Environment and Ecology 41 (4D) : 3066—3076, October—December 2023
Article DOI: https://doi.org/10.60151/envec/CZBM6874
ISSN 0970-0420

Delineation of Groundwater Potential Zones Utilising Geospatial Multi Criteria Technique in Jakholi Block of a Himalayan District, Rudraprayag, India

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Received 25 June 2023, Accepted 13 November 2023, Published on 29 December 2023

ABSTRACT

Groundwater mapping is critical for satisfying people's water needs. An attempt has been made to delineate the groundwater potential zone for Jakholi block in the Rudraprayag district of Uttarakhand, India. An innovation in groundwater research that aids in evaluating, observing, and sustaining groundwater resources is the coalscence of remote sensing data with the Geographical Information System (GIS) in order to groundwater resources. Several groundwater potential zones for assessing groundwater availability in Jakholi block have been identified in this article utilizing remote sensing and GIS methodologies. Throughout the study, nine thematic layers were evaluated for designating groundwater potential zones: Geomorphology, geology, lineament density, drainage density, slope, soil texture, precipitation, relief and land use/land cover. Thematic layers were then transformed to raster using a GIS platform. After giving weights and score to individual layer, overlay analysis has been practised to identify five zones: Very good, good, moderate, poor, and very poor. The majority of the territory is in a zone with poor groundwater prospect. The outcome illustrates groundwater potential zones in the research region and has been shown to be useful in improving ground water resource planning and management.

Keywords Groundwater, GIS, Potential zones, Planning, Management.

INTRODUCTION

Groundwater is stored in aquifers, which are layers of porous rock and sediment that can hold water and it can be drained into lakes or streams, blasted up spontaneously by springs, or both (Ayazi *et al*. 2010, Neshat *et al.* 2013). When groundwater rises up or flows into surface—the water bodies we espy like lakes, spring water and river flowage—it restores and maintains surface water levels regardless of it is underground (Yeh *et al.* 2016). Groundwater makes our rivers more imperishable (WWAP 2018). Over 90% of the people living in interior areas, who do not receive water services from a county/city water department or private water business, rely on it for drinking water (Mukherjee *et al.* 2015).

Due to the tremendous strain of population growth and urbanization, the worldwide effects of weather and climate change, persistent drought conditions, and a lack of precipitation, groundwater demand is dramatically rising (Joshi *et al.* 2018, Pra-

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manik *et al.* 2018). A rapid drop in the groundwater table has been caused by excessive consumption of the subterranean resource (MacDonald *et al.* 2016, Patra *et al.* 2018). One of the most significant impediments of protecting groundwater is that it naturally occurs underground (Jaturon *et al.* 2014). Since groundwater levels are not discernible with the naked eye, supplies may be mistakenly polluted or even underutilized, which would imply that more water would be pulled out of the ground than could be responsibly replenished.

However, there are ways to recharge and replenish groundwater. It can happen inadvertently when humans take steps to restore groundwater levels by rerouting water so that it would be absorbed into the ground through canals, basins, or ponds, or it can happen spontaneously when rain and snowmelt seep in through the ruptures and fissures beneath the land's surface (Nampak *et al*. 2014).

The prevalence of groundwater is subjected to the structural features of the surface or subterrane and its interplay with hydrology of the region (Saud 2010). When the vent spaces in soil or rock get absolutely waterlogged, groundwater forms below the Earth's surface. When rainfall insinuates throughout soil and exudes below to create groundwater, it becomes a component of the hydrologic cycle (Senthil Kumar and Shankar 2014). To conclude the hydrologic cycle, groundwater will ultimately rise to the surface and discharge into rivers, lakes, springs, or the ocean.

It is essential to evaluate, strategy, and keep track of groundwater potential to maintain groundwater availability amid the expanding population concentration and our reliance on subsurface (RGNDWM 2015). In order to secure regional livelihoods that provide alternatives for adaptation, sustainable groundwater usage and good planning are required for retaining foreseeable water supply through replenishment of groundwater and increased infiltration.

