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# Mapping Groundwater Potential Zones Using Remote Sensing and GIS Techniques in Sainj River Sub-Watershed, Kullu, Himachal Pradesh

**PAWAN KUMAR THAKUR[1]*, BHIM CHAND[2], MANISH KUMAR[3], VAIBHAV E. GOSAVI[4], NARESH KUMAR VERMA[5] AND D. K TRIPATHI[6]**
[1]*Forest Ecology and Climate Change Division, Himalayan Forest Research Institute, Conifer Campus, Panthaghati Shimla, 171 013, Himachal Pradesh India.*
[2]*G. B. Pant National Institute of Himalayan Environment, Himachal Regional Centre, Mohal-Kullu, 175126, Himachal Pradesh, India.*
[3]*Department of Geography, Central University of Haryana, Mahendergarh, 123031, Haryana, India.*
[4]*G. B. Pant National Institute of Himalayan Environment, Kosi-Katarmal, Almora, 263643, Uttarakhand, India.*
[5]*Special Center for National Security Studies, Jawaharlal Nehru University, New Mehrauli Road, New Delhi, 110067, India.*
[6]*Rana Pratap Post Graduate College, Sultanpur, 228001, Uttar Pradesh, India.*
E-mail: thakurpawankumar0431@gmail.com, bs.geographer@gmail.com, manish.ks1@gmail.com, vaibhavgosavi8@gmail.com, nareshrai.jnu@gmail.com, tripathidk.geoinformatics@gmail.com
***Corresponding author**

## ABSTRACT

Ensuring the availability of drinking and irrigation water for populations living in the mountainous environment has been an important challenge for researchers, spatial planners, and policymakers. A stronger contribution to addressing this challenge may emerge from the identification and mapping of groundwater potential zones in undulating terrain. The present study is an attempt to find out the groundwater potential zones using state-of-the-art technologies of Remote Sensing (RS) and Geographic Information System (GIS) selecting a study area of the Sainj river sub-watershed (area 81 Km$^2$) in Kullu of Himachal Pradesh, India. The associated thematic layers were generated utilizing Landsat-8 (OLI) satellite data from October 2016, Survey of India (SOI) Toposheet (Scale 1:50,000), and Arc GIS 10.5 software. Seven various thematic layers viz., Geology, Soil, Geomorphology, Land Use Land Cover (LULC), Slope, Lineament, and Drainage Density were applied for the identification of groundwater potential zones. The watershed delineation and contour lines (100 m interval) generation were performed using Digital Elevation Model (DEM). The LULC map was prepared through supervised classification using the Support Vector Machine (SVM) method in ENVI (Environmental Visualization Imagine) 5.3 and ERDAS Imagine 2020 (Earth Resource Data Analysis System) softwares. The spatial analyst tool of Arc GIS 10.5 was used to identify groundwater potential zones using the weighted overlay method. The study indicates that the spatial variations in groundwater occurrence are largely controlled by geological structures, landforms, and slopes in the study area. Five groundwater potential zones were identified and mapped in the study area viz., very poor (1.1 Km$^2$, 1.36%), poor (7.3 Km$^2$, 9.03%), moderate to good (67.2 Km$^2$, 83.17%), good (4 Km$^2$, 4.95%) and very good (1.2 Km$^2$, 1.49%).

Key words: Groundwater Potential Zones, SVM, Geological Structures, Lineaments, and Weighted Overlay Method.

## INTRODUCTION

Groundwater is a vital natural resource that sustains human health, economic development, and ecological diversity in any region. In both urban and rural areas, it is the primary source of drinking water and irrigation. It is one of the most important renewable natural resources, and humankind's life and development are strongly dependent on it. Groundwater establishes limits on agricultural development, population density, and the level of living standard. In recent decades, the ever-increasing human and animal population has increased the demand for water, as a result of which water is scarce in many regions of the world. Groundwater development is emphasized in order to meet the ever-increasing demand for water for domestic, agricultural, and industrial applications, and it is also employed for a variety of other purposes because of its widespread availability, low degree of contamination, and client accessibility (Murthy 2000, Sener et al. 2005, Ibrahim-Bathis and Ahmed 2016). Hence, it requires proper management in order to ensure long-term sustainability.

Groundwater is a type of water that fills every hole in a geological layer. Water-bearing formations in the earth's crust serve as transmission and storage channels. The establishment of porosity determines the presence of groundwater in a geological formation and the extent to which it can be exploited. Runoff is increased by high relief and steep slopes, while infiltration is increased by topographical depressions. In comparison to a low drainage density area, a high drainage density area enhances surface runoff. Rivers, ponds, and other sources of surface water can serve as recharge zones (Murugesan et al. 2012). Groundwater development programs necessitate a significant amount of trans-disciplinary data from a variety of sources. Because groundwater is a subterranean phenomenon, its assessment is dependent on an indirect examination of some directly observable terrain aspects such as geological, geomorphological, and structural characteristics and their hydrological characteristics.

