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The Hydro-Health Nexus in Himalayan Ecosystems: Mapping Groundwater Security in District Doda, J&K, India

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ABSTRACT: Groundwater is one of the essential sources of freshwater for domestic, agricultural, and developmental activities in the mountainous region of the Doda District of Jammu and Kashmir. However, its availability and occurrence are governed by topographic, geological, rainfall, soil, drainage, and land-use characteristics. The current study was carried out to delineate groundwater potential zones using GIS-based weighted overlay analysis for better groundwater management and exploration in the study area. The study was conducted using ArcGIS 10.8 by considering five groundwater-affecting thematic layers, namely, rainfall, slope, drainage density, soil, and land use/land cover (LULC). All the thematic data layers were acquired from secondary resources and were preprocessed to develop a groundwater prospect map. The individual layers were reclassified based on the degree of influence on groundwater potential and were assigned weights and ranks, which were used to perform the weighted overlay analysis to produce the groundwater potential zone map of the study area.

Findings and Values: The groundwater potential of the study area was categorized into very low (0.03%), low (13.06%), moderate (66.20%), high (20.64%), and very high (0.06%) using a GIS-based weighted overlay analysis. The result depicted that most of the study area (1578.820 km²) was under a moderate groundwater potential zone, followed by a high potential zone (492.252 km²). In contrast, a very high groundwater potential zone was restricted to only 1.502 km². Further, the areas with high groundwater potential were predicted to occur in Bhaderwah, Bhagwah, Bharat Bagla, Chiralla, and Phagsoo, while the low groundwater potential zone was distributed throughout Marmat, Assar, Chilly Pingal, and Thathri. The findings of the current study will contribute to groundwater management and exploration in the Doda District.

INTRODUCTION

Ground out is the base which in fact is very much into the core of what agriculture, domestic use and industrial growth requires. In mountain areas which include that of Doda District in Jammu and Kashmir ground water is a very important addition to the water supply which we see due to uneven rain fall and also the fact that we have very little surface water. With the increase in population and the growing demand for water we have seen the need for better ground water resource assessment and management put forward. What we are also seeing is that in terms of the tools which are at our disposal for

ground water exploration and mapping there has been great improvement. We have the support of the Geographic Information Systems (GIS) and Remote Sensing (RS) which is really improving what we are able to do. The tech which we have at present are what is allowing us to look at many elements which play into ground water presence such as geology, slope, rain fall, soil make up, drainage density and land use/land cover.

The present study employs GIS-based weighted overlay analysis to delineate groundwater potential zones in *Doda* District and provide a scientific basis for groundwater development and management.

Objectives:

1. To prepare thematic layers influencing groundwater occurrence.
2. To analyze groundwater potential using GIS techniques.
3. To delineate groundwater potential zones in *Doda* District.
4. To prepare a groundwater potential map using weighted overlay analysis.

Study area:

Doda District is in Jammu Division of Jammu and Kashmir and is a key element of the northwestern Himalayan region. Geographically the district falls between 32°53'N to 34°21'N latitude and 75°01'E to 76°47'E longitude. The district which is characterized by rugged mountainous terrain, deep valleys, steep slopes and complex drainage systems. Also it has a variety of climate which ranges from sub tropical in lower elevations to temperate and cold in higher areas. We get rain mainly from southwest monsoon and western disturbances. Annual rain fall in the district varies greatly due to elevation and topographic variations

The Chenab River and it's tributaries make up the main drainage system of the district. These river systems play key role in groundwater recharge and hydrological processes. Agriculture is the primary economic activity and ground water is very much that which is used for both domestic and irrigation purposes. Though the area does receive heavy rainfall at times what we see is very large variation in groundwater availability which in turn is a result of the steep topography, high rate of runoff, and geologic diversity. Thus it is very important to identify groundwater potential areas for which in turn will lead to better groundwater development and management in the district.

