mainly composed of (1) alluvium (2) calcareous sand, gravel and conglomerate, (3) sandstone, (4) shale (5) silt sand, clay, gravel and (6) limestone (Fig. 5). The porosity and permeability of these materials (aquifer media) is good and is capable to hold appreciable water, thus are very sensitive to groundwater contamination. Good porous aquifer media has been given to high ratings, whereas impervious aquifer media was given to low rating. Ratings were given to aquifer media, and the rating of 6 has been assigned to sandstone and 8 to limestone. The assigned rating, weightage and index to aquifer media are given in Table 2.

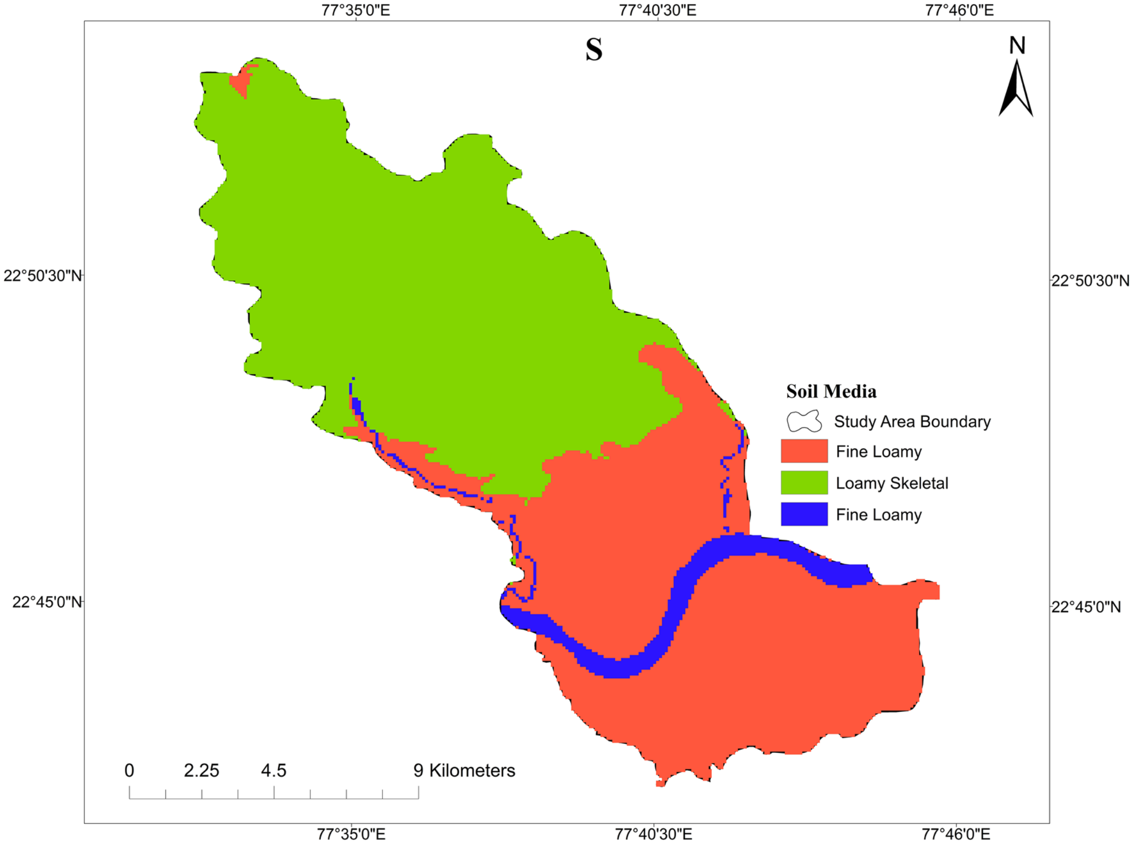

Fig. 6 Soil media

Soil media

Soil media has an important role to determine the amount of recharge and potential of contaminates to reach to the groundwater. The thickness of soil influence on movement of water so on effect the movement of contaminants to groundwater (Lee 2003). In the study, soil media map has been extracted from the soil map of Madhya Pradesh (NBSSS and LUP) by extracting various soil classes present in the area. The area is characterized of two broad soil classes: (1) fine loamy and (2) loamy skeletal soil (Fig. 6). Both the soil classes possess good hydraulic properties. Fine loamy soils have occupied the southernmost part of the area along both sides of Narmada River. Loamy skeletal soils are exposed towards north-eastern side and have occupied major part of the area. Rating to soil parameter has been assigned on the basis of their permeability and texture. Rating of 4 has been given to fine loam and 10 to loamy skeletal soil. The assigned rating, weightage and index to the soil media are given in Table 2.

Topography

In the study, topography has been shown in the form of slope. Plain topography or low slope areas have capability to retain water for long time, thus enhances the recharge of groundwater as well as contaminant movement. Slope of the area has been derived by processing of the SRTM imagery in ArcGIS environment. Slope map of the area has been prepared which was further divided into five classes (Fig. 7). Most part of the area falls in low slope class where slope varies from 2 to 6%. This slope class was found in groundwater dividing areas. Steep slope areas were seen along the southern marginal parts of the area. Rating of 1–10 has been given to slope parameter. High rating has been assigned to flat or plain area, because water retains there for longer time that provides sufficient time to pollutant to infiltrate into the soil and reaches to groundwater. Low rating has been assigned to steep slope areas, because it discourages the recharge practices and encourages the surface runoff processes, thus has the least chances of groundwater contamination. Rating,