Satellite RS gives a comprehensive view that aids in the identification and delineation of diverse landforms, linear features, structural elements, and topographical characteristics, all of which are important indicators of groundwater potentiality. It offers data on the earth's surface that is multi-spectral, multi-temporal, and multi-sensor (Krishnamurthy and Srinivas 1995, Singh and Prakash 2002, NRSA 2008, Avtar et al. 2010, Chowdhury et al. 2010, Rashid et al. 2011, Ibrahim-Bathis and Ahmed 2016). Groundwater potential zones are defined using a variety of methodologies, including geological, geophysical, and RS techniques. Additionally, it provides details on the studied hydrological cycle, LULC variations, temperature changes caused by interactions between the land and the atmosphere, water stress in vegetation, and other aspects (Thakur and Gosavi 2018). The speedy and cost-effective delineations of groundwater potential zones are made possible by systematic integration of these data with follow-up hydro-geological inquiry. The ability to generate data in both spatial and temporal dimensions, which is essential for successful prediction and validation, is a benefit of utilizing RS and GIS for hydrological studies and monitoring (Burrough 1986, Dar et al. 2010, Kumar and Shankar 2014). On the hand, RS provides significant background data on soils, land use, vegetation, surface and groundwater geology, and settlements in connection with groundwater facts from the regional viewpoint. Traditional methods such as hydrological, geological, and geophysical methodologies were used to identify groundwater potential zones (McNeill 1991, Lillesand and Kiefer 1994, Teeuw 1995, Meijerink 1996, Edet and Okereke 1997, Sander et al. 1996, Taylor and Howard 2000, Shahid et al. 2000, Srivastava and Bhattacharya 2006). However, with the introduction of powerful computers and digital approaches, different traditional methods have been combined with RS and GIS technologies in current scenarios (Chenini et al. 2010, Machiwal et al. 2011, Talabi and Tijani 2011). GIS provides an appropriate framework for dealing with large and complicated spatial data in natural ecosystem services (Jenson and Trautwein 1987, Burrough 1986). As a result, for adequate appraisal, exploitation, and management to ensure sustainable development, a systematic strategy for groundwater investigation employing current practices is required. In the light of the above facts, the present study is an attempt to identify and map out the groundwater potential zones using state-of-the-art technologies of RS and GIS in the Sainj river sub-watershed with an area of 81 Km2, Himachal Pradesh, India, and suggested strategies for utilizing groundwater po$^{t}$entials in the study area.

## MATERIALS AND METHODS

### Study area

The Sainj River Sub-Watershed studied region is situated in the Lesser Himalaya extended latitudes 31°43' 3" to 31°48' 51" N and longitudes 77°13' 28" to 77°20' 13" E (area 81 Km$^2$, Kullu district, Himachal Pradesh) (Fig. 1). This area is basically hilly, with deep and narrow valleys divided by spurs and peaks. The tract's elevation ranges from 978 meters (m) near the mouth to 3200 m above mean sea level (AMSL) at the highest hilly point in the Sainj river sub-watershed. The watershed has

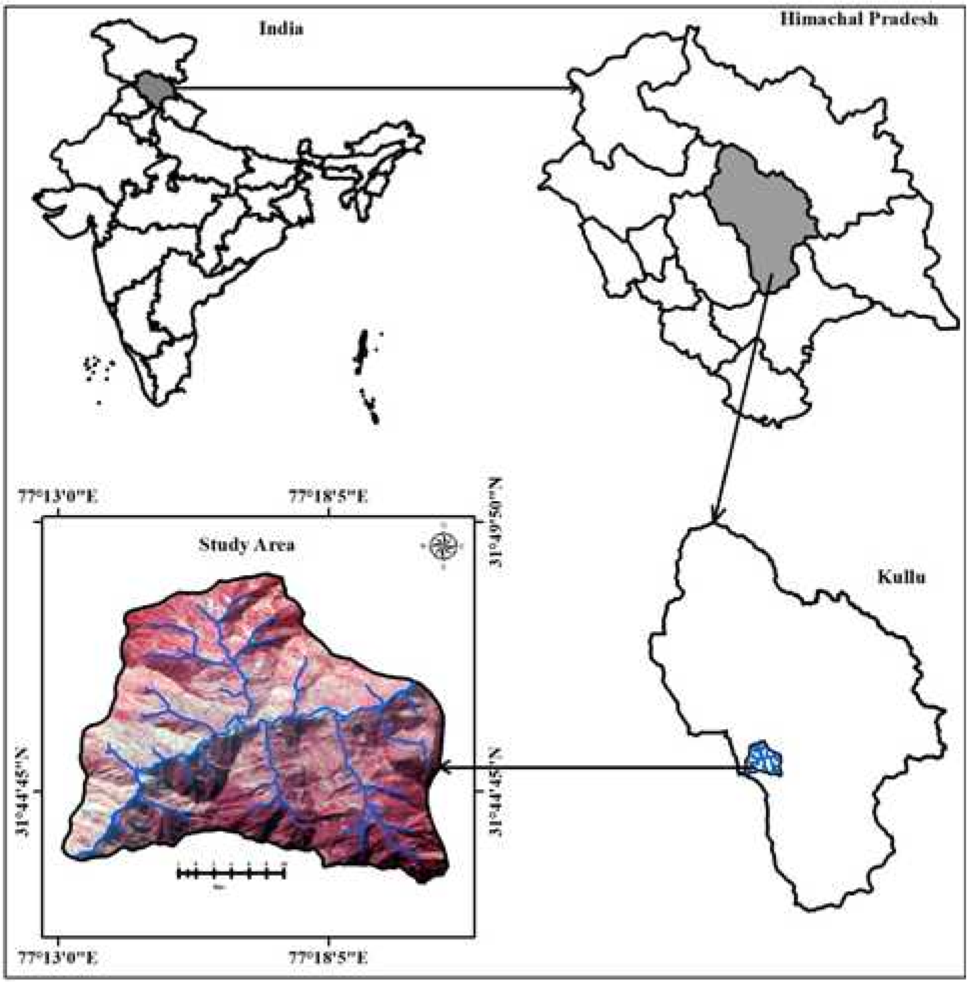

Figure 1. Location map of the study area

moderate to high rough topography that ranges from moderate to high. Granites, quartzite, Sillimanite, gneisses, schist, and limestone are among the intrusive rocks. The climate is usually moderate and alpine. There are four distinct seasons in the Sainj river sub-watershed i.e., spring (April to June), rainy/summer (July to September), autumn (October to November), and winter. Rainfall is average for the majority of the year, but it is heavy during the monsoon season, which lasts from mid-June to mid-September. The watershed climate is primarily moderate temperate in the winter, with an average annual rainfall of 1000 mm. During the winter season, the region receives about 345 millimeters of snow, which is largely confined to the upper portions of the Sainj river watershed. The villages in the catchment region are largely rain-fed, and there is a water deficit for home and agricultural usage along the river valley's slope.

