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GEOSPATIAL AND AHP TECHNIQUES FOR SELECTION OF POTENTIAL ZONES FOR WATER HARVESTING IN DEHRADUN, UTTARAKHAND

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ABSTRACT

Unsustainable groundwater use is a major concern for many developing nations and is becoming a more noticeable issue. Encroachment of the natural resources with a growing population has further intricated the hydrological processes resulting in steadily disappearing of surface water bodies leading to an additional load on the groundwater. Geospatial techniques play an important role in mapping, monitoring and analyzing for conservation and management of water resources. The present study used geospatial tools to delineate potential sites for water harvesting in Dehradun district, Uttarakhand, India. Eight essential parameters namely geomorphology, Lithology, Slope, Soil, NDVI, LULC, Lineament density and drainage density were assimilated.

Landsat 9 and Alos Palsar have been employed to derive the satellite- based landuse/landcover and terrain information respectively in the ArcGIS environment. Further, Analytical Hierarchy Process (AHP) was utilized to assign the weights to various thematic layers and consistency ratios were computed to calibrate the AHP. All the parameters were integrated using weighted overlay analysis in a GIS environment to delineate the potential zones for water harvesting. The study reveals that the study area can be categorized into three groundwater potential zones; high, medium, and low. The results may facilitate quick decision-making for sustainable groundwater management and artificial recharge schemes for the augmentation of groundwater in Dehradun.

Keywords: *Water Harvesting, Groundwater, Geospatial, AHP, Sustainability, Dehradun*

INTRODUCTION

Water is one of the most important natural resources for human health and biologicaldiversity.Its future as a key aspect of environmental and biodiversity activities will be ensured by protecting it from degradation and properly managing its use.A third of the global total is reported to use groundwater for drinking (Jose, Jayasree, Kumar, & Rajendran, 2012). Irrigation and domestic purposes in India mainly rely on groundwater. In rural areas, 80% of the groundwater is used for domestic purposes. Groundwater is also used to meet 50% of urban and industrial requirements. It also serves as a source of water for more than half of the irrigated land (CentralGround Water Board, 2014).Water levels have been drastically declining in numerous areas of the nation during the last two decades due to increased extraction. To cater to the growing demand for water, the mapping of groundwaterpotential zones is pivotal for the construction and planning of water harvesting.

The use of GIS and remote sensing is significant in delineating the potential zones. According to the research, combining thematic maps created using traditional and remote sensing techniques with GIS yields more accurate results (Jose et al., 2012).The use of different thematic layers such as geology, geomorphology, drainage density, lineament, soil, and lithology,has beenusedto identify possible groundwater zones by various researchers (Ganapuram et al.2009; Magesh et al.2012; Nagaragan et al.2009; Solomon and Quiel,2006; Chowdhury et al.2009; Saha et al.2010; Muralitharan et al.2015; Pankaj Kumar et al.2016).

In the present study, an attempt is made to identify the potential water harvesting sites in Dehradun using GIS and remote sensing.

STUDY AREA

The study area covers Dehradun, which is the administrative headquarters and interim capital of the Indian state of Uttarakhand. It covers an area of 3088 sq. Km. and extends between 29º57' N to 31º01' North Latitudes and 77º38' E to 78º14' East Longitudes (Figure 1). The elevation of Dehradun ranges from 226 m to 3018 m. The topography is comprehensively characterized into two hydrogeological regions, namely, the Gangetic Alluvial Plain and the Himalayan Mountain Belt. Due to the existence of different types of landforms, the geological set-up in the region offers a variety of hydrological conditions. Thus, the region is partitioned into three hydrological units: the Himalayan Mountain Belt, the Siwaliks Range, and the Doon Alluvial Fill (Doon rock) (Gautam and Biswas 2016).

