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Delineation of Groundwater Potential Zones Using GIS and Analytical Hierarchy Process in Jammu District, Jammu and Kashmir, India

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Abstract
Groundwater resources in India are under increasing stress due to rapid population growth, intensive land use, and climate variability. Effective delineation of groundwater potential zones (GPZs) is therefore essential for sustainable management. This study integrates Remote Sensing, GIS, and the Analytic Hierarchy Process (AHP) to delineate GPZs in Jammu district using eight thematic layers: geology, geomorphology, lineament density, slope, land use/land cover, soil, drainage density, and elevation. Weighted Overlay Analysis has been applied to generate a composite groundwater potential map at 30 × 30 m resolution. The results classify the district into five categories: very low, low, moderate, high, and very high potential zones. Very low zones are confined to northern hilly terrain with steep slopes and impermeable formations, while very high zones occur in active floodplains and young alluvial deposits adjacent to river channels. The study highlights spatial variability in groundwater occurrence and provides a scientific basis for sustainable groundwater development and recharge planning.
Keywords: *AHP, Groundwater Potential Zone, WOA, Jammu.*

INTRODUCTION

India's dependence on groundwater is profound: nearly 60% of irrigated agriculture and 85% of drinking water supplies rely on it, with 90% of rural and 50% of urban populations depending on groundwater for domestic use (National Water Policy, 2012). Despite comprising 18% of the world's population, India possesses only 4% of global renewable water resources, making it the largest consumer of groundwater globally with annual extractions of 230 km³. Rapid depletion has been observed over the past two decades, with reports indicating that millions face high to extremely high-water stress (NITI Aayog, 2018; Murmu et al. 2019). It is also important to mention here that 65 % of the total geographical area in India is covered by hard rock formations with low porosity (less than 5 per cent) and very low permeability (10-1 to 10-5 m/day) (Nagarajan et al. 2009). Furthermore, India's water deficit is projected to remain steady as the country's population is expected to grow to 1600 million by 2050 (Shubham et al. 2022).

Groundwater occurrence and its spatial distribution are strongly controlled by the geological and geomorphological setting of a region, while physiographic elements like slope, drainage, soil, and land use influence runoff, infiltration, and percolation processes are decided by the physiographic elements (Doke et al. 2021). Groundwater potential is governed by the combined influence of factors such as geology, geomorphology, lineament density, slope, drainage characteristics, soil, land use/land cover, and elevation. These factors affect the movement, storage, and recharge of groundwater in different ways (Doke et al. 2021; Chaitanya et al. 2021). For example, permeable geological formations, favourable geomorphic units, gentle slopes, suitable soil characteristics, and areas with greater lineament development generally enhance infiltration and groundwater storage, whereas steep slopes, dense drainage, and impermeable formations tend to favour surface runoff over infiltration (Murmu et al. 2019). The delineation of groundwater potential zones is particularly important in regions experiencing increasing water demand and changing land-use patterns. Such assessments can support the identification of favourable areas for groundwater exploration, artificial recharge, and sustainable groundwater development.

In recent years, GIS-based Multi-Criteria Decision-Making Analysis (MCDMA), particularly the Analytic Hierarchy Process (AHP), has been widely applied for groundwater potential zone (GPZ) mapping. These approaches enable the integration of several thematic factors by assigning relative weights according to their influence on groundwater occurrence. The resulting groundwater potential maps provide a spatial framework for identifying areas suitable for groundwater development and recharge interventions. Although machine-learning approaches have increasingly been used to improve prediction accuracy, GIS-based AHP remains particularly useful because of its transparent and systematic weighting procedure and its applicability in regions where detailed hydrogeological datasets are limited (Sharma et al. 2024).

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Therefore, the present study integrates Remote Sensing, GIS, and the Analytic Hierarchy Process to delineate groundwater potential zones in Jammu district. The assessment considers major controlling factors, including geology, geomorphology, lineament density, slope, land use/land cover, soil, drainage density, and elevation. The integration of these thematic layers provides a spatial representation of groundwater potential and helps identify areas that are relatively more favourable for groundwater occurrence and future management interventions.

2. Study Area

Jammu district is geographically located between approximately 32°50′ N to 33°30′ N latitudes and 74°24′ E to 75°18′ E longitudes. The district is circumscribed by Udhampur district to the north and north-east, Samba district to the east and south-east, Sialkot (Pakistan) to the west, and the Bhimber region of Pakistan-occupied Kashmir along with Rajouri district to the north-west (Fig. 1.). The district derives its name from its headquarters, Jammu, which also serves as the winter capital of the Union Territory and is widely known as the "City of Temples". It covers an area of about 2342 km2 of which 2,190 km2 constitutes the rural sector and 152 km2 comprises the urban sector.

