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Groundwater Prospect Zone Mapping: A Geospatial Investigation with Decision Making in Mahendergarh District, Haryana

Manju Kumari, Surender Singh and Anil Kumar[1]*
Department of Geography, Lovely Professional University, Punjab, India
[1]Bharati Vidyapeeth's College of Engineering, New Delhi – 110063, India
✉ dranilchhikara@gmail.com

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Abstract: Groundwater is a prime resource for anthropogenic activity as agriculture, industry, and domestic use, especially in arid and semi-arid regions like Mahendergarh District, Haryana. Unsustainable extraction practices of groundwater with limited recharge rates pose significant challenges to groundwater management. This study utilised remote sensing data, hydrological parameters, geographic information systems (GIS), analytical hierarchical process, multi-decision criterion, receiver operating charts, area under curve, consistency index and constancy ratio. The present study aims to identify areas potential for groundwater extraction. Based on the above methodology, the study area is classified under good, fair, poor and very poor classes (60.82 sq. km (3.2%), 805.10 sq. km (41.8%), 839.03 sq. km. (43.4%) and 223.05 sq. km (11.6%)). By integrating these findings into a comprehensive management strategy, policymakers and stakeholders can make informed decisions to ensure the long-term viability of groundwater resources in the region.

Key words: Geospatial analysis, Mahendergarh, remote sensing, GIS.

Introduction

Groundwater is the major component of the water cycle, which fulfil the water demand for various activities (Glesson et al., 2012). It is the main resource for agriculture, industries, communities, and urbanisation (Wada et al., 2012). Globally, near about 34% of groundwater is used by rural and urban areas (Kadam et al., 2021) while input of the resources is very low because arid and semi-arid region of the world has global average rainfall (Kumar, 2018; Pinto et al., 2017). That's why, the depletion of groundwater is occurring at an alarming rate. Over-exploitation, increasing pollution and climatic variation are the leading factors for groundwater depletion and make it a global concern (Famiglietti, 2014; Wada et al., 2016). Increasing demand for groundwater resources for industry, unprecedented urban growth and agriculture have led to increased stress on the resource reserves (Shah, 2009). The mismanaged groundwater concept is a phenomenon dating back to geological times, which has not only influenced the local ecological system but has also contributed to the huge challenge of water scarcity and degradation of the environment (Gleeson et al., 2012). But now these days, with the help of geospatial techniques groundwater resource studies have become more successive, accurate, cheaper and easier (Kadam et al., 2019; Kumar & Singh, 2021). The technology comprises remote sensing, GIS, GPS and information technology, and offers thematic mapping (Kumar,

*Corresponding Author

2017) with very fine resolution and concise observation of groundwater (Kaliraj et al., 2014). Groundwater resource modelling through this technology is more advantageous rather than conventional methods as various constraints can be displayed on a map (Kumar et al., 2020). Many studies used geospatial applications as well as various decision-making approaches to provide additional real-time results in groundwater resources assessment. Some approaches like analytical hierarchy process (Chakraborty et al., 2018; Rajasekhar et al., 2019); artificial neural network (Lee et al., 2020); fuzzy logic (Rajasekhar et al., 2019); multi-criteria decision making (Machiwal et al., 2011), and multi influencing factor (Datta et al., 2020) are used. Delineation of groundwater zones has become more developed with the advancement of remote sensing data and GIS processing (Rahamti et al., 2015).

As a result, it has become essential to improve ground management practices for permanent water protection on the global surface. Seen in the Indian context, the subcontinent presents a unique set of challenges and solutions related to groundwater resources (Shamsudduha et al., 2019). Indian economy is purely based on the agriculture sector which is totally water-intensive sector (Mukherji, 2006). In Haryana, groundwater resource is the backbone of irrigation in agriculture for supporting crop cultivation and food security (Mukherji, 2006). The complex interactions between cultivation demand, increasing industrial activity and rapid urbanisation highlight the need for abstract and region-specific approaches to its management (Shamsudduha et al., 2019).

In Mahendergarh District, Haryana, the geospatial application has been employed by numerous researchers to assess groundwater prospect zones (Raju et al., 2019). Due to the hardness of rocks, traditional hydrological approaches have rarely been used in this area. Therefore, the study is based on a practical investigation into the adaptation of water resource management in the Mahendergarh district of Haryana, using advanced geospatial methods. The study area exhibits in drought-prone conditions throughout the year because the area has low rainfall frequency and intensity. So, the cropping system of the study area is purely based on an irrigation system which led to stress on the resources. Thus, the objective of our investigation is to assess the availability of groundwater in this area, using the analytical hierarchical process to make informed decisions and to contribute to sustainable water resource management by providing scientific insight. The integrated geospatial analysis with hydrogeological methods to address issues related to groundwater resources. This research highlights the complex dynamics of the water supply system in Mahendergarh district, which will provide a basis for developing such systems that will certify sustainable use and management of this vital resource.