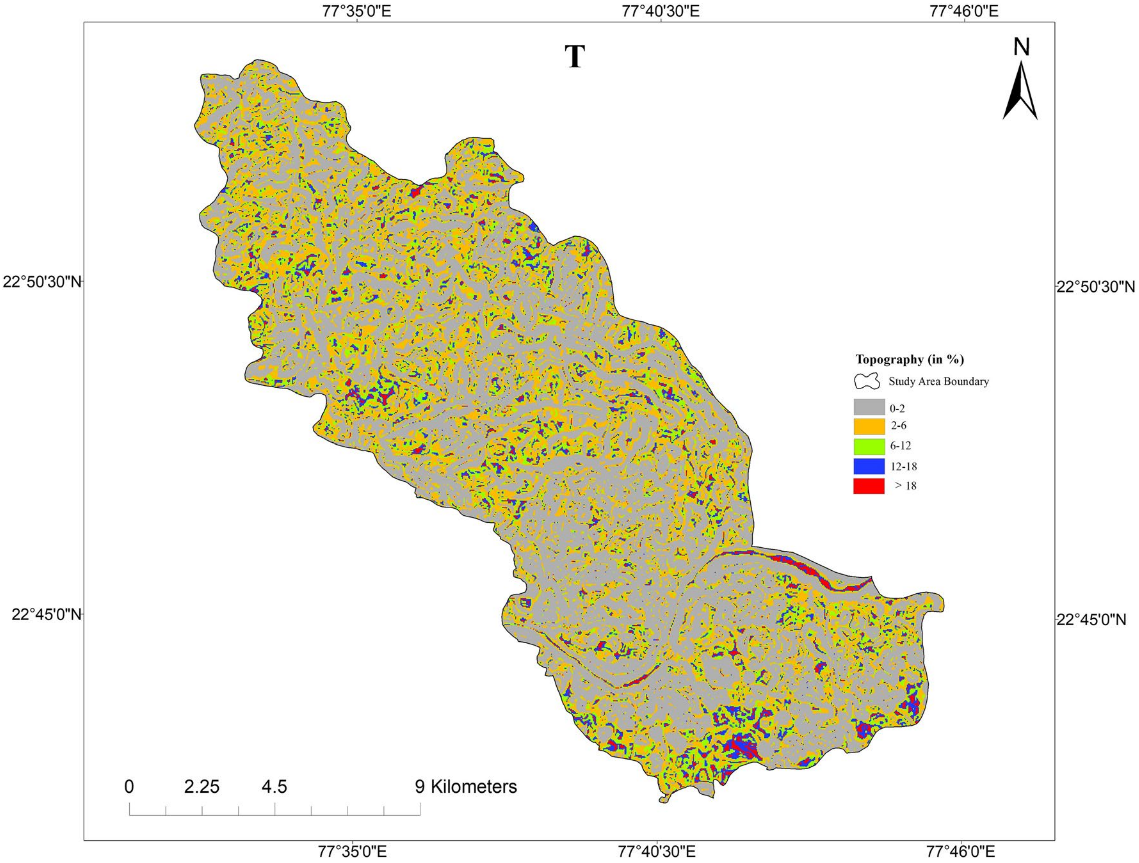

Fig. 7 Topography

weightage and index prepared for the topography parameter are given in Table 2.

Impact of the vadose zone

Vadose zone is the zone lying between the ground surface and water table. The infiltrate water has to pass through this zone to reach to water table. Thus, permeability of the material of this zone led great impact on the recharge rate and contaminant movement. Vadose zone media has been derived from the prevailing lithology of the area that comprises of alluvium, sand, silt, gravel, clay, limestone, calcareous sand, gravel and conglomerate (Fig. 8). Rating to this parameter has been given which varies from 1 to 9. Rating of 1 was assigned to the low porous media, whereas rating of 9 has been given to the highly permeable vadose zone media. The assigned rating, weightage and index to the parameter are given in Table 2.

Hydraulic conductivity

The ability of an aquifer media (soil or rock) to allow water to pass through it is called hydraulic conductivity. Good hydraulic conductivity material has been given higher rating. This property is directly proportional to the permeability of the media. It also controls the rate of contaminant movement. Hydraulic conductivity values for the material composed the area were taken from the defined hydraulic conductivity values for different soil and rock materials (Rahman 2008). Hydraulic conductivity map of the area has been prepared which is presented in Fig. 9. Rating, weightage and index prepared for hydraulic conductivity are given in Table 2. It has been seen that most part of the area is composed of the materials which possess good hydraulic conductivity. Rating to this parameter has been given which ranges from 3 to 10. Low rating of 3 has been given to shale, whereas high rating of 10 to calcareous sand, gravel and conglomerate (unconsolidated porous media).