## Data used

The study used data from the Survey of India (SOI) toposheets no. 53E/2, 53E/3, 53E/4 and 53E/5 on a 1:15.000 scale. The Landsat 8 (OLI) satellite data, with a resolution of 30 m and seven bands dated October 2016, were integrated with PAN data using key component analysis. Thematic maps were generated using reference maps obtained from SOI toposheets, visual analysis of satellite data, and additional data which was provided accessible. Weights were allocated to each of these components based on their relative relevance using seven parameters: geology, geomorphology, soil, LULC, slope, lineament density, and drainage density maps. The groundwater potential map was created using these attributes, which were utilized to create a database in Arc GIS. The sequential steps in this investigation are depicted in the flowchart (Fig. 2).

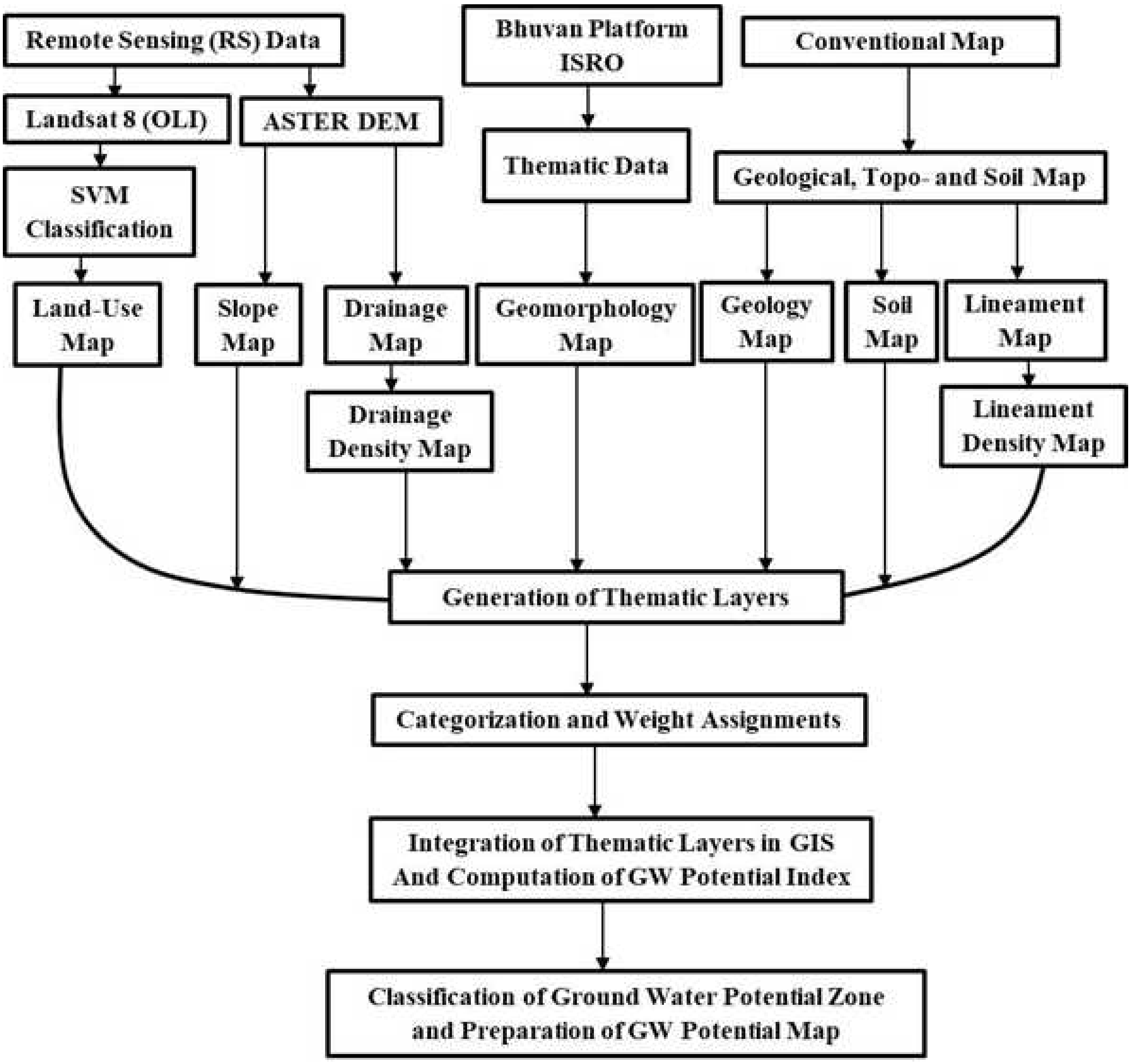

Figure 2. Methodology flow chart

**Software used**

Digitization and analysis were performed using Arc GIS 10.5 software, ERDAS Imagine 2020, ENVI 5.0, and Geomatica 2017. These were employed for digitization of the obtained maps, georeferencing, and creating a database on characteristics. The vector-based geospatial data analysis and visualization application ArcGIS 10.5 provides the user with the ability to retrieve, examine, and generate results.

**Field data collection**

A map was constructed prior to field interpretation, and GPS survey data was used to get ground truth information. Recent satellite data was used to determine current land-use class placement points throughout the field investigation. Numerous units were classified according to their geomorphic provinces and hydrological characteristics. During pre-field interpretation, major lineaments/faults impacting the area and mass movement activities were also analyzed. Comparative investigation of the geology, lineament, geomorphology, hydrology, and LULC required visual interpretation of the research area's satellite data depicted in Tables 1, 2, and Fig 6. The baseline map was updated with data to generate overlays of geology, geomorphology, and LULC that were utilizing the SVM classification algorithm.

