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ORIGINAL ARTICLE

A GIS based DRASTIC model for assessing groundwater vulnerability of Katri Watershed, Dhanbad, India

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Abstract Groundwater vulnerability assessment could be defined as the degree of assimilation capacity of the area to the contaminant from surrounding surface above the aquifer. It has become an important element for sustainable natural resource management and proper landuse planning. This study aims at estimating shallow aquifer vulnerability by applying the GIS based DRASTIC model in Katri watershed, Dhanbad, Jharkhand. The probable groundwater quality decline due to various anthropogenic activities within the Katri watershed has necessitated this study using a combination of DRASTIC and GIS method as an effective method for groundwater pollution risk assessment. This model is based on the seven hydrogeological data layers that provide the input to the modelling. It corresponds to the initials of seven layers i.e. Depth of water, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone and hydraulic Conductivity. The mapping of the DRASTIC index allows us to delineate zones with various degrees of pollution vulnerability. The study reveals that about 16.91 % of the watershed area is exposed to high-risk, 30.69 % exposed to medium-risk, and 52.4 % exposed to low risk. The south eastern and south western parts of the watershed are dominated by high vulnerability classes while the south, north western and lower middle portions are characterized by moderate vulnerability classes. The elevated northern, north eastern, and middle part of the study area displayed low aquifer vulnerability.

Keywords DRASTIC · GIS · Vulnerability · Groundwater · Katri watershed

Introduction

Water plays a vital role in every biological society in the globe. The socio economic development of a region predominantly depends on the availability of good quality water. There are significant sources of defuse and point pollution of groundwater from land use activities, urbanization, lack of proper sewerage, intensive agriculture and large amount of domestic and industrial effluents poorly discharged. These factors can cause severe deterioration of both quality and quantity of groundwater resource (UNESCO 1998; Polemio et al. 2009). In developing countries as India, the most available source of potable water supply is groundwater. In India, as also observed in the other parts of the world, the drinking water sector heavily depends on aquifers (Saha and Alam 2014). Presently, 85 % of rural domestic needs are catered from groundwater (CGWB 2011). On the other hand, in urban areas, where reservoir-based water supply is generally the source, nowadays groundwater is also playing an important role. Access to drinking water in India has increased over the past few decades with the tremendous adverse impact of unsafe water for health (Singh et al. 2013a). Scarcity of clean and potable drinking water has emerged in recent years as one of the most serious developmental issues in many parts of West Bengal,

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Jharkhand, Orissa, Western Uttar Pradesh, Andhra Pradesh, Rajasthan and Punjab (Tiwari and Singh 2014).

Vulnerability assessment has been conducted as an essential part of protection strategies for land use planning and groundwater protection zoning (Foster 1988). In fact the term ''vulnerability of groundwater to contamination'' was first used by (Margat 1968). ''Groundwater vulnerability'' is used in the opposite sense to the term natural protection against contamination. Groundwater vulnerability to contamination was defined by the (National Research Council 1993) as ''the groundwater vulnerability to contamination is the tendency or likelihood for contaminants to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer'' (NRC 1993, p 16). As can be inferred from the above definition, groundwater vulnerability is not an absolute or measurable property, but an indication of the relative possibility with which contamination of groundwater resources will occur. This understanding implies a very basic vulnerability concept that all groundwater is vulnerable.

There is rapid expansion of groundwater vulnerability assessment in past decade, as well as the development and improvement of various new techniques and methods applied to the assessment of groundwater vulnerability. GIS is an effective technique for the zone mapping and risk assessment on environmental health problems. GIS can be useful for taking quick decisions as graphical representation would be easy to take a policy decision by the makers (Singh et al. 2013b). GIS techniques have been becoming the most commonly used platform for assessment of groundwater vulnerability (Al-Adamat et al. 2003; Becker 2006; Almasri 2008; Rahman 2008; Umar et al. 2009; Saha and Alam 2014; Nasri et al. 2015) along with the use of remote sensing techniques (Yeh et al. 2006), statistical method (Burkart et al. 1999; Fred et al. 2002), environmental isotope and water chemistry method (Sadek and El-Samie 2001), and fuzzy mathematical method (Zhou et al. 2010). The aim of the study is proper understanding of the aquifer system and hydro-geological setting of the area for development and safe exploitation of groundwater.

Study area

The study area chosen for this study is Katri River watershed (Fig. 1), located in the north western part of Dhanbad district, Jharkhand, India. The Katri river which rises in the foot hills bellow parasnath and travels through the coalfield area, and then the river joins with the Damodar River after completing a 26.04 mile (42 km) course. The Katri River basin lies in north-east part of Dhanbad district and occupying about 355 km^2 of land area. Area is included in Survey of India (SOI) toposheets no. 73I/1, 73I/5and 73I/6. Topographically the area is undulating, with the elevation ranging from 85 to 422 m and highly dissected landscape. Climatically, the study area experience sub-tropical climate, It has a hot summer and a cold winter. The climate of the area is characterized by general dryness except during the brief span of monsoon season.