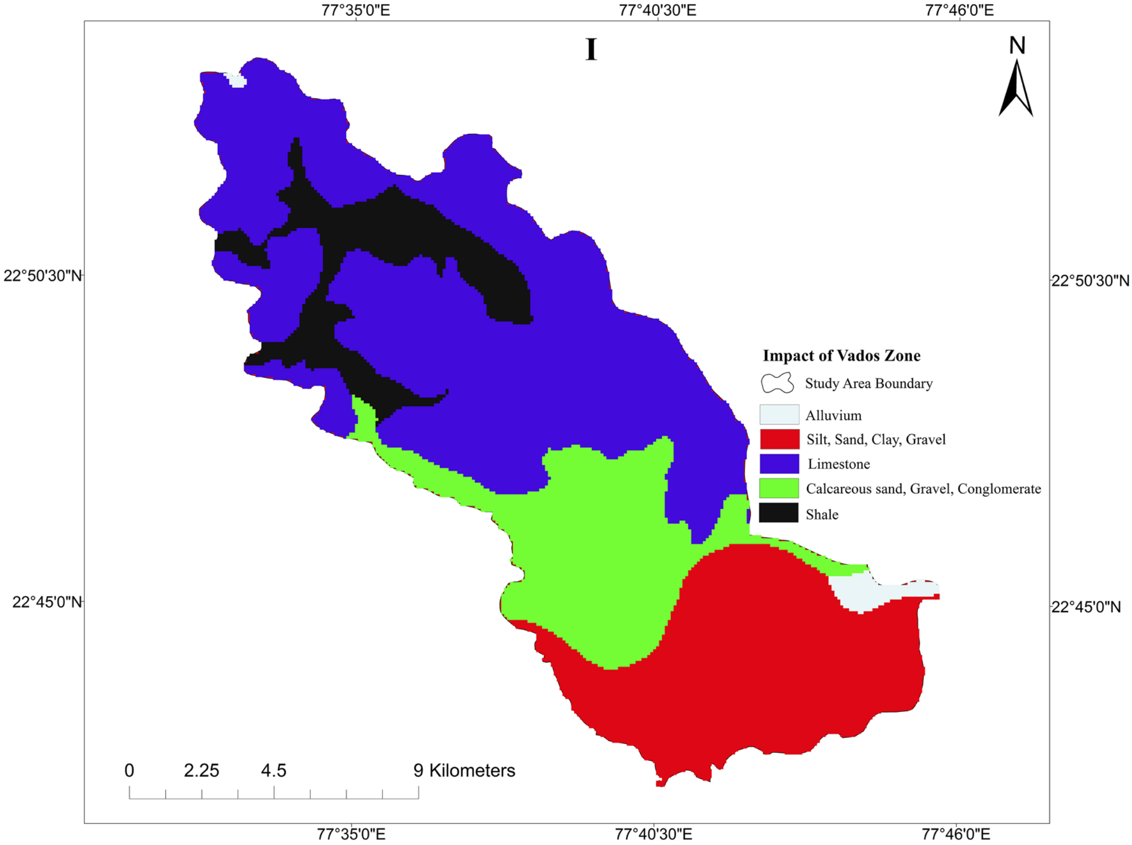

Fig. 8 Impact of vadose zone

DRASTIC index

DRASTIC index of the area has been computed by equating all seven data layers using Eq. (1). DRASTIC index of the area calculated varies from 66 to 170 which were further divided into five classes. Groundwater vulnerability map generated (Fig. 10) shows the groundwater contamination vulnerable zones. The area covered by each groundwater contamination vulnerable zone has been calculated in ArcGIS and is given in Table 3. The study reveals that 9.89% of the area falls in very low groundwater contamination vulnerable zone, 10.52% of area falls in low groundwater contamination vulnerable zone, 42.35% area in medium GW contamination vulnerable zone, and 27.39% area comes under high GW contamination vulnerable zone and 9.85% area comes under very high GW contamination vulnerable zone (Table 3). Areas of high and very high contamination zone are mainly located in the south-eastern side of the area, where the physical factors such as plain topography, shallow groundwater depth, porous soil and aquifer media and seepage from water body favour the groundwater recharge practices. All these factors support to groundwater recharge as well as contamination in the area. The south-western part of the area falls in no risk to medium groundwater contamination zone, because of the steep topography, presence of hard rocks and impervious surfaces that discourage the groundwater recharge processes. Further, the obtained model results were validated by determining the sulphide concentration in groundwater of the identified groundwater contamination vulnerable zones. The study reveals that sulphide concentration reported in very high GW vulnerable zone varies from 14 to 17 mg/L, followed by 11–14 mg/L in high, 7–11 mg/L in moderate, 4–7 mg/L in low and 1–4 mg/L in very low GW contamination vulnerable zone.