Table 1. Themes of the groundwater potential layers with associated weights

| Themes | Assigned Values |
|---|---|
| Geology | 7 |
| Soil | 6 |
| Geomorphology | 5 |
| LULC | 4 |
| Slope | 3 |
| Lineament Density | 2 |
| Drainage Density | 1 |

### Method of index overlay

The weighted combination of maps was investigated employing the index overlays method. This particular weighted model employs binary input maps with a single weight component for each map (Saaty 1980). In contrast, multiclass maps are used, with a distinct rating value being assigned to each class. In this scenario, the weights of the thematic layers as well as the map classes that appear on each output map are assigned a distinct score. In the attribute table for each input map, it is convenient to define the score. It is possible to define the average rating as the following formula.

$$S = \Sigma S_{ij} W_i / \Sigma W_i$$

$i = 1$ to $n$ (no. of thematic layers)

$j = 1$ to $m$ (no. of classes in theme)

Where Wi is indeed the weight of the input thematic map, S ij is indeed the rating for the jth class of the ith thematic map, and S seems to be the weighted rating for this study area item (polygon pixel) and j value will depend on the class that is present where you are located. There must be a list of ratings for every thematic map, one for individually mapping classes. Class grades can be entered into an attribute table using an editor so that the modeling process can access information. It is possible to modify the attribute table without altering the process. In the case that several classes obtain ratings that seem to be negative, the output map will automatically set the area where each class occurs to class 0 (zero).

### Counting several thematic layers

Additionally, groundwater formation and growth are influenced by LULC. The study's LULC map was derived using Supervised Classification using SVM algorithms from the 2016 Landsat-8 (OLI) satellite data. The amount of water that infiltrates, and consequently, the pace of groundwater recharge is significantly influenced by the soil zone. The size of the soil grains and the corresponding hydrological parameters have a significant impact on the rate of infiltration. A grading system was created for the integration of several themed maps. Various classes of particular themes were given a number grading system ranging from 1 to 7, depending on the degree to which individual categories influenced the groundwater regime in the region shown in Table 2. Geomorphology is the study of how different landforms and topographical characteristics interact with one another. The weathered/fractured quartzite, limestone, slate, schist, and phyllite, among other minerals, characterize the zone with very good groundwater potential. The zone has a moderate to good (medium) potential for groundwater and is frequently found to contain granite, car-biotite, met basalt, and granite gneiss. Granitoid, gneisses, and migmatite are commonly found underneath low groundwater zone locations. As well, surface water is an important geomorphological factor in the formation and structure of landscapes and landforms, hydro-geomorphological investigations are required for the design and implementation of groundwater research. Although a geomorphologic component, the slope affects the infiltration and recharging of a groundwater system as a result, the nature of the slope in combination with other geomorphic elements can serve as a predictor of a region's groundwater prognosis. The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM) of 2010 with 30 m spatial resolution using the assigned threshold values, the geomorphology and slope thematic maps were generated (Saraf and Choudhary 1998, Prasad et al. 2008). The equal weightage integration method was used to assign weights to every thematic map in an attempt to eliminate all subjectivity from the analysis of coding ratings (Kumar et al. 2007, Preeja et al. 2011). Thematic maps generated in raster format were all superimposed to produce groundwater potential zones, which exhibited various groundwater prospective areas depending on the parameter selected in Arc GIS 10.5 software.

Table 2. Various factors for groundwater potential zones are ranked and weighted

| **Parameters** | **Classes** | **Individual weights** | **Total weight** |
|---|---|---|---|
| Geology | Kharo, Rohtang Gneissic Complex | 2 | |
| | Khamrada | 5 | |
| | Bhalan | 4 | |
| | Banjar | 3 | |
| | Jeori-Wangtu/Bandal Gneissic Complex | 1 | 20 |
| Soil | Shallow, Sandy-Skeletal Loamy Soils | 1 | |
| | Shallow, Loamy Soils | 2 | |
| | Shallow, Medium Deep Loamy Solis | 3 | |
| | Medium Deep, Loamy Solis | 4 | |
| | Deep, Loamy Solis | 5 | 17 |
| Geomorphology | Highly Dissected Hills and Valleys | 2 | |
| | Water Bodies | 7 | |
| | Moderately Dissected Hills and valleys | 1 | |
| | Anthropogenic Terrain | 5 | |
| | Younger Alluvial Plain | 6 | |
| | Denudational Origin-Mass Wasting Products | 4 | |
| | Piedmont Alluvial Plain | 3 | 25 |
| LULC | Water Bodies | 6 | |
| | Built-up/Settlements | 2 | |
| | Forest area | 5 | |
| | Agriculture/Crop | 3 | |
| | Vegetation | 4 | |
| | Bare Land/Open Scrub | 1 | 15 |
| Slope | 0 – 17 % | 5 | |
| | 17 – 27% | 4 | |
| | 27 – 36% | 3 | |
| | 36 – 45% | 2 | |
| | 45 – 70% | 1 | 13 |
| Lineament Density (Km/Km$^2$) | 0.00 – 0.26 | 1 | |
| | 0.27 – 0.63 | 2 | |
| | 0.64 – 1.02 | 3 | |
| | 1.03 – 1.99 | 4 | 5 |
| Drainage Density(Km/Km$^2$) | 0 – 1.2 (Very Poor) | 1 | |
| | 1.2 – 2.4 (Poor) | 2 | |
| | 2.4 – 3.6 (Moderate to Good) | 3 | |
| | 3.6 - 4.8 (Good) | 4 | |
| | 4.8 – 6 (Very Good) | 5 | 5 |

## RESULTS AND DISCUSSION

### Geology/Lithology

To better understand the distribution and occurrence of groundwater, this study examined five different types of lithological characteristics (Table 2). The Sainj river sub-watershed lithological map is depicted (Fig. 3). In addition to the geological groups of the Sainj river sub-watershed, which are visible from north to south, the separate categories of Vaikrita, Kullu, Rampur, and Jeori-Wangtu are superimposed. A variety of study sites have been developed along this thrust at the Kharo Rohtang Gneissic Complex, Khamrada, Bhallan, Banjar, and Jeori-Wangtu/Bandal Gneissic Complex. Sillimanite, kyanite-biotite schist, quartzite, gneiss, migmatite, car-phyllite, limestone, quartzite, slate, phyllite, quartzite, metabasaltic, quartzite, phyllite, granitoids, gneisses, and migmatites compensate the lithological structure of the area being studied. Along this boundary, the Jeori-Wangtu/Bandal Gneissic Complex rocks replace that of the Kharo Rotange Gneissic complex because of the significant boundary thrust. The Khamrada and Bhallan formations along with lithology types including limestone, slate, and phyllite provide the highest groundwater recharge in this investigation.