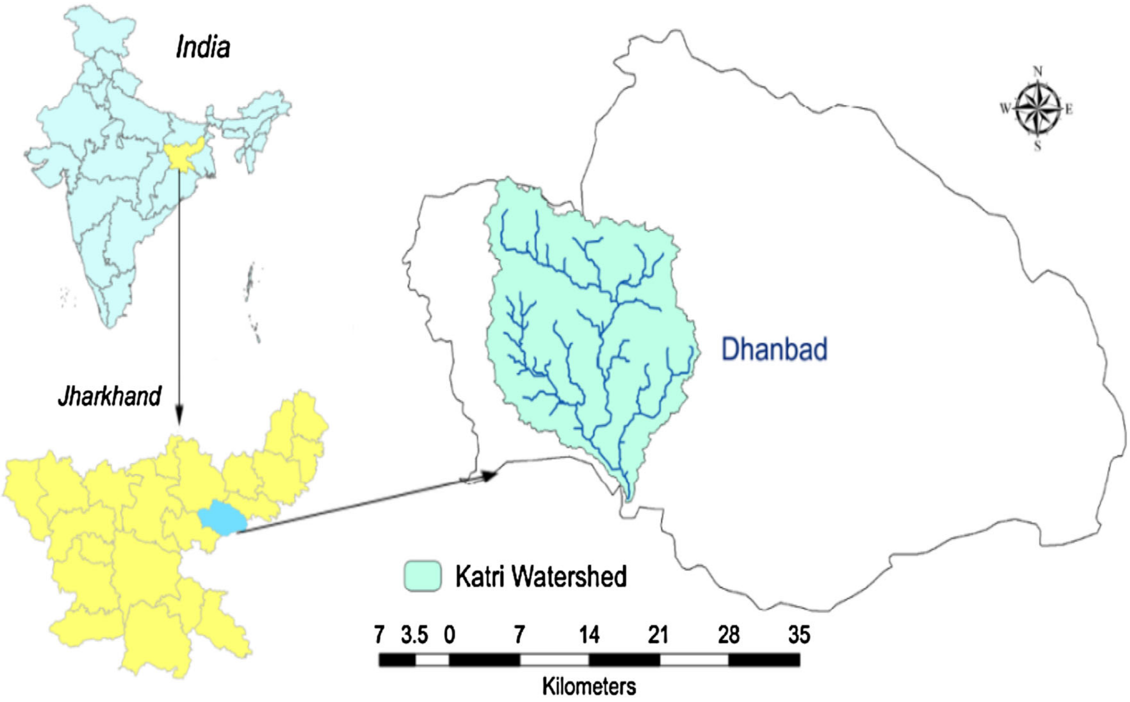


Fig. 1 Study area

Geology

The study area region lies on the eastern part of Chhotanagpur plateau and has an undulating topography with three distinct geomorphic features from north to south, (a) the hill ranges in north western part, (b) the coalfield in southern and eastern part, and (c) the undulating upland and intervening alluvial fill low valleys with isolated bare ridges between them in north. The metamorphic terrain of the region is underlain by a wide range of geological

Fig. 2 Geology of study area

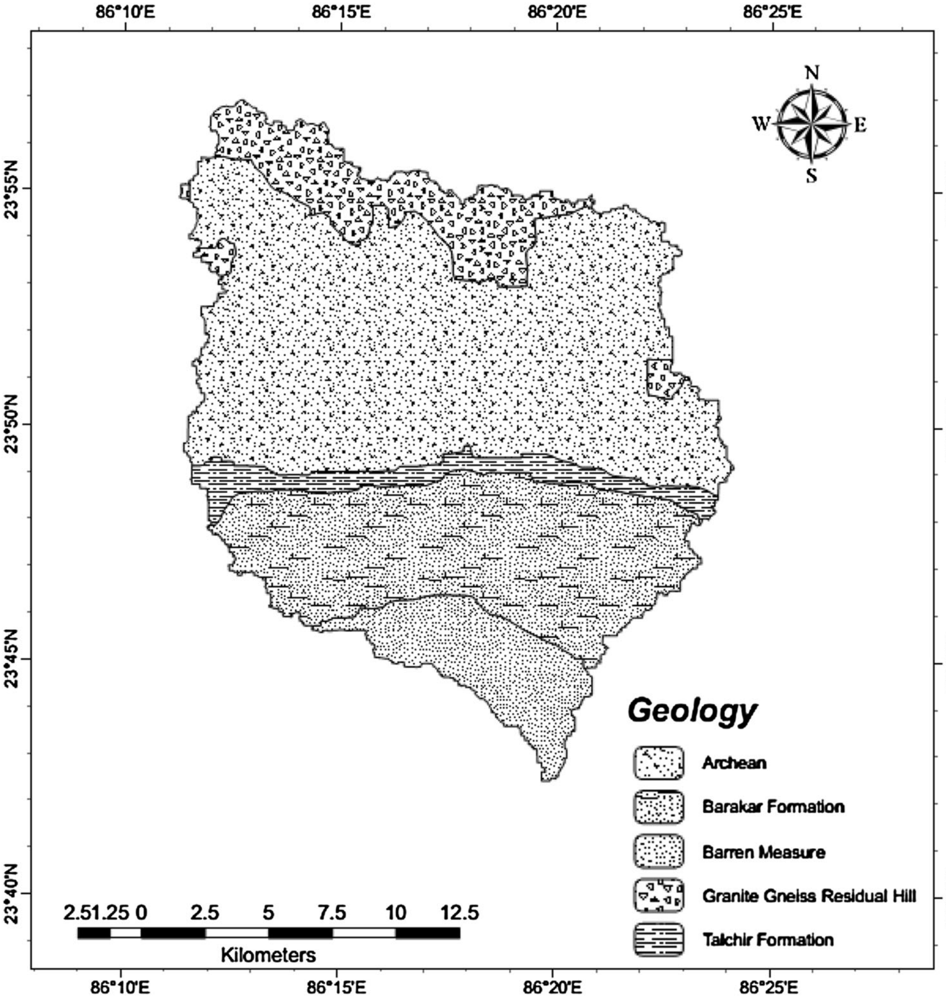


Fig. 3 Methodology Flowchart

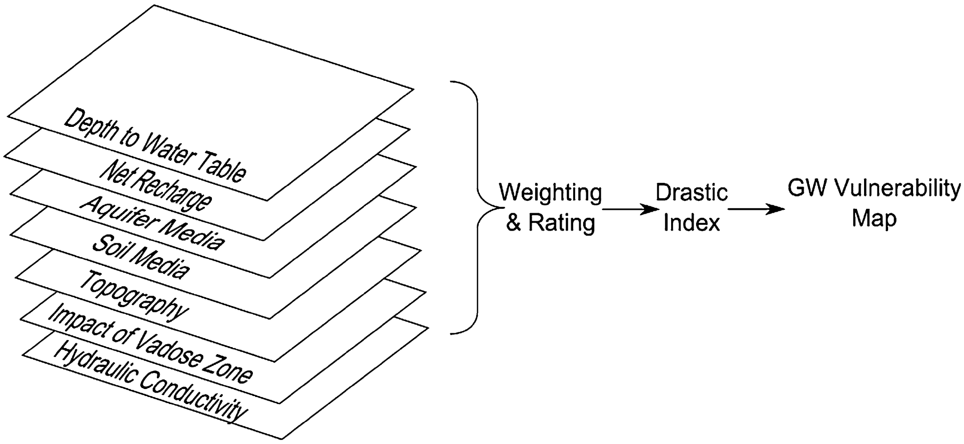
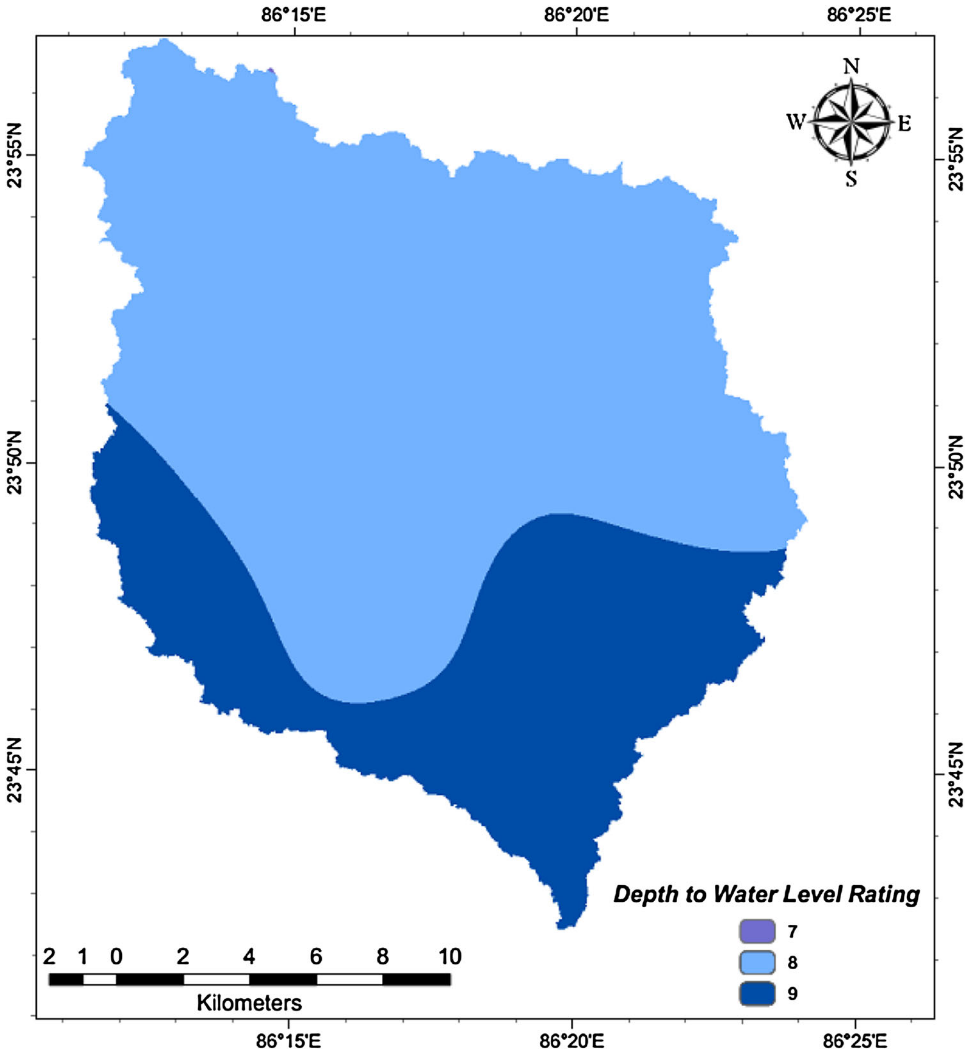