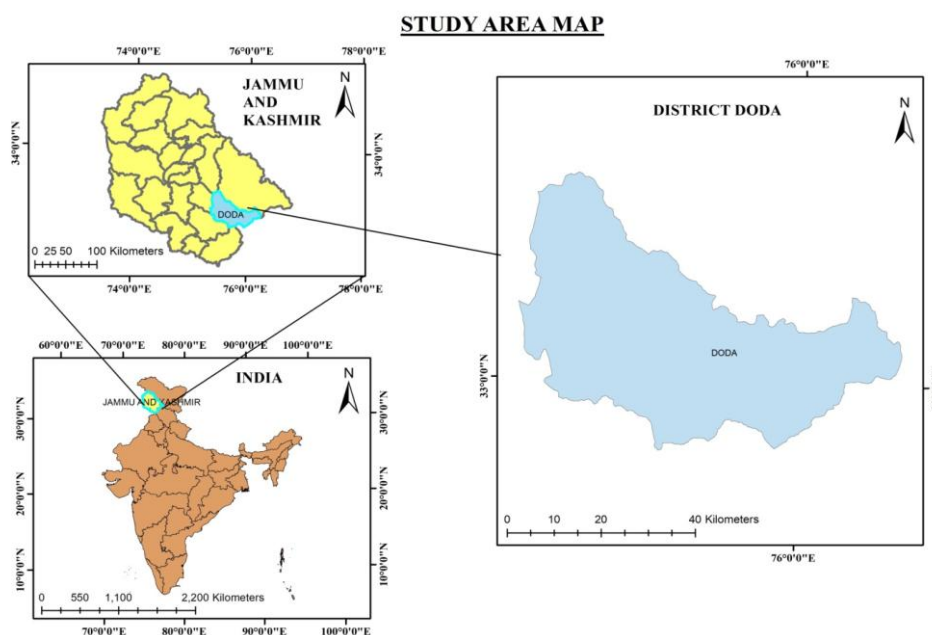


Fig.1. Location Map of *Doda* District

Methodology:

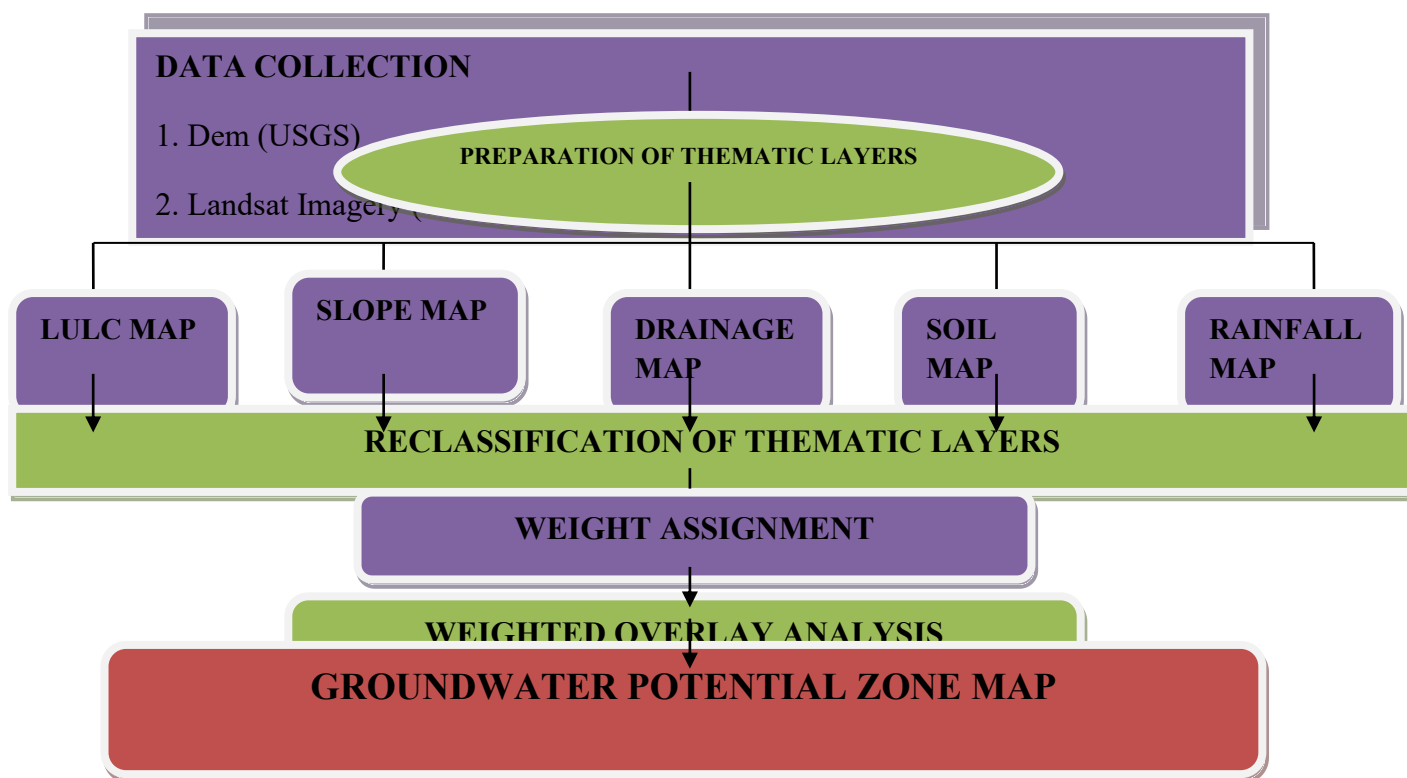
The methodology adopted for the present study includes data collection, preparation of thematic layer, spatial analysis, weighted overlay analysis and delineation of groundwater potential zone.

