Artificial Ground Water Recharge Planning Using Geospatial Techniques in Hamirpur Himachal Pradesh, India

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Abstract: Groundwater resources can be sustainably managed by the artificial recharge. The objective of present study is to formulate a methodology to delineate the zones favourable for artificial recharge and to recommend sites where artificial recharge structures can be constructed in Hamirpur (H.P.), India. Remote Sensing and Geographic Information System (GIS) are used in the study. Seven parameters influencing groundwater recharge viz. slope, drainage density, land use/land cover, geomorphology, geology, lineament density and soil texture are used as input in GIS software. Base maps for all these influencing factors are collected from different departments and organizations to prepare thematic maps. After developing the thematic layers, suitable ranking and weightage is assigned to each factor depending upon its ability to fluctuate the rate of groundwater recharge using Multi-Influencing Factor technique. Results of the study depicts that most areas in Hamirpur have 'moderate' recharge potential (around 73%), whereas 18% have 'high' recharge potential and only 9% have 'poor' recharge potential. The results can be used by developers and administrators for better planning and administration of groundwater resources in Hamirpur.

Keywords: Groundwater, Artificial recharge, Remote Sensing, Geographic Information System

1. Introduction

Groundwater is a significant natural resource supporting well-being of humans, economic development and sustainability of agriculture. Above 90% rural population and around 30% population in urban areas depend upon groundwater for fulfilling their domestic needs (Huerta *et al.,* 2019). Aquifer replenishment with the water available on land surface is known as ground water recharge. Just like precipitation, groundwater recharge is expressed as an average rate of 'mm' of water per year (Bhattacharya 2010). Excessive utilization of groundwater resources due to increasing population results in mismanagement and degradation of the quality and quantity of this important natural resource in most parts of the world and India in particular (Yadav 2018). One of the best methods to replenish the groundwater is Artificial Recharge.

Compared to natural recharge (rainfall), artificial recharge is a better alternative to recharge the groundwater (Saha *et al.,* 2018). Artificial recharge is used to make a direct entry of the available surface water into the ground by using different techniques such as spreading of water on land surface, constructing recharge wells or influencing the natural hydrologic conditions to increase the rate of infiltration.

Geospatial techniques such as Geographic Information System and Remote Sensing can be integrated together to determine the potential areas of groundwater (Samson and Elangovan 2015). A review of using the integrated approach of these geospatial techniques in mapping the potential zones of groundwater has been presented by Navane & Sahoo (2017).

For studying the nature of water resources, a complete knowledge about the different geologic, geomorphic and structural units present in the study area are required. Modern technology of remote sensing can be used to study most of these aspects using satellite images. The remotely sensed data that is obtained from the satellites play a significant role in evaluation and development of water resources, and can be used to obtain immediate and important information about the parameters controlling occurrence and movement of groundwater. The main factors influencing the motion and location of groundwater are lineaments present in the area, geology and geomorphology (Lakshmi and Kumar 2018). An organized study of all these influencing parameters might leads to better results of the delineation process. The aim of study is to delineate the potential recharge zones and to recommend appropriate recharge structures at the identified locations. This can be fulfilled by completing the following objectives:

i. Preparing of thematic maps of factors affecting the recharge of groundwater.
ii. Assigning proper weightage and ranking using Multi-Influencing Factor technique.
iii. Identifying locations where recharge structures can be constructed and suggest suitable recharge structure.

Study Area

Hamirpur is the centrally located district of Himachal Pradesh falling within the latitudes 31°21’00” and 31°53’00” N and longitudes of 76°20’00” and 77°45’00” E in toposheets 53A05, 53A06, 53A07, 53A09, 53A10 and 53A11 from Survey of India (SOI). Climatically, Hamirpur is a moderate rainfall district having an average rainfall of 1340 mm and 82% of the total rainfall occurs during the monsoon season (from July to September). Geomorphologically, mostly hilly and undulating terrain is present in the district. The altitudinal variation is between 600m to 900m above the mean sea level. Drainage system of Beas river and Sutlej river are formed in the N-W and E-S parts of the district respectively. Drainage pattern is dendritic and sub dendritic in the study area and the drainage density varies from medium to coarse. Major streams present in the district are Kunah Khad and Man Khad. These major streams along with some minor streams like Sukkar Khad and Sir Khad joins the River Beas. According to the CGWB report 2011 Hamirpur is a district that falls under safe category because of the groundwater resources, not fully explored and lots of scope is available for future development of groundwater resources. Location map of the study area is shown in Figure 1.

