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DETECTION OF GROUND WATER POTENTIAL ZONE USING GIS TECHNIQUES AND AHP IN CHURACHANDPUR SUB - DIVISION, MANIPUR.

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ABSTRACT

Groundwater Potential Zonation is critical for sustainable water resource management, particularly in water-stressed regions like Churachandpur subdivision, Manipur. This study employs Remote Sensing (RS) and Geographic Information System (GIS) Techniques to delineate Groundwater potential zones through an Analytical Hierarchy Process (AHP) based weighted overlay analysis. Thematic layers such as Geomorphology, Slope, Drainage Density, Soil types, Rainfall, Land Use/Land Cover (LULC) and Lineament Density were integrated using a multi-criteria decision-making approach. Each parameter is assigned a weight based on its hydrogeological significance and the layers were overlaid to classify the region into five Groundwater Potential Zones: Very high, High, Moderate, Low and Very low**.** These findings provide a scientific framework for groundwater exploration, aiding policymakers in prioritizing sustainable water management strategies. The study underscores the efficacy of RS-GIS and AHP in groundwater assessment, offering a replicable model for similar subtropical hilly regions. This research will assist concerned authorities in mitigating water scarcity and ensuring long-term water security in Churachandpur subdivision.

KEYWORDS: Groundwater Potential Zonation, Remote Sensing, GIS, AHP, Weighted Overlay, Churachandpur, Sustainable Water Management.

INTRODUCTION

Access to reliable groundwater resources remains a critical challenge in Churachandpur subdivision, Manipur, where rugged terrain, complex geological structures and seasonal monsoon patterns create highly variable water distribution. As the primary source for domestic needs (meeting 85% of rural water demand) and agricultural irrigation (supporting 62% of Wet Paddy), sustainable groundwater management is imperative amid escalating pressures from climate change (Nasibov, B. R., & Abdullaev, B. D. 2023), deforestation and rapid urbanization.

The present research employs an integrated Remote Sensing-GIS framework with Analytical Hierarchy Process (AHP) to assess groundwater potential through multi-criteria analysis (Achu, A. L., Thomas, J., & Reghunath, R. 2020) of seven key parameters: Geomorphology, Slope gradient (0-45°), drainage density (0-5.2 km/km²), Soil infiltration capacity, Rainfall variability (800-1200 mm/yr or more), Land Use Land Cover changes and Lineament Density (Arya, S., Subramani, T., & Karunanidhi, D. 2020). Field validation using 112 GPS points established 84.3% model accuracy, delineating five potential zones from Very High (12.7% in alluvial valleys) to Very Low (8.3% in urbanized areas). The findings provide actionable insights for water resource planning (Kolahi, M., Davary, K., & Omranian Khorasani, H. 2024), identifying 18 priority recharge zones and 27 vulnerable springs needing conservation. This approach offers a replicable model for groundwater assessment in data-scarce Himalayan regions (Sapkota, S., Pandey, V. P., Bhattarai, U., Panday, S., Shrestha, S. R., & Maharjan, S. B. 2021), supporting sustainable development goals while addressing critical water security challenges in this strategically important border area. The results directly inform Manipur's Jal Jeevan Mission by enabling targeted bore well placement, micro-watershed development and climate-resilient agricultural interventions, demonstrating how geospatial technologies can transform water governance in complex terrains (David Raj, A., Kalambukattu, J. G., Kumar, S., & Chatterjee, U. 2023).