Table 1 Weight, ranges and ratings of the seven DRASTIC parameters

Parameter	Data sources	Class	Rating	Weight
Depth to water table (feet)	Well inventory	0–5	10	5
		5–10	9	
		10–20	8	
		20–30	7	
		30–50	5	
		50–75	3	
		75–100	2	
		100+	1	
Net Recharge (in/year)	Rainfall & hydro—geology	0–2	1	4
		2–3	2	
		3–6	5	
		6–8	7	
		8+	9	
Aquifer media	Hydrogeology map	Massive shale	2	3
		Metamorphic/igneous	3	
		Weather metamorphic/igneous	4	
		Glacial Till	5	
		Bedded sandstone, shale sequences, massive sandstone, massive limestone	6	
		Sand and gravel	8	
		Basalt	9	
		Karst limestone	10	
Soil Media	Soil map	Thin or absent/gravel	10	2
		Sand	9	
		Shrinking/aggregating clay	7	
		Sandy loam	6	
		Loam	5	
		Silty loam	4	
		Clay loam	3	
		Non-shrinking/non-aggregating clay	1	
Topography (% Slope)	Cartosat 1 DEM	0–2	10	1
		2–6	9	
		6–12	5	
		12–18	3	
		18+	1	
Impact of vadose zone media	Geology	Silt/clay	1	5
		Shale	3	
		Granite/gneiss	4	
		Sandstone/large limestone formation	6	
		Basalt	9	
		Small limestone formation	10	
Hydraulic conductivity (GPD/ft^2)	Well inventory	1–100	1	3
		100–300	2	
		300–700	4	
		700–1000	6	
		1000–2000	8	
		2000+	10	

Fig. 4 Depth to water level rating map

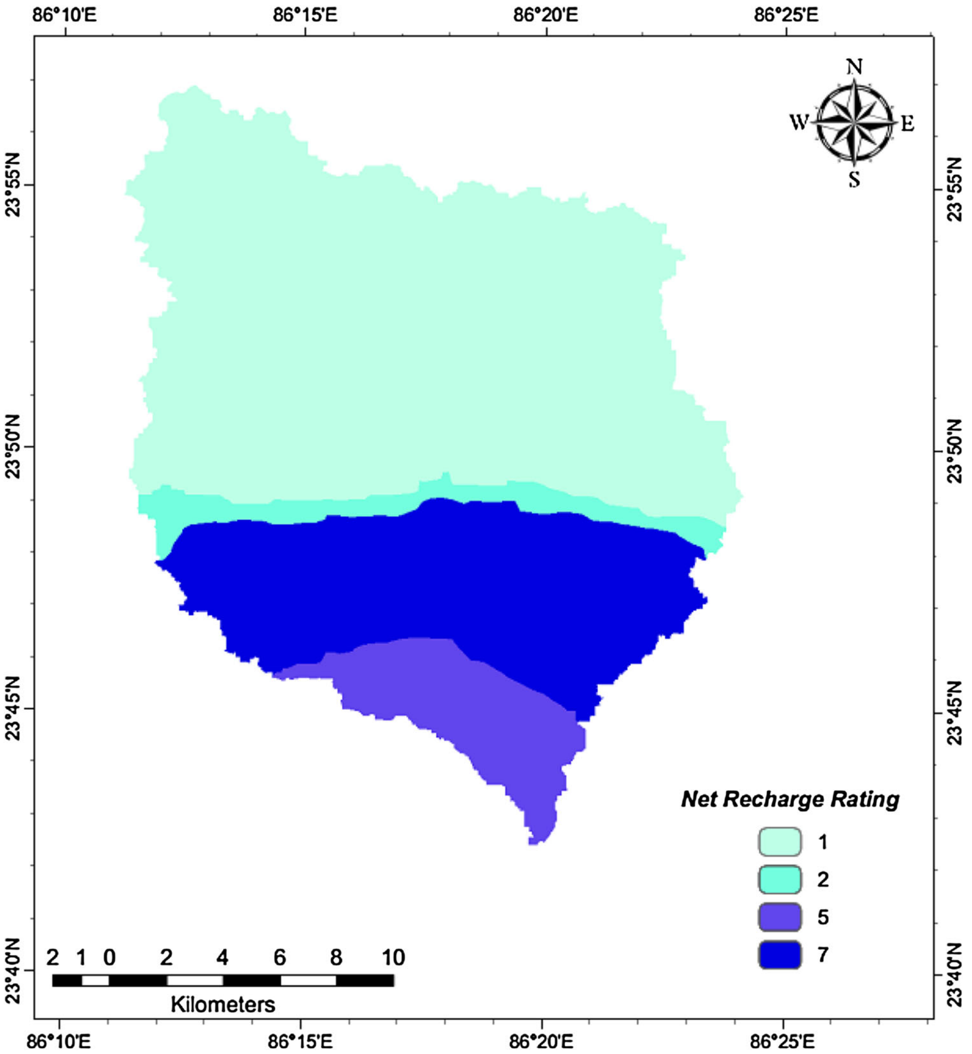


formations ranging in age from Archaean to Recent. The Archeans and Gondwanas constitute the major parts. Thin veneer of quaternary alluvial deposits occurs in the topographic depressions along the Damodar Rivers. From geological point view Katri watershed can be divided into five parts (Fig. 2) (i) northern part consists with granite gneiss residual hill, (ii) upper middle portion approximate half of the are covered by gneiss and schist (Archean Formation), (iii) middle portion consist with gneiss shale and sandstone, (iv) Barakar formation are consist with white to buff colour coarse medium sandstone and grit shale and (v) Barren measure rang is the main geological formation of the lower part of the study area. Strictly speaking there are no large stretches of what may be called as plains in this Basin area. However, the lie of the country in Chas and Chandankeary may be taken as low up-lands where cultivation is practised.