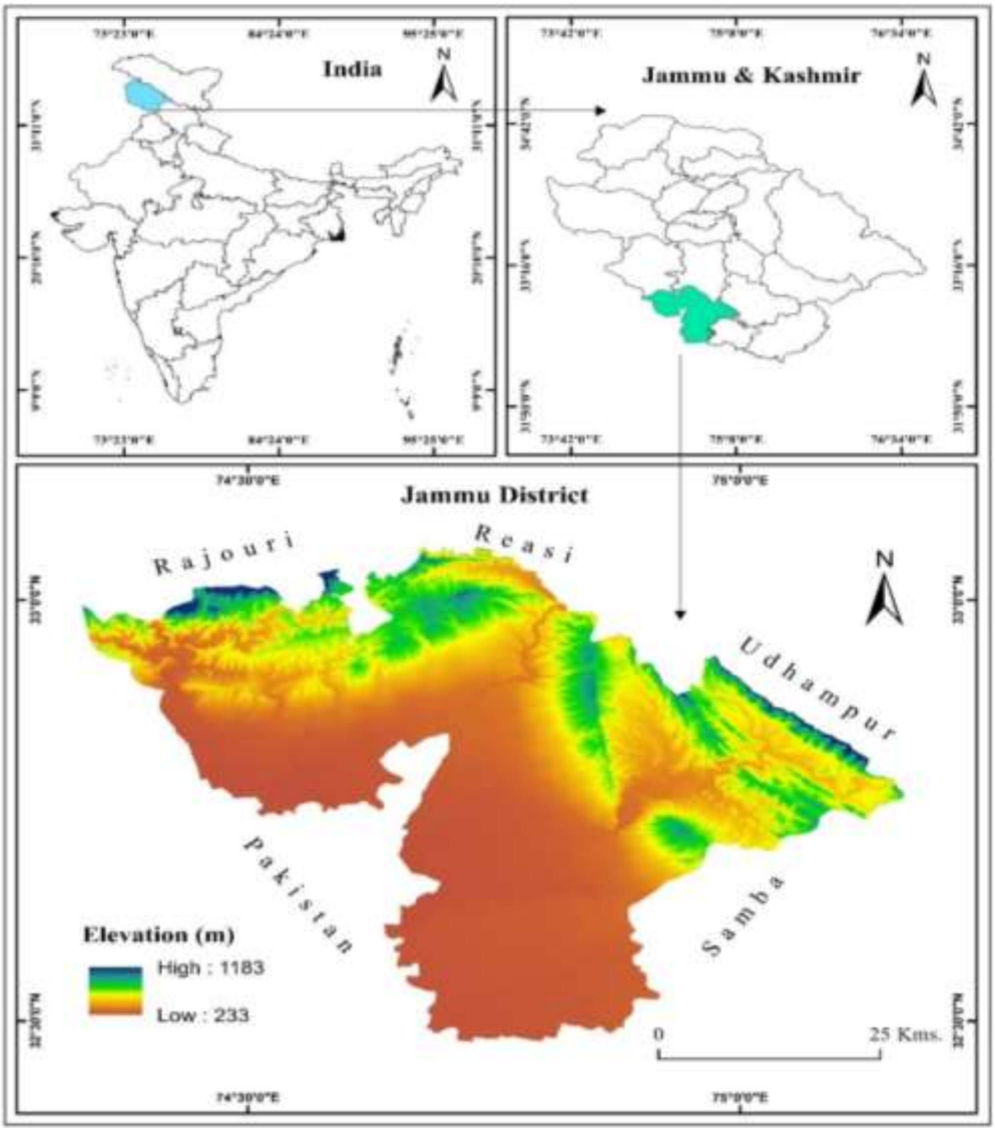

Fig. 1. Location map of study area.

3. DATABASE AND METHODOLOGY

3.1. Delineation of Groundwater Potential Zones

In the present study, eight criteria have been selected for groundwater potential mapping after reviewing various published studies and considering their influence on groundwater occurrence and recharge. The Analytic Hierarchy Process (AHP), Multi-Criteria Decision-Making (MCDM) technique, have been adopted to delineate groundwater potential zones (GPZs) using the following steps:

- Selection of groundwater influencing criteria based on literature review and study objectives.
- Preparation of thematic layers for each selected criterion using GIS techniques.
- Development of the Pairwise Comparison Matrix (PCM) using the AHP approach.
- Calculation of normalized weights for each criterion according to their relative importance.
- Assignment of scores/ranks to the sub-criteria based on groundwater suitability.
- Integration of weighted thematic layers through weighted overlay analysis in GIS.
- Generation of the GPZ map.
- Validation and accuracy assessment of the generated GPZ map.

3.2. Criteria Selection and Thematic Mapping

Groundwater recharge and occurrence are strongly influenced by various physiographic and environmental factors (Anusha et al. 2023; Zolekar (2018)). Several previous studies on groundwater potential assessment have widely utilized parameters including lithology, geomorphology, drainage density, lineament density, rainfall, soil, LULC and proximity to rivers for the delineation of groundwater potential zones (Das and Pal (2019); Maity and Mandal (2017; Singh (2008). These criteria are considered significant because each factor contributes differently to groundwater recharge and subsurface water movement. The integrated influence of these parameters plays an important role in identifying areas with varying groundwater potential (Yeh et al. 2016). In the present study, eight major criteria have been selected for GPZs mapping based on their hydrogeological significance and availability of spatial data. The selected criteria include Geology (G), Geomorphology (GG), Slope (SL), Land-Use/Land-Cover (LULC), Drainage Density (DD), Lineament Density (LD), Soil (S), and Elevation (E). Thematic maps corresponding to each criterion have been prepared in the GIS environment. To maintain consistency and improve the accuracy of geospatial analysis, all thematic layers have been converted into raster format and resampled to a uniform spatial resolution of 30 m for integrated analysis and weighted overlay processing within the GIS environment. The selected parameters collectively provide a comprehensive understanding of the factors controlling groundwater distribution in the study area.

3.3 Analytical Hierarchy Process (AHP)

The AHP proposed by Saaty (Saaty (2005)) is an effective multi-criteria decision-making technique for addressing complex spatial and environmental issues, particularly in groundwater resource assessment (Zolekar and Bhagat (2015)). This approach is widely preferred because it provides a systematic, cost-effective, and less time-intensive framework while ensuring comparatively accurate and reliable results in spatial analysis (Das (2017); Jabeen et al. 2025). A significant advantage of the AHP technique is its capability to incorporate both qualitative judgments and quantitative measurements within a unified analytical framework (Forman (1993). The method allows the integration of expert knowledge with mathematical evaluation, thereby improving the reliability of decision-making processes. Furthermore, AHP offers flexibility in revising or rearranging parameter rankings whenever inconsistencies or lower levels of accuracy are identified. This adaptability makes the method highly suitable for environmental modelling and groundwater potential mapping, where multiple interrelated factors must be considered simultaneously.

In AHP, the estimation of parameter weights is carried out through the construction of a Pairwise Comparison Matrix (PCM), in which parameters are compared with one another according to their relative significance in influencing groundwater conditions. In the present study, a mathematically based AHP framework has been employed to calculate parameter weights and assign suitability scores to their corresponding sub-parameters. To minimize bias and subjectivity in the ranking process, an extensive review of relevant literature and previous studies was conducted before assigning comparative importance values. The selected parameters collectively contribute to the identification and delineation of potential groundwater zones within the study area. The PCM has been developed using Saaty's standard 1–9 rating scale, where values represent the degree of relative importance between parameters. Through this process, each thematic factor has been evaluated in relation to others based on its contribution to groundwater recharge and accumulation. The derived judgments have subsequently been used to establish a hierarchical structure representing the significance level of individual parameters.