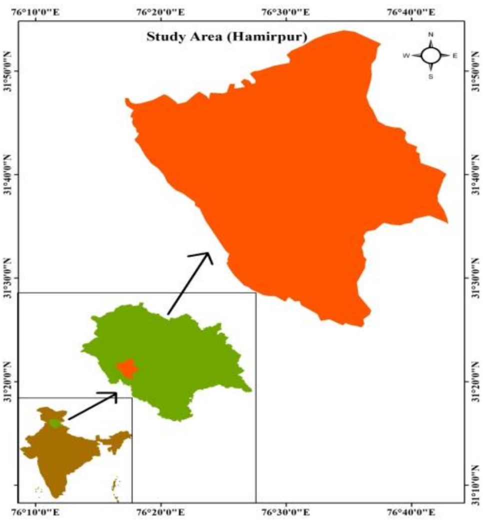

Figure 1. Location map of Hamirpur

2. Material and Methods

The factors influencing groundwater recharge are slope, drainage density, geology, geomorphology, lineament density, land use/land cover and soil texture. All the considered factors and their sources of base map collection are summarized below in Table 1. Using the base map of these factors, different thematic maps will be prepared in the GIS software.

Table 1. Factors influencing groundwater recharge and their source of data collection

S.No.	Factors	Source of Collection
1	Slope	Survey of India (SOI) Toposheets/Digital Elevation Model (DEM)
2	Drainage	DEM from EarthExplorer United States Geological Survey (USGS)
3	Geology	Groundwater Prospects Map
4	Geomorphology	Satellite images from Bhuvan (Indian Space Research Organization)
5	Lineament	Groundwater Prospects Map
6	Land use/ land cover	Landsat image from EarthExplorer USGS
7	Soil	National Bureau of Soil Survey (NBSS)

After collecting all the base maps and preparing thematic maps a final groundwater potential zone map is obtained. The methodology adopted to prepare the final resultant map is shown below in Figure 2.

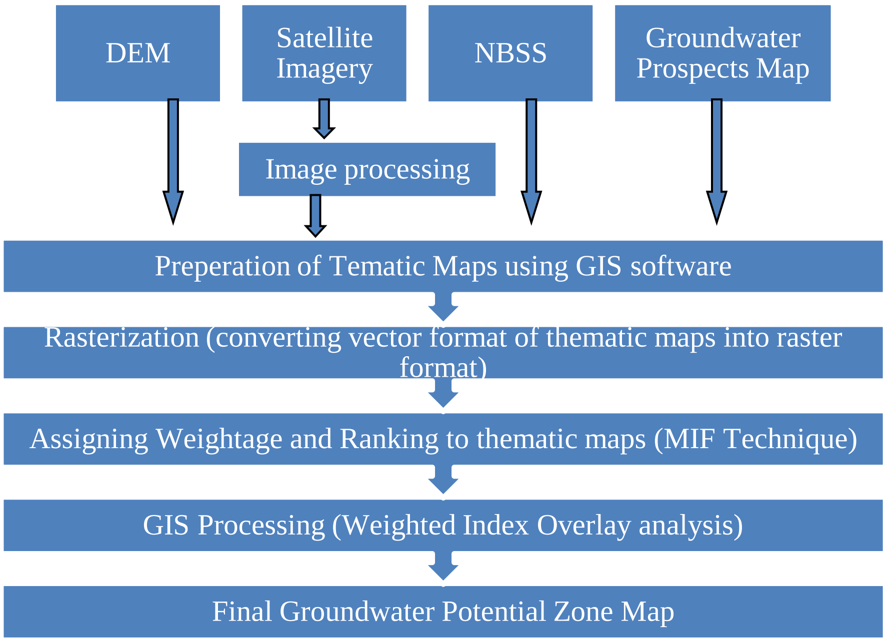

Figure 2. Flow chart showing the delineation process

Multi-Influencing Factor Technique

This technique evaluates the individual weight that has been given to each factor considered i.e., slope, drainage density, geology, etc. Each factor under consideration influence some other factor, but the effect varies from factor to factor. The study of this inter-relationship among different factors is done with the help of Multi-Influencing Factor (MIF) Technique. All the relations are weighted according to their impact on groundwater recharge. The representative total weightage of any factor is the sum of all the weights from other factors. Factors having major and minor impacts on the factor under consideration are summarized in Table 2. Factors having high value of total weightage have greater influence on groundwater potential as compared to the factors having smaller value of total weightage. All these factors along with their potential weights are integrated together using Weighted Overlay Index tool in ArcGIS software to obtain the final groundwater potential zone map.