Research Area

The special feature of Haryana State is that two important rivers Ghagghar and Yamuna Basin are present. Specifically, Mahendergarh district is located in the southwestern part of Haryana, with a geographical area of 1928 square km. Mahendergarh district lies between longitude of 75° 50′ 52″ to 76° 20′ 22″ E and latitude of 27° 50′ 12″ to 28° 30′ 02″ N. According to the Soil and Land Use Survey (AISLUS, 1988), a major part of the district is the Yamuna basin and is drained by seasonal rivers. It has two separate watersheds connected to Krishnawati and the Dohan. The district lies in an arid to semi-arid region. The highest temperature has been recorded in summer and the lowest temperature in winter. The average annual rainfall of the study area is 592 mm and 74% of the total rainfall is received during the south-west monsoon in July, August and September. The landscape of Mahendergarh district mainly consists of dry land along with inter watershed, sandy plains, changing sand dunes, stable sand dunes, isolated roads and isolated forests, isolated mountain ranges and solitary branches. Geologically, the study area is classified into three categories Undiff Aeolian Sediments, quaternary; Ajabgarh group, Paleoproterozoic Mesoproterozoic and Alwar group. Major soil types of the study area are loam, sandy clay loam, clay loam and loam. Krishnawati and Dohan create irregular flood plains which are associated with a sandy terrain and stabilised dunes having carriable morphological features. Figure 1 displays the location of the study area.

Methodology

To achieve the objective of optimising groundwater resource management in the present study, methodology is classified into three categories data input, data processing and output. For the data input process, satellite images and DEM data were downloaded from the Bhuvan portal, toposheets from SOI, secondary maps from the HARSAC site and rainfall data from the IMD department. In Data processing, various thematic layers have been prepared as geomorphological features, geological features, lineament density, slope, soil types, drainage density, drainage order, rainfall, land

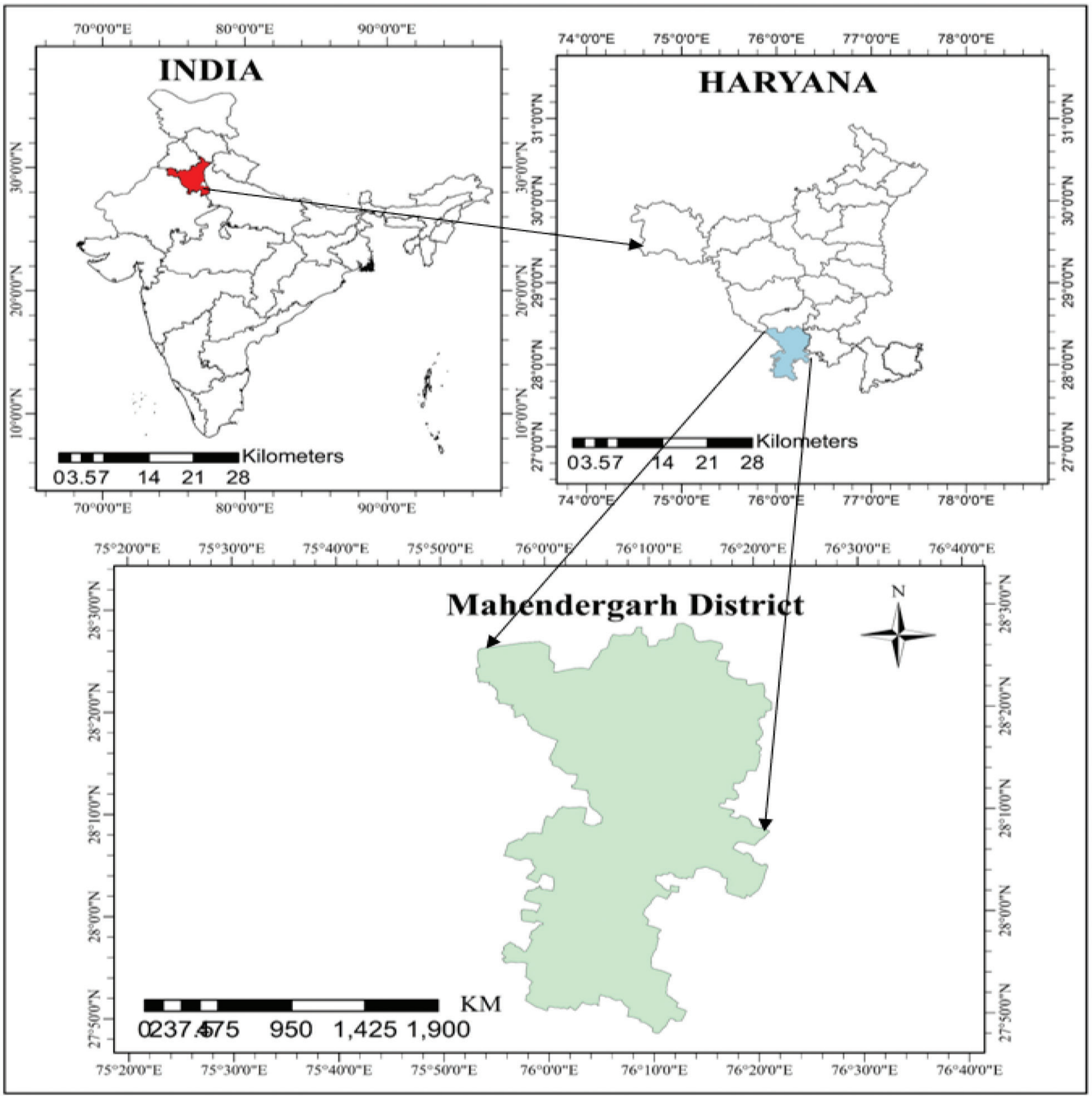


Figure 1: Location map.

use and land cover using this data. In data output, the analytical hierarchical process method is used to prepare groundwater potential zones. Detailed methodology is given in Figure 2.