Subsequently, the matrix was normalized to generate the Normalized Pairwise Comparison Matrix (NPCM). For this, each individual value is divided by the total sum of the respective column values. Thereafter, the normalized values within each row have been summed and averaged by dividing them by the total number of parameters considered in the matrix. The obtained values which represent the final weights have been assigned to each parameter. The calculated weights ranged between 0 and 1, where higher values indicated greater influence on groundwater potentiality. Additionally, the cumulative sum of all parameter weights was maintained equal to 1, ensuring consistency and reliability in the weighting procedure (Malczewski (2017).

3.4. Consistency Ratio (CR)

During the pairwise comparison process in the AHP, some degree of inconsistency may occur because the judgments are based on expert evaluation. Therefore, it is essential to assess the logical consistency of the pairwise comparisons to ensure that the assigned weights are reliable. The Consistency Ratio (CR) introduced by Saaty (1980), is widely used to evaluate the consistency of the decision-maker's judgments. The CR is determined by comparing the Consistency Index (CI) with the Random Index (RI). This measure verifies the reliability of the weights derived from the Normalized Pairwise Comparison Matrix (NPCM). A CR value of 0.10 (10%) or less indicates that the pairwise comparisons are sufficiently consistent and that the calculated weights are acceptable for further analysis. Conversely, if the CR exceeds 0.10, the pairwise judgments should be re-evaluated and revised to improve consistency (Saaty (1997)

$$\text{Consistency Ratio (CR)} = \text{CI}/\text{RI} \tag{1}$$

3.5. Score Determination

A suitability scoring system ranging from 1 to 5 has been adopted to assign scores to the sub-criteria of each thematic parameter based on their relative contribution to groundwater occurrence and recharge potential. The scoring has been carried out by considering the favourability of each sub-criterion for groundwater accumulation, supported by hydrogeological knowledge and evidence from previous studies. The highest score (5) has been assigned to sub-criteria that provide the most favorable conditions for groundwater potential, whereas the lowest score (1) has been allocated to those considered least suitable. Intermediate scores are assigned to sub-criteria exhibiting moderate levels of suitability, reflecting their relative influence on groundwater occurrence. This ranking approach enables the differentiation of areas according to their groundwater potential while maintaining consistency across all thematic layers. Accordingly, suitability scores have been assigned to the sub-criteria of the selected parameters. These scores were subsequently integrated with the corresponding AHP-derived parameter weights to generate the GPZs map. This combined weighting and scoring approach provides a comprehensive evaluation of the spatial variability in groundwater potential across the study area.

3.6. Weighted Overlay Analysis (WOA)

The Weighted Overlay Analysis (WOA) is a widely used spatial multi-criteria evaluation technique for integrating multiple thematic layers to identify suitable locations for a particular purpose. In groundwater studies, this approach facilitates the combination of diverse environmental and hydrogeological parameters by converting them into a common measurement scale, thereby enabling a comprehensive assessment of groundwater potential. In the present study, the WOA tool has been employed to delineate GPZs. All selected thematic layers were first reclassified using a standardized suitability scale ranging from 1 to 5, where the assigned scores reflected the relative favourability of each sub-parameter for groundwater occurrence, as described in the previous section. The reclassified raster layers have been then incorporated into the weighted overlay model within the GIS environment. Each raster cell has been assigned its corresponding suitability score, while the thematic layers have been weighted according to the normalized weights derived from the AHP. The final groundwater potential index has been obtained by multiplying the suitability score of each raster cell by the respective parameter weight and then summing the weighted contributions of all thematic layers. This procedure ensured that parameters with greater influence on groundwater occurrence had a proportionally higher contribution to the final output. The resulting weighted overlay raster have subsequently classified into five groundwater potential categories based on the FAO (1976) classification scheme. These classes represent different levels of groundwater potential, ranging from very low to very high, thereby providing a spatial representation of groundwater availability across the study area.

$$S = \sum_{i=1}^{n} (wi.xi) \tag{2}$$

where S is total GPZ score, wi denotes weight of GPZ criteria, xi Indicates sub-criteria score of i GPZ criteria, and n represents total number of GPZ criteria.

4. RESULT AND DISCUSSION

4.1. Weight assignment using MCDA based AHP technique

The Analytical Hierarchy Process (AHP) is a widely used multi-criteria decision-making (MCDM) technique that decomposes a complex decision problem into a hierarchical structure based on pairwise comparisons of the relative importance of different criteria and sub-criteria (Saaty (2005)). In the present study, a pairwise comparison matrix has been developed for the selected thematic layers to evaluate their relative importance in influencing groundwater potential (Table 1.). The pairwise comparisons have been performed using Saaty's fundamental scale, wherein the relative importance of one criterion over another has been assessed based on expert judgement. Eight thematic layers, namely Geology (G), Geomorphology (GG), Lineament Density (LD), Slope (SL), Land Use/Land Cover (LULC), Soil (S), Drainage Density (DD), and Elevation (E), have been identified as the major factors controlling groundwater occurrence in the study area.

The pairwise comparison matrix has been subsequently normalised to derive the relative weights of each criterion, and the resulting normalised matrix have been presented in Table 2. Based on the normalised matrix, the Priority Weights (eigenvector values), Consistency Vector (CV), and percentage Influence of each thematic layer have been calculated and are presented in Table 3.

The results indicate that Geology (G) is the most influential factor in governing groundwater potential, with the highest priority weight of 0.299, followed by Geomorphology (GG) with a weight of 0.231. The highest weight assigned to geology highlights the dominant role of lithological characteristics, rock permeability, and aquifer properties in controlling groundwater occurrence and storage within the study area. Similarly, geomorphology exerts a significant influence by regulating infiltration, runoff, and groundwater recharge. The remaining thematic layers, namely Lineament Density (0.134), Slope (0.122), Land Use/Land Cover (0.096), Soil (0.062), Drainage Density (0.034), and Elevation (0.022), have been assigned comparatively lower weights, indicating their relatively lesser, yet significant, contribution to groundwater potential delineation.