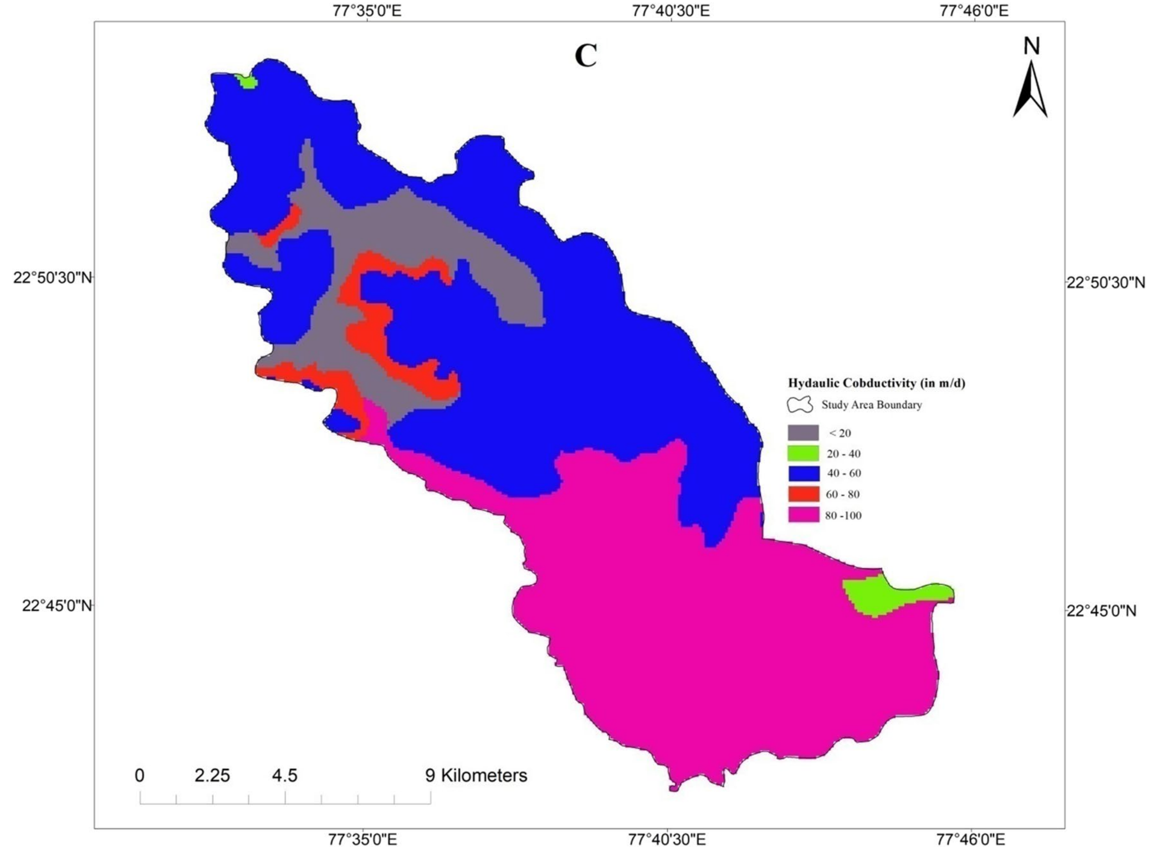

Fig. 9 Hydraulic conductivity

Conclusion

In the study, an integrated approach of GIS and field observations was carried out for the assessment of groundwater contamination vulnerability of Budhni and Hoshangabad industrial area. DRASTIC model which is based on seven hydrogeological parameters has been used to determine the GW vulnerability index of the area. The derived groundwater vulnerability index varies from 66 to 170 and was classified into five zones. The study reveals that 9.89% of the area has very least contamination chances and was demarcated as very low GW contamination vulnerability zone, 10.52% of the area comes in low GW contamination vulnerability zone, and 42.35% area falls in moderate GW contamination vulnerability zone. A major part of the area that covers 27.39% is demarcated as high GW contamination vulnerability zone, and 9.85% is under great threat demarcated as very high GW contamination vulnerability zone. Further, the model results have been validated by observed sulphide concentration in the groundwater of the delineated contamination vulnerable zones that shows sulphide varying from 1 to 4 mg/L in very low GW vulnerable zone followed by 4–7 mg/L