Remote sensing and geographic information systems, with its asset of geographical and chronological accessibility and influence of not ony the Earth surface but also of subsurface data encompassing extensive and sequestered locale in just a brief amount of time, have enormous opportunities in groundwater hydrology for navigating, surveillance, and safeguarding the riches of groundwater (Kumar *et al.* 2022). Researchers are now accustomed to incorporating numerous thematic maps of the planet's plane and beneath using remote sensing (RS) and geographic information system (GIS) techniques that determine groundwater prospective zones for exploration, growth, and efficient utilization of groundwater assets (Nag and Kundu 2018). More recently, GIS-based Multi-Criteria Decision Analysis (MCDA) tools have made it incredibly simple to choose which parameters should come first (Saaty 2000, 2008). Analytical Heirarchy Process (AHP) is commonly used to methodically weigh different elements and sub-factors and to compare different criteria pair by pair (Panahi *et al.* 2017).

The Jakholi Block of Rudraprayag district of Uttarakhand state, India, had its groundwater prospective zone mapped in the current study by integrating thematic maps of geomorphology, geology, landuse landcover, soil texture, drainage density, lineament density, relief, precipitation and slope into the geographic realm of a GIS environment. The abovementioned nine key elements, that govern the potential groundwater recharge considerably (Kumar *et al.* 2022), were employed in this study. Both spatial and hydrologic data were digitized using GIS technology, and a basic database was developed.

MATERIALS AND METHODS

Study area

Uttarakhand has been halved into division viz., Garhwal and Kumaon, with a total of 13 districts. Garhwal incorporate districts of Tehri Garhwal, Dehradun, Pauri Garhwal, Chamoli, Rudraprayag, Haridwar, and Uttarkashi. Other six districts namely Pithoragarh, Nainital, Champawat, Almora, Udham Singh Nagar and Bageshwar come under administrative division of Kumaon. Jakholi block of Rudraprayag district is stationed between the coordinate 30° 37'N to 30°15'N and 79°03' to 78°50'E, spread over an area of 497 km^2. The block is bounded by Tehri garhwal district in west, Rudraprayag block in south and Ukhimath block in north and east (Fig.1). The

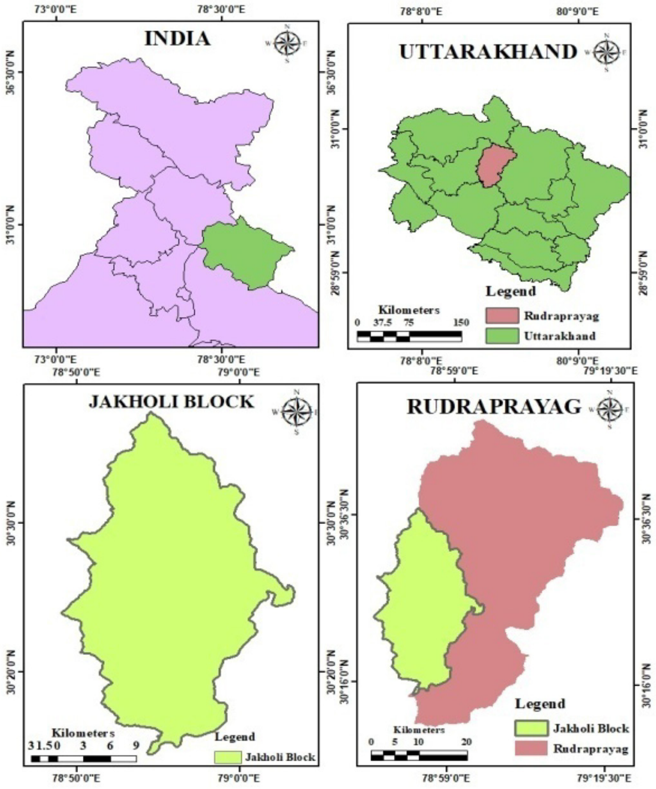

Fig. 1. Location map of the study area.

block includes 133 villages account for an estimated population of 74,759 (Census of India 2011).

Data sources

Groundwater potential sites were identified employing a variety of theme maps that were created utilizing satellite-based data and other, previously released thematic maps. The USGS's SRTM (DEM-30 m spatial resolution) has been implemented to develop relief, drainage, and slope maps. The Geological Survey of India (GSI)'s site, which has a scale of 1:150,000, was used to access the strata. High resolution gridded data of Climate Research Unit 4.01 (University of East Angilia) has provided rainfall statistics. Use of sentinel 2b satellite image has been made to create the LULC map of the research region. Toposheets from Survery of India (Toposheet No.: 53J/14, 53J/15 and 53N/3) on the 1:50,000 scale were examined for a variety of natural ground-based geospatial data. Soil map was prepared as per data provided by Soil Landuse and Survey of India (SLUSI), Pusa, New Delhi.

Table 1. Influence and score value of each factor.