The consistency of the pairwise comparison matrix has been evaluated by calculating the maximum eigenvalue (λmax), Consistency Index (CI), and Consistency Ratio (CR). The computed maximum eigenvalue is λmax = 8.42, resulting in a Consistency Index (CI) of 0.06. Using a Random Index (RI) value of 1.41 for an 8 × 8 comparison matrix, the Consistency Ratio (CR) has been calculated as 0.04, i.e., 4%. Since the obtained CR is less than the acceptable threshold of 0.10 (10%), this result confirms that the pairwise comparison matrix is logically consistent and that the parameter weights obtained through the AHP methodology are reliable and suitable for groundwater potential zone assessment.

Table 1. Pairwise comparison matrix for AHP.

Criteria	G	GG	LD	SL	LULC	S	DD	E
G	1	2	2	3	5	5	7	7
GG	1/2	1	2	3	3	5	7	7
LD	1/2	1/2	1	1	1	3	5	7
SL	1/3	1/3	1	1	1	3	5	7
LULC	1/5	1/3	1	1	1	2	3	5
S	1/5	1/5	1/3	1/3	1/2	1	3	5
DD	1/7	1/7	1/5	1/5	1/3	1/3	1	3
E	1/7	1/7	1/7	1/7	1/5	1/5	1/3	1

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Table 2. Normalized pairwise comparison matrix for AHP.

Criteria	G	GG	LD	SL	LULC	S	DD	E	Weighted Sum
G	0.30	0.46	0.27	0.37	0.48	0.31	0.24	0.15	2.58
GG	0.15	0.23	0.27	0.37	0.29	0.31	0.24	0.15	2.00
LD	0.15	0.12	0.13	0.12	0.10	0.19	0.17	0.15	1.13
SL	0.10	0.08	0.13	0.12	0.10	0.19	0.17	0.15	1.04
LULC	0.06	0.08	0.13	0.12	0.10	0.12	0.10	0.11	0.82
S	0.06	0.05	0.04	0.04	0.05	0.06	0.10	0.11	0.51
DD	0.04	0.03	0.03	0.02	0.03	0.02	0.03	0.07	0.28
E	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.02	0.18

Table 3. AHP-derived priority weights, weighted sums, consistency values and percentage influence of thematic layers.

	Priority Weight	Weighted Sum	CV	%influence
G	0.299	2.58	8.62	29.9
GG	0.231	2.00	8.68	23.1
LD	0.134	1.13	8.41	13.4
SL	0.122	1.04	8.51	12.2
LULC	0.096	0.82	8.59	9.6
S	0.062	0.51	8.28	6.2
DD	0.034	0.28	8.22	3.4
E	0.022	0.18	8.06	2.2

Table 4. Weights and scores of criteria and their sub-criteria.

Criteria	Weight	Influence (%)	Sub-Criterian	Score
Geology	0.29	29.9	Siwalik Kandi Sirowal	1 3 5

Geomorphology	0.23	23	Highly Dissected Structural Hills Moderately Dissected Structural Hills Low Dissected Structural Hills Piedmonts Older Flood Plain Older Alluvial Plain Water Body Active Flood Plain Young Alluvial Plain	1 2 2 3 4 4 4 5 5
Lineament Density	0.13	13	Very Low Low Moderate High Very High	1 2 3 4 5
Slope	0.12	12	Very Steep Steep Moderate Gentle Level to Gentle	1 2 3 4 5
LULC	0.09	9	Built Up Barren Land Agricultural Land Forest Water Body	1 2 3 4 5
Soil	0.06	6	Very Fine Loamy Fine Loamy Loamy Skeletal Coarse Loamy Recent	1 2 3 4 5
Drainage Density	0.03	3	Very High High Moderate Low Very Low	1 2 3 4 5
Elevation	0.02	2	Very High High Moderate Low Very Low	1 2 3 4 5

4.2. Reclassified Influencing factors for groundwater potential zones

4.2.1. Geology Layer

The geological foundation of any area is a critical factor that controls groundwater availability because the infiltration and runoff rate mostly rely on the porosity and permeability of particular types of rocks (Doke et al. 2021). Geological texture plays an important role The Jammu district has been divided into 3 major geological zones: Siwaliks, Kandi belt and Southern Sirowal plains. Siwalik range rises gradually from the northern part of the study area and merges in the south with the Plains. On the other hand, southern outer plains lie on the foothills of Siwalik. This region is further divided into Kandi in the north and Sirowal in the south. Kandi belt mainly constitutes of conglomerates, boulders, pebbles, gravels, sand stone with considerable amount of clay and Siwalik rocks formed during Mio-Pliocene age. Sirowal belt comprises of unconsolidated sediments in the form of terraces and coalescent alluvial fans formed due to seasonal streams draining of Siwalik. The reclassified map of geology has been presented in Fig. 2. Highest rank is given to sirowal plains while lowest rank is given to Siwalik hills.

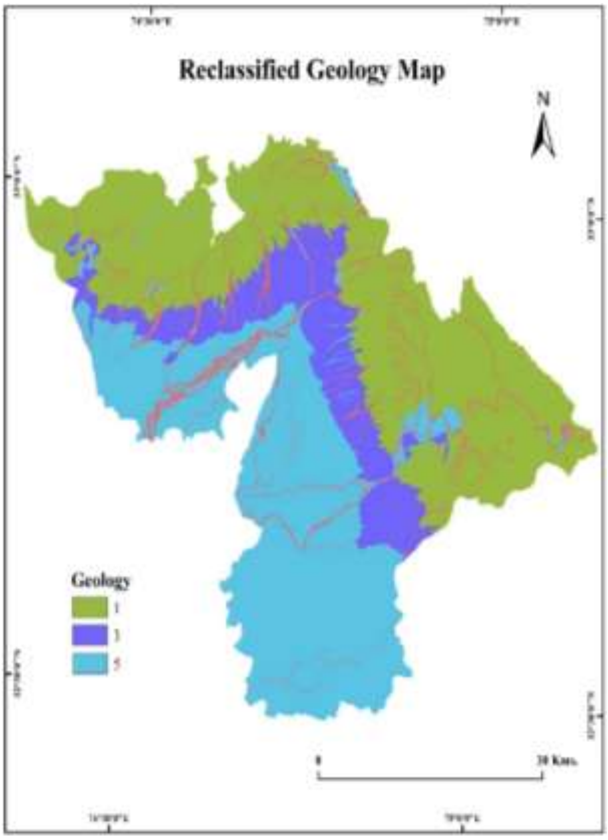

Fig. 2. Reclassified map of Geology.