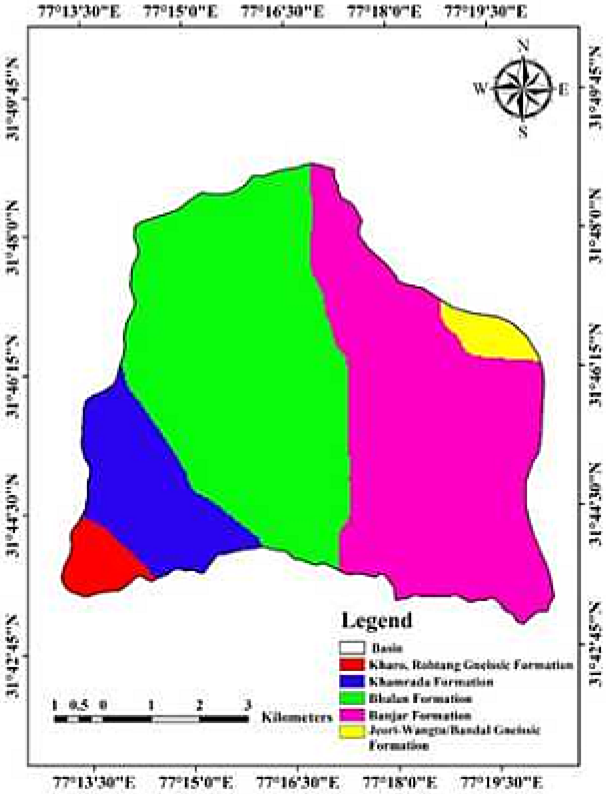

Figure 3. Map of Geology (based on the GMR of the States of India, with scale 1:50,000)

### Soil

Infiltration is inhibited with fine-grained soils because of their apparent **low p**ermeability, while water can easily infiltrate into coarse-grained soil components because of their high permeability. Five major soil types were identified in this investigation i.e., shallow sandy-skeletal loamy soils, shallow loam, shallow medium deep loam, medium deep loam, and deep loam are depicted (Fig. 4). Severe erosion is linked to deep, well-drained, coarse-loamy soils with loamy surfaces and deep, somewhat excessively drained, thermic, fine-loamy soils on moderately steep slopes with loamy surfaces. On the other hand, severe erosion is associated with shallow, excessively drained, sandy-skeletal soils on extremely steep slopes with a sandy surface, and considerable stoniness is associated with rock outcrop sand content/coarse material, and permeability was assigned high weight values. As a consequence, loam soils were assigned a weightage

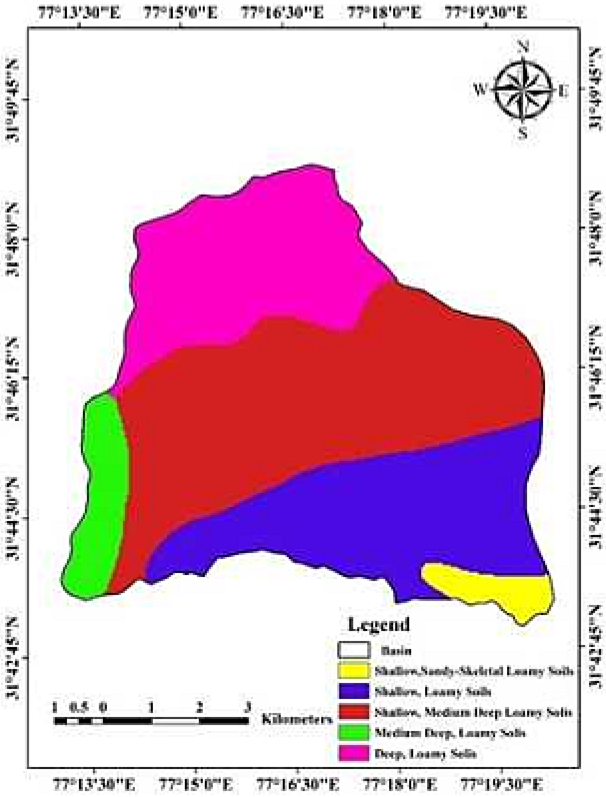

Figure 4. Soil composition of the study area

component of 5, which indicates extremely good groundwater potentials, such as in contrast to deep, loamy soils, which had a factor of 5 indicating high groundwater potentials, and sandy loam units were given a weightage factor of 1.

## Geomorphology

Using RS satellite of the study area, seven fundamental geomorphological groups were identified and delineated based on their relative heights (Fig. 5). A location's response to groundwater occurrence is significantly influenced by its geomorphological features (Nossin 1971, Thomas et al. 2009). As a consequence, linking geomorphological aspects to a basin's hydrological features makes understanding its hydrological behavior much easier (El Gammal et al. 2013). Illustrations of a structured origin included water bodies, highly dissects hills and valleys, and other geomorphological features. The structural sources are somewhat dissected hills and valleys. The terrain with anthropogenic origin, piedmont alluvial plain, fluvial origin, fluvial origin, denudational origin, and mass wasting products was identified in the study area. The Sainj river sub-watershed encompasses an area of 40.61 km2 that is divided into dissected hills and valleys. There is only 0.76 km2 of wat$^{e}$r in the Sainj river sub-watershed. The hills and valleys of the 33.19 k$^{m}$2 Sainj river sub-watershed region are significantly divided. The Sainj river sub-watershed contains 0.02 km2 of anthropogenic terrain. The alluvial plain zone of the study area has younger measures as well as an area covering 0.04 km2. The study area's piedmont alluvial plain zone, which covers an area of 0.10 km$^2$, and the denudational mass wasting products, which cover an area of 0.10 km$^2$, constitute the geomorphology element. The influence of various geomorphologica$^{l}$ units on groundwater infiltration has been ranked.