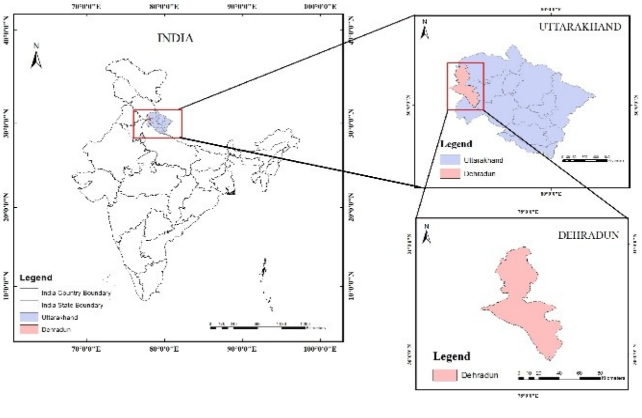

Fig.1: Location map of the Study area

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MATERIALS AND METHODS

The spatial data used in this study has been collected from multiple sources to derive the various input thematic layers. The details of data and its source is given in Table 1.

Table 1. Detailed sources of database

ATTRIBUTE	*SOURCE*
LULC, NDVI	*Landsat 9 USGS (30×30m) [Path/Row: 145/40, Acquired date: 2022–04-5, Scene center time: 05:12:36.5326780Z]* *https://earthexplorer.usgs.gov/*
Geomorphology	*Geological Survey of India (Scale-1:250,000) https://bhukosh.gsi.gov.in/*
Soil Map, Lithology	*National Bureau of Soil Survey & Land Use Planning (1:1,000,000) https://nbsslup.icar.gov.in/*
Lineament density	*Geological Survey of India (Scale-1:250,000) https://bhukosh.gsi.gov.in/*
Drainage Map, Slope	*ALOS PALSAR DEM (12.5×12.5m)* https://asf.alaska.edu/data-sets/derived-data-sets/alos-palsar-rtc/alos-palsar-radiometric-terrain-correction/

METHODOLOGY

Remote sensing technologyis used in the present study to identify the geological features, topography, and distribution of the rivers in the region. Additionally, the Land Utilization Survey Database, geologic maps, and on-site investigation were adopted to quantitatively and qualitatively describe the hydro-geological conditions of the area.The influence of the factors ofgroundwater recharge and the interaction between the factors were examined. Weighting values were assigned according to the on-site situation. The distribution of the groundwaterrecharge potential zone was determined bycoordinating it with the space integrating function ofthe geographical information system (GIS). Figure 2 illustrates the flowchart of this investigation.

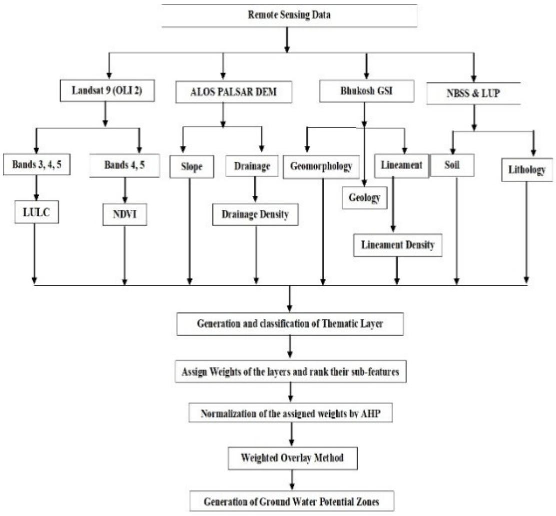

Fig 2. Flowchart of Methodology

Weighted Overlay Method

To address multicriteria problems like site selection and suitability models, the Weighted Overlay tool employs one of the most widely used methodologies for overlay analysis.Weighted Index Overlay Analysis is a straightforward and simple method for combining multiclass maps. The technique has the advantage of including human judgment into the analysis. The relative relevance of a parameter and the objective is represented by a weight.

Ranks were allocated to each independent parameter of each thematic map during the weighted overlay analysis, and weights were allocated based on the influence of the various parameters. The weights and rankings were determined based on the previous literature sources (Krishnamurthy et al 1996, Saraf & Chowdhary 1998).

Analytical Hierarchy Process (AHP).

In order to achieve sound decision-making, an AHP strategy is a methodology that integrates bothempirical evidence and the subjective opinion of experts (Ener et al. 2011).It also connects significant and insignificant components to create a ratio and abstract scale ofpriorities, which is necessary to make complex decisions (Al Khalil 2002; Sólnes 2003).It aids in the identification andweighting of selection criteria, as well as in the analysis and ramping up of the decision-making process.