Thematic Mapping

All the required thematic layers as geomorphology, geology, slope, soil type, drainage density, lineament density and rainfall for groundwater potential zone mapping were prepared with the help of Arc GIS 10.6 software using LANDSAT 8, Carto DEM Version-3 R1 data by applying unsupervised image classification and spatial analytical methods (Kumar & Singh, 2021). Soil and geological layers were prepared using HARSAC-prepared maps. Topographical map and Cartosat data used to fill analysis, flow direction, flow accumulation, drainage order, drainage density and lineament maps. Digital elevation model, Aspect, Slope, hill shading and contours were also prepared using Cartosat data. Out of all these layers, eight layers of rainfall, geology, slope, drainage density, land use and land cover, lineament density and soil types (Rajasekhar et al., 2022) are considered for the analytical hierarchical process to interlinkage of groundwater potential zone mapping.

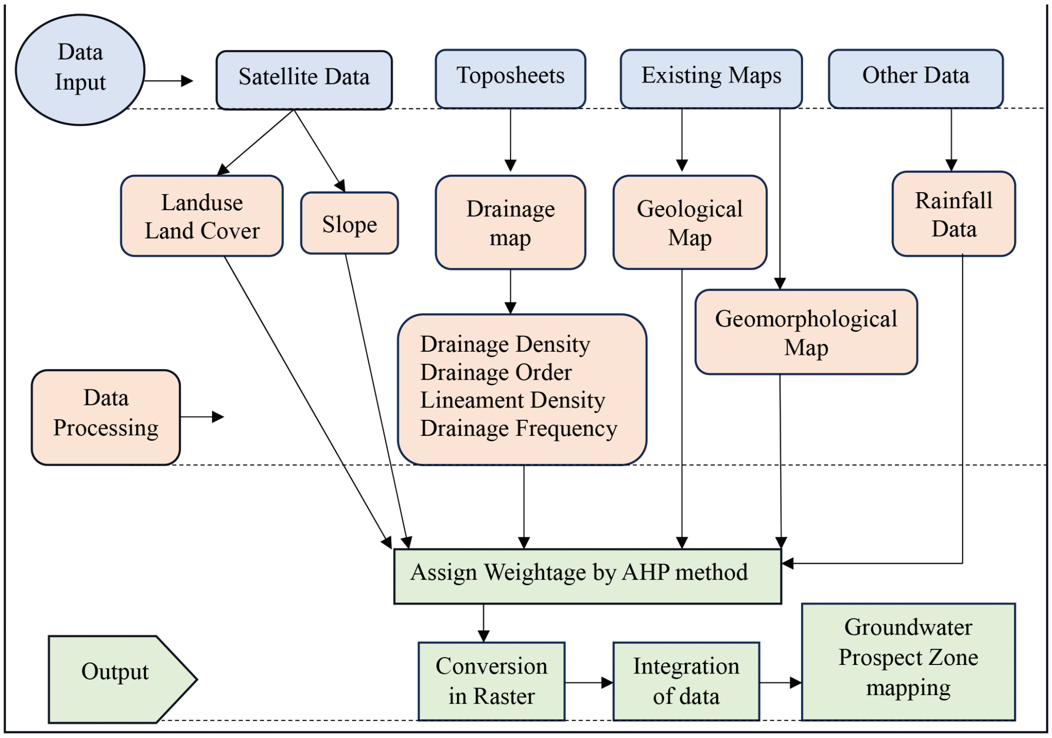


Figure 2: Detailed methodology.

Geological Mapping and Analytical Hierarchical Process

The study area is covered by loam and clay loamy soil with relic Aravali ranges in the southwestern part to the middle and northeastern part. Mainly three geological units' Aeolian sediments (Quaternary age) covered an area of 91.2 %; the Ajabgarh group with Delhi subgroup covered an area of 2.92 %; and the Alwar group covered an area of 5.88 % are present in the study area (Figure 4). Mahendergarh district have granite/gneiss northern and central part; quartzite almost found groups; basic rocks in central and western part; schist/ slate/ phyllite in the northern and central part; calc rocks in northern and western part; and pegmatite in the north-eastern, central and southeastern part. All these geological units are assigned weights (Table 1 and Figure 3) based on the scale of their porosity and permeability for influencing the groundwater potential zone in the area (Rajasekhar et al., 2022).