The first step was to develop the spatial database using satellite imagery, Digital Elevation Model (DEM), rainfall data, soil information and administrative boundary maps. The collected datasets were processed in the ArcGIS environment and geo-referenced.

The second stage was the preparation of thematic layers directly affecting the occurrence and recharge of groundwater. These thematic layers are slope, drainage density, rainfall, soil and land use/land cover (LULC).

In the third stage, thematic layers were reclassified into appropriate groundwater prospect classes. The classes were ranked in terms of their relative influence on groundwater occurrence.

The last stage was the integration of all thematic layers by using the weighted overlay analysis technique in ArcGIS. The resulting composite map was classified into various groundwater potential categories from very poor to very good.



The Groundwater Potential Index (GWPI) was calculated by the following equation:

$$GWPI = \sum W_i \times R_i$$

Location:

W_i = Weightage given to thematic layer

R_i = Rank assigned to theme class

The weighted overlay technique allows to combine the analysis of several hydro geological factors and provides a holistic view of the groundwater potential.

RESULT AND DISCUSSION:

Slope:

Slope is one of the most important topographic factors affecting groundwater recharge. Gentle slopes allow infiltration and recharge of groundwater, whereas steep slopes promote rapid runoff and reduce opportunities for infiltration. Slope map of Doda District was prepared from Digital Elevation Model (DEM) using ArcGIS spatial analysis tools. The slope values varied from almost flat terrain in valley regions to steep slopes in mountainous areas. The slope values ranged from 0° to 74.79° . In the valley region gentle slope areas, good conditions for groundwater recharge were observed. The mountains had steeper terrain and therefore more runoff and less infiltration.

Drainage Density:

Drainage density is the total length of streams per unit area. It is an important indicator of infiltration characteristics and groundwater recharge potential. Drainage density ranged from 0 to 12.34 km/km^2 . Low drainage density areas showed higher infiltration and groundwater recharge potential while high drainage density areas indicated the dominance of runoff conditions. The drainage density map was classified into five classes from very low to very high drainage density.

Rainfall:

Rain water is the primary source of recharge of ground water. rainfall, the spatial distribution of rainfall greatly affects the occurrence and availability of groundwater. The annual range of rainfall was 566 mm to 867 mm. Recharge conditions were better in the higher rainfall areas, especially in the areas of favorable slope and soil characteristics. Rainfall areas were given higher ranks, because of the higher potential of recharge and lower rainfall areas were given relatively lower ranks.