The prioritization of elements within each section of the hierarchy were obtained by evaluating each set of elements pairwise for each element in the higher section. A pair comparison matrix is used to compartmentalize the hierarchy. For analytic hierarchical decision-making, a nine-point scale ranging from 1 (insignificance or equal significance) to 9 (high preference or absolutesignificance) is utilized. This pairwise comparison assesses each factor's contribution separately (Rezaei-Moghaddam & Karami 2008). Each pair of components in a given element group is assessed separately in AHP to determine their relative relevance.

Normalization of the assigned weight

Normalization of the allocated weight was done in the study. In this process, the geometric mean is calculated first, followed by the normalizing of parameter weights.

The Geometric mean is calculated by dividing the total score weight by the total number of parameters.

$$Geometric\ Mean = \frac{Total\ Score\ Weight}{Total\ Number\ of\ Parameter}$$

The indicator of multi parameter analysis of groundwater mapping is normalized weight. The geometric mean is used to calculate normalized weight, which is derived by assigning a weight to each parameter feature class.

$$Normalised\ weight = \frac{Assigned\ weight\ of\ parameter}{Geometric\ Mean}$$

Delineation of Groundwater Potential Zones

The groundwater potential index (GWPI) is a unitless measure that can be used to quantify the Groundwater Potential Zones within a specific area.

$$GWPI = \sum_{w=1}^{m} \times \sum_{j=1}^{n} (Wj \times Xi)$$

Where,

Wj→ Normalized weight of the j parameter;

Xi→ weight of the i class of the parameter;

m → No. of parameters;

n→ No. of classes with the specified parameter.

The assigned ranks, calculated normalized weights and consistency ratios of respective classes of a particular theme are given in Table 2.

Table 2. Categorization of factors influencing Groundwater recharge Potential Zones

Thematic Layer	% influence	Induvidual features	Weightage
Geomorphology	17	Moderately Dissected Structural Hills and Valleys	2
		Low Dissected Structural Hills and Valleys	2
		Piedmont Slope	2
		Mass Wasting Products	1
		Older Alluvial Plain	5
		Younger Alluvial Plain	5
		Older Flood Plain	5
		Piedmont Alluvial Plain	5
		Active Flood plain	5
		River	5
		Highly Dissected Structural Hills and Valleys	1
		Dam and Reservoir	5
Slope	16	Levelled	5
		Gently	4
		Moderate	3
		Strongly	2
		Steep Slope	1
Lineament Density	8	Very Low	1
		Low	2
		Moderate	3
		High	4
		Very High	5
Drainage Density	9	Low	5
		Moderate	4
		High	3
		Very High	1
Soil	17	Sandy	5
		Loamy	3
		Clayey	1
		Loamy Skeletal	4
		Waterbodies	5
Lithology	17	Alluvium	5
		Colluvium	5
		Sandstone	5
		Granite Gniess	1
		Waterbodies	5
NDVI	9	Very Low	1
		Low	2
		Moderate	3
		High	4
		Very high	5
Land Use/ Land Cover	7	Trees	5
		Built up Area	2
		Waterbodies	5
		Barren land	1
		Crops	4

RESULTS AND DISCUSSION

Geomorphology

The study of the earth's form (landform), its description, and formation is known as geomorphology. The Geomorphological map of the study area is given at Figure 3.

The structural evolution of geological formation determines the geomorphology of a place. Geomorphology is the study of landforms and structural characteristics. Many of the features are conducive to groundwater occurrence and are categorized according to groundwater potentiality. Flood plains, somewhat dissected hills and valleys, pediments, Pedi plain complex, quarry and mine damp, tank and river are the principal geomorphological features.

Dehradun is situated between the Lesser Himalayan Mussoorie Ranges to the north and the Siwalik Ranges to the south. Important Geomorphic units in Dehradun

(i) Lesser Himalaya hills

The hanging wall of the Main Boundary thrust to the north is home to the Lesser Himalaya ranges. Lesser Himalayan rocks, such as argillites, phyllites, quartzite, carbonate, and slates, make up the majority of this unit.

(ii) Dissected hills

The middle and upper Siwalik rocks, which are predominantly sandstone and conglomerate, make up the dissected hills section.