Factor	Weight	Influence	Domain of effect	Score
Geomorphology	.266	26.6	Anthropogenic terrain	2
			Mass wasting product	3
			Peidmont alluvial plain	3
			Younger alluvial plain	4
			Highly dissected hills and valleys	2
			Moderately dissected hills and valleys	3
			River	5
Geology	.218	21.8	Basic meta (volcanics)	4
			Basic rocks	2
			Biotite gniess, quartzite and schist	4
			Gravel, silt, sand and clay	4
			Epidiorite	2

Table 1. Continued.

Factor	Weight	Influence	Domain of effect	Score
			Limestone,shale and dolomite	3
			Porphyritic Nonfoliated Granite	2
			Quartzite and slate	4
			Quartizite, phyllite and amphibolite	5
			Slate and tuff	3
			Schist, Gniess ,marble and basic intrusive	2
			Schistose grit, slate with volcanics	3
Lineament density	.066	6.6	Low	2
			Moderate	3
			High	4
			Very high	5
Drainage density	.059	5.9	0-1.62	5
			1.63-3.25	4
			3.26-4.87	3
			4.88-6.50	2
			6.51-8.12	1
Soil type	.044	4.4	Clay loam	1
			Loam	3
			Loamy sand	3
			Loamy very fine sand	2
			Sandy clay loam	4
			Sandy loam	5
			Silty clay loam	2
			Silty loam	2
Rainfall (mm)	.030	3	916-990	1
			991-1040	2
			1041-1090	3
			1091-1140	4
			1141-1190	5
LULC	.020	2	Water bodies	5
			Forest cover	3
			Agriculture cropland	4
			Build up area	4
			Barren rocky land	1
			Range land	3
Slope (%)	.156	15.6	<15	5
			15.1-30	4
			30.1-45	3
			>45	1
Relief (m)	.137	13.7	<1,136	5
			1,137-1,556	4
			1,557-1,956	3
			1,957-2,349	2
			2,350-2,784	2
			>2,785	1

Assignment of weight and consistency analysis: Groundwater prospective zone mapping is accomplished by amalgamating satellite procured multi thematic maps employing GIS techniques. Each thematic map's component classes are given a weighting based on their traits and interactions with groundwater (Table 1). The attribute table (Table 1) illustrates the allocated weight values for each class for each of the thematic layers that are incorporated into the GIS environment. According to the maximum value acquired as good groundwater potential zone and the minimal value gained as nowt or disagrreable groundwater potential zone, the groundwater zones are divided into five separate groups. The AHP approach suggested by Saaty (1980) was used to create decision-making matrices (Table 2) to give weights to the multiple variables, thematic layer of each criterion, and sub-parameters, and measure their relative relevance. Finalising the weighting of the various levels involved field research, an analysis of the published literature, and the advice of specialists in the field. Based on a thorough questionnaire outlining the influencing characteristics and sub-parameters employed in the investigation and development of groundwater in this mountainous area, the authors contacted experts for this.

The consistency ratio (CR) was estimated using the following fundamental procedures, and the indicator's weight is as follows :

Pair-wise elements matrix (Normalization)

$$\left\{ \begin{matrix} P_{11} & P_{12} & \cdots & P_{1n} \\ P_{21} & P_{22} & \cdots & P_{2n} \\ P_{31} & P_{32} & \cdots & P_{3n} \\ P_{n1} & \cdots & \cdots & P_{nn} \end{matrix} \right\} \qquad \text{(Table 2)}$$

In step 1, column-wise summation values calculated as:

$$Pij = \sum_{i}^{n} = 1Pij \qquad (1)$$

In step 2, divide each component in equa. 1 to generate a synthesised matrix (Table 3) :

Table 2. Pair-wise comparison matrix for MCDM problem. Source: Calculated by researcher.

Main criteria	Geomor-phology	Geology	Slope	Relief	Lineament density	Drainage density	Soil type	Rainfall	LULC
Geomorphology	1	2	3	3	4	4	5	6	7
Geology	0.5	1	2	3	4	4	5	7	8
Slope	0.33	0.5	1	2	3	4	5	5	6
Relief	0.33	0.33	0.5	1	3	4	5	5	7
Lineament density	0.25	0.25	0.33	0.33	1	1	2	3	5
Drainage density	0.25	0.25	0.25	0.25	1	1	1	3	5
Soil type	0.2	0.2	0.2	0.2	0.5	1	1	2	3
Rainfall	0.17	0.14	0.2	0.2	0.33	0.33	0.5	1	2
LULC	0.17	0.13	0.17	0.14	0.2	0.2	0.33	0.5	1

Table 3. Synthesized matrix for MCDM. Source : Calculated by researcher.