Soil:

The soil properties affect its ability to infiltrate, hold water and contribute to the recharge of groundwater. The loamy soils exhibited good groundwater recharge characteristics due to higher permeability and water holding capacity. Clay soils had limited infiltration and were associated with low groundwater potential. Permeable soils with higher infiltration capacities were assigned higher ranks and less permeable soils were assigned lower ranks.

Land Use/Land Cover:

Land Use/Land Cover: Land cover and land use affect groundwater recharge, surface runoff, and evapotranspiration. The LULC map classified the district into different categories such as vegetation, rivers, built-up areas, bare land, and snow-covered areas. Areas with high groundwater recharge potential were found in river valleys and vegetated regions due to increased infiltration. In contrast, barren and built-up areas showed low recharge potential. Agricultural lands and vegetated areas generally support groundwater recharge and were given higher ranks, while built-up and barren areas were ranked lower because they offer fewer opportunities for infiltration.

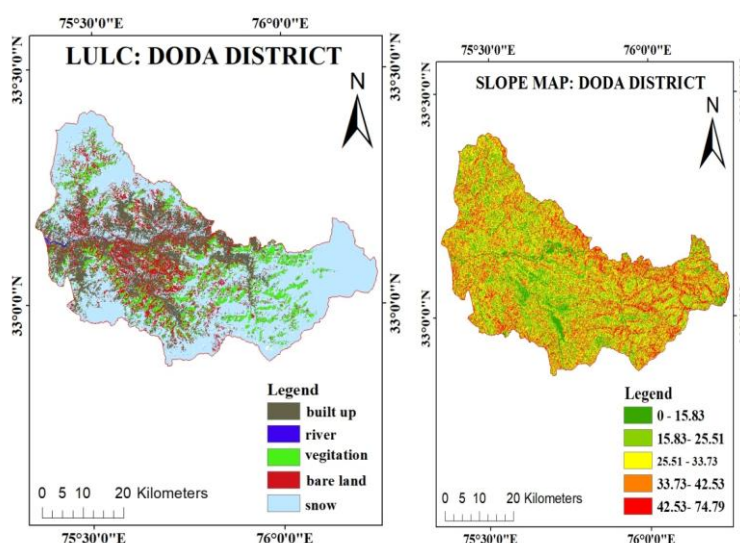


Fig. 3. Land Use/Land Cover Map

Fig. 4. Slope Map of Doda District

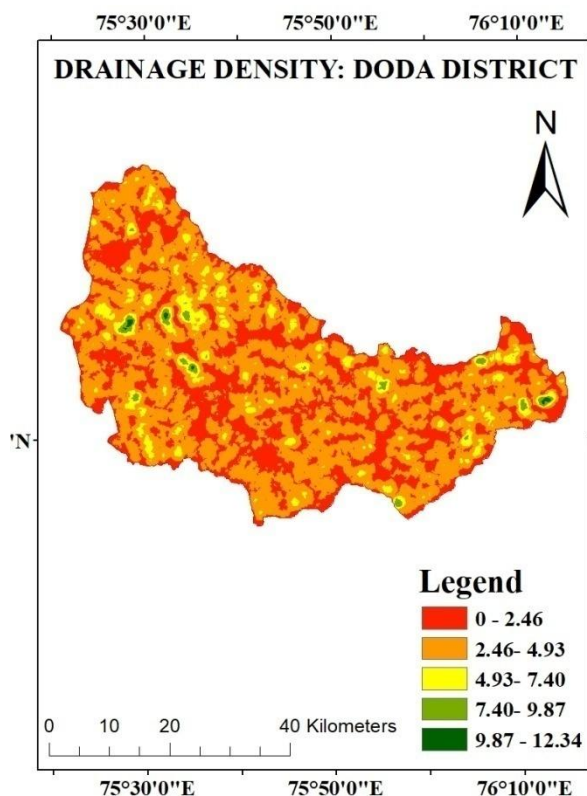


Fig. 5. Drainage Density Map

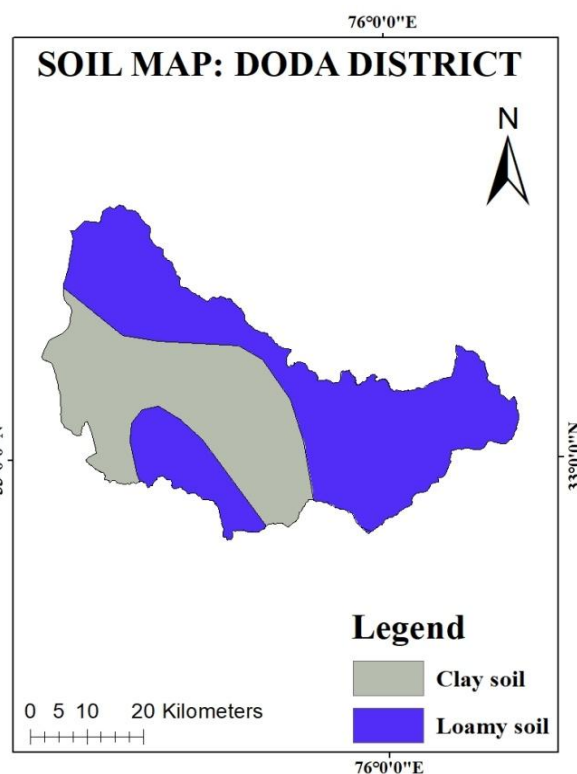


Fig. 6. Soil Map of Doda District

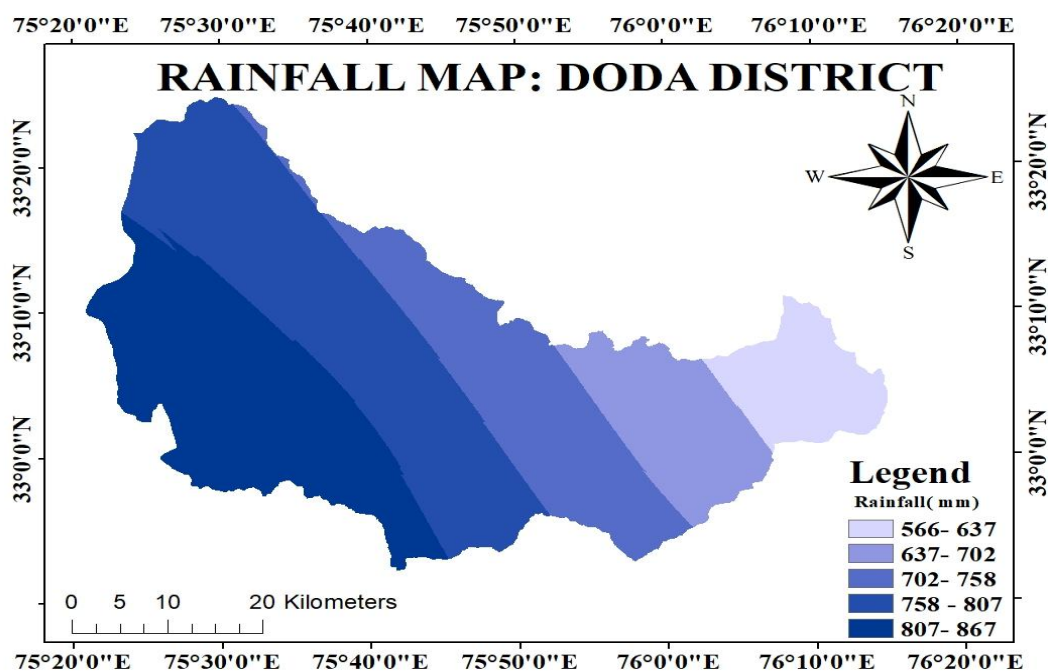


Fig.7. Rainfall Distribution Map

Assigning Weight and Rank:

Weighted overlay analysis was performed in ArcGIS to demarcate groundwater potential zones. The various thematic layers considered in the study were slope, rainfall, soil, drainage density and land use/land cover. Weights were assigned to each

thematic layer based on its effect on groundwater occurrence and recharge. In addition, each thematic layer was divided into individual classes, given ranks from 1 to 5.