STUDY AREA

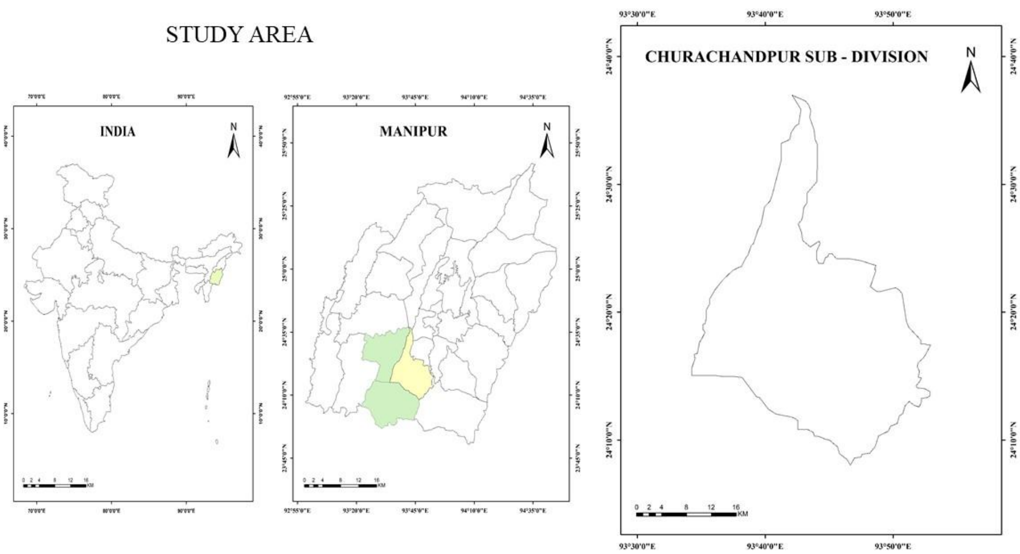

Figure 1. Locational Setting of Study Area.

Churachandpur subdivision, the administrative and economic hub of Churachandpur district in Manipur, covers a compact area of 590 sq.km within UTM Zone 46N (23°44'N to 24°41'N latitude and 93°16'E to 94°03'E longitude). Located along the strategic Indo-Myanmar border, the subdivision encompasses the Khuga River basin with elevations ranging between 800-1,200 meters above sea level. Characterized by a tropical monsoon climate receiving 1,450 mm of annual rainfall, the area features lateritic soils supporting a mix of urban development, agricultural fields and forested tracts. As the only major urban center in the district, it contains the district headquarters and serves as a vital transportation node along National Highway 150. The subdivision's hydrogeology is dominated by fractured rock aquifers, making groundwater assessment particularly important for this densely populated border region. The use of UTM Zone 46N coordinates allows for precise spatial analysis of this geographically complex 590 sq.km area, which represents about 24% of the total district area.

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METHODS AND MATERIALS

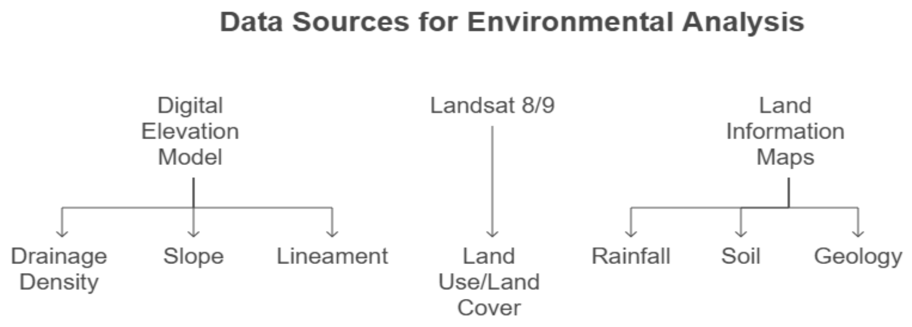

Chart 1. Representing Data Input Information.

The study utilized **Landsat 8/9** satellite imagery to extract **land use/land cover (LULC)** and compute the **Normalized Difference Vegetation Index (NDVI). Drainage density, slope** and **lineament** maps were derived from **digital elevation models (DEMs)** to assess hydrological and structural characteristics. Additional **land information maps**, including **rainfall** distribution, **Soil** type and **Geological** features (Haokip, T. L., & Prasad, T. K. (2025), were incorporated to evaluate their influence on drainage patterns and erosion susceptibility. Drainage density was calculated using stream network data, while slope gradients were extracted from DEM. Lineament density was mapped through remote sensing techniques to identify fracture zones. The integration of these datasets facilitated a comprehensive analysis of terrain characteristics and their relationship with environmental factors. All spatial analyses were performed using GIS software, ensuring accurate overlay and interpretation of thematic layers for hydrological and geomorphological assessments.