Main criteria	Geomor-phology	Geology	Slope	Relief	Lineament density	Drainage density	Soil type	Rainfall	LULC	Weight
Geomorphology	0.31	0.42	0.39	0.3	0.23	0.2	0.2	0.18	0.16	0.266
Geology	0.16	0.21	0.26	0.3	0.23	0.2	0.2	0.22	0.18	0.218
Slope	0.1	0.1	0.13	0.2	0.18	0.2	0.2	0.15	0.14	0.156
Relief	0.1	0.07	0.07	0.1	0.18	0.2	0.2	0.15	0.16	0.137
Lineament density	0.08	0.05	0.04	0.03	0.06	0.05	0.08	0.09	0.11	0.066
Drainage density	0.08	0.05	0.03	0.02	0.06	0.05	0.04	0.09	0.11	0.059
Soil type	0.06	0.04	0.03	0.02	0.03	0.05	0.04	0.06	0.07	0.044
Rainfall	0.05	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.05	0.030
LULC	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.020

$$\mathrm{Pij} = \frac{\mathrm{Pij}}{\sum_{i}^{n} = 1\ \mathrm{Pij}} \qquad (2)$$

In order to create a weighted matrix (priority vector), divide the total of each value of the synthesised matrix by the criterion number (n).

$$\mathrm{Wij} = \frac{\sum_{i}^{n} = 1\mathrm{Pij}}{n} \qquad (3)$$

Consistency vector is determined as follows:

$$\begin{Bmatrix} P_{11} & P_{12} & \cdots & P_{1n} \\ P_{21} & P_{22} & \cdots & P_{2n} \\ P_{31} & P_{32} & \cdots & P_{3n} \\ P_{n1} & \cdots & \cdots & P_{nn} \end{Bmatrix} \times \begin{Bmatrix} W_{13} \\ W_{23} \\ W_{33} \end{Bmatrix} = \begin{Bmatrix} cv_{13} \\ cv_{23} \\ cv_{33} \end{Bmatrix}$$

$$\lambda\mathrm{max} = \sum_{i-1}^{n} = \mathrm{CVij} \qquad (4)$$

Maximum eigen value (λ) = 9.776

Consistency index (CI) = (λ-n) / (n-1) = .097,
Random index (RI) = 1.46
Consistency ratio (CR) = (CI/RI) = .0651

To be acceptable, the CR value must be about 0.10 or below. In the current study, CR has been calculated as .0651, suggesting the matrix to be acceptable.

RESULTS AND DISCUSSION

Geomorphology : Groundwater presence, flow, and evolution may be directly inferred from geomorphologic characteristics (Machiwal *et al.* 2011). A total of seven geomorphologic features have been identified (Fig. 2), such as: Anthropogenic terrain, Mass wasting product, Peidmont alluvial Plain, Younger alluvial Plain, Waterbody– River, Highly and mpderately Dissected Hills and Valleys. A very high value of 5 was given to the Alluvial Plains and Water Body-River among these morphological characteristics because of their felicitous condition. Dissected hills and valleys, however, are awarded a very low

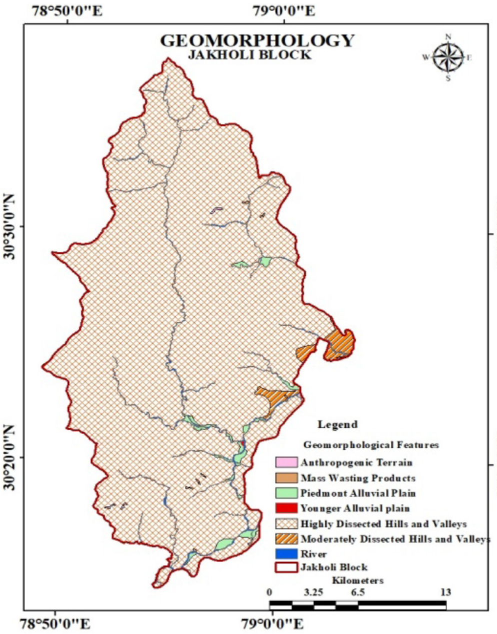

Fig. 2. Geomorphology map.

score of 2 (low priority) since they are unseemly for water potential zones.