Geomorphological Features and Analytical Hierarchical Process

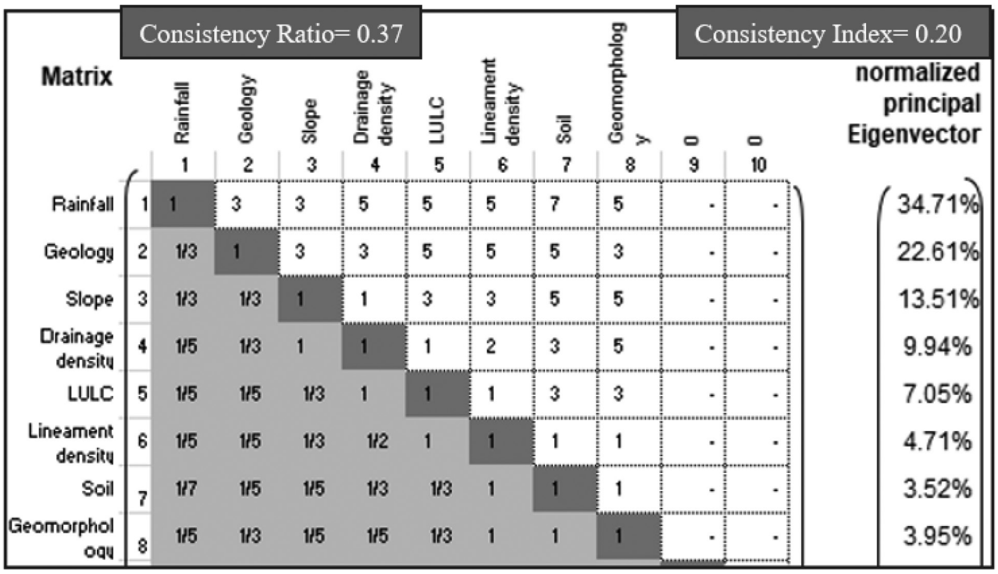
Geomorphologically, the study area is classified into different classes as aeolian plains, alluvial plains, pediments, denudational hills and dune complex (Figure 4) and analysed with the analytical hierarchical process (Table 1 and Figure 3). The major geomorphological unit is aeolian plains (86.4 %) followed by sand dunes (6.86 %), pediments (3.04%), alluvial plains (1.89 %) and hills (1.81%). Aeolian plains are found in southwestern, southeastern, central and northwestern parts; dune complexes in scattered patches in southern, western, and central parts; alluvial plain in the northeastern part; hills range spreads from southern to northern direction covered by pediments.

Soil Types and Analytical Hierarchical Process

The soil types and texture of the study area are classified into four categories (Figure 4) loam (56.4%), sandy-clay-loam (9.2%), sandy loam (33.3%) and clay-loam (1.1%) and examined groundwater potential zone by analytical hierarchical process (Table 1 and Figure 3). Loam soil is found in northern, northwestern and northeastern; sandy-clay-loam in southern and eastern part; sandy-loam in middle, southwestern and clay-loam in scattered patches. The common thickness of the soil cover of the area is 0.3 to 1 meter (Rajasekhar et al., 2022). Based on infiltration, high prospects and low prospects of groundwater are available in loamy and clay soil.

LULC and Analytical Hierarchical Process

The study area is classified under mainly five cases as agricultural land, built up area, vegetation, fallow land and waterbody (Figure 4) and analysed by analytical hierarchical process (Table 1 and Figure 3). Maximum



Consistency Ratio= 0.37 | Consistency Index= 0.20

Matrix		Rainfall	Geology	Slope	Drainage density	LULC	Lineament density	Soil	Geomorpholog y	0	0	normalized principal Eigenvector
		1	2	3	4	5	6	7	8	9	10	
Rainfall	1	1	3	3	5	5	5	7	5	-	-	34.71%
Geology	2	1/3	1	3	3	5	5	5	3	-	-	22.61%
Slope	3	1/3	1/3	1	1	3	3	5	5	-	-	13.51%
Drainage density	4	1/5	1/3	1	1	1	2	3	5	-	-	9.94%
LULC	5	1/5	1/5	1/3	1	1	1	3	3	-	-	7.05%
Lineament density	6	1/5	1/5	1/3	1/2	1	1	1	1	-	-	4.71%
Soil	7	1/7	1/5	1/5	1/3	1/3	1	1	1	-	-	3.52%
Geomorphol ogy	8	1/5	1/3	1/5	1/5	1/3	1	1	1	-	-	3.95%

Figure 3: Matrix for analytical hierarchical process.

Table 1: Criteria, scale and weightage for groundwater potential zoning

Criteria		*More important*	*Scale*	*Weightage (%)*	*Normalised weightage*
A	*B*	*A or B*			
Rainfall	Geology	A	3	34.7	0.35
	Slope	A	3		
	Drainage Density	A	5		
	LULC	A	5		
	Lineament Density	A	5		
	Soil	A	7		
	Geomorphology	A	5		
Geology	Slope	A	3	22.6	0.23
	Drainage Density	A	3		
	LULC	A	5		
	Lineament Density	A	5		
	Soil	A	5		
	Geomorphology	A	3		
Slope	Drainage Density	A	1	13.5	0.13
	LULC	A	3		
	Lineament Density	A	3		
	Soil	A	5		
	Geomorphology	A	5		
Drainage Density	LULC	A	1	9.9	0.1
	Lineament Density	A	2		
	Soil	A	3		
	Geomorphology	A	5		
LULC	Lineament Density	A	1	7.0	0.07
	Soil	A	3		
	Geomorphology	A	3		
Lineament Density	Soil	A	1	4.7	0.05
	Geomorphology	A	1		
Soil	Geomorphology	A	1	3.5	0.03
Geomorphology	-	A	1	4.1	0.04