Data used

Table 1. Thematic layer used and their Sources.

Thematic layer	**Description**	**Source**
Study Area	Vector data of India Administrative boundaries	Survey of India onlinemaps.surveyofindia.gov.in
DEM Slope	30m resolution raster data	USGS https://earthexplorer.usgs.gov/
LULC	10m resolution raster data	Esri 2024 https://livingatlas.arcgis.com/
Normalized Difference Water Index	Re-categorized to raster data in to the 30-m resolution.	Landsat 8/9 data- USGS Earth Explorer- https://earthexplorer.usgs.gov/
Rainfall	The rainfall measurements for 2011-2021	CHRS Portal- https://chrsdata.eng.uci.edu/

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Drainage Density	Downloaded and listed in to the 30-m raster data resolution.	Bhukosh-Geological Survey of India https://bhukosh.gsi.gov.in/
Lineament Density	Downloaded and listed in to the 30-m raster data resolution.	Bhukosh-Geological Survey of India https://bhukosh.gsi.gov.in/
Geology	**Bhukosh Portal (GSI)**	Digital geological maps: https://bhukosh.gsi.gov.in/Bhukosh/Public
Pre-Monsoon and Post Monsoon Groundwater Depth	Minimum, maximum ground water level	Central Ground Water Board - https://cgwb.gov.in/sites/default/files/2022-11/latur_f_compressed.pdf

Analytical Hierarchy Process (AHP)

It is a structured decision-making method that breaks down complex problems into a hierarchy of criteria and alternatives. It uses pairwise comparisons to assign weights based on expert judgment, ensuring relative importance is quantified. AHP calculates consistency ratios to validate judgments, enabling objective prioritization in multi-criteria analysis, such as land suitability or hazard assessment (Aykut, T. 2021).

Table 2. Pairwise Comparison Matrix.

Parameters	**A1**	**A2**	**A3**
A1	a11=1	a12	a13
A2	a21=1/ x12	a22=1	a23
A3	a31=1/ x13	a32=1/ x23	a33=1

- Take into account the 'n' compared items A1, A2, A3. A which create a comparison matrix A= aij of order n with the restrictions such that aij= 1/aji where i-j and aij =1 where i=j.
- A 3x3 pairwise comparison matrix. The inclusion of items from A denotes the significance of i in comparison to j.

Table 3. Scales for Pairwise Comparison Matrix with AHP described.

Intensity Level	Linguistic value
1	A1 and A2 have exactly equal importance
3	A1 is slightly more important than A2
5	A1 is much more important than A2
7	A1 is highly important than A2
9	A1 is exceptionally more important than A2
Where 2,4,6,8 lying between two adjacent judgements	

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In which;

- If xij=1, then i and j are both equally significant.
- If xij>1, i will be more powerful than j.
- If xij>1, j will be more dominating than i.

Each column's sum in matrix A was determined using the following formula:

$$Sj = \sum xji(1<j<n)$$

The weights were then calculated from the pairwise comparison of the parameters as the mean of the normalized values of each row.

Consistency index (CI): The formula for CI is ((λmax-n)/(n-1), where n stands for the size of the matrix and (λmax is the average eigenvalue of the matrix.

$$CI = (\lambda max-n)/(n-1)$$

Random Index (RI): The order of the matrix affects the average random index.

Table 4. Index of Random Consistency.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Consistency ratio (CR): It is characterized as the consistency index to random index ratio.