Lineament density : The faulting and fracture zones that result in enhanced peripheral perviousness and penetrability are shown by lineaments. Fig. 3. shows the lineament density map of the study region. The data were reclassified into four categories—low, moderate, high, and very high—by carefully evaluating

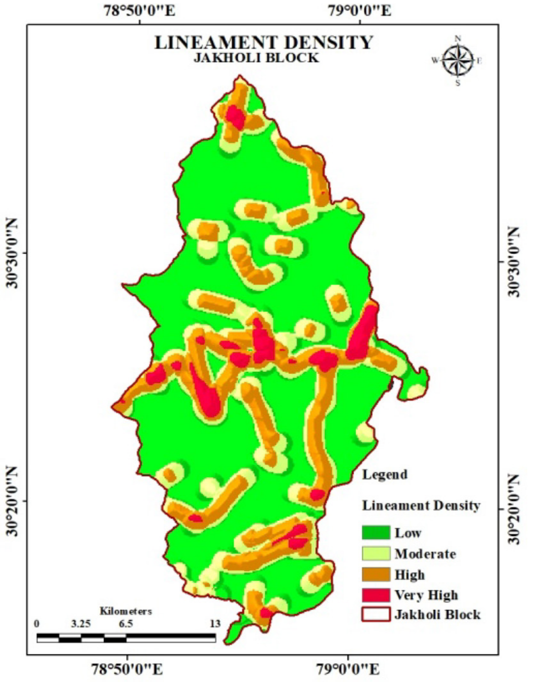

Fig. 3. Lineament density map.

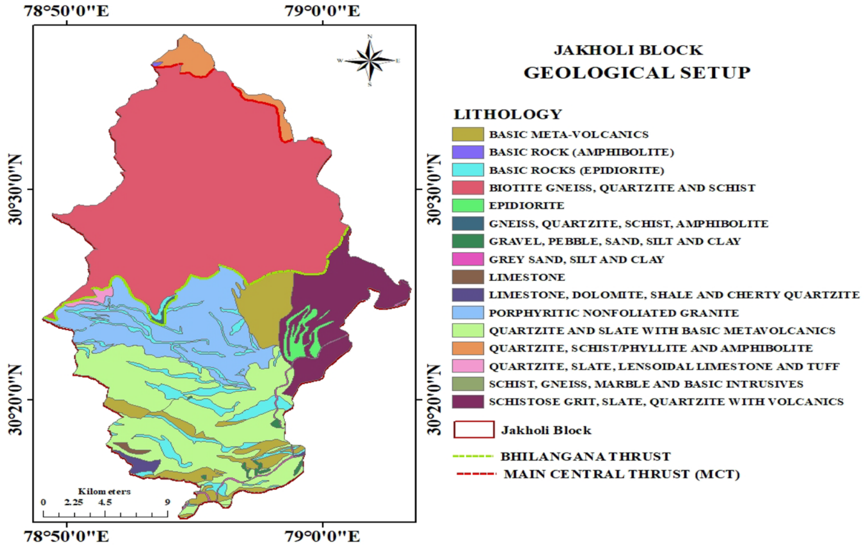

Fig. 4. Geology map of the study area.

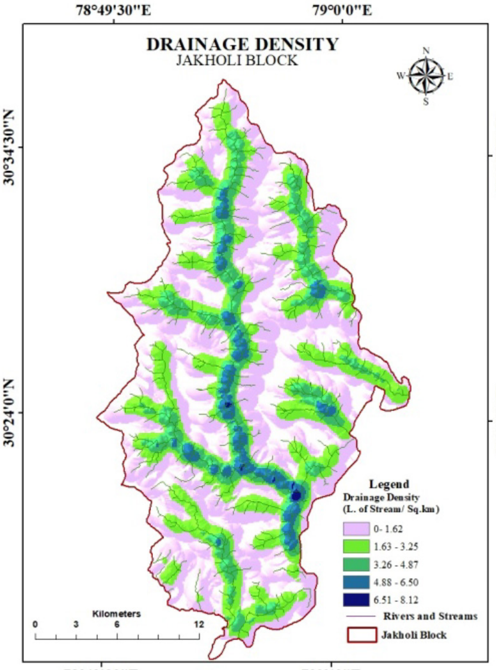

Fig. 5. Drainage density.