Table 2. Inter-relationship between the factors concerning groundwater recharge zone

S.No	Considered factors	Major Impacts	Minor Impacts
1.	Slope	Geology	LULC, Geomorphology
2.	Geology	Drainage density, Slope, Soil, Lineament density	
3.	Soil	LULC	
4.	Drainage Density	LULC	Lineament density
5.	Geomorphology	LULC	Drainage density, Soil
6.	Land Use Land Cover	Drainage density, Geomorphology	Lineament density, Soil, Slope, Geology
7.	Lineament Density	Drainage density, LULC	

Weighted Overlay Index Technique

Influence of a factor on other factors is studied using MIF technique. After calculating the individual potential weight of each factor, all the thematic layers are overlaid on each other in weighted combination to obtain the final groundwater recharge zone map. Thematic layer having highest weight should be put at the top. All the other layers are overlaid in the decreasing order of their weights. After the series of overlaying is finalized, ‘weighted overlay’ analysis tool is applied. Weighted overlay analysis tool in GIS software provide the final map which divides the whole study area into different potential zones.

3. Result and Discussion

All the thematic maps are prepared using the methods and techniques described in the above section. Collection of the base is the initial step for preparation of thematic maps. The procedure adopted and the final thematic map is discussed here in this section.

Preparation of thematic maps

Slope Map

Slope can be used as important suitability parameter for the recharge of groundwater since it influences the infiltration capacity of water into the groundwater. Smaller the value of slope, smaller will be surface runoff and greater will be the value of infiltration and vice-versa. Variation in the value of slope in Hamirpur district is from 0 to 59 (in percentage). The final map of Hamirpur is shown in Figure 3.

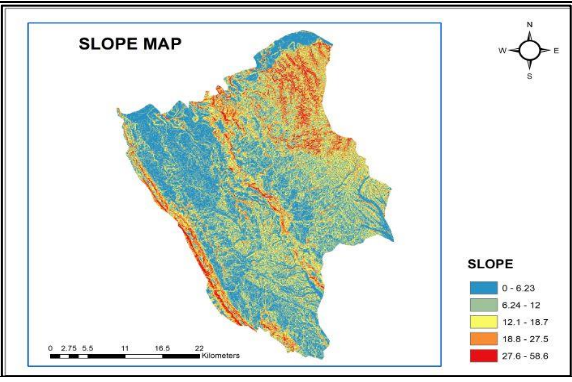

Figure 3. Slope Map

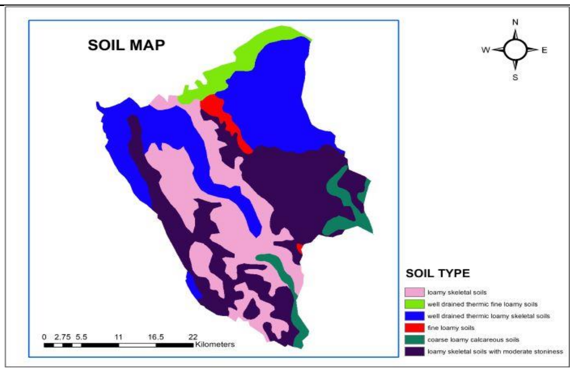

Figure 4. Soil Map

Soil Map

Soil type and texture of any area largely influence the seepage and percolation of surface water into the groundwater, hence directly influencing the recharge capacity of the soil. Soils having high infiltration rate will be best suitable for artificial recharge whereas soils having low infiltration are not considered good for artificial recharge. Alluvial soils and non-calcic soils are the major types of soils present in Hamirpur. Most of the area in Hamirpur is covered by non-calcic loamy soils. Due to the variation in the value of slope, loamy soil also vary in the study area. Figure 4 shows the various types of soil present in Hamirpur district.