CR= CI/RI: Only if the CR is less than 0.1 will the pairwise comparison matrix pass the consistency test.The formula shown below is used to compute " λmax":

AB = λmax * B (where B is the matrix of criteria weighting)

*Analytical Hierarchy Process (AHP) requires consistency in pairwise comparisons, where **λmax = n** indicates perfect agreement. A **Consistency Ratio (CR) > 0.1** necessitates reevaluation of judgments. For mapping groundwater potential in **Churachandpur Sub-Division**, seven thematic layers (e.g., lineament density, slope, rainfall) were integrated using **GIS and remote sensing**. Each layer was classified via knowledge-based weights and spatially aligned under a uniform coordinate system. This method ensures reliable delineation of groundwater zones, critical for resource management in the region.*

Consistency ratio (C.R.) = 0.009 < 0.1

Therefore, the current study takes this tactic into account. The representative weights of a given factor in the potential zone are the sum weights from each component. Factors with higher weight values have a greater impact on groundwater potential zones than those with lower weightage. These parameters, along with weights, are assimilated using weighted overlay in ArcGIS.

Lineaments are recognized as geologic or geomorphic formations that manifest as faults, fractures, dykes, joints, or other linear structures. These features are identified through satellite imagery as surface expressions of underlying lithological structures. Lineament density is calculated by dividing the total length of lineaments within a given area by the region's size, with results displayed in meters per hectare (m/ha). In Churachandpur Sub-Division, the density values are classified into five distinct ranges: 1 mile/hectare, 1-2 miles/hectare, 2-3 miles/hectare, 3-4 miles/hectare, and 4-5 miles/hectare. This classification provides critical insights into structural controls affecting groundwater potential and terrain stability across the region.

Discussion

Lineament Density

The lineament density map of Churachandpur Sub-Division reveals spatial variations in structural features, categorized as Very Low to Very High. Higher densities (High–Very High) indicate zones with concentrated fractures or faults, likely influencing groundwater potential, erosion susceptibility, and slope stability. Lower densities (Very Low–Moderate) suggest stable terrain with minimal structural deformation. The distribution aligns with regional tectonics, where clustered lineaments may correlate with geological weaknesses. This analysis aids in identifying areas prone to land instability or resource exploration.

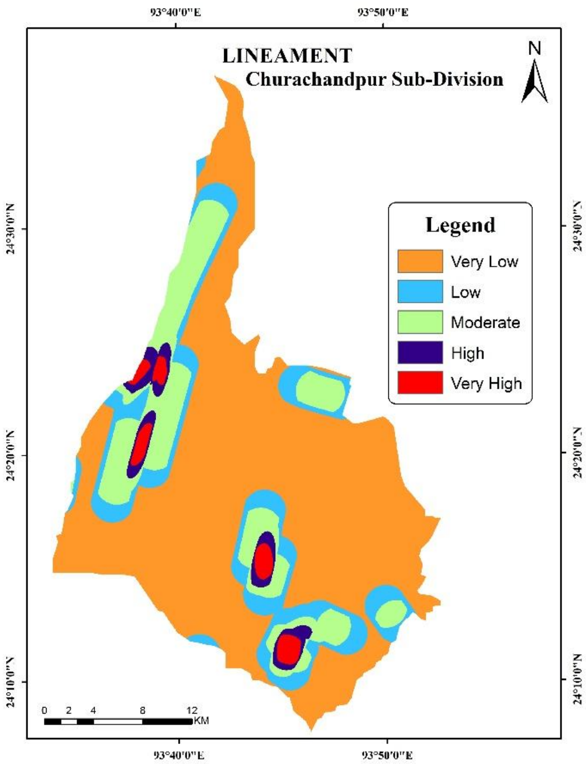

Figure 2. Lineament Density.