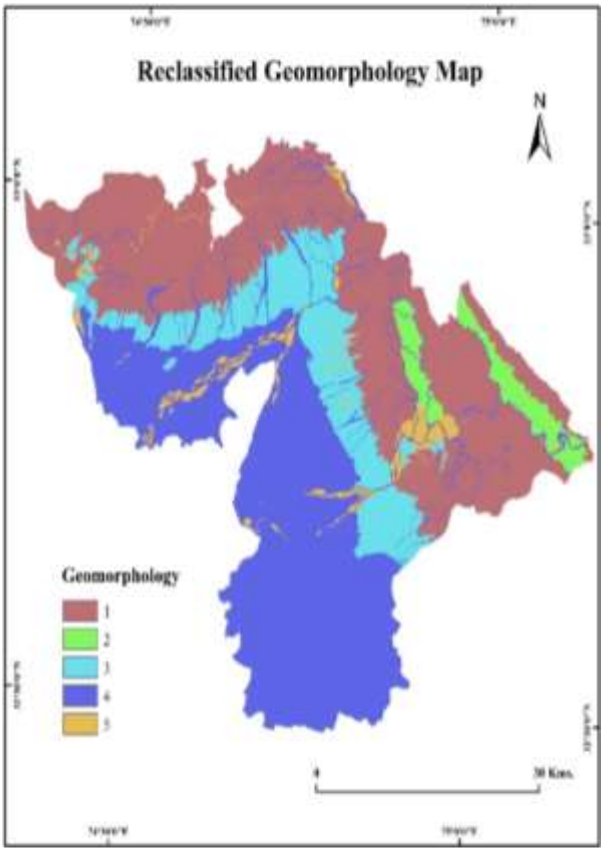

Fig. 3. Reclassified map of Geomorphology.

4.2.2. Geomorphology Layer

Geomorphology, encompasses the surface landforms and topography, constitutes an imperative parameter in hydrogeological investigations. It serves as one of the most significant criteria for delineating groundwater potential zones, as geomorphic landscapes exert a direct influence on groundwater movement, occurrence, and recharge processes (Kumar et al. 2008). It provides insights into the spatial distribution of landscape features and the processes that shape them including thermal variations, freezing and thawing activity, geochemical interactions, and hydrological flow regime, all of which exert a direct impact on groundwater levels within a region (Arulbalaji et al. 2019).

In the study area, nine distinct geomorphological units have been identified, including low dissected hills, moderately dissected hills, and highly dissected structural hills, older alluvial plains, young alluvial plains, new flood plains, older flood plains, water bodies and piedmonts. The identified landforms have been assigned groundwater suitability ranks on a scale 1 to 5, reflecting their hydrogeomorphological attributes (Table 4). Water bodies, young alluvial plains and flood plains have been assigned with the highest suitability rating due to their favourable recharge conditions and high permeability. Piedmonts and dissected hills have been assigned intermediate suitability ranks depending on their relative groundwater recharge potential. In contrast, dissected structural hills have been ranked the lowest as steep slopes, limited infiltration capacity and high surface runoff restrict groundwater potential. The geomorphology of the study area has been presented in Fig. 3.

4.2.3. Lineament Density Layer

Geological lineaments including fractures, faults, and joints are mainly associated with zones of structural weakness that exhibit good porosity and permeability (Sabita roy et al. 2019). Areas situated along the convergence zones of lineaments are considered as highly favourable sites for groundwater storage owing to their high infiltration rate and permeability (Saranya and saravanam (2020)) Lineament density emerges as a critical parameter in assessing the potential zones of groundwater because areas with higher lineament density generally reflect higher groundwater possibilities (Doke et al. 2019; Ghosh et al. 2020). To quantify this relationship, a lineament density map has been generated using the line density tool in GIS, revealing spatial variations in lineament density across the study area, ranging from 0 to 1.6 km/km2 (Fig. 4.).

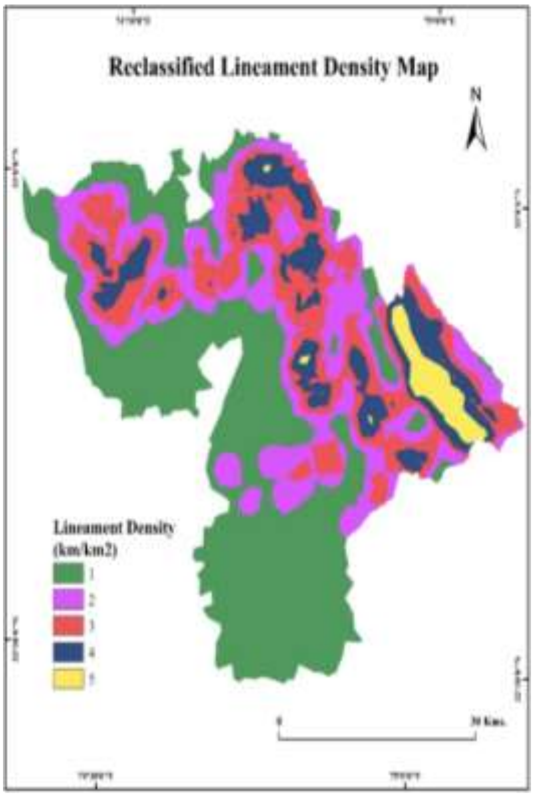

Fig. 4. Reclassified map of Lineament Density.