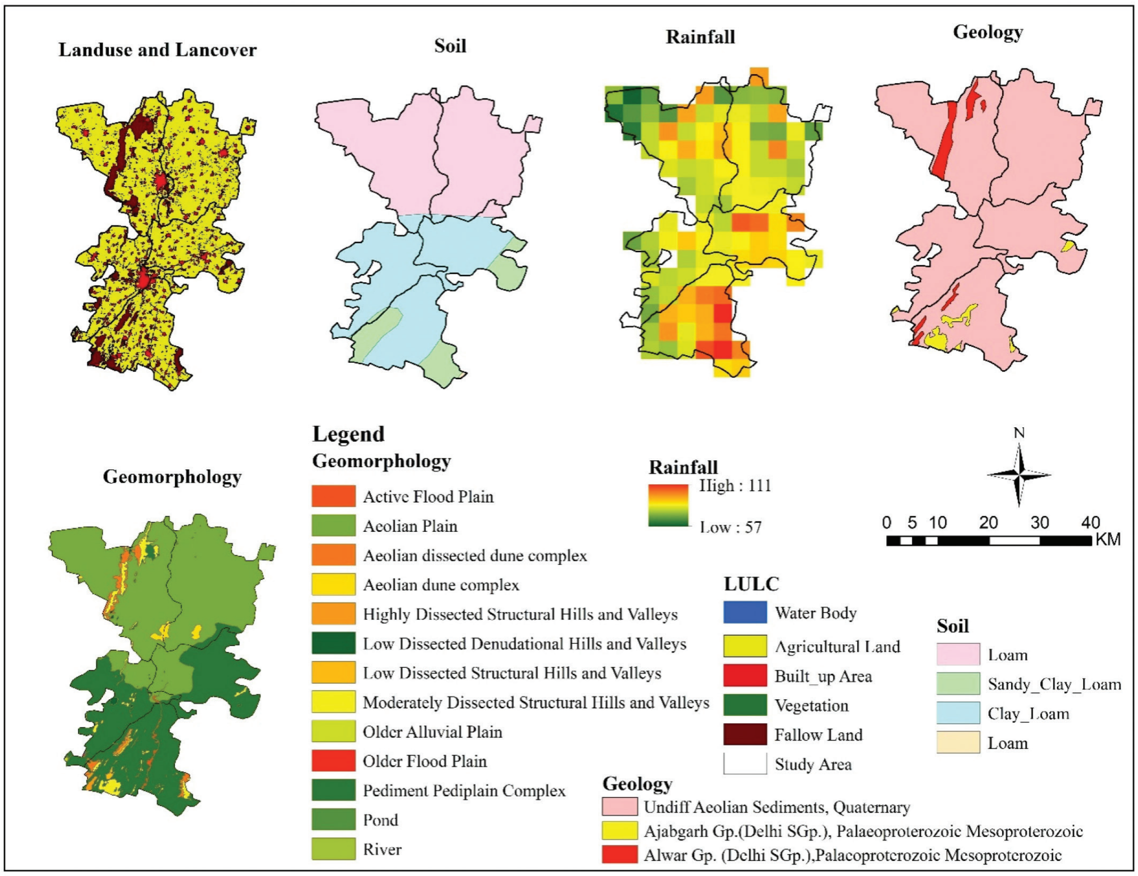


Figure 4: Thematic mapping of the study area.

area of the study lies under an agriculture class (86.45 %) followed by follow land (7.9 %), built-up area (3.2), vegetation (2.1 %), and water body (0.35 %). Mustard, barley, wheat and bajra are the major crops of the study area which needed a low water supply. Hence, the area under agriculture and vegetation is suitable for groundwater potential zoning while built-up areas and fallow land have the lowest feasibility (Rajasekhar et al., 2022).

Rainfall and Analytical Hierarchical Process

Mahendergarh district received annual rainfall of 57 mm to 111 mm (Figure 4). Rainfall is the main source of groundwater recharge through infiltration and percolation. That's why, rainfall is assigned first rank and higher priority in the analytical hierarchical process (Table 1 and Figure 3). So, it is the main factor for the analytical hierarchical process that affects the groundwater potential zone and analytical hierarchical process. The northern, northeastern and northwestern part of the study area receives the lowest rainfall while the southwestern, central and southeastern parts of the district has the maximum rainfall. So, the area having maximum rainfall has the maximum feasibility of groundwater potential zoning while the lowest rainfall area has the lowest feasibility in the district (Rajasekhar et al., 2022).

Slope Mapping and Analytical Hierarchical Process

The digital elevation model determines the land use pattern of any area. Cartosat DEM data is used to prepare DEM, aspect, slope, hill shading, and contour maps of the study area (Figure 5). The slope of Mahendergarh district is found in the south-to-north direction. Slope also determines geomorphology, land use/land cover, soil characteristics, and surface and subsurface runoff. The highest degree of slope is noticed in the hilly region of the study area having the lowest groundwater potential zoning (Rajasekhar et al., 2022). Because a steep slope has high runoff with the lowest infiltration. A lower degree of slope has the highest groundwater potential zoning due to higher infiltration than runoff. Based on the slope factor, groundwater potential zoning is assessed by assigning weightage (Table 1 and Figure 3).