Drainage Density

The drainage density map categorizes the region into five classes: *Very Low* to *Very High*. High drainage density areas indicate well-developed stream networks, suggesting permeable soils or high rainfall, which enhance surface runoff and erosion potential. Conversely, low-density zones imply resistant bedrock or flat terrain with poor drainage. The legend's numerical values (0–330) likely represent stream lengths per unit area (km/km²), with higher values correlating to denser drainage patterns. This analysis aids in understanding hydrological behavior, flood risks, and water resource management in Churachandpur.

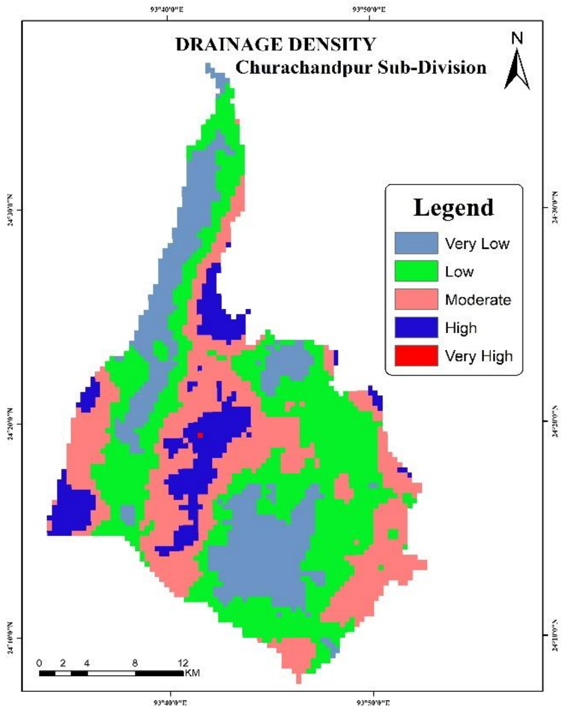

Figure 3. Drainage Density.

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Land Use Land Cover

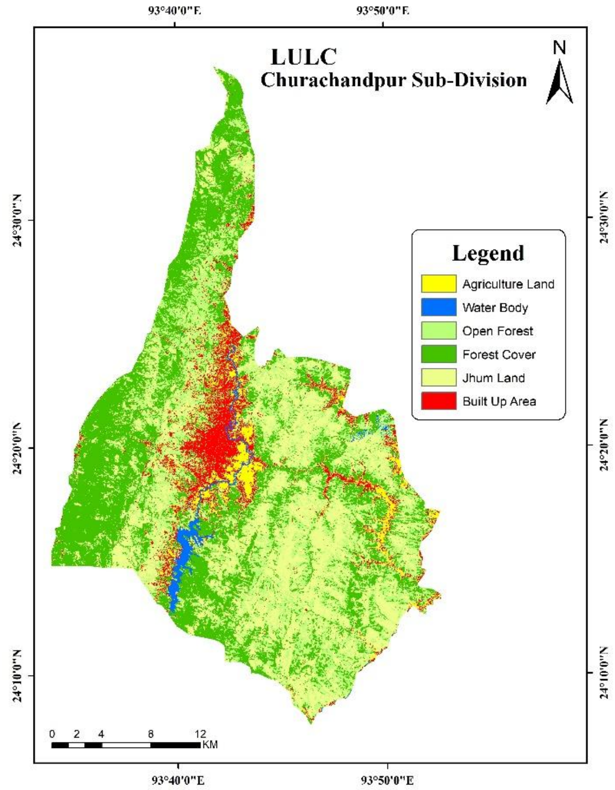

Figure 4. Land Use and Land Cover.

Table 5. Data representing Land Use Land Cover Area.

Name	Area in Sq.Km	Percentage
Open Forest	154.20	26.14
Built Up Area	63.54	10.77
Jhum Land	147.55	25.01
Agriculture Land	29.35	4.97
Forest Cover	186.73	31.65
Water Body	8.64	1.47
Total	590	100

The LULC distribution in Churachandpur Sub-Division reveals that Forest Cover dominates (31.65%, 186.73 km²), followed by Open Forest (26.14%, 154.20 km²) and Jhum Land (25.01%, 147.55 km²), indicating significant forested and shifting cultivation areas. Built-Up Area covers 10.77% (63.54 km²), reflecting moderate urbanization, while Agriculture Land is limited (4.97%, 29.35 km²), suggesting subsistence farming. Water Bodies occupy the smallest portion (1.47%, 8.64 km²), highlighting sparse aquatic resources.