(iii) Floodplain

The Yamuna, Suarna, Sitala Rao, and Asan, which drain the study area, all feature significant floodplains. The floodplains have an average slope of 0° to 1° and an elevation of 420 to 660 meters.

(iv) Terraces

Terraces are farmed areas that range in height from 480 to 720 meters. Gravels and pebblesin a sandy matrix make up the majority of terraces. Because of the presence of barren landand cultivated areas, the NDVI values of these surfaces are almost zero or slightly positive.

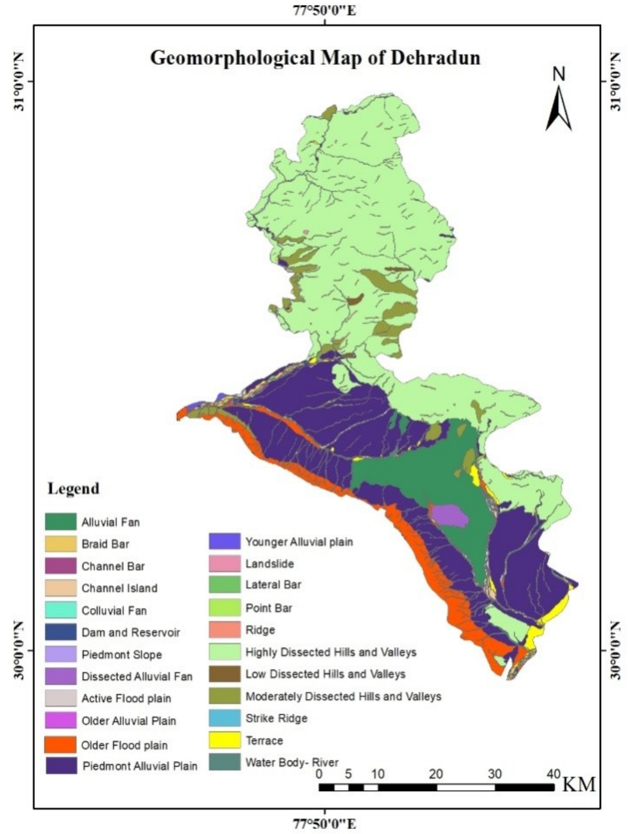

Fig 3. Geomorphology map of the study area

Slope

The slope indicates the local and regional relief that has an impact on groundwater recharge into aquifers. The slope gradient is extensively employed in the definition of Groundwater Potential Zones since it directly regulates surface water penetration. Region with the larger runoff, possess high slope gradient so it has low Groundwater Potential. A low slope gradient, on theother hand, restricts water movement and so increases infiltration. As indicated in Figure 4, the study area has a slope ranging from 0 to 80 degrees.

For flat or gentle slope, which is attributed to high infiltration and low runoff, the class with the lowestslope value is given the highest rank, while the class with the greatest slope value is given the lowest rank due to the comparatively high runoff and low infiltration.