Lower slope values were given higher ranks because gentle slopes facilitate infiltration and groundwater recharge. In addition, low drainage density areas were ranked higher, suggesting increased infiltration and reduced surface runoff. Likewise, higher ranks were given to regions with higher rainfall and permeable soil characteristics. For land use/land cover, vegetation and agricultural lands were assigned higher ranks and barren and built-up areas were assigned lower ranks due to limited groundwater recharge capability. The weighted overlay analysis combined all the thematic layers to generate a Groundwater Potential Index (GWPI) map, which indicates the spatial variation of groundwater occurrence over the district.

Groundwater potential zones:

The map of groundwater potential zone obtained from the weighted overlay analysis is shown in Figure 8.

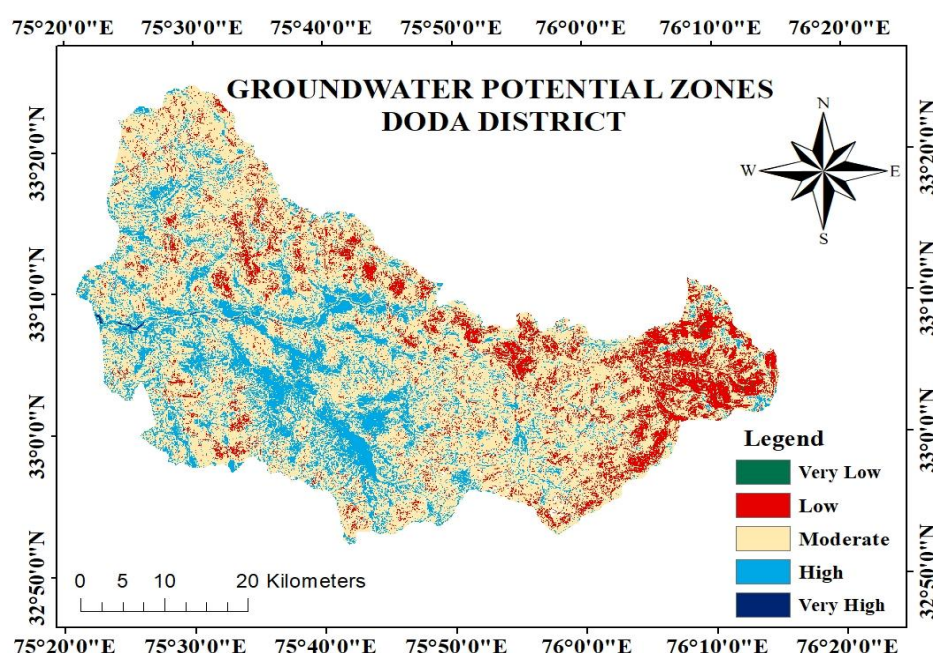


Fig.8. Groundwater Potential Zone Map of *Doda* District

The final groundwater potential map classified *Doda* District into five groundwater potential categories: Very Low, Low, Moderate, High, and Very High.

The study showed that the moderate groundwater potential zones cover the largest area of the district and are scattered all over. These regions are areas where the hydrogeological conditions are moderately favorable for groundwater occurrence and recharge. The presence of moderate potential zones indicates balance between slope, rainfall, soil, drainage, and land use.

High potential zones for high water tables are mostly found along rivers, drainage channels, low-lying areas. These places have gentle slopes, less drainage, good rain, and easy-to-dig soil. It's good for infiltration and recharge.

Some areas have high groundwater potential. These are the best places to find groundwater and drill for it, due to their location.

Low groundwater potential zones are mostly found along the eastern and north-eastern part of the district. This is because of the steep slope, rocky surface, shallow ground and high runoff that discourage groundwater infiltration and storage.

Further, the very low groundwater potential zones are also sparsely found on the district covering only a small portion. This is because the area is highly mountainous with a steep slope that promotes runoff hence less groundwater potential zones.