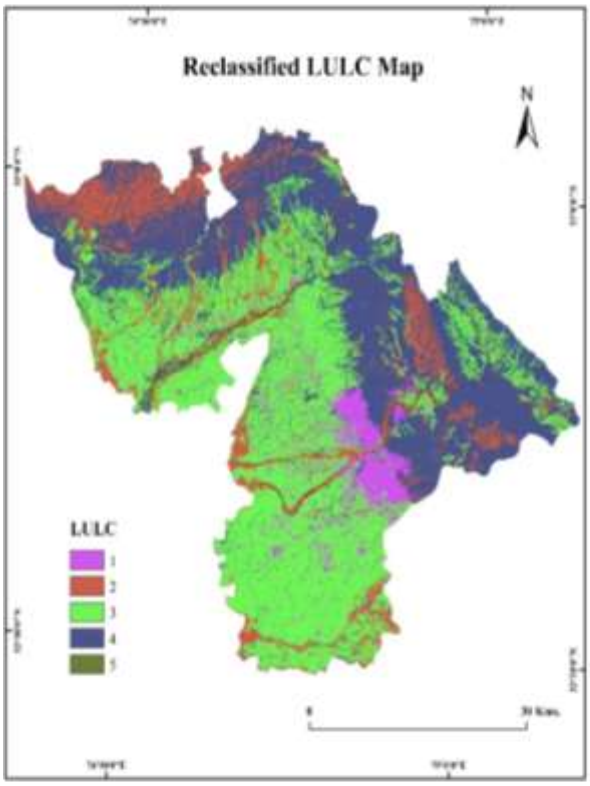

Fig. 5. Reclassified map of Land Use/Land Cover.

4.2.4. Land Use Land Cover (LULC) Layer

LULC plays an important role in determining groundwater potential, exerting significant influence on both the availability and management of groundwater resources. LULC plays a pivotal role in sustainable groundwater management by regulating recharge processes and modifying water demand resources (Abijith et al. 2020). LULC permits the surface water to percolate into aquifers, while simultaneously affecting groundwater availability through alterations in recharge sites and consumption patterns (Pramanik (2017)). In forested and agricultural land, reduced surface runoff and enhanced infiltration promote groundwater recharge, whereas impervious areas like built up hinder infiltration and intensify runoff (Roy et al. 2020). Therefore, higher suitability ranks are given to water bodies, agricultural and forest areas due to their favourable recharge capacity, while built-up area are assigned lower ranks. The reclassified LULC map of the district has been presented in Fig. 5.

4.2.5. Slope

Slope is recognized as a significant parameter in the assessment of groundwater potential as it directly governs infiltration, groundwater recharge and surface runoff (Bagyaraj et al. 2013). Terrain with steep slope yield less recharge due to accelerated runoff, which reduces the residence time of water at the surface and restricts infiltration into saturated zones (Ghosh et al. 2016, Nunes et al. 2021). Conversely, areas with gentle slope facilitate higher percolation as slower runoff enhances infiltration capacity. Within the study area, slope values range between 0 and 71.4°, reflecting spatial variability in groundwater recharge potential. The slope map has been generated from DEM of the study area and is further reclassified into five categories (Fig. 6.).

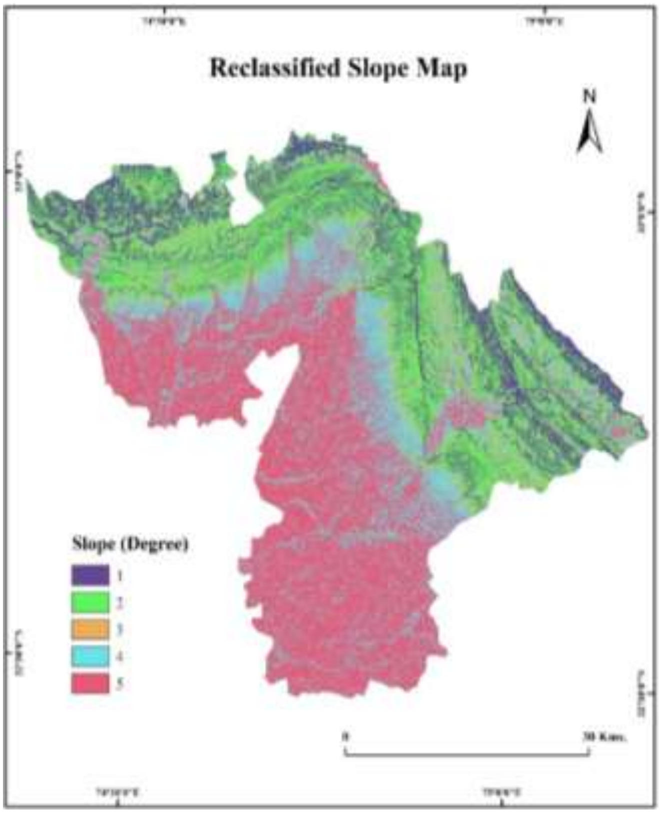

Fig. 6. Reclassified map of Slope.