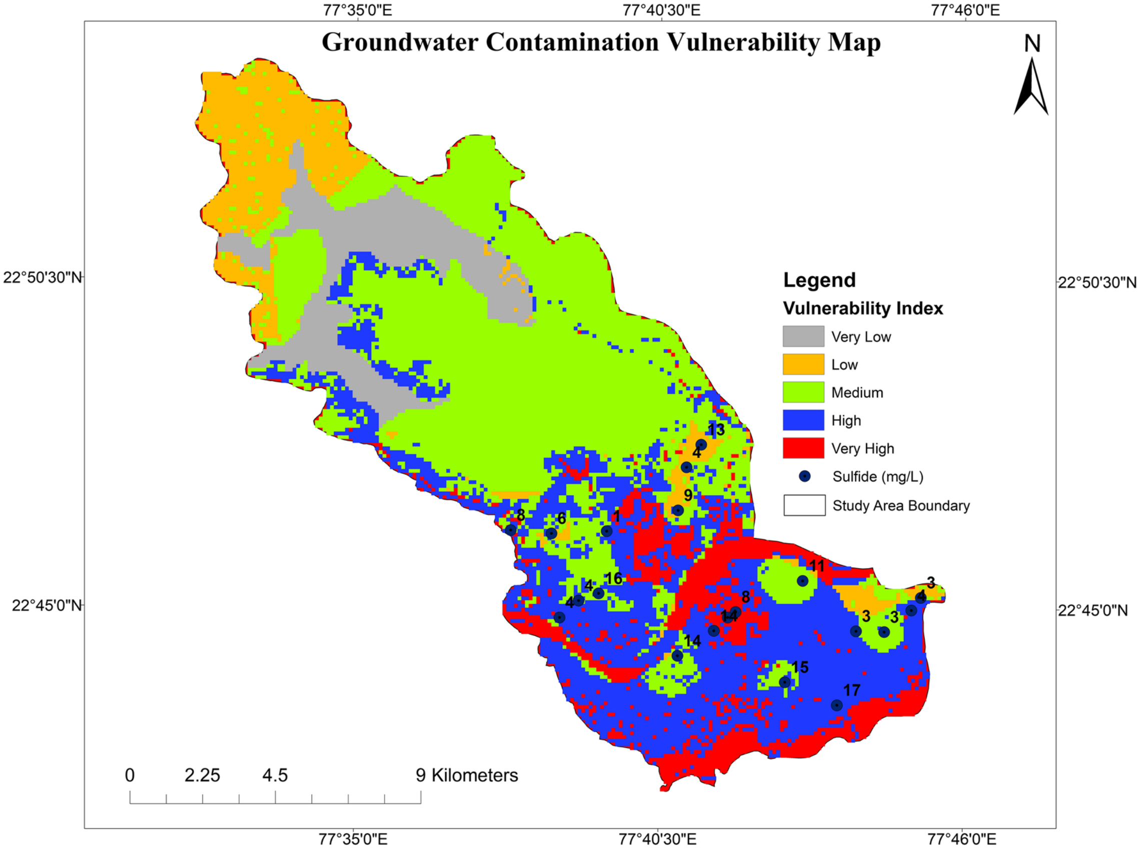

Fig. 10 Groundwater vulnerability contamination map

Table 3 Groundwater contamination vulnerability zone distribution

DRASTIC index	Range	Area (%)	Sulphide (mg/L)
Very low groundwater contamination potential	66–85	9.89	1–4
Low groundwater contamination potential	86–110	10.52	4–7
Medium groundwater contamination potential	120–130	42.35	7–11
High groundwater contamination potential	140–140	27.39	11–14
Very high groundwater contamination potential	150–170	9.85	14–17

in low, 7–11 mg/L in moderate, 11–14 mg/L in high and 14–17 mg/L in very high GW contamination vulnerable zone. The study has proved that the model is applicable for the existing hydrogeological setting of the area and can be used as best tool for groundwater resources management.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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