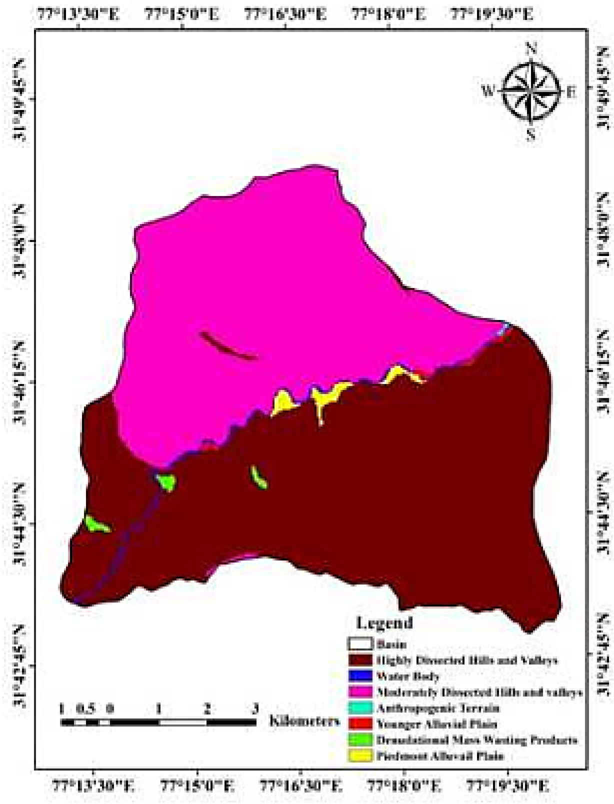

Figure 5. Geomorphology map of the study area

## Land Use Land Cover (LULC)

The types of LULC categories are shown in Figures 6 and 7 with Ground Control Point (GCP) and spatial information were derived from the LULC map of the Sainj river sub-watershed. LULC has both positive and negative effects on groundwater recharge (Todd and Mays 2005, Shaban et al. 2006, Chowdhury et al. 2009, Rawat and Manish 2015).

Figure 6. Status of LULC categories in October, 2016: (a) dense forest patch and agriculture/plantation, (b) water reservoir of Parbati-III hydropower NHPC Limited, and (c) hilly built-up/settlements, vegetation and broad leaf tree

LULC has an impact on groundwater occurrence and development. The thematic map was used to identify the vegetation (grass and grazing lands, and forest plantations), water bodies (rivers and streams), built-up areas/settlements, and open bare soil surfaces/outcrops regions as LULC components for this research. Trees may promote recharge by decreasing runoff and capturing and gently infiltrating water droplets, while they can increase water loss via evapotranspiration. Land-cover classes were created to aid in the identification and understanding of an area's land-use pattern using remote sensing image interpretation. Crops/Agricultural, fallow land, Himalayan moist temperate dense forest, flora, grassland, exposed rock, settlements/built-up, barren terrain, and water bodies are all taken into consideration under the SVM classification techniques. The detection of significant groundwater recharge for forest and vegetation regions is aided by positive and negative changes in LULC, which leads to a reduction in runoff. Groundwater recharge for the most important components, such as thick forest and vegetation-covered grassland, is calculated using the Sainj river sub-watershed. The present study observed water bodies, built-up areas, forest areas, vegetation/grass/scrub, agriculture/crops, and barren land/open scrub. The Himalayan moist temperate dense forest was the most common land use, accounting for 32.23 km$^2$ (approximately 39.65 %), followed by vegetation, accounting for 12.66 km$^2$ (about 15.58 %). Agriculture and farmland cover around 15.75 km$^2$, (about 19.38%) of the total land area. Settlements and built-up areas occupied 9.46 km$^2$ (11.65 %) of the entire area, barren land/open scrub covers roughly 10.17 km$^2$ (12.52 %), and water bodies covered approximately 0.98 km$^2$ (1.22 %) respectively. Based on the geologic structure and original soil conditions, it is expected that the distribution of land use might increase groundwater recharge when associated with a relatively high precipitation amount of 1,000 mm.

### Slope

The variation in height over a portion of a surface is referred to as slope**.** The slope of the ground has an impact on its stability. The research region has a slope of less than 0-14 % to more than 50-70 % (Fig. 8).