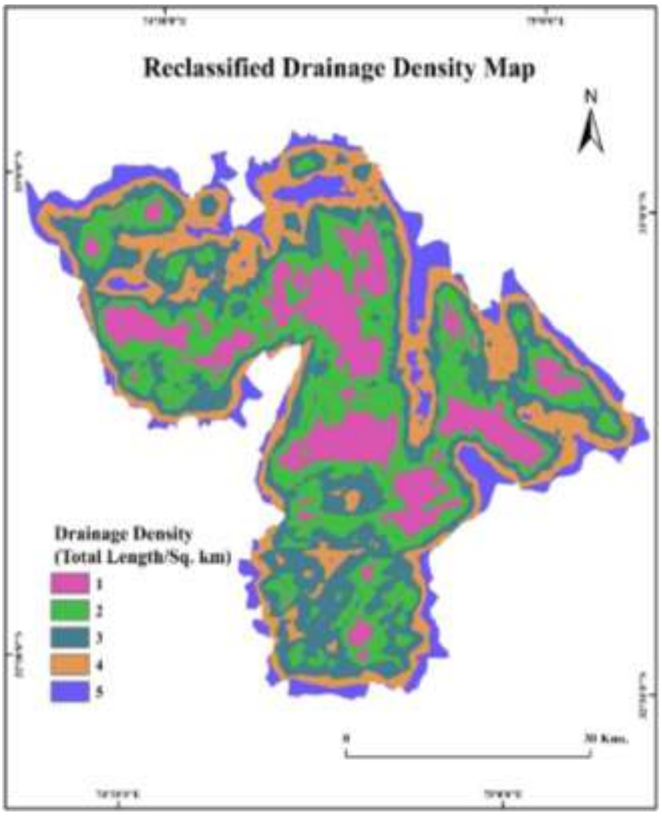

Fig. 7. Reclassified map of Drainage Density.

4.2.6. Drainage Density

Drainage density plays a key role in evaluating groundwater availability. It offers an important index of infiltration capacity and functions inversely with permeability. It is determined by dividing the cumulative length of streams within a drainage basin by its total area (Nithya et al. 2019). In this study, drainage density of Jammu district has been derived from the DEM. For the assessment of groundwater potential, drainage density has further been reclassified according to its potential contribution, i.e., very low, low, moderate, high, very high. High drainage density has assigned lower weightage as it reflects limited infiltration and reduced groundwater potential due to rapid runoff. Conversely, low drainage density has been assigned higher weightage since slower runoff enhances high infiltration property, thereby favouring groundwater recharge and availability. The reclassified drainage density map of the study region has been presented in Fig. 7.

4.2.7. Soil Properties Layer

Soil represents a fundamental parameter influencing groundwater potentiality in any area. The texture of soil described by the relative proportions of silt, sand and clay, determines both water holding and infiltration capacity (Zomlota et al. 2015, Jasrotia et al. 2016). The loamy soil has more permeability and porosity rate compared to clay soils, thereby, facilitating higher infiltration. Conversely, fine-textured soils are characterized by reduced infiltration rate due to their compact structure. In Jammu district, soils have been identified as coarse loamy, fine loamy, very fine loamy, loamy skeletal and recent deposits (Fig. 8.).

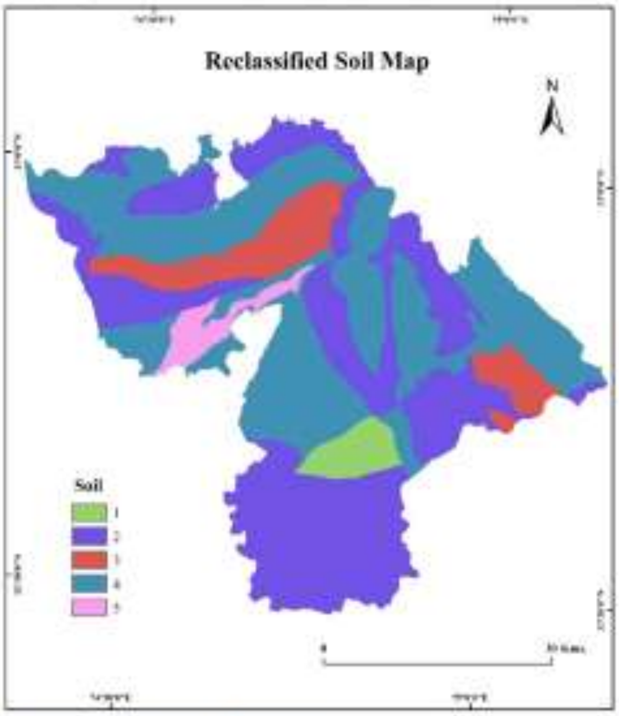

Fig. 8. Reclassified map of Soil.

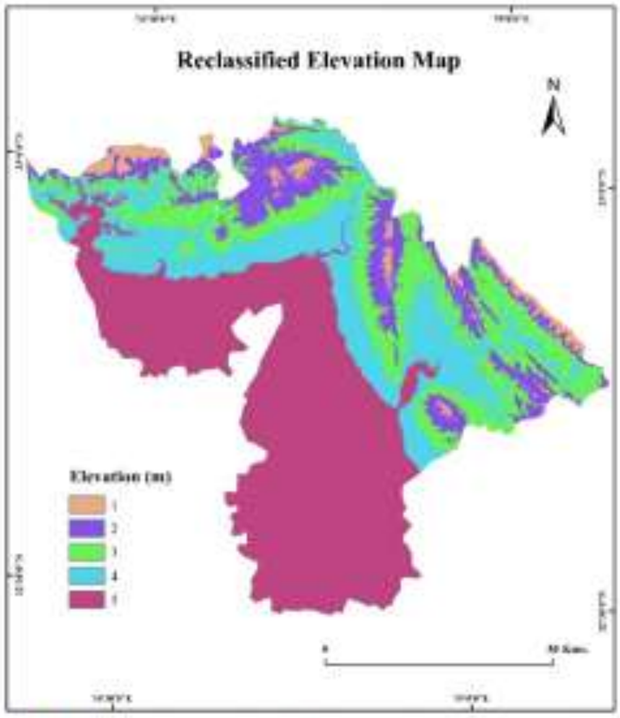

Fig. 9. Reclassified map of Elevation.

4.2.8. Elevation Layer

Elevation is recognized as a significant morphological parameter in the delineation of groundwater potential zones (Souei and zouaghi (2021)). The elevation map of Jammu district has been obtained from ASTER DEM, with values ranging between 233 to 1183 m. A large portion of the study area has been assigned the highest weight due to their relatively low elevation. The elevation map has subsequently been reclassified into five distinct categories to facilitate groundwater prospect evaluation (Fig. 9.).