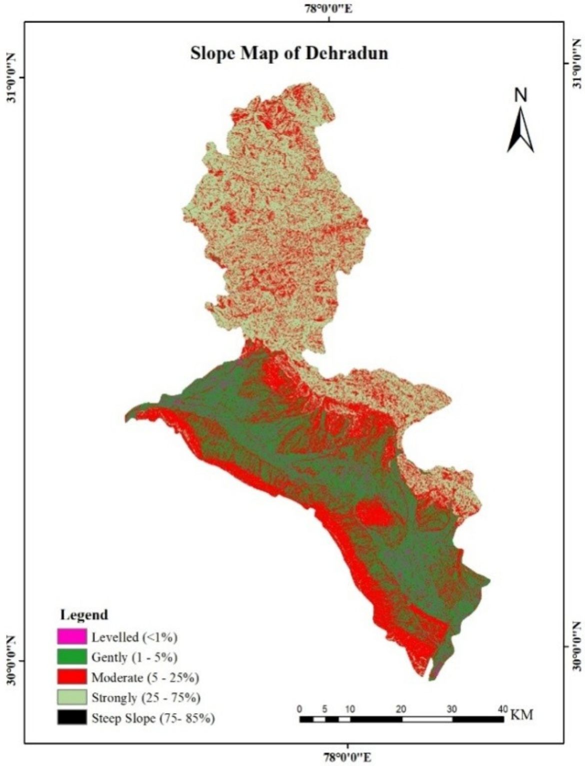

Fig 4.Slope map of the study area

Drainage Density

Drainage density reveals the closeness of channel spacing as well as the composition of the surface material. Quantifying drainage density and type of drainage provides information on runoff, infiltration, relief, and permeability. Surface materials as well as subsurface formation are revealed by drainage patterns, for example, dendritic drainage implies homogeneous rocks, while trellis, rectangular, and parallel drainage patterns suggest structural and lithological control. The physical and climatic factors of the drainage basin influence drainage density. It is a crucial component in determining the groundwater potential zone.

A flat area with relatively permeable subsoil under heavy vegetation is more likely to have low drainage density. In hilly terrain, regions with scarce vegetation, and impermeable subsoil, will have high drainage density.

Low drainage density indicates coarse drainage texture, and high drainage density indicates fine drainage texture. In comparison to a low drainage density region, a high drainage density region can give rise to lesser infiltration, resulting in poor GWPZs. Rivers and other water bodies are widely recognized as critical sources of groundwater recharge.

High drainage density value indicates high runoff and low groundwater potential. As a result, the low drainage density area is given a high ranking. The Drainage Density map of the study area is shown in Fig. 5.

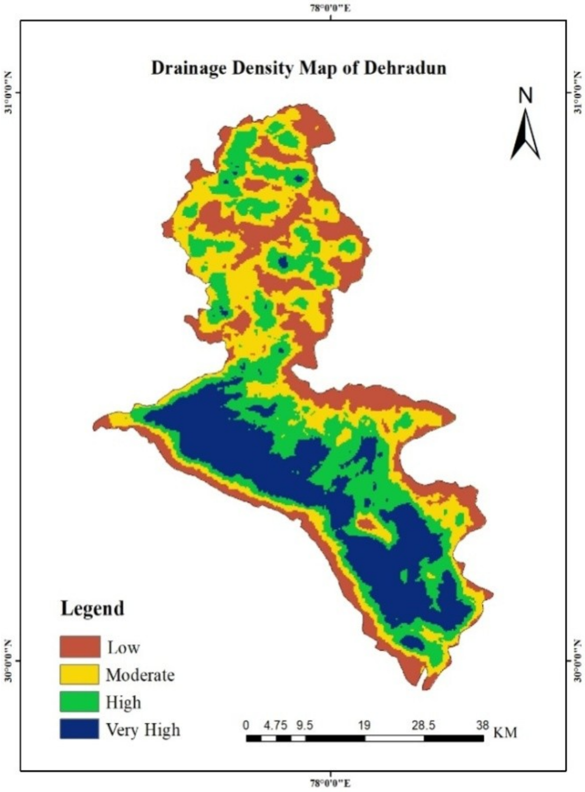

Fig 5. *Drainage density map of the study area*

Soil

The lithosphere, hydrosphere, atmosphere, and biosphere interact to alter the physical and chemical weathering of rocks which results in the formation of soil. The rate of infiltration and percolation into an aquifer is mostly determined by the soil. Thesize, shape, and arrangement of soil grains, as well as the pore system that corresponds to them, can have asignificant impact on vertical and lateral water movement.

It has a substantial impact on the quantity of recharge water that may seep into the ground and is linked to infiltration, percolation, as well as permeability. The properties of the soil play a significant impact in groundwater recharge. The data source of the soil map is National Bureau of Soil Survey and Land Use Planning (NBSS & LUP).

The soil map derived from National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) has been categorized into four classes, with values assigned to each class based on their impact on groundwater occurrence. Infiltration is slower when the soil texture is finer. Loamy soil dominates the district of Dehradun. The different soil types found in the study area are shown in Fig. 6, their extent is described below:

(i) Clayey soil

It is of fine texture hence infiltration is slower.

(ii) Loamy soil

It exhibits moderately fine hence Loamy soil has greater infiltration capacity that Clayey soil.

(iii) Loamy Skeletal soil

It has moderately coarse texture so infiltration capacity is high.