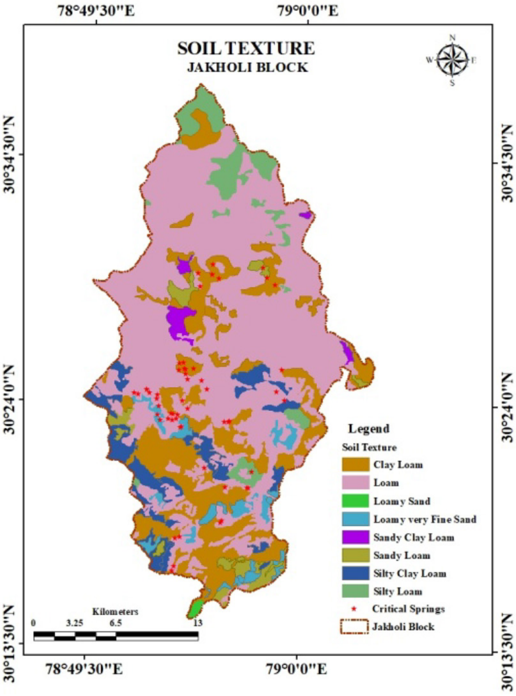

Fig. 6. Soil texture.

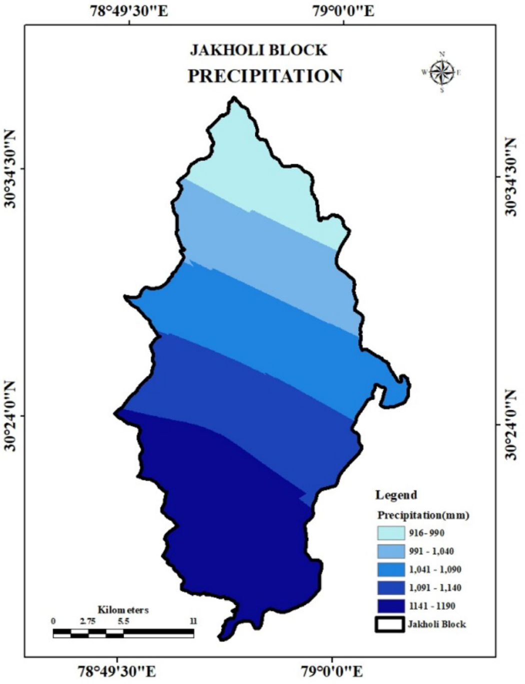

Fig. 7. Precipitation map.

the results. Based on immediacy of the lineaments, the classes for lineament density are given. It is discovered that as the distance from the lineaments increases, the strength of the groundwater potential weakens. For classes with high densities, high weight is given, and low weight is given to low density values.

Geology : A geological map of the research region has been shown in Fig. 4. The permeability and porosity of rocks determine the conveyance and presence of groundwater (Pande *et al.* 2022). Primary rock type such as biotite gneiss, quartzite, basic meta-volcanis, phyllite, schistose, slate and were most often found in the study area. Limestone, dolomite, quartzite and slate were exposed to places where groundwater potential was extremely probable. While granite-dominated and its concomitants, such as porphyritic, Nonfoliated Granite, mica and schist, are widely distributed in north and north east of the study area, they are thought to be less permeable to surface water as a result and are therefore thought to have a limited amount of groundwater potential.

Drainage density : Due to its relationship with

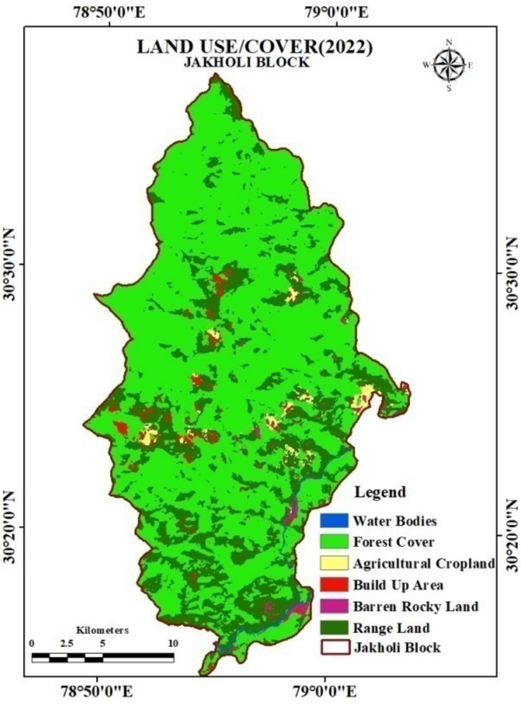

Fig. 8. LULC map.