Geomorphology Map

The underground flow of water is controlled by geomorphic units present beneath the surface. Recharge capacity of any surface is greatly influenced by geomorphology of the area. Major geomorphic units present in Hamirpur are (i) Structural hills & uplands, and (ii) Valley/ alluvial plains. Satellite image downloaded from National Remote Sensing Centre (NRSC), Bhuvan is used to obtain the Geomorphology Map of Hamirpur. Geomorphic units present in Hamirpur as shown in Figure 5 are highly dissected hills & valleys, piedmont alluvial plains, moderately dissected hills & valleys and piedmont slope.

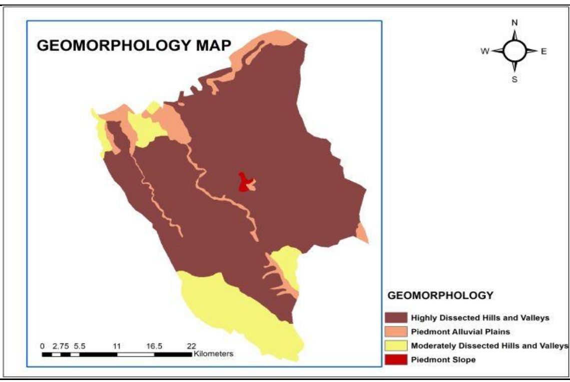

Figure 5. Geomorphology Map

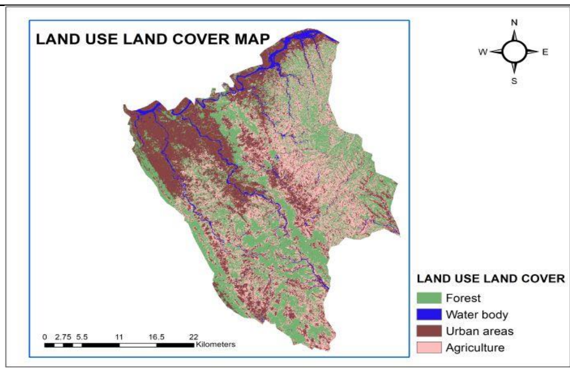

Figure 6. Land Use Land Cover Map

Land Use Land Cover Map:

Different types of LULC units present in Hamirpur are forests, water bodies, urban areas and agricultural land. LULC is prepared using Landsat image downloaded from EarthExplorer

United State Geological Survey (USGS). Figure 6 shows the final LULC map which is prepared using ‘Maximum Likelihood Classification’ tool in GIS software. The vegetative cover at any area is directly related to surface runoff hence also influence recharge capacity. More the density of vegetative cover greater will be infiltration rate and smaller will be runoff from the surface. Water bodies show the highest recharge capacity whereas for urban area recharge is almost negligible because of the construction of paved surface which facilitates large runoff.

Drainage Density Map

For any catchment area, ratio of total distance travelled by all the major and minor rivers to the total surface area is defined as Drainage Density expressed as km/km^2. To evaluate the groundwater prospects at any area drainage density is an important parameter since it is always related to porosity and permeability of any surface. Higher value of drainage density results high runoff and low infiltration, which directly affects the recharge capability. Figure 7 shows drainage density variation in the study area.

Geology Map

Various geological units present in Hamirpur area are (i) Alluvium/valley fill, and (ii) Siwalik hills. The geology map is prepared using Ground Water Prospects Map for each toposheet (53A05, 53A06, 53A07, 53A09, 53A10 and 53A11) covering Hamirpur collected from National Remote Sensing Agency, Department of Space and Government of India. Major area of Hamirpur is covered by Boulder Conglomerate.