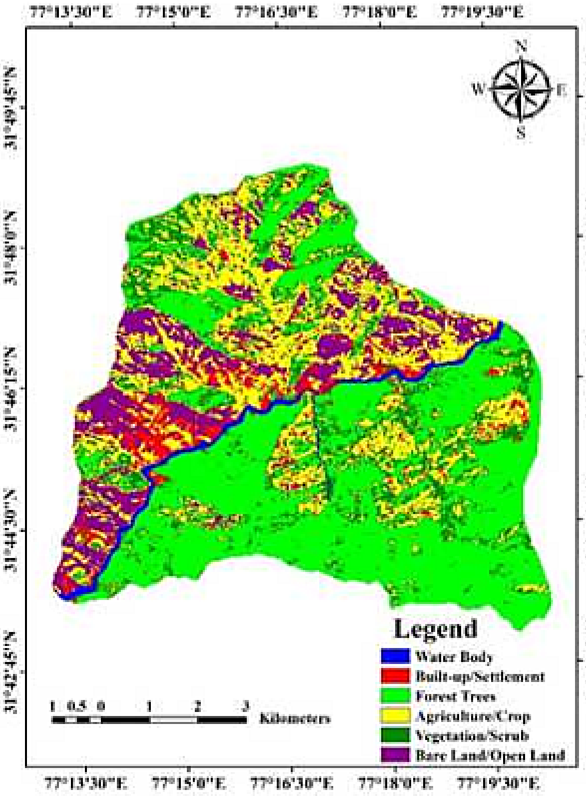

Figure 7. Land Use Land Cover map of the study area

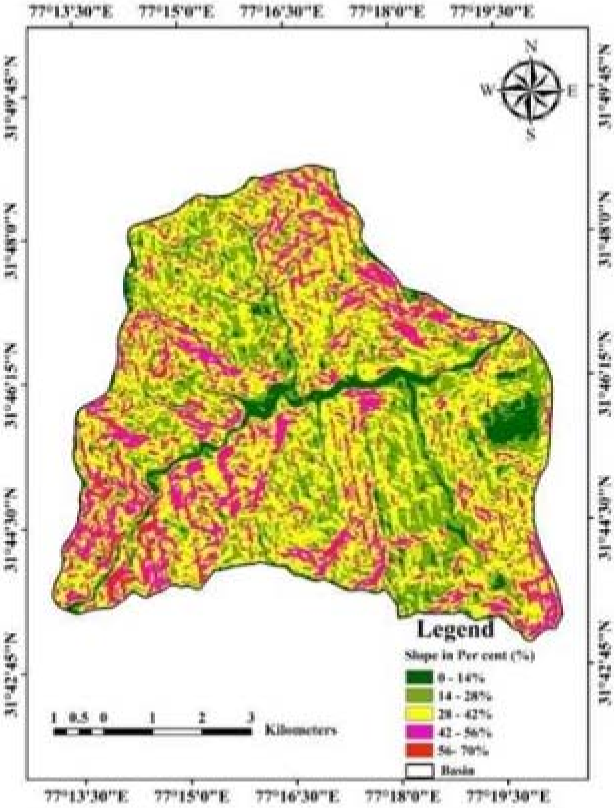

Figure 8. Slope map of the study area

Slope is one of the elements governing the infiltration and recharging of the groundwater system, hence the type of slope, combined with other geomorphic characteristics, may offer an indicator of an area's groundwater prospects. Surface runoff is minimal in low slope areas, providing more time for rainfall penetration, while high slope areas increase strong runoff with limited residence time for infiltration and recharging. The province's steep slopes were mostly located in the north-south direction. The area's terrain is flat in the center. The majority of mountainous terrains have a high slope. The steepness/gradient of a slope is significant because it affects groundwater recharge (IMSD 1995, Rokade et al. 2007). In contrast to steep regions that cause runoff, flat lands are capable of retaining rainfall and facilitating groundwater recharge. As water drains quickly off the surface, a low slope indicates the existence of high groundwater potential zones, whereas a high slope indicates the presence of poor groundwater potential zones.

### Lineaments

Lineaments, faults, fractures, and joints are linear features that are important for increasing bed rock permeability depicted (Fig. 9). A surface feature described as a lineament can be either a simple or composite liner, as defined by O'Leary et al. 1976, whose components are organized in an orthogonal or oblique connection. Because the presence of lineaments typically indicates the presence of a permeable zone, a lineament density map is a quantitative assessment of the length of a linear feature per unit area, which may be used to infer groundwater potentials. Once these structural properties are discovered using digital remote sensing data, the distance to structure map is constructed using the distance function. Those that live near buildings develop a secondary porosity that assists in water percolation better than those who live farther away. As a consequence, locations near geological formations get a higher rating. Folded structures in the form of synclines and anticlines may be seen across the study area. The boundary is more visible around the center of the study area due to the variation in topography. In this study, the area is identified by rapid fluctuations in slope, which, according to remote sensing data, appears as a deep trench covering the E-W and N-S directions.

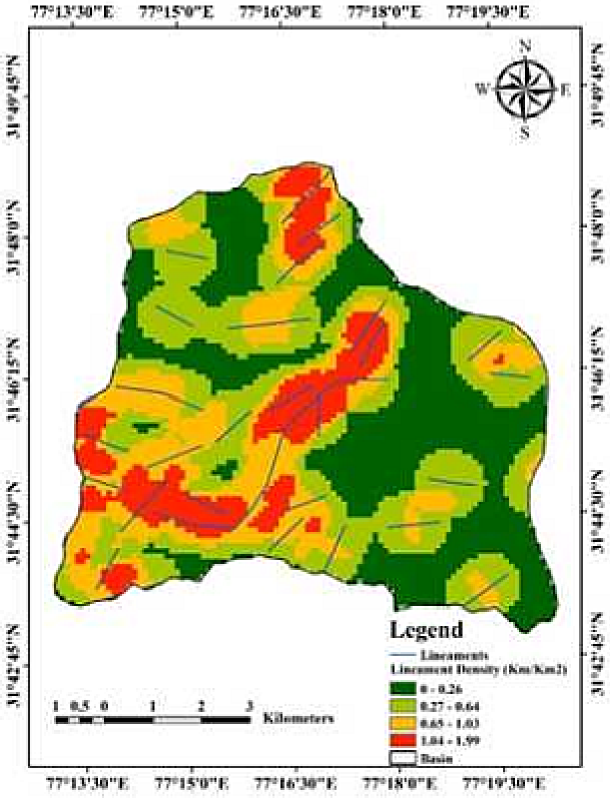

Figure 9. Lineament Density map of the study area

### Extraction of drainage density

In this research, the recharging potential of the drainage network was assessed using a comprehensive morphometric analysis using the Arc GIS Hydrology tool in the Arc GIS software depicted (Fig. 10). Every terrain's drainage pattern reflects the features of the surface and underlying rocks. Runoff loses the majority of the water from precipitation in areas with a higher number of streams per unit area (Tribe 1991, Shaban et al. 2006, Sreedevi et al. 2009). The drainage channels are closer together as the runoff gets stronger, whereas the likelihood of recharging or potential groundwater zones increases with decreasing drainage density. Additionally, it has been proposed to use drainage density, or the total length of drainage systems per unit area, as a permeability indicator, low drainage density is related to permeable environments (Meijerink 2007). The drainage originates from V and U-shaped valleys as well as dissected hills and valleys were identified, along plateaus, and ridges