(iv) Sandy soil

It is of coarse texture hence the infiltration is higher than the loamy skeletal soil.

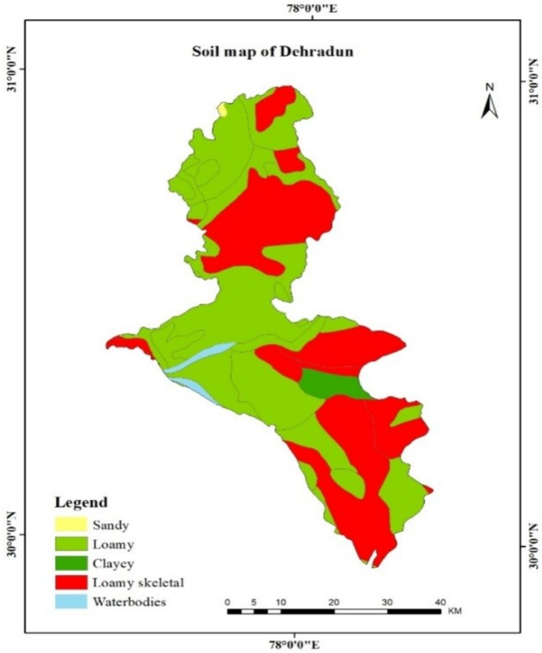

Fig 6. Soil map of the study area

Land Use/ Land Cover

One of the most important factors influencing the distribution and maintenance of groundwater is land use/ land cover. Infiltration and surface runoff are directly influenced by land use and cover. In terms of run-off and infiltration capacity, different types of land use have diverse impacts. Groundwater recharge is often significantly influenced by forest cover. Fallow land and built-up areas enhance run-off, but forest cover increases infiltration. The supervised Maximum Likelihood (MLC) model in ArcMap 10.4. 1 was used to deriveland use/ land cover using OLI 2 sensorimages ofresolution 30m x 30m, from the Landsat 9 satellite. Bands 3, 4 and 5 were utilized.

Trees, built- up area, water bodies, barren land and crops are among the five major LULC features identified in the Dehradun district. The details are given in Figure 7.

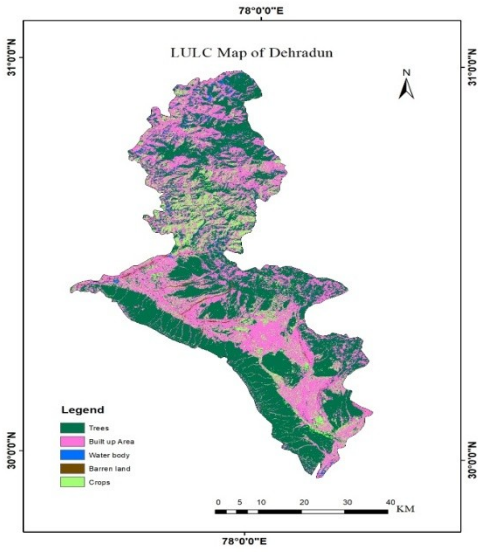

Fig7. Land use/land cover map of the study area

NormalizedDifference Vegetation Index (NDVI)

The NDVI (Normalized Difference Vegetation Index) measures long-term changes in vegetation. The NDVI can be related to fluctuations in groundwater levels (Aguilar et al. 2012) and groundwater flow discharge. The NDVI map (Figure 8) was created in ArcMap 10.4.1 using OLI 2 sensor images from Landsat 9.

The predefined formula **NDVI= (NIR- RED)/ (NIR+ RED)** is added to the Raster calculator of ArcMap 10.4.1, where NIR is Band 5 image and RED is Band 4 image.

The NDVI values of the study area ranged from -0.08 to 0.5, and were then classified into five classes.