Hydrology

Groundwater occurs in the area under unconfined condition in the weathered zones at shallow depths in most of the litho units in the Achaeans and almost all the litho units in the Gondwana. Groundwater occurs under conned to semi-confined condition where the fractures are deep seated and are unconnected with the top weathered zone. The aquifer geometry for shallow and deeper aquifer has been established through hydrogeological studies, exploration, the surface and subsurface geophysical studies in

Fig. 5 Net recharge rating map



the district covering all geological formations. The aquifer can be divided into two zones, shallow and deeper aquifer.

Methodology

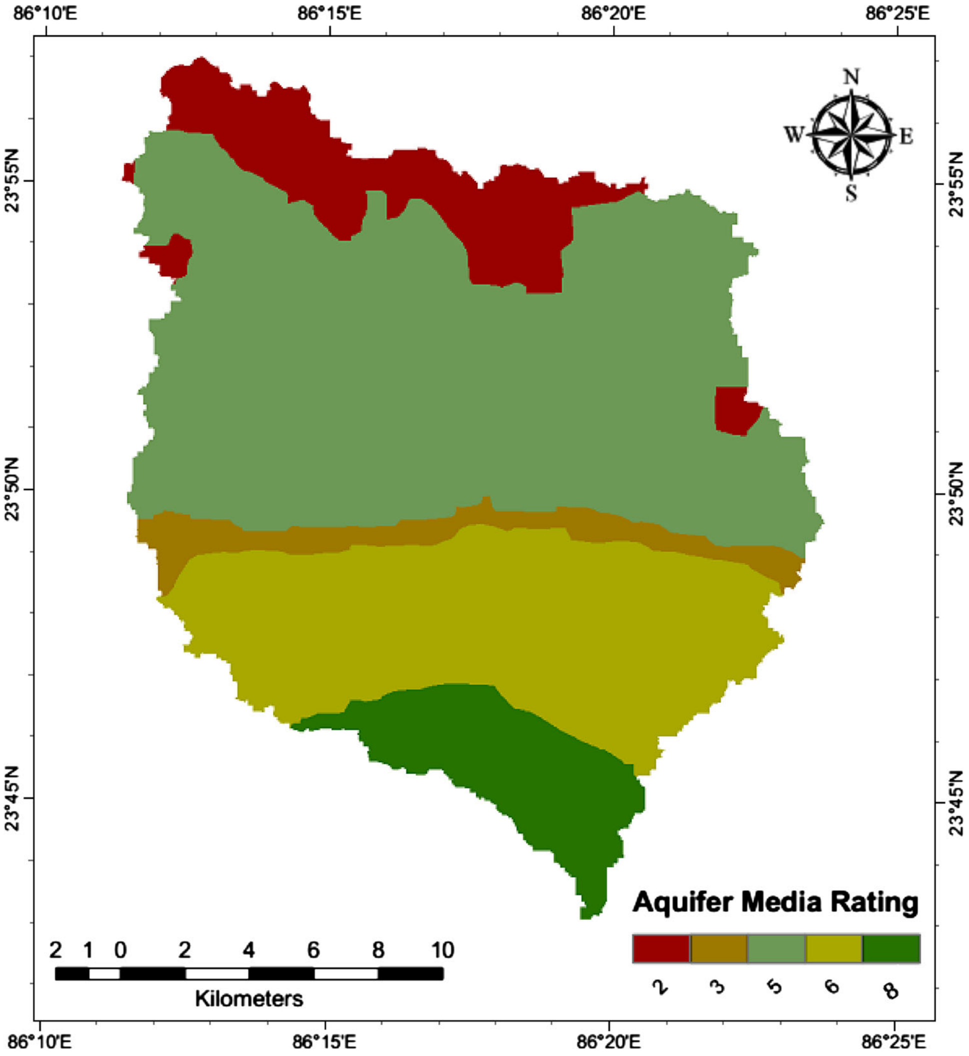
In present watershed area, GIS based DRASTIC model has been applied to determine the degree of susceptibility to groundwater pollution. DRASTIC was developed in USA by the Environmental Protection Agency in 1987 to evaluate the potential for groundwater contamination (Aller et al. 1987). This method is based on hydrogeological parameters which govern the occurrence and movement of groundwater into the system. The DRASTIC model considers seven parameters, which taken together, provide the acronym. These are Depth to groundwater, net Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone and hydraulic Conductivity (Fig. 3). These seven parameters are pooled in a simple linear equation after they have been standardized from the physical range scale to a one to ten-grade relative scale. Each parameter is multiplied by a weighting coefficient as given in Table 1. In this system, the degree of vulnerability to pollution in groundwater is based on numerical index value. These index numbers are derived from rating and weights assigned to every thematic layer.

The equation for determining the DRASTIC Index (DI) is:

$$DI = Dr \times Dw + Rr \times Rw + Ar \times Aw + Sr \times Sw + Tr \times Tw + Ir \times Iw + Cr \times Cw$$

where, D = Depth to groundwater, R = net Recharge, A = Aquifer media, S = Soil media, T = Topography, I = Impact of the vadose zone, C = hydraulic Conductivity, r = rating, w = weighting.