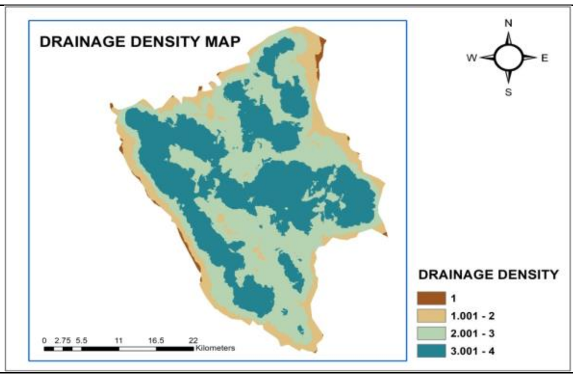

Figure 7. Drainage Density Map

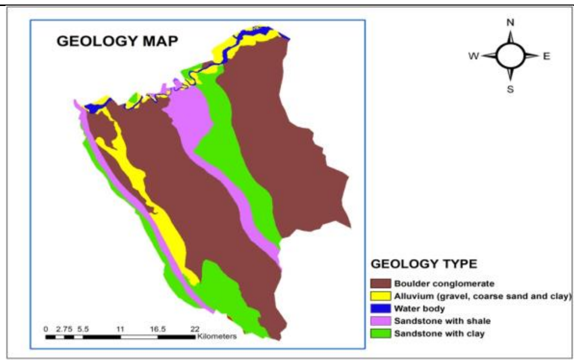

Figure 8. Geology Map

Lineament Map

Linear features such as joints, fractures and folds that are present beneath the surface of earth constitute Lineaments of any area. Water holding capacity of these lineaments is very good and acts as a good conductor of water transmission. Presence of lineaments in any area is considered good as they increase the porosity, hydraulic conductivity and permeability of land surface. The lineaments exist in Hamirpur are shown in Figure 9 shown below.

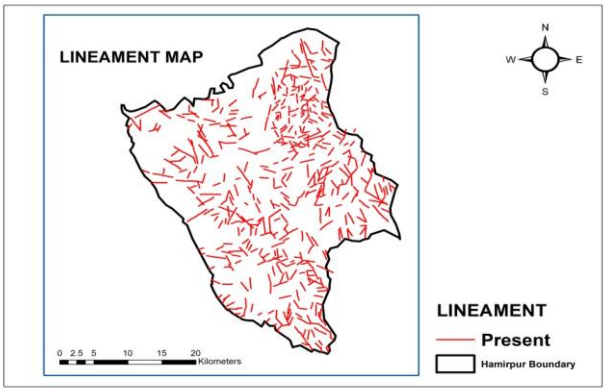

Figure 9. Lineament Map

Assignment of Weightage and Ranking to each factor

Weights and ranks are provided to each factor and the parameter associated with factor. Individual weights are allotted to each factor using Multi-influencing Factor Technique. Weightage given for each major impact is 1 where 0.5 weightage is given for minor impact. The summation of all the weights will give the individual weight of each influencing factor. Table 3 shows the individual weights given to each factor.

The proposed score or the final individual weight is calculated using the formula given below:

$$\frac{P+Q}{\sum(P+Q)}\times 100 \quad (1)$$

Here P shows major impacts and Q shows minor impacts between two influencing factors

Table 3. Relative Rates and Final Individual Weights for each influencing factor

S.No	Factors	Major Impact Score (P)	Minor Impact Score (Q)	Relative Rates (P+Q)	Final Individual Weight
1.	Slope	1	0.5+0.5	2	12
2.	Geology	1+1+1+1		4	24
3.	Soil	1		1	7
4.	Drainage Density	1	0.5	1.5	9
5.	Geomorphology	1	05+0.5	2	12
6.	LULC	1+1	0.5+0.5+0.5+0.5	4	24
7.	Lineament Density	1+1		2	12
			TOTAL	16.5	100

After deciding the individual weights, rank is being provided to each associated parameter on the basis of their influence on groundwater recharge. Concerned weights and the ranks given to each parameter is described below in Table 4.

Table 4. Rank and weightage allotted to various factors and parameters

S.No	Factors/ Themes	Associated Parameter	Rank (in words)	Rank (in number)	Weightage (%)

1.	LULC	Agricultural land	High	2	24
		Water bodies	Very High	1	
		Forest land	Moderate	3	
		Urban areas	Poor	5	
2.	Geology	Alluvium mixture of gravel, coarse sand and clay	Very High	1	24
		Boulder Conglomerate			
		Sandstone with clay	Poor	4	
		Sandstone with shale	Very Poor	5	
			High	2	
3.	Lineament Density	Present	Very High	1	12
		Not Present	Very Poor	5	
4.	Geomorphology	Highly dissected hills & valleys	Poor	4	12
		Piedmont alluvial plains	Very High	1	
		Moderately dissected hills & valleys	Moderate	3	
		Piedmont slope	High	2	
5.	Slope	0 – 6.23%	Very High	1	12
		6.23 – 12%	High	2	
		12.1 – 18.7%	Moderate	3	
		18.8 – 27.5%	Very Poor	5	
		27.6 – 58.6%	Very Poor	5	
6.	Drainage density	3.001 – 4 km/km	Poor	4	9
		2.001 – 3 km/km	Moderate	3	
		1.001 – 2 km/km	High	2	
		0 – 1 km/km	Very High	1	
7.	Soil type	Loamy skeletal soil	Poor	4	7
		Well drained thermic fine loamy soil	Poor	4	
		Well drained thermic loamy skeletal soil	High	2	
		Fine loamy soil	Very Poor	5	
		Coarse loamy calcareous soil	Moderate	3	
		Loamy skeletal soil with moderate stoniness	Very High	1	