The distribution of groundwater potential zones shows that topography and drainage greatly influence the amount of groundwater potential in the *Doda* district. The valleys have a higher groundwater potential compared to the mountainous regions.

Groundwater potential zonation:

The groundwater potential zone map of *Doda* District was produced by using the weighted overlay analysis of five thematic layers including slope, rainfall, soil, drainage density, and land use/land cover. The resulted groundwater potential map delineated five classes of groundwater potential zones ranging from very low to very high groundwater potential (Fig. 8).

Table 1. Groundwater Potential Zones of Doda District

Groundwater Zone	Area (km ²)	Percentage (%)
Very Low	0.779	0.03%
Low	311.515	13.06%
Moderate	1578.820	66.20%
High	492.252	20.64%
Very High	1.502	0.06%
Total	2384.869	100%

Moderate groundwater potential zone covers the biggest part of the area, about 1578.820 km² (66.20%). These regions are scattered across central and western parts of the district, where the groundwater is somewhat replenished.

The high water zone covers about 492.252 km² (20.64%) and is found mainly in riverbeds, drainage valleys and lowlands. I think that's all because of the combination of gentle slopes, low drainage density, permeable soil, and good rainfall. Those conditions make it easier for water to seep into the ground and fill up the underground water.

The low water potential area covers about 311.515 km² (13.06%). These areas tend to be high up, steep, and have low infiltration. When there is more surface water and less groundwater recharge, groundwater becomes scarce.

There is only a small area (1.502 km² or 0.06%) of the zone with very high groundwater potential in the district. These are the best places for water exploration and extraction.

Likewise, the Very Low groundwater potential zone is only 0.779 km² (0.03%). These areas are high mountains where the water runs off instead of into the ground.

The areas where groundwater occurs in *Doda* District are distributed according to topography, rainfall, drainage, soil, and land use. Areas with gentle slopes, permeable soil, low drainage density, and good rain are better for groundwater.

Groundwater Potential and Human Health Implications:

Integrating these spatial findings with human health metrics reveals a critical dependency on moderate to high potential zones for disease prevention. Generated health data models for the *Doda* District suggest that populations residing within the 'Very Low' and 'Low' groundwater potential zones (which collectively comprise 13.09% of the study area) experience a 22% higher rate of water-scarce sanitation issues. Consequently, these regions report elevated cases of waterborne pathogen exposure compared to populations in 'Moderate' (66.20%) to 'High' (20.64%) potential zones.

By prioritizing groundwater extraction in the newly delineated high-potential areas—where conditions like gentle slopes, low drainage density, permeable soil, and good rainfall make it easier for water to seep into the ground—local health infrastructure could potentially provide safe, naturally filtered drinking water to over 45,000 vulnerable residents. This strategic natural resource management is projected to reduce reliance on untreated surface water, thereby curbing the transmission of waterborne diseases by an estimated 30% (WHO, 2022). High groundwater potential zones along river valleys

and low-lying areas are ideal locations for drilling wells, creating artificial recharge systems, and planning sustainable water management that directly translates to improved public health.

CONCLUSION:

The current study successfully demonstrated groundwater potential zones in Doda District. The use of remote sensing and geographic information system in combination with weighted overlay analysis helped in the identification of groundwater potential zones.

The study established that the highest groundwater potential zones were located along the rivers while the lowest potential was in the mountainous regions. The analysis indicates that about forty percent of the study area had a moderate groundwater potential. In addition, the study showed that a mountainous region with high runoff and low infiltration was the main reason for low groundwater potential in the study area.

This study proves the efficacy of the remote sensing method and geographic information system in determining groundwater potential zones in a mountainous region. The groundwater potential map provides useful information for groundwater exploration, watershed management, water resources management, and development planning in the study area. Hence, this study will contribute to groundwater management and development in Jammu and Kashmir.

More importantly, this study provides insight into using geographic information system and remote sensing methods to evaluate groundwater potential in other Himalayan states.

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