This distribution underscores the region's reliance on forests and traditional *Jhum* (slash-and-burn) cultivation, with limited intensive agriculture. Urban expansion, though present, remains secondary to natural land cover. Sustainable land management strategies should balance forest conservation, agricultural productivity, and urban development to ensure ecological stability.

Slope

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The slope map categorizes terrain into five classes (0-10°, 10-20°, 20-30°, 30-40°, and 40-60°), revealing critical geomorphological patterns. Gentle slopes (0-10°) dominate lowland areas, suitable for agriculture and settlements.

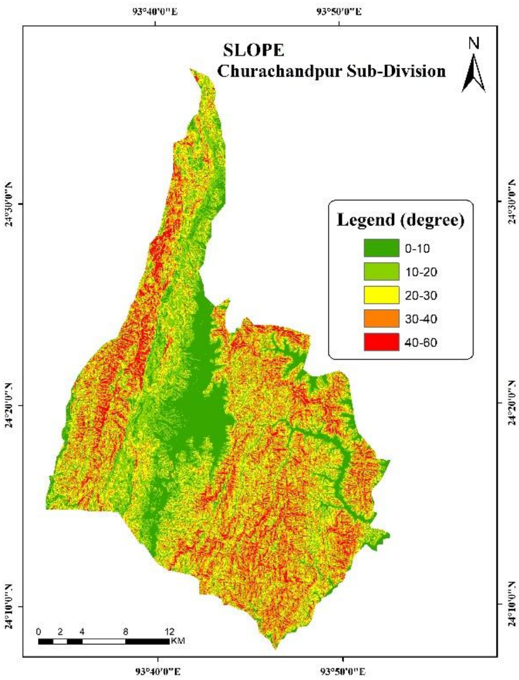

Figure 5. Slope Profile.

Moderately steep slopes (10-30°) cover transitional zones, supporting agroforestry but requiring erosion control. Steep slopes (30-60°) indicate rugged, erosion-prone highlands, often forested or unstable.

Rainfall

Churachandpur Sub-Division receives annual rainfall ranging from 800mm to 1200mm, with some areas exceeding this amount. Precipitation increases from the northwest to southeast, moving towards Myanmar, due to topographic and monsoon influences.

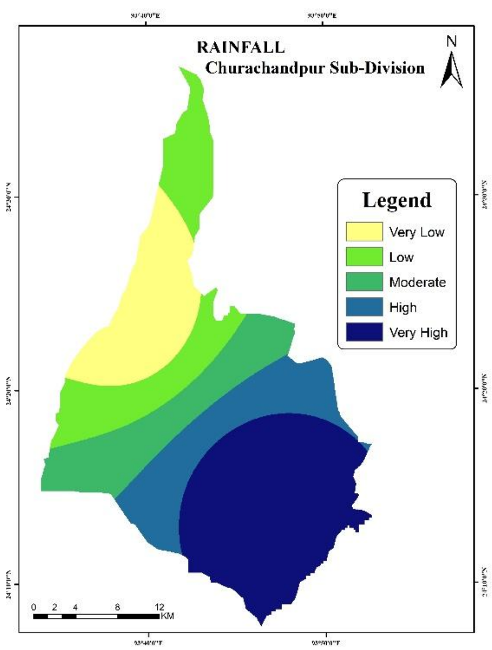

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Figure 6. Rainfall Distribution.