Fig. 6 Aquifer media rating map



Results and discussion

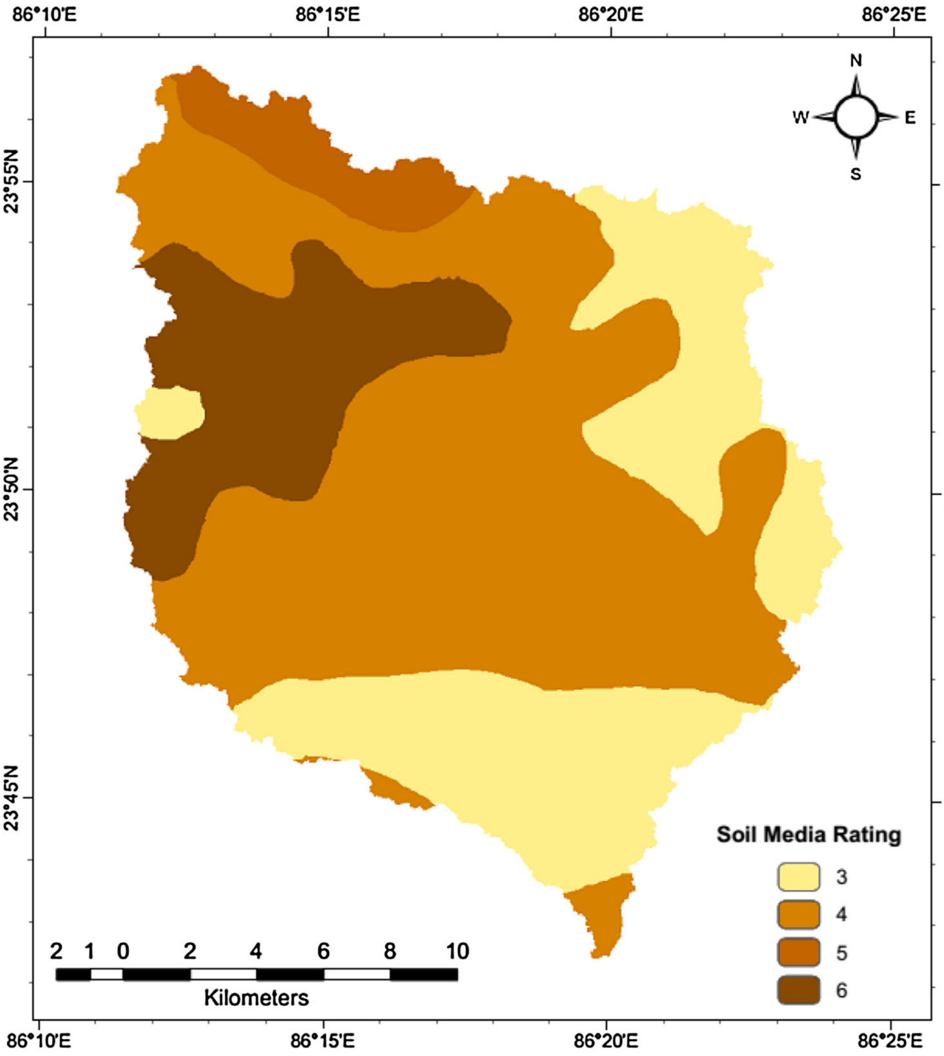
Depth to water

Depth to water level is one of the most important factors because it determines the thickness of material through which infiltrating water must travel before reaching the aquifer. In general, the aquifer potential protection increases with depth to water. In this case, water level depth of 13 observation wells have been taken during the post-monsoon season 2012. The maximum and minimum of water level depths are 20.47 and 7.64 ftbgl respectively. The average water level is 12.01 ftbgl. These point data were contoured by interpolating and divided into three categories i.e. 5–10, 10–20, and 20–30 feet and assigned the variable ratings of 9, 8 and 7 (Fig. 4). Thereafter, it was converted into grid to make it raster data for GIS operation. The depth-to-water table interval range, DRASTIC rating, weight, and resulting index are portrayed in Table 1. Areas with high water tables are vulnerable because pollutants have short distances to travel before contacting the groundwater. So, the deeper ground water level are low vulnerable and smaller the rating value. Water level is deeper towards north western margin whereas it is shallow in southern lower part.

Net recharge

The net recharge is the amount of water from precipitation and artificial sources available to migrate down to the groundwater. Recharge water is, therefore, a significant vehicle for percolating and transporting contaminants

Fig. 7 Soil rating map



within the vadose zone to the saturated zone (aquifer) (Rahman 2008). It carries the solid and liquid contaminants to the water table and also increases the water table. Katri watershed is in a depression as described earlier. As a result Katri watershed gets recharged by both the rivers and also from open minings dam-water that contributes more to the groundwater pollution because mining of coal, and other related substances. Coal mines are a major source of contaminants (Singh et al. 2010; Singh et al. 2013c; Verma and Singh 2013; Mahato et al. 2014; Tiwari et al. 2015). The net recharge varies from 1.42 to 7.57 inches/year. Net recharge was divided into four categories i.e. 0–2, 2–3, 3–6 and 6–8 inches/year and assigned the variable ratings of 1, 2, 5 and 7 (Fig. 5). Lower portion of the study area has high groundwater recharge rate and is at high risk because of permeable pathway from the surface to the water table and the north-west part of the study area are at low risk zone because low recharge rate.

Aquifer media

Aquifer media refers to the nature of geologic formation which serves as aquifer like sand and gravel in case of alluvium while weathered zone and secondary porosities (fracture/joint) in case of hard rock. The nature and\ rate of flow (hydraulic conductivity) of an aquifer is controlled by its framework material called media. The media also exert a major control over the pollutant's route and path length (Saha and Alam 2014). The rating 8 has been assigned to fine grain sand stone (Barren Measure). The typical rating 6 has been assigned to the aquifer media, chosen as white to buff colour coarse and medium sand stone and grit shale (Barakar Formation). The typical value 3 has been assigned to the aquifer media, chosen as gneiss shale and ne sandstone (Talchir formation) and the typical rating 5 has been assigned to the metamorphic aquifers (gneiss and schist, Archean formation). The igneous aquifers (Granite, gneiss)