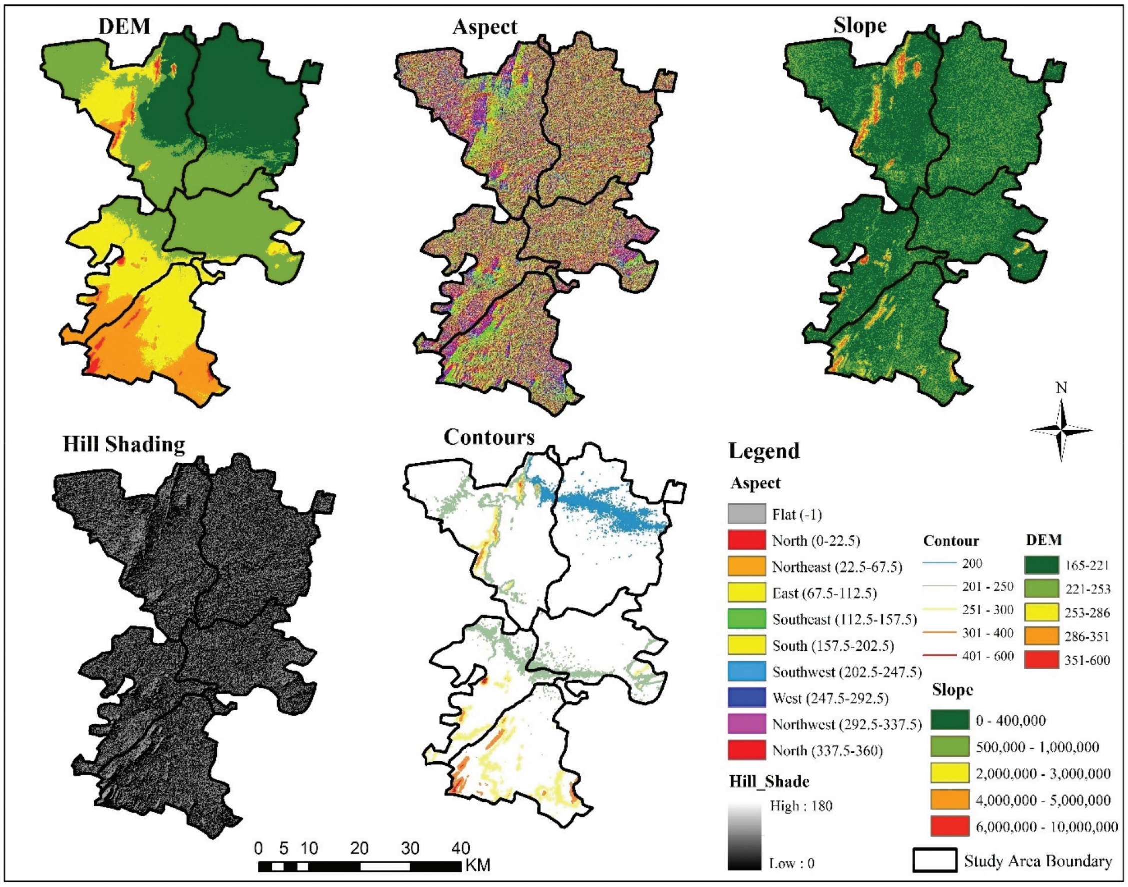


Figure 5: Slope mapping of the study area.

Drainage Density, Lineament Density and Analytical Hierarchical Process

Morphometric study of any area plays an important role in the identification and delineation of groundwater potential zoning. Based on Cartosat data it is used to prepare to fill, flow-direction, flow-accumulation, drainage order, drainage density and lineament map (Figure 6). For integrating these layer drainage densities and lineament densities identified and analysed by assigning weightage by analytical hierarchical process (Table 1 and Figure 3). Higher drainage density support higher runoff (lower permeability) having low groundwater potential zone while lower drainage density has highest groundwater potential zoning (higher permeability). Lineament study classifies the area into five categories (Figure 6). Most of the study area lies under the lower lineament density class. Higher lineament supports higher groundwater potential zoning and lower lineament density has lower lineament groundwater potential zoning.

Analytical Hierarchical Process

Commonly, the analytical hierarchical process is used by various researchers for decision-making analysis. The analytical hierarchical process assigns weightage to the pair comparison matrix based on the researchers understanding and flexibility (Rajasekhar et al., 2022). Matrix prepared for analytical hierarchical process offer a hierarchal decision-making process. In the present study, an analytical hierarchical process is applied to analyse each and every factor required for groundwater potential zoning in the study area. The method assesses the importance of thematic parameters, weightage, normalization weightage, and consistency ratio. Based on the hierarchical order, it is decided that recognises the priority importance of influencing factors of features at different levels of the hierarchy. All the factors are compared in different groups to get qualitative and authentic data. The Goepal method (Table 1) is used to obtain data for groundwater potential zoning in the study area.

Pairwise Comparison Matrix

A diagonal matrix is prepared by employing the values in the higher triangle and their inverse values are used to form the triangular Matrix. The normalised principal