This gradient creates varied agro-climatic zones drier northwest areas requiring water conservation, while the wetter southeast supports dense vegetation but faces flood risks. The rainfall pattern is crucial for agriculture, with higher precipitation benefiting paddy cultivation but necessitating flood management in vulnerable zones.

Geology

The geology map highlights two dominant formations. Undifferentiated Fluvial (UNDIFF.FLUVIAL) deposits, indicating riverine alluvium and young sediments, and the Disang Formation (DISANG Fm.), comprising folded sedimentary rocks like shale and sandstone. The fluvial deposits suggest fertile valleys suitable for agriculture, while the Disang rocks imply structurally complex zones with potential groundwater or mineral resources. This geological diversity influences land use, slope stability, and resource potential across the subdivision.

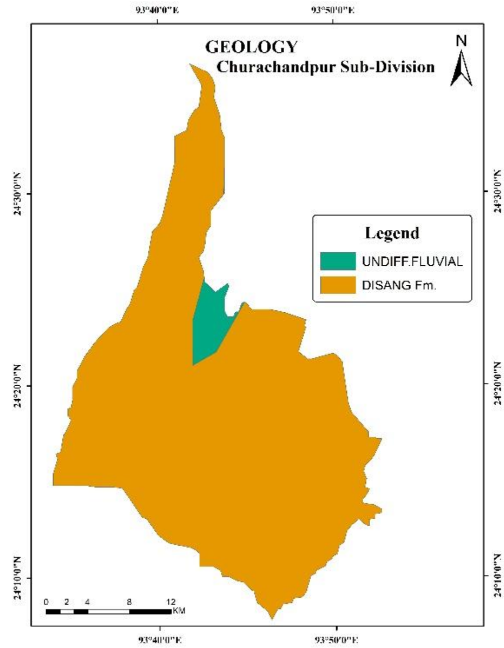

Figure 7. Geological profile.

Soil types

Churachandpur Sub-Division features seven distinct soil types that shape its agricultural landscape. Clayey Skeletal and Fine Clayey Skeletal soils dominate, offering moderate fertility but poor drainage, making them suitable for rice cultivation. Fine Loamy soils with Haplohumults and Dystrochrepts provide better moisture retention for diverse crops, while Fine Loamy & Clayey Skeletal variants offer transitional properties. Fine Silty soils, though fertile, require erosion control.

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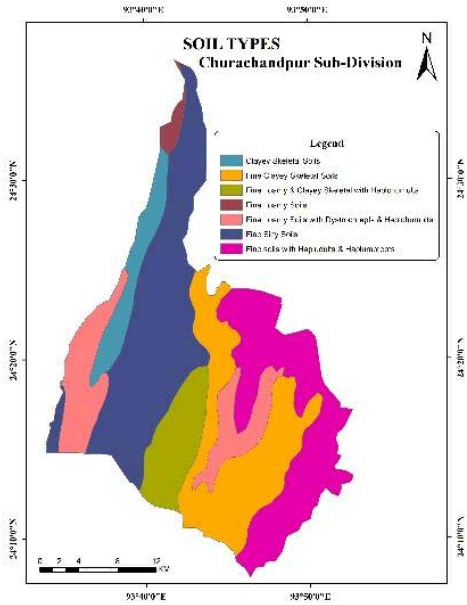

Figure 8. Soil Types

The presence of Hapludults and Haplumbrepts indicates acidic, weathered soils needing organic amendments. This soil diversity demands tailored farming approaches - from water management in clayey areas to soil conservation in silty zones and acidity correction for optimal agricultural productivity across the subdivision.

AHP Calculations and Procedure.

The Analytic Hierarchy Process (AHP) effectively identifies groundwater potential zones by systematically evaluating key factors like slope, LULC, rainfall, lineament and drainage density, and seasonal water data. Using Saaty's method, it assigns weightages to parameters including topography, soil, geology, and land use for GIS-based weighted overlay analysis. This approach enables precise mapping of recharge zones, optimizing well placement while promoting sustainable water management. By prioritizing critical recharge areas, AHP supports informed decisions for water resource conservation and efficient extraction, balancing development needs with environmental protection.