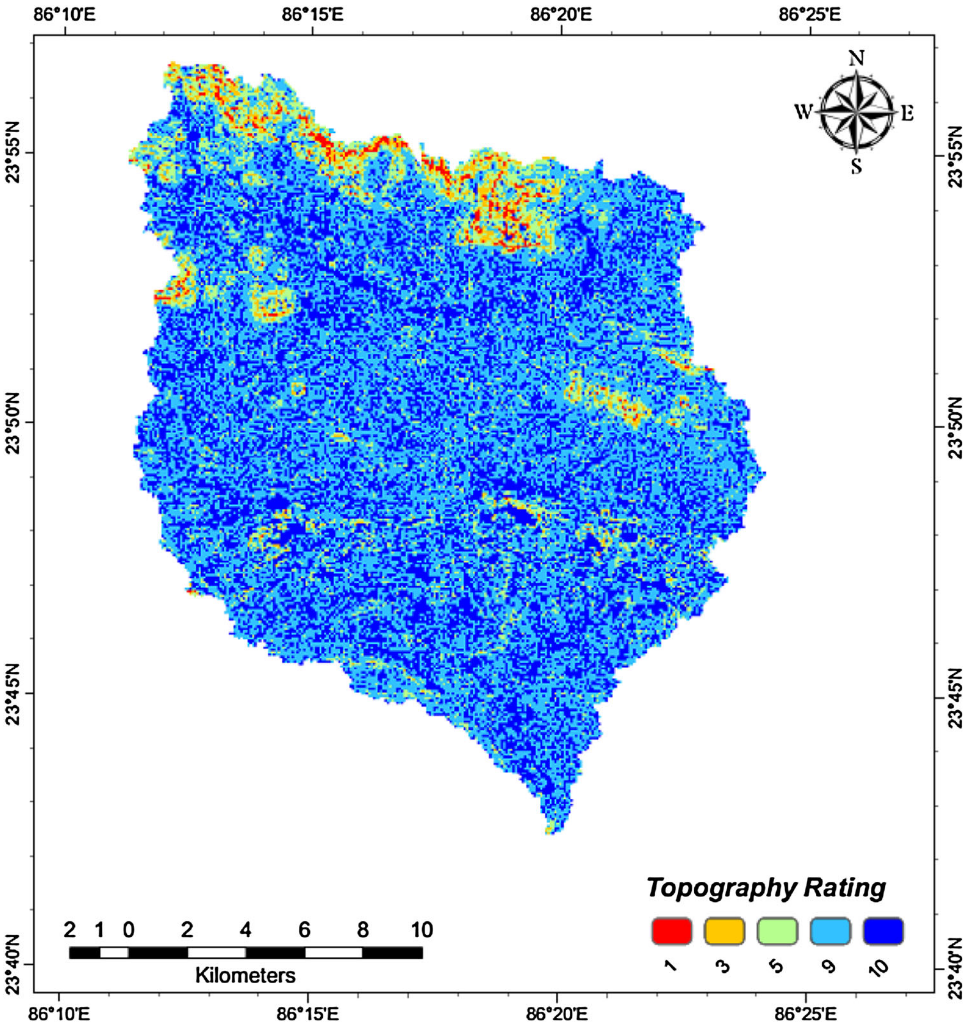


Fig. 8 Topography rating map

have low yields and a typical rating of two has been assigned to this aquifer (Fig. 6).

Soil media

Soil is commonly considered the upper weathered zone of the earth which averages 1.8 m or less. It has a significant impact on the amount of recharge water which can infiltrate into the ground and hence, influence the ability of a contaminant to move vertically into the vadose zone (Umar et al. 2009). There are six types of soil present in the study area such as genteelly loamy, coarse loamy, very genteelly slopping loamy, fine loamy, fine soil with loamy surface texture and moderate erosion, fine loamy soil on very genteelly slopping land with loamy surface texture. The major part of the area (about 145 km^2) is covered by fine soil on very genteelly slopping land with loamy surface texture, whereas genteelly loamy soil with loamy surface texture and sever erosion is present in lesser extent, covering an area of (about 2.59 km^2). Based on the presence of clay, its rating has been assigned because it reduces the permeability of soil and rate of infiltration of solvent into the aquifer. On the basis of porosity (Freeze and Cherry 1979), Coarse loamy has been given highest rating of six and least value for fine loamy as three (Fig. 7).

Topography

The slope of land surface and its variation is referred as topography. In areas with low slope, runoff water is retained for longer periods, allowing higher infiltration, thus having a greater pollution potential. Topography map has been generated from cartosat 1 DEM. It is described in the form of slope in DRASTIC Model, which is one of the factors controlling the infiltration of water into

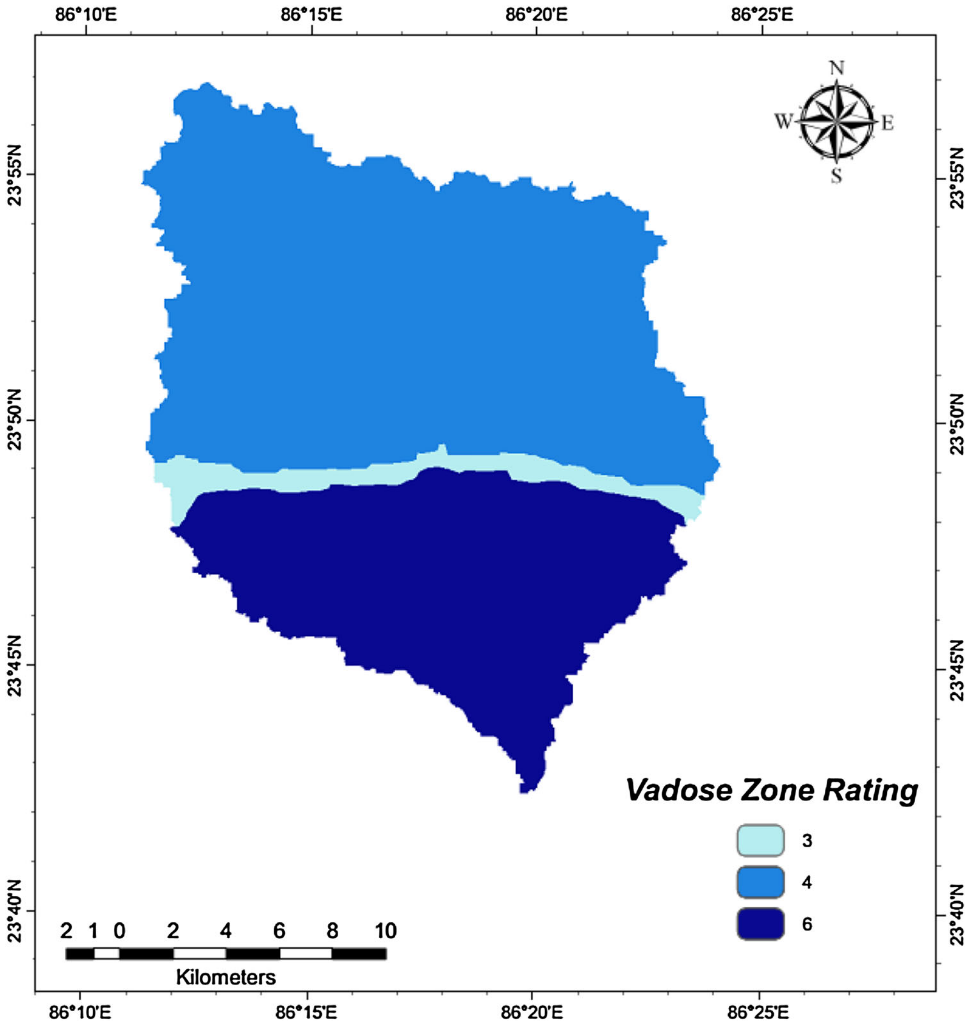


Fig. 9 Impact of vadose zone rating map

subsurface; hence, an indicator for the suitability for groundwater pollution prospect. The slope of the area, varies from 0 % to more than 35.77 %. The slopes have been classified into five categories, i.e., 0–2, 2–6, 6–12, 12–18 %, and more than 18 % and assigned the variable ratings of 10, 9, 5, 3, and 1 (Fig. 8). Most of the study area occupies slope category of 2–6. In the model parameter, the slope varying from nearly level to very gentle has been assigned maximum rating of 10 where at least value has been assigned to very steep slope.