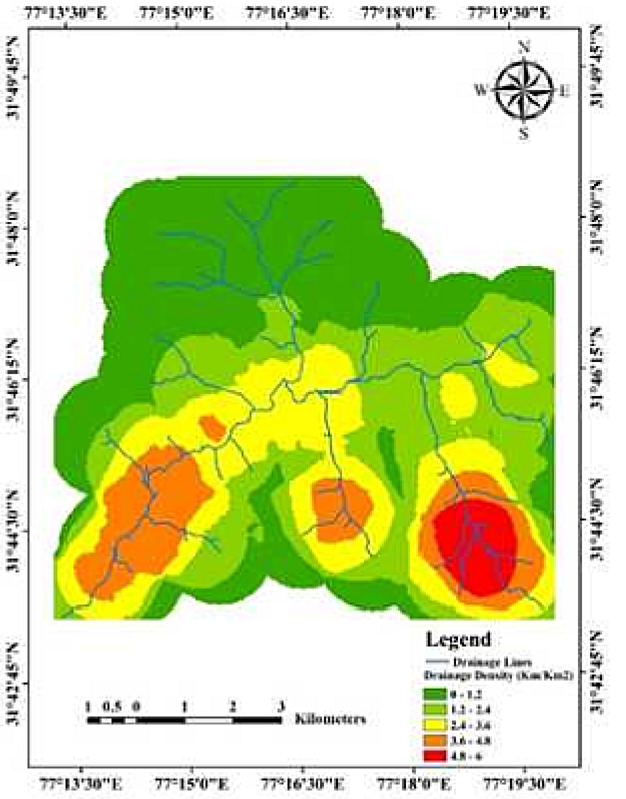

Figure 10. Drainage Density map of the study area

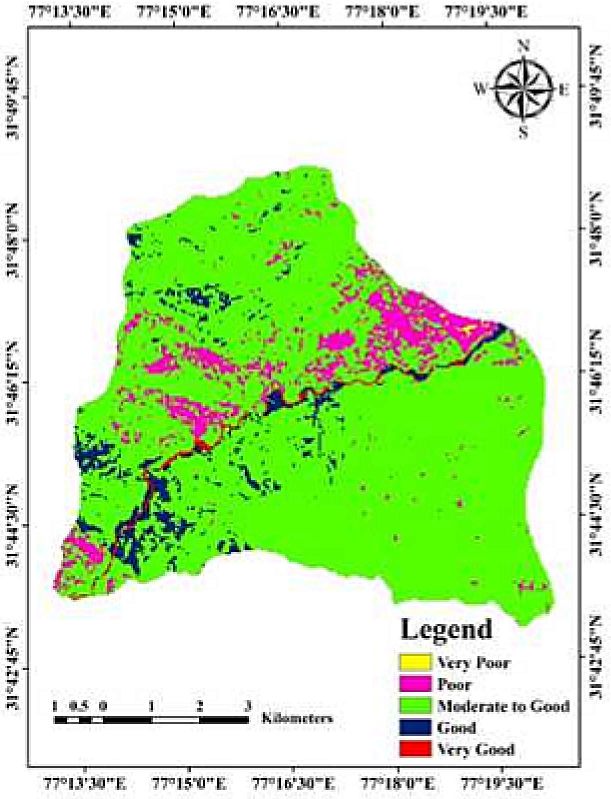

Figure 11. Potential groundwater zones of the study area

in the study area's northern and eastern regions.

**Groundwater potential zone classification**

Five distinct groundwater potential zon**es** have been identified for the research area based on the finding that the region can be separated into five different groundwater potential zones, namely, very poor, poor, moderate to good, good, and very good with an increase in groundwater potential depicted (Fig. 11). The study region extreme eastern and central portions have particularly high potential generally, according to the groundwater potential map. A comprehensive review of the groundwater potential map revealed that, in addition to geological control, rainfall and soil patterns are primarily responsible for the distribution. Additionally, areas of the study area are triggered by granitoids, gneisses, and migmatite, particularly in the northern and eastern parts. Which, on the one hand, are defined by their limited groundwater potential and low annual rainfall. On the other hand, areas undergirded by quartzite and quartz-schist, limestone due to the presence of lineament and evidently considerable weathering, and sites overlain by granitic rocks have a high groundwater potential, but regions overlain by granitic rocks have a medium potential. As well, the top and uppermost portions of the research area include high slope percentages, severely dissected hills, and valleys with rock outcrops that may be the cause of limited groundwater potential. The high groundwater potential seen in the core regions of the study area may be explained by factors such as high drainage density (high soil wetness), high rainfall, and low slope percentages, all of which may facilitate water infiltration into the groundwater system.

## CONCLUSIONS

In this research, multispectral RS and GIS based data were applied on the other hand, five groundwater potential zones were identified in the Sainj river sub-watershed. Groundwater occurrence and movement are influenced by thematic maps that include a variety of geological and hydro-geomorphological data. The integrated groundwater potential map was developed using the weighting provided to various aspects of themed maps. There are five groundwater potential zones in the study area such as very poor, poor, moderate to good, good, and very good. A total area of 1.1 km$^2$ represents 1.36% (very poor), 7.3 km$^2$ (9.03%) poor, 67.2 km$^2$ (83.17%) moderate to good, 4 km$^2$ (4.95%) good, and 1.2 km$^2$ (1.49%) very good. The goal of this investigation was to find soil descriptions in order to determine how much wet and dry land there was. Denudational hills are generally used as drainage zones due to their extensively dissected slopes and valleys (V and U shaped). The final map, in the form of a prospecting map, would provide personal information on where to pursue groundwater and how to properly explore it to local authorities and planners. The findings of the study will assist concerned decision-makers in developing an effective groundwater exploitation strategy for the hilly study regions' groundwater potential information, which will aid in the successful selection of optimal locations for water extraction.

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