Groundwater Recharge Zone Map

After successfully deriving the weightage of each factor using MIF technique, all the thematic maps are integrated together with the derived weights and ranks during weighted overlay analysis in ArcGIS 10.3.1 software to obtain the final groundwater potential zone map (Figure 10). From figure 10 it is observed that around 73% of the study area has ‘Moderate’ recharge capability. ‘High’ recharge capability is shown by 18% of the study area and around 9% study area has ‘Poor’ recharge capability.

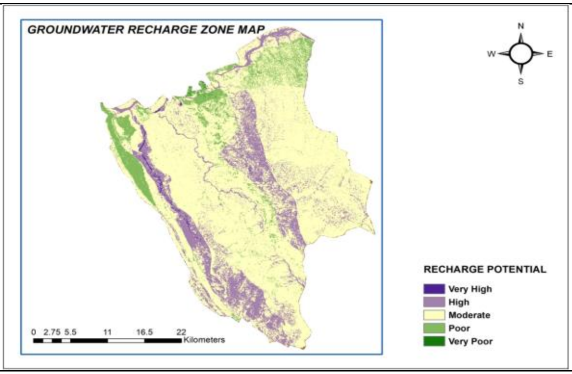

Figure 10. Distribution of groundwater potential zone in Hamirpur

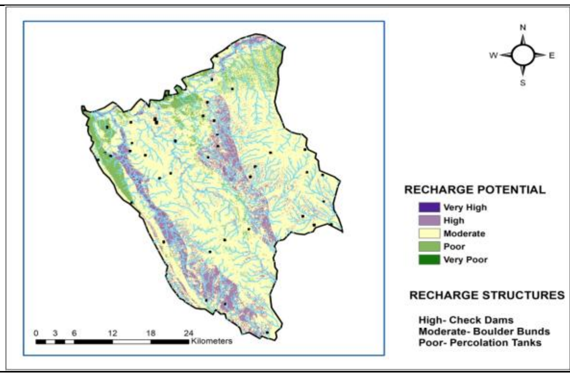

Figure 11. Identified Location Map

Construction of artificial recharge structure is one of the best ways to augment the groundwater sources. One objective of the study is to recommend artificial recharge structure for the sites identified over the various potential zones. To exactly identify the locations where these structures are to be built, overlaying drainage density and lineament density thematic maps can be obtained. The locations where these structures can be constructed are shown in Figure 11. In Figure 11 the black points show the position of artificial recharge structures. Different recharge structures suggested for identified locations are listed in Table 5.

Table 5. Recharge structures for respective potential zones

S.No	Recharge Potential	Suggested Structure
1.	High (18%)	Check Dams
2.	Moderate (73%)	Boulder Bunds
3.	Poor (9%)	Percolation Tanks

4. Conclusion

The results obtained from present study revealed that geospatial techniques are potentially powerful for delineating different potential zones of groundwater considering seven parameters influencing groundwater recharge viz. slope, drainage density, land use/land cover, geomorphology, geology, lineament density and soil texture. Base maps of the influencing factors are collected from different departments and organizations to develop thematic maps. After thematic layers developed, suitable ranking and weightage is assigned to each factor depending upon its ability to fluctuate the rate of groundwater recharge using Multi-Influencing Factor technique. Results of the study depicts that most areas in Hamirpur have ‘moderate’ recharge potential (around 73%), whereas 18% have ‘high’ recharge potential and only 9% have ‘poor’ recharge potential. These results can be used to prepare a proper exploration plan for groundwater resources, so as to have a long term sustainability of this limited resource. The final groundwater recharge zone map is obtained in the form of prospects map which can be utilized by planners and administrators to look for the groundwater resources in the study area, followed by suitable exploration.

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