Impact of vadose zone

The vadose zone's influence on aquifer pollution potential is essentially similar to that of soil cover, depending on its permeability, and on the attenuation characteristics of the media. The impact of vadose zone is a complex phenomenon, combining aquifer media and topographic characteristics. Movement of water within the vadose zone is studied in hydro-geology, and is of importance to contaminant transport (Rahman 2008). Impact of vadose zone was prepared from the lithological cross sections obtained from the borehole data. The vadose zone has been classified into five categories. The typical rating 6 has been assigned to the vadose zone consisting fine grain sandstone. The typical value 6 has also been assigned to Barakar formation consisting white to buff colour coarse to medium sandstone, grit and shale. The Talchir formation consist of gneiss, shale and fine sandstone, is present in a narrow strip between Archean and Barakar formation, the typical value three has been assigned to this vadose zone. The rating three has been assigned to the gneiss, shale and fine

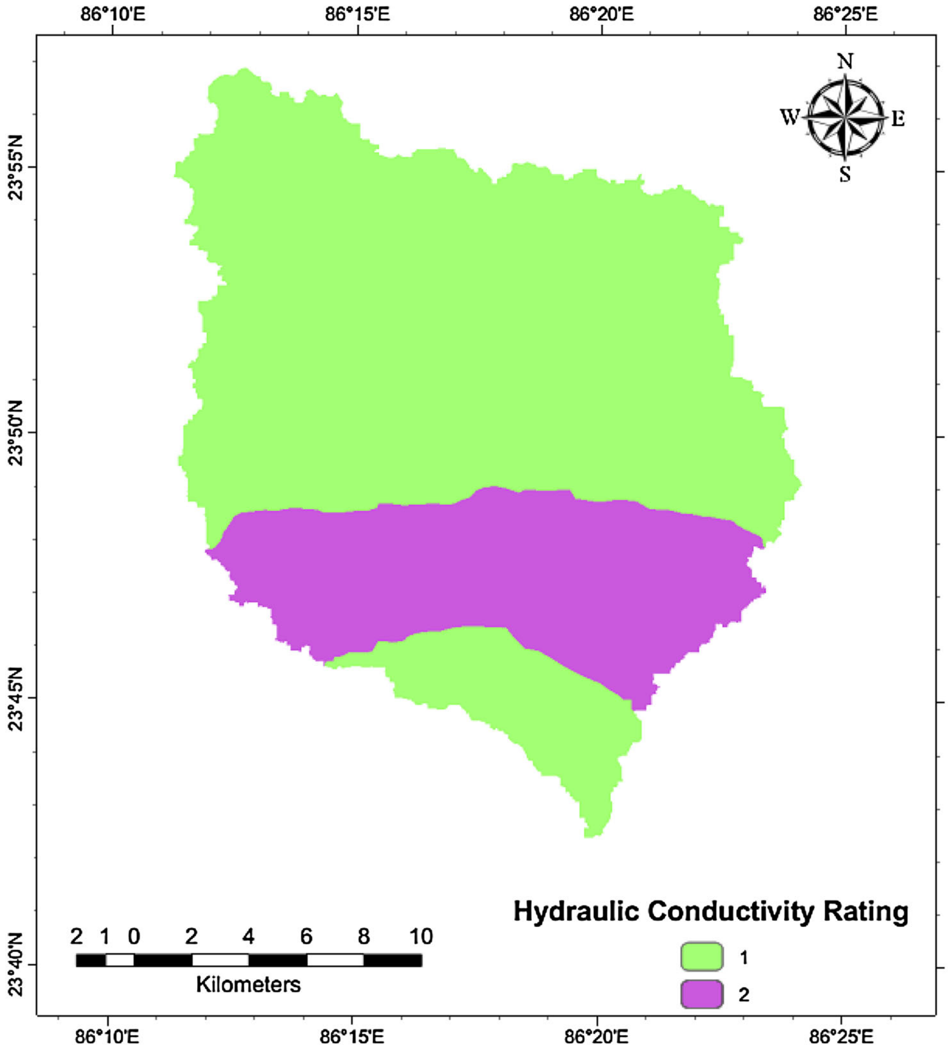


Fig. 10 Hydraulic conductivity rating map

sandstone (Talchir formation) vadose zone. The typical rating four has been assigned to the gneiss and schist (Archean formation) vadose zone. The rating four has been assigned to the granite gneiss residual hill (granite gneiss) vadose zone media (Fig. 9).

Hydraulic conductivity

Groundwater always remains under movement, and hydraulic conductivity expresses the ability of aquifer to transmit water (Saha and Alam 2014). This component thus determines at which rate the pollutants move through an aquifer (Aller et al. 1987). Hydraulic conductivity values were calculated after calculating transmissibility from pumping test data and have been mapped as shown in Fig. 10. An aquifer with high conductivity is vulnerable to substantial contamination as a plume of contamination can move easily through the aquifer. Therefore, it is a function of the grain size, shape, sorting and packing of the aquifer materials and properties of the fluid passing through the aquifer. In this basis hydraulic conductivity (k) were estimated on the ranges provide in the DRASTIC method and validated using values from the literature and pumping test in nearby areas. The different hydraulic conductivity zones in the area were defined and assigned ratings according to DRASTIC rating.

Vulnerability index map

The DRASTIC method allows for easy interpretation of data by non-technical experts and in particular can be used for education purposes. The main purpose of this work was not to evaluate the sensitiveness of each of the parameters to computing the overall index, therefore the optimal use of the parameters most relevant as presented by Rahman (2008) was not done in this research. All seven parameters