4.3. Mapping of Groundwater Potential Zones

After determining the final normal weights of all eight thematic layers and their sub-criteria features, all the thematic layers have been converted into raster format with a common spatial resolution of 30* 30 m and all the reclassified raster layers have been then integrated with the help of Weighted Overlay Analysis tool in ArcGIS software in order to delineate groundwater potential zone using the following equation:

$$\mathrm{GWPZ} = \sum \mathrm{G_x G_y} + \mathrm{GG_X GG_y} + \mathrm{LD_X LD_y} + \mathrm{Sl_x Sl_y} + \mathrm{LULC_x LULC_y} + \mathrm{S_x S_y} + \mathrm{DD_x DD_y} + \mathrm{E_x E_y} \quad (3)$$

Where GWPZ stands for Groundwater Potential Zones, x for criteria map layers and y for sub- criteria map layer. All the major criteria have been weighted with the percentage of influence of each layer, whereas the sub-criteria according to the score given to each class according to their significance level (Table 4.). The result obtained for the potential zones have been then classified into five categories, i.e., Very Low, Low, Moderate, High and Very High (Fig. 10.).

The Very Low groundwater potential zone occupies only a limited portion of the study area and is mainly confined to isolated patches within the northern hilly terrain. These areas are characterised by steep slopes, highly dissected structural hills, comparatively impermeable geological formations, and high surface runoff. Consequently, rainfall rapidly flows downslope with limited infiltration, resulting in poor groundwater recharge and low groundwater storage potential.

The Low groundwater potential zone is predominantly distributed across the northern and eastern parts of the district. These regions are generally associated with dissected hills and elevated terrain where relatively steep slopes, low infiltration capacity, and limited weathered material reduce groundwater recharge. The hydrogeological conditions in these areas are therefore less favourable for groundwater occurrence.

The Moderate groundwater potential zone represents transitional areas exhibiting moderate hydrogeological conditions and constitutes the largest portion of the study area (Table 5). These regions are generally associated with piedmonts, moderate sloping terrain, and moderately permeable geological formations. Although groundwater recharge is favourable, it is influenced by local variations in lithology, soil characteristics, and land use, resulting in moderate groundwater availability.

The High groundwater potential zone is mainly distributed across the alluvial plains and older floodplains in the southern and south-western parts of the district. This region is characterised by relatively flat topography, favourable geological formations, alluvial deposits, higher infiltration capacity, and comparatively lower surface runoff. The combined influence of gentle slopes, permeable soils, and suitable hydrogeological conditions enhances groundwater recharge, making these areas suitable for groundwater development under sustainable management practices.

The Very High groundwater potential zone is concentrated primarily in the active floodplains and young alluvial deposits located adjacent to major river channels. These areas are characterized by highly permeable unconsolidated sediments, flat topography, and excellent recharge conditions, making them the most favourable zones for groundwater occurrence and storage. The combination of favourable geological, geomorphological, and hydrological conditions contributes to the highest groundwater potential in these regions.

Overall, the groundwater potential map demonstrates a gradual improvement in groundwater potential from the northern hilly region towards the southern alluvial plains of Jammu district. The distribution closely corresponds with the physiography and geological characteristics of the district, where the mountainous terrain exhibits lower groundwater potential due to high runoff and limited infiltration, whereas the alluvial plains exhibit higher groundwater potential owing to favourable aquifer conditions, gentle slopes, and enhanced recharge.

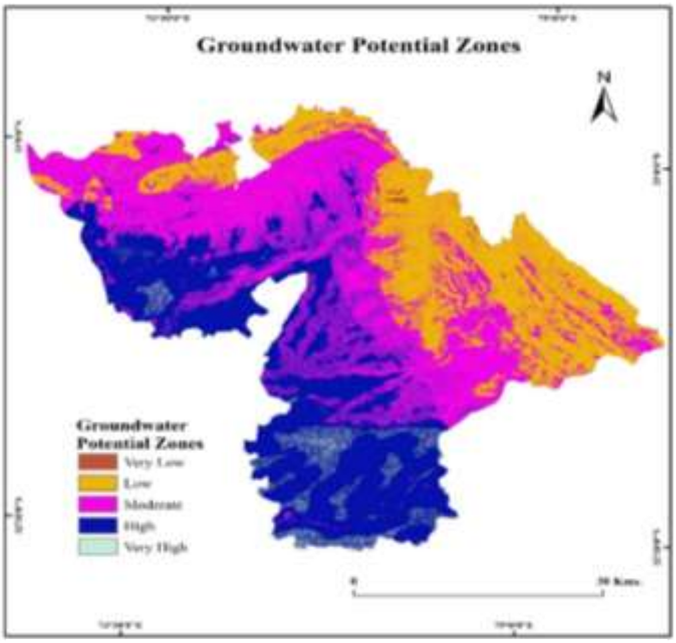

Fig. 10. Groundwater potential zone map of Jammu

Table 5. Areal extent of different groundwater potential zones in Jammu district.

Groundwater Potential Zones	Area (km2)	Area (%)
Very Low	3.44	0.14
Low	573.48	24.67
Moderate	871.35	37.5
High	829.20	35.7
Very High	46.43	1.99
Total	2323.9	100

CONCLUSION

In nutshell, the groundwater potential zonation of Jammu district has been carried out using AHP-based weighted overlay analysis by integrating eight thematic layers, namely geology, geomorphology, lineament density, LULC, slope, drainage density, soil properties and elevation. The results demonstrate that groundwater potential is controlled by the combined influence of geological, geomorphological, topographic and hydrological conditions. Among the thematic layers, geology and geomorphology emerged as the most influential factors, receiving the highest weights of 0.299 and 0.231, respectively.

The study area has been classified into Very Low, Low, Moderate, High and Very High potential zones. The Very Low and Low zones are mainly concentrated in the northern hilly areas due to steep slopes, high runoff and limited infiltration, whereas the High and Very High zones are predominantly distributed across the southern alluvial plains, where favourable geology, gentle slopes, permeable soils and better recharge conditions prevail.

Overall, the spatial pattern reveals a progressive increase in groundwater potential from the northern hilly terrain towards the southern alluvial plains. The generated groundwater potential map provides a useful basis for identifying favourable areas for groundwater development, and sustainable groundwater management in Jammu district.

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