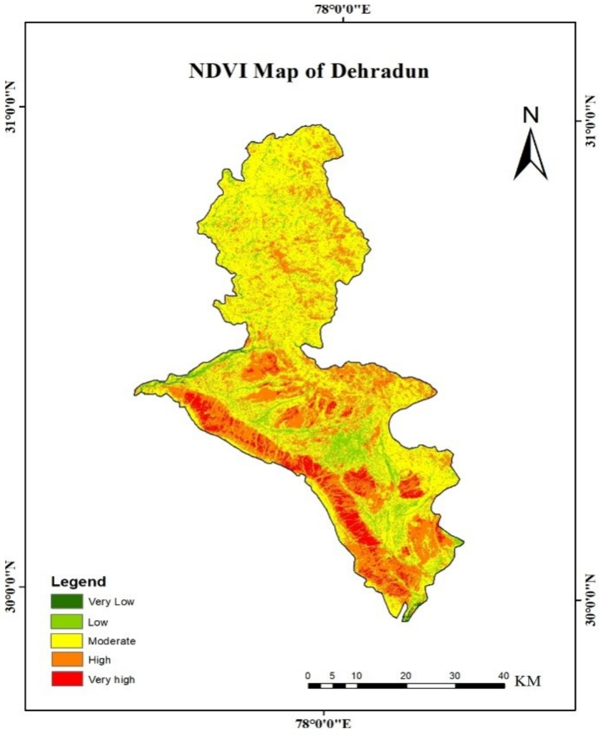

Fig 8.NDVI map of the study area

Lineament Density

Groundwater occurrences and movements are influenced by lineaments, which are linear and curvilinear structural features. Surface run-off is infiltrated into the subsurface by lineaments such as joints and fractures. Lineaments are regarded to have significant groundwater potential.

Groundwater development is influenced by lineament density. Due to good porosity and infiltration, locations with very high lineament density are regarded to have good groundwater potentiality and are assigned a higher rank, whereas areas with extremely low lineament density areregarded to have poor groundwater potentiality and are assigned a lower rank.

The lineament map was created using the BHUKOSH-GSI website. Further use of the Spatial Analyst tool in ArcMap 10.4.1 Software resulted inthe generation of a Lineament Density map. The Figure 9 shows how the entire region iscategorized into five classes based on lineament density.

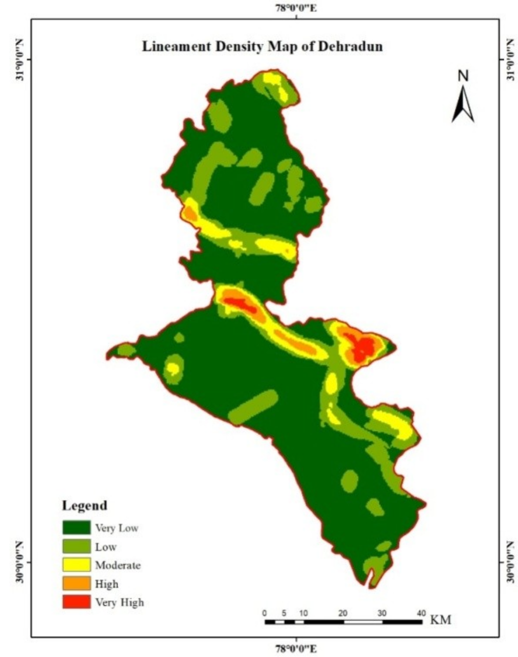

Fig 9. Lineament density map of the study area

Lithology

The physical nature of rocks in a certain area is expressed in terms of texture, color, mineralogy, and thickness, and it is referred to as lithology. Lithology influences porosity and water permeability, which affects the specific storage of groundwater. It's a vital consideration for interpreting, identifying, and mapping groundwater zones. The nature and distribution of aquifers and aquitards in a geologic system are influenced by lithology.

The lithological map (Figure 10) of the study area, Dehradun was generated using data from the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP). The study area is made up of lithological units listed namely Alluvium, Colluvium, Sandstone, Granite Gneiss and Waterbodies.