Fig. 11 DRASTIC index map

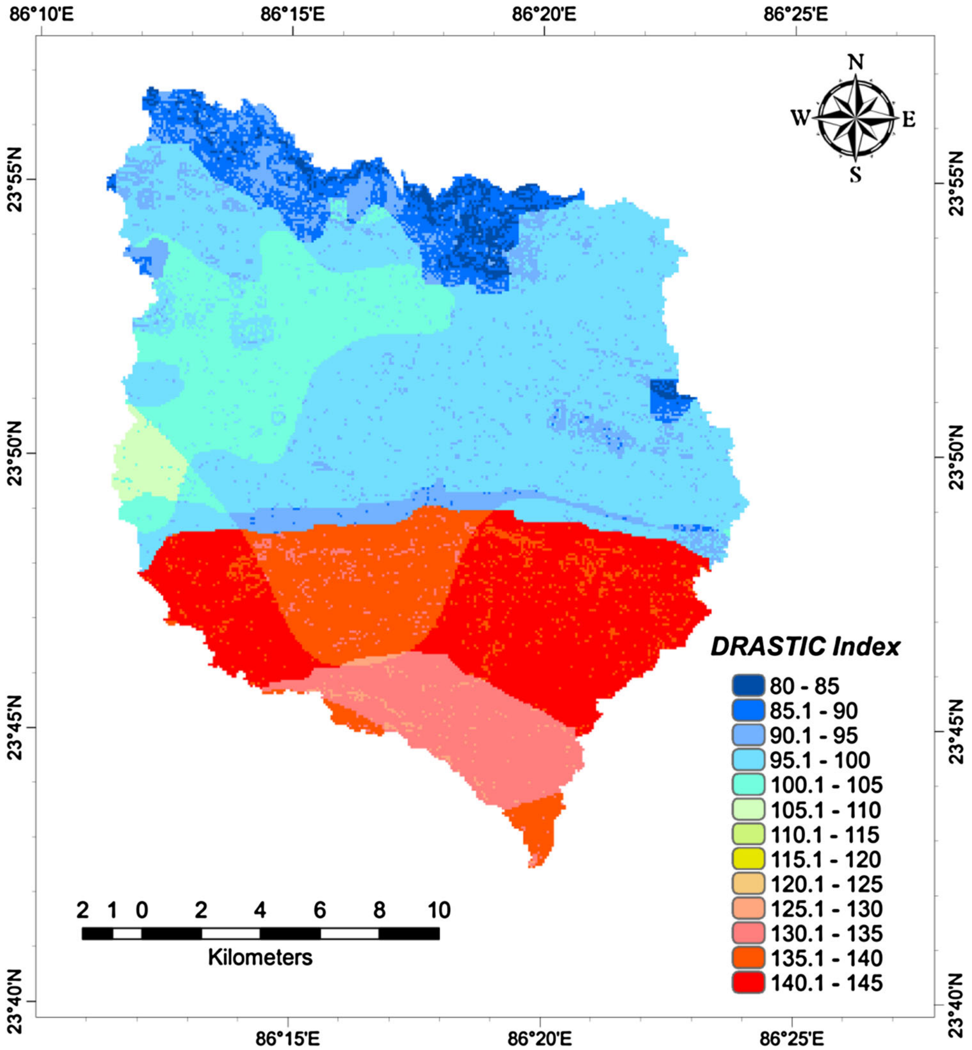


Table 2 Vulnerability zone distribution

Index range	Area	Percentage of area	Vulnerability class
<100	185.92	52.40	Low
100–140	108.87	30.69	Moderate
>140	59.99	16.91	High

were used since it was easy deriving them from all relevant data source. In this way, a reliable approximate estimate of the index was achieved.

The estimated DRASTIC index map gives an indication of the prevailing vulnerability in this watershed. The estimated index values vary between 80 and 145 and the map is portrayed in Fig. 11. The study shows that about 16.91 % of the watershed area is exposed to high-risk, 30.69 % exposed to medium-risk, and 52.4 % exposed to low risk (Table 2). The south eastern and south western parts of the watershed are dominated by high vulnerability classes while the south, north western and lower middle portions are characterized by moderate vulnerability classes. The elevated northern, north eastern, and middle part of the study area displayed low aquifer vulnerability (Fig. 12).

Conclusion

In the study, an attempt has been made to assess aquifer vulnerability in Katri watershed. The task was accomplished by using the DRASTIC model. Based on the result, the vulnerable zones were classified into three zone namely low, moderate and high vulnerable zones. The study has showed that 52.4 % of the total area was under the low vulnerable zone, mainly due to the presence of the higher depth of water level and high elevation (Topography). About 16.91 % of the area was under high vulnerable zone

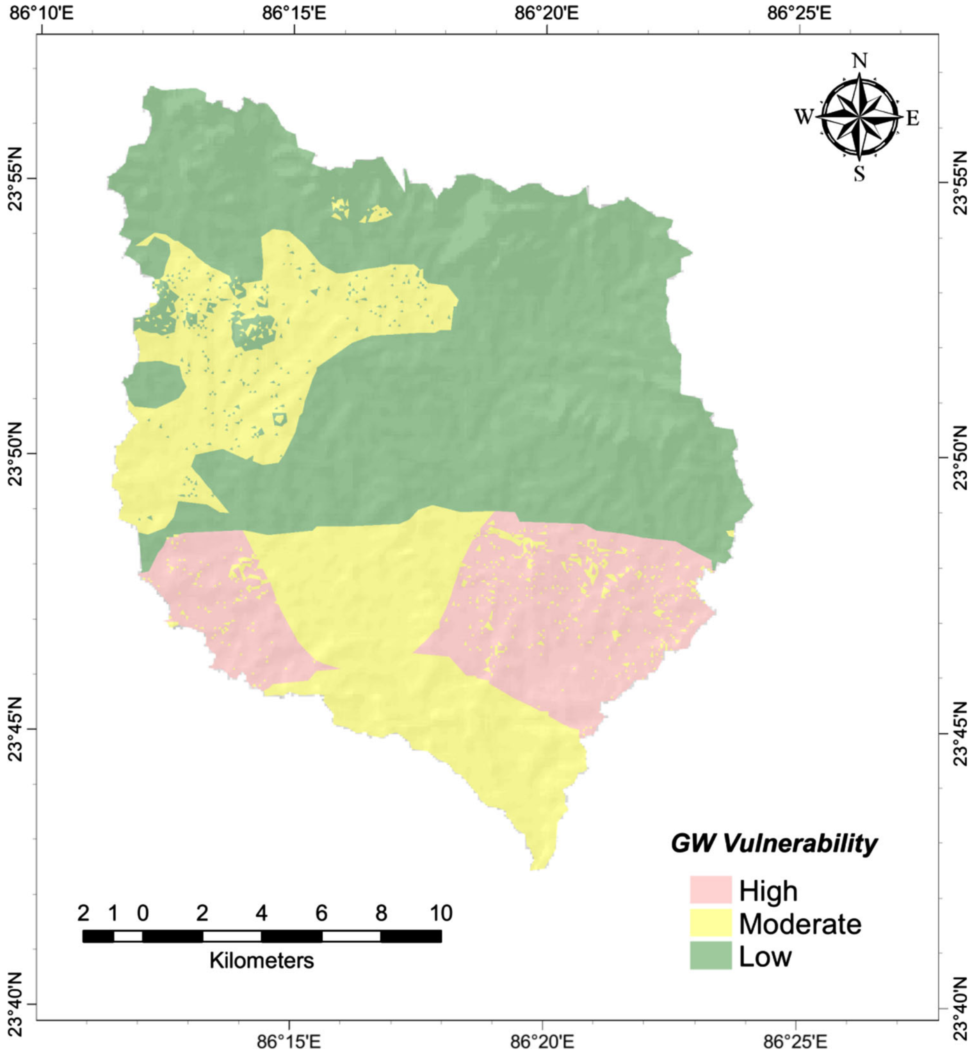


Fig. 12 Groundwater vulnerability map

which could be due to the reason that the middle SE and SW part received a considerable amount of water from the surface resources. High vulnerability is found due to shallow depth of water level, permeable vadose zone and high net recharge rate in and around the study area.

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