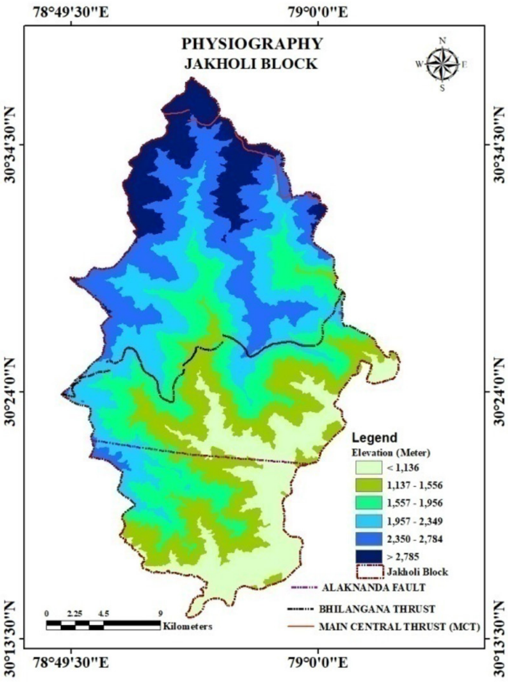

Fig. 9. Relief map.

surface run-off and permeability, drainage density indirectly discloses a region's capacity for groundwater; this is why it was once thought to be one of the indications of groundwater occurrence. The relationship between drainage density and permeability is reciprocal; in other words, the higher the drainage density, the higher and the runoff. Less drainage density means a larger chance of groundwater recharge or potential. The genesis of a well-developed and fine drainage system is surface runoff, which tends to be focused the less permeable rock is, the less rainwater penetration occurs (Jaiswal *et al.* 2003). Considering the drainage density of the region (Fig. 5), it has been grouped into five classes: 0-1.62, 1.63-3.25, 3.26-4.87, 4.88-6.50 and 6.51-8.12. Accordingly, class 1 and 2 assigned excellent; class 3 is moderately good and class 4 and 5 are poor for groundwater potential.

Soil texture : The composition of soil has a substantial effect on the total quantity of water that can seep into its deeper layers and affect the replenishment of ground water. The hydrodynamic attributes of the soil and its texture are the primary elements addressed for determining the pace of absorption. The soil map of the Jakholi block is shown in Fig. 6. According to Zomlot *et al.* (2015), loamy soils have the highest likelihood of groundwater recharge, which indicates that the location is more favorable for groundwater potential. The soil texture in the region is mainly loam mixed with variety of other types like sand, very fine sand, Sandy clay, Silty Clay, Silt and sandy loamy. Thereafter, a good score of 5 has been given to sandy loamy soil and least score of 1 is given to clay loam soil.

Precipitation : The primary source in hydrological cycle and the substantial determining factor for a region's groundwater is rainfall. The rainfall data from 2022 is used in this investigation. Rainfall varies from 916 to 1190 millimeters each year. The amount of rainfall and its time of occurance determine the amount of infiltration. Stunted concentration and continuous rain coerce more infltration than run-off and vice versa. High rainfall receives high weights, and vice versa. Jakholi Block's spatial interpolation map of rainfall is shown in Fig. 7.

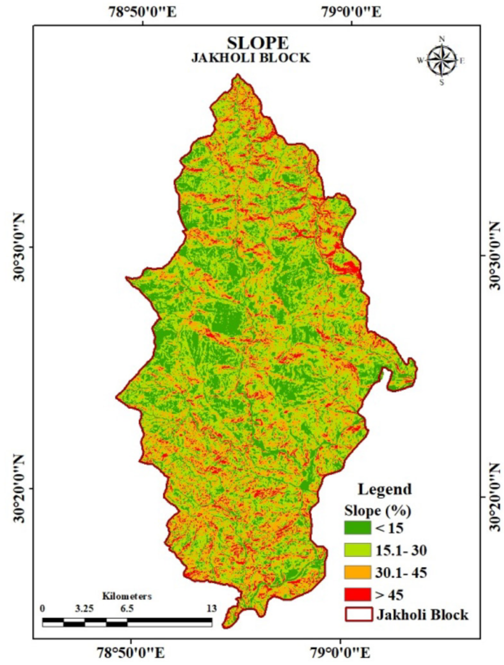

Fig. 10. Slope map.