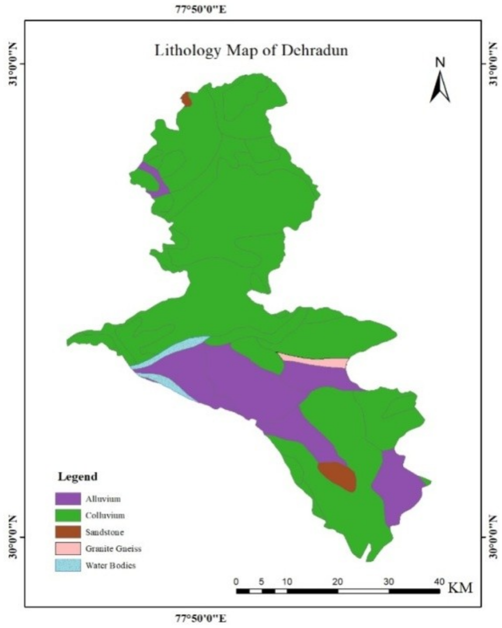

Fig 10.Lithology map of the study area

Delineationof Groundwater Potential Zones

The prospective groundwater zones of the study area were delineated by using weighted overlay analysis of various thematic maps such as drainage density, slope, lithology, soil data, lineament density, LULC, geomorphology, and NDVI using remote sensing and GIS methodologies. The technique of using user-defined ranks based on theoretical aspects of infiltration, runoff, permeability, and adequate moisture conditions. Different themes are given appropriate weighting based on their impact on groundwater movement and storage. Based on the criteria of groundwater flow and potentiality, a rank and score are assigned to each feature in a thematic layer. The interrelationships among the components were used to determine the magnitude of each factor's influence on groundwater recharge. The feature with the largest groundwater potentiality received the highest ranking, while the lowest received the least. All of the thematic maps that control groundwater occurrence are overlaid after converting to raster format of the same cell size, after assigning weightage to different themes and ranks to features. An integrated groundwater potential zone map was prepared using weighted sum tool in Arc GIS software and depending on their ability to hold groundwater, the potential zones in the area are classified as high, moderate, or low groundwater potential zones.

The map of Groundwater potential zones of the area of study, Dehradun, generated using this method is shown in Figure 11.

The areal extent of high groundwater potential zone in Dehradun is 19 km^2 and moderate zone is around 1739 km^2. According to the Table 3 given below, 56.4 % of the total groundwater potential zones fall into the Moderate potential zone, 43% into the Low potential zone, and 0.6 % into the High potential zone.

Table 3. Results Showing Groundwater recharge potential zones in the study area

Potential Zones	Area (%)	Area (Km^2)
Low	43	1330
Moderate	56.4	1739
High	0.6	19

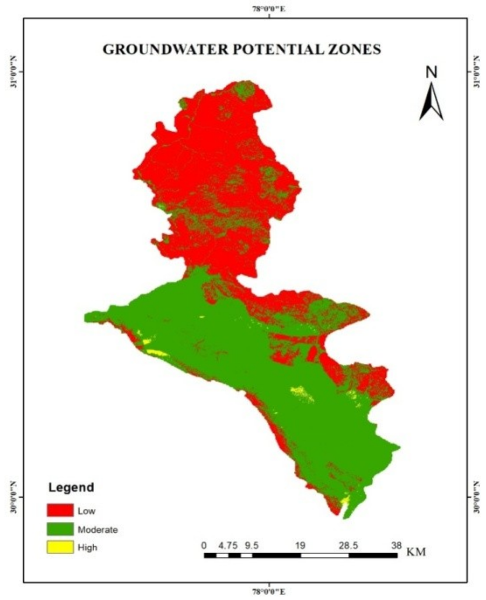

Fig 11. Map showing Groundwater recharge potential zones in the study area

CONCLUSION

This analysis successfully delineated the prospective groundwater resources in Dehradun, Uttarakhand, utilizing remote sensing, GIS, and weighted overlay techniques that facilitate quick decision-making for sustainable groundwater management. Thematic layers of land-use, soil map, drainage density, slope, lithology, lineament density, geomorphology, and NDVI were generated using satellite images, topographic maps, and conventional data sets. The different thematiclayers were allocated a proportional weight through weighted overlay analysis using the GIS environment, to delineate the prospective groundwater map of the study area. In terms ofgroundwater prospect, the area of study is divided into three zones: high, moderate, and low.

These outcomes can be linked to the futuregroundwater management initiatives and artificial recharge schemes of Dehradun, in order to maintain adequate groundwater levels. To investigate the potential groundwater levels in Dehradun, this study established the connection between geology, lithology, and remote sensing data. The maps created as a result, can be beneficial to water policymakers as an increased awareness of areas where groundwater is scarce.

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