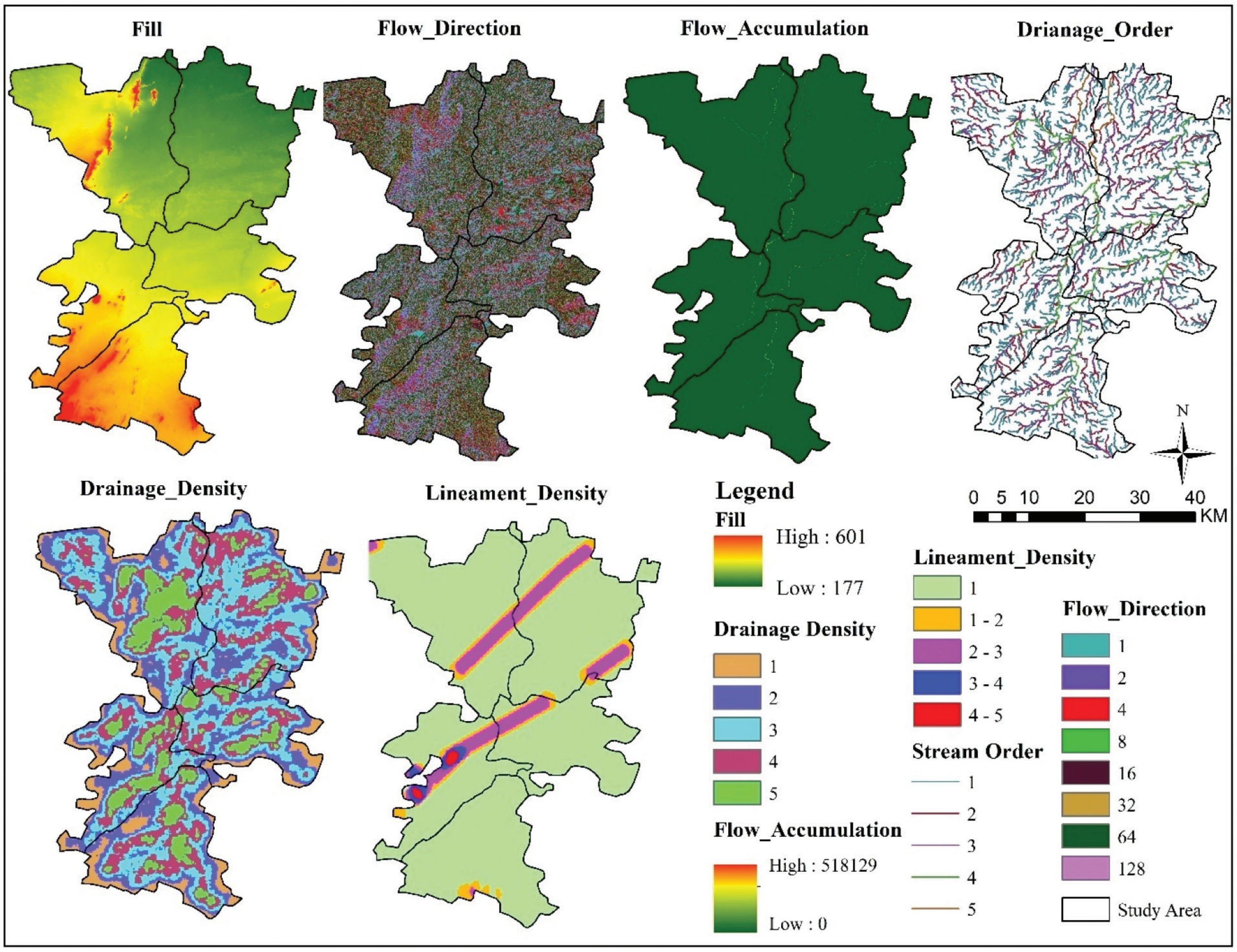


Figure 6: Drainage aspects mapping.

eigen vector is determined by averaging to confirm the consistency of the priority vector (Rajasekhar et al., 2022). The principal eigenvalue is calculated by summing the products of each eigenvector component with the total of the columns in the mutual matrix, as shown in Figure 3. This key eigenvalue is utilised to assess the consistency of judgments by analysing the consistency ratio. A consistency ratio below 0.1 indicates that the weights assigned have a high level of certainty (Kadam et al., 2018). The Consistency Index is calculated using the below equation 1 and the comparison matrix to compare all parameters for calculating the constancy ratio (equation 2) (Rajasekhar et al., 2022).

$$CI = \frac{\text{Consistany vector–criteria/factor}}{\text{criteria} - 1} \quad (1)$$

$$CR = \frac{\text{Consistany Index}}{\text{Random Consistany Indexc}} \quad (2)$$

Accuracy Assessment

Accuracy assessment of the finding by area under curve and receiver operating chart methods. Near about 30 dug well samples were collected to measure their groundwater fluctuation for relating and comparing to the finding of groundwater potential zone mapping. Area under curve has a 0 to 1 scale (Rajasekhar et al., 2022) which shows the accuracy of obtaining results (near 0 shows incorrect prediction and near 1 shows accurate prediction).

Results and Discussion

In this analysis, groundwater potential mapping evaluation was done using basic indicators that support the relative importance of various features affecting the groundwater and its related aspects. Based on the weightage of groups of thematic layers in an analytical hierarchical approach, the weightage was assigned each and every thematic layer (Table 1). The consistency index and consistency ratio are 0.2 and 0.37 (Figure 3). It shows a higher consistency because these values are lower than the threshold value. Based on this analytical hierarchical approach criterion, analysis and ranking were used in the last section to illustrate the direction for groundwater potential zoning mapping in the study area. The groundwater potential zones in the study are categorised into four levels: good, fair, poor, and very poor (Figure 8). The groundwater potential zoning results show the area (Table 2) under good, fair, poor and very poor classes are 60.82 sq. km (3.2 %), 805.10 sq. km (41.8%), 839.03 sq. km. (43.4) and 223.05 sq. km (11.6%). The study area experiences water deficiency, which occurs when precipitation does not meet evapotranspiration despite soil measures. Because the soil type in the current study region is sandy to silt loam, an average soil moisture content of 100 mm to 150 mm can be maintained. The rate of actual evapotranspiration is determined by the availability of soil moisture and the intensity of solar radiation (Chander, 2021). During the winter, actual evapotranspiration is lower than in the summer. Northern, northeastern and northwestern parts have lower actual recharge groundwater than southwestern, central and southeastern parts.

These results are quantified and their accuracy is assessed by calculating the area under curve with receiver operating characteristics. The receiver operating chart is very valuable for making classifications and displaying them to understand the value of the area under the curve by studying the practices and making connections. When arrangement and examples are provided, the receiver operating chart offers positive to negative consequences. If the resurgence field presents a very high image due to less instability it is understood to be positive. If it has been classified as an act of concealment due to high fluctuation in the storage of groundwater, it should be reported as an act of wrongful concealment or negative. The receiver operating chart and area under curve were analysed on the level of groundwater (estimated 0. 85) present in the sampled wells (Figure 7). It shows the 85% accuracy of groundwater potential zone mapping in the study area.