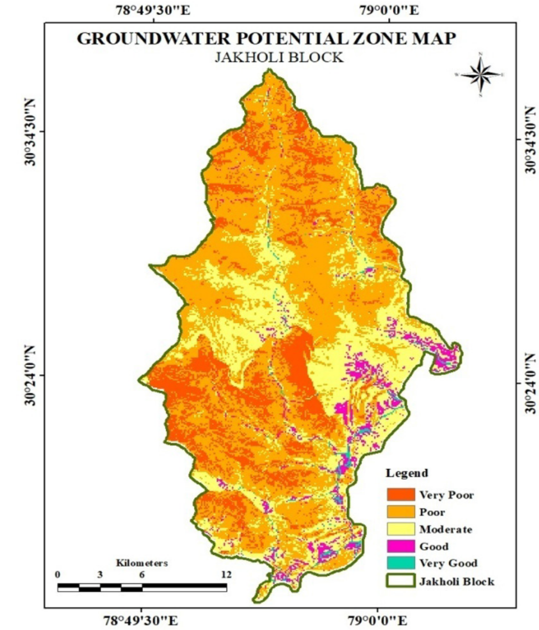

Fig. 11. Groundwater potential zones of Jakholi block.

LULC : The procedure of infiltration, transpiration, and permeability was controlled using LULC. In 2022, forest cover accounted for the majority of LULCs, followed by range land, agricultural land, and build up area, barren rocky land and water body (Fig. 8). The range land was given a modest score of 3. For the percolation and recharge process, the agricultural cropland is preferable because loose soils encourage water infiltration to the subsurface. The build up area and agricultural cropland class received a commendable score of 4. A very low score (1) was given to barren rocky land considering its low infiltration and percolation rate.

Relief (m) : Areas with steep elevations are associated with high runoff and low infiltration rates (Godebo 2005). The study area has been divided into the six relief classes. In general, the block falls within the categories of valley and moderate slope regions (Fig. 9). Less durable lithologies can occasionally be found in the lower elevation region. More groundwater can replenish as a result. With a noticeable elevation increase, the remaining classes (1,557-1,956m) to (>2785m) include undulating, heavily dissected hills and valleys. High relief is subjected to high runoff and consequently is given low weightage.

Slope (%) : The slope, which expresses inclination of any gsurface, is an important topographical feature. Slope of any region has significant reverberations on surface runoff and penetration rate. Rainwater flows speedily downs a slope having great steepness, highly inclined slopes capitulate smaller recharge. In such situation, rainwater lacks the sufficient time to dwell for extended periods to reach the saturated zone and replenish it. The slope map of the Jakholi block is shown in Fig. 10. Five kinds of slope values were created, including fat (<15), mild (15.1-30), medium (30.1-45), and extremely steep (>45). A significant weight is given to slopes that are fatty and mild. For steep and very steep slopes, the weight is modest.

Groundwater potential zones : Given the vitality of the geomorphological traits it is apparent that the area has few possibilities for tapping into groundwater resources because the area around it has very diverse hydro-geomorphological conditions. In these conditions, the environment for groundwater is strongly influenced by a number of terrain parameters, including geomorphology, geology, lineament density, drainage density, soil texture, precipitation, land use/ land cover, slope, and relief. The lower portions of the Lastar gad and Mandakini River valleys offer considerable potential for groundwater development. Due to the valley floor slope's plain to nearly plain surface, ideal hydro-geological conditions, and the existence of perennial rivers nearby, these areas experience substantial water recharge. Jakholi block has been grouped into five separate zones on the groundwater potential zone map: Very good, good, moderate, poor and very poor (Fig. 11). About 5% of the total area represents the 'very good' zone and 9.80% of area falls under 'good' groundwater potential zone. 29.27% of the block's area was identified as having moderate underground water prospective, indicating the presence of enough peripheral porosity sources, such as joints, thrusts, faults, fractures, and lineaments. Groundwater access is poor in more than 50% of the area; as a result, this area required additional hydro-geomorphological and geological research at the miniscule level to understand its geohydrology.

In contemplation of maintaining appropriate groundwater use, the present research's findings can be applied as a management reference for any future artificial replenishment projects in the studied region. The result of the data analysis was a major layer of the area's prospective groundwater, which will aid in decision-making to pinpoint the likely groundwater locations in the block for the advancement of viable groundwater.

ACKNOWLEDGMENT

The authors are thankful to Soil and Landuse Survey of India, Pusa, New Delhi for providing soil data of the region. Also, authors are grateful to the distinguish personalities that helped in completion of this article by providing their valuable suggestions and time.

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