The acquired result is validated by collecting the sample from 30 dug wells to measure their groundwater fluctuation for relating and comparing to the finding of groundwater potential zone mapping. Only 10% of dug wells showed consistently same groundwater level in the northeastern part while 40%, 35% and 15 % of samples from dug wells showed less fluctuation, high fluctuation, and very high fluctuation. Thus, the research based on its results leads to a more accurate understanding of the groundwater potential zone mapping in the study area, which is used to improve the effectiveness of its management. Policy makers can develop an effective resource management solution for the research area based on the findings of the study.

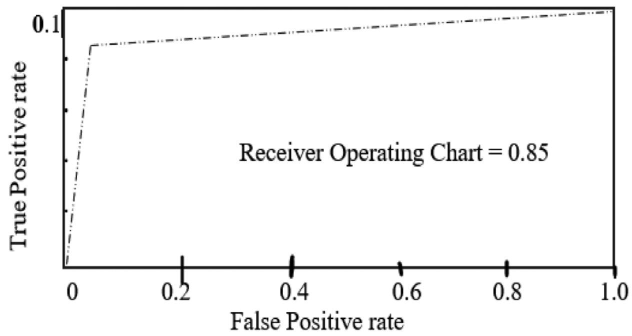


Figure 7: Receiving operating curve.

The groundwater extraction strategy in Mahendergarh district has significant socioeconomic and environmental consequences. On the socioeconomic side, benefits include increased agricultural productivity and better livelihoods for local farmers. However, these advantages come with significant environmental consequences. The strategy may deplete groundwater resources, reduce water quality, and have a negative impact on local ecosystems, such as biodiversity loss and disruption of natural water cycles. Furthermore, over-extraction may lead to long-term unsustainable development, making it critical to strike a balance between immediate socioeconomic gains and long-term environmental health.

Table 2: Groundwater potential area

Groundwater potential zone	*Area (km²)*	*Area (%)*
Good	60.82	3.2
Fair	805.10	41.8
Poor	839.03	43.4
Very Poor	223.05	11.6

Conclusion

The present study shows that the geospatial approach is a very effective application for identifying groundwater potential zoning at different scales (Kumar & Sing, 2021; Rajasekhar et al., 2022). The research uses this technology to highlight the spatial variations of groundwater potential by utilising multi-criterion,

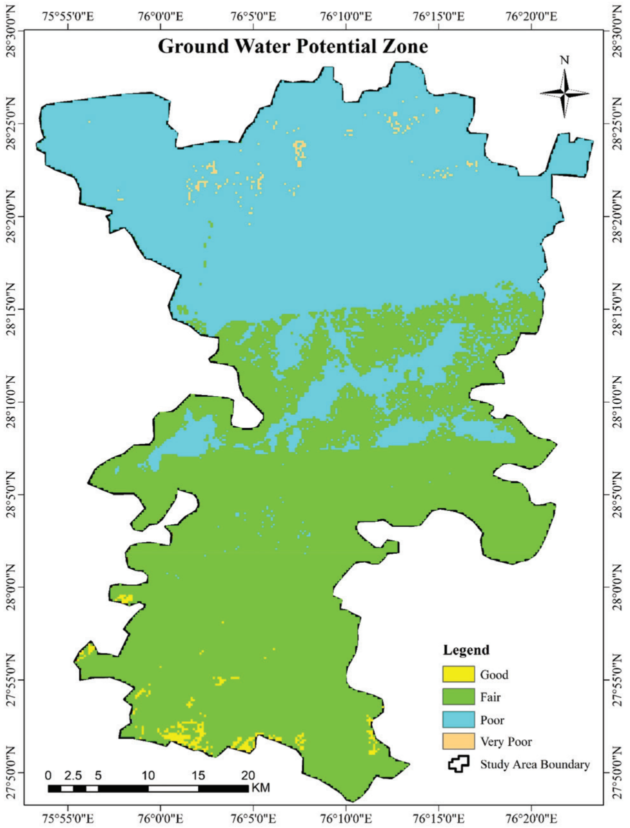


Figure 8: Groundwater potential mapping.

decision-making methods in the Mahendergarh district, Haryana. A good groundwater potential zone exists in mainly the southern part of the study area with some scatter patches found in the western and eastern parts of the study area. Fair groundwater potential zone available in southern, southwestern, southeastern and lower middle parts of the study area. Poor groundwater potential zones present in the northern, northwestern, northeastern and upper-middle parts of the district. A very poor potential zone was found in northern part of the study area in scattered patches. The validation of the results is performed by the verification with groundwater potential zoning mapping of 30 dig well accuracy measurements. The area under the curve shows 85% accuracy for the analytical hierarchical process. The analytical hierarchical process totally depends upon the importance of relative thematic layers present in the area. Installing rooftop rainwater harvesting, building recharge structures, and plugging abandoned wells for monsoon runoff are some solutions to the problem of decreasing water levels. To improve rainfall and groundwater recharge, cultivate crops that use less water, fortify the network of canals, and encourage afforestation. Thus, an integrated approach-based groundwater potential map may be more beneficial for decision and policy-making processes.

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