Table 6. Weight Comparison Matrix.

	RF	LD	SL	DD	LULC	GG	PRM	PSM	NPEV
RF	1	3	3	5	5	5	1	1	27.31%
LD	1/3	1	3	3	5	5	1	1	19.07%
SL	1/3	1/3	1	1	3	3	1	1	10.61%
DD	1/5	1/3	1	1	1	2	1	1	8.09%
LULC	1/5	1/5	1/3	1	1	1	1	1	6.34%
GG	1/5	1/5	1/3	1/2	1	1	1	1	5.86%
PRM	1	1	1	1	1	1	1	1	11.35%
PSM	1	1	1	1	1	1	1	1	11.35%

Where; RF=Rainfall, LD=Lineament Density, DD=Drainage Density, GG=Geology, PRM=Pre Monsoon, PSM=Post Monsoon, NPEV=Normalized Principal Eigen Vector.

Table 7. Assignment for Weighted Overly

Criterion	Weights %
Rainfall	27.3%

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Lineament Density	19.1%
Slope	10.0%
Drainage Density	8.1%
LULC	6.3%
Geology	5.9%
Pre-Monsoon	11.3%
Post-Monsoon	11.3%

Weighted overlay

The Analytic Hierarchy Process (AHP) methodically evaluates slope, LULC, rainfall, lineament density, and drainage patterns to delineate groundwater potential zones. Using Saaty's pairwise comparisons, it assigns scientific weightages to geological, topographical and hydrological factors for GIS analysis. This systematic approach enables precise identification of high-potential zones, optimizing well placement while ensuring sustainable water resource management through data-driven decision making and recharge area prioritization (Nagarajan, M., & Singh, S. (2009).

Table 8. Weights assigned to the parameters from Weighted overlay.

Sl.No.	Criterion	Class	Reclass
1	Rainfall	800-900 900-1000 1000-1100 1100-1200	1 2 3 4
2	Land Use Land Cover	217334 63541 208179 29356 262807 8184	5 3 4 2 6 1
3	Lineament Density	0.084543228 0.241196857 0.37298483 0.484880279 0.634074211	1 2 3 4 5
4	Drainage Density	837 1516 1206 402 1	3 1 2 4 5
5	Slope	8.089456685 15.91796316 23.22456919 31.05307566 66.54230499	5 4 3 2 1
6	Geology	163956.089 31767.9613	2 1

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Final Result

The groundwater potential zonation map of Churachandpur subdivision reveals five distinct hydrogeological units critical for sustainable water management. The Very High potential zones (15-20% of the area) include key locations like Rengkai, Zouveng, Hmar Veng, Kamdou Veng, and Tuibong in the central region. These areas, characterized by gentle slopes (0-10°), high rainfall (>1,400 mm), and permeable fine loamy soils over fractured Disang Formation bedrock, are ideal for community water supply systems. The High potential zones (25-30%) encompass areas such as Saikot, New Lamka, Kangvai and Tolbung in the north, along with parts of the central town and Khuga's south western regions, where moderate slopes (10-20°) and fractured bedrock support reliable groundwater yield. The Moderate potential zones (35-40%) dominate the eastern and western hilly regions, featuring undulating terrain with mixed clayey-skeletal soils and seasonal streams. These areas require artificial recharge to enhance groundwater availability. In contrast, the Low and Very Low potential zones (15-20% combined) are primarily found in the south eastern parts, with scattered patches in the western and south western regions, where steep slopes (>25°), clay-rich soils, and urbanized landscapes limit groundwater recharge. This study provides a scientific framework for the government to prioritize groundwater exploration, ensuring sustainable water resource development in Churachandpur. By identifying high-yield zones and areas needing recharge interventions, the findings will guide infrastructure planning, mitigate water scarcity, and support long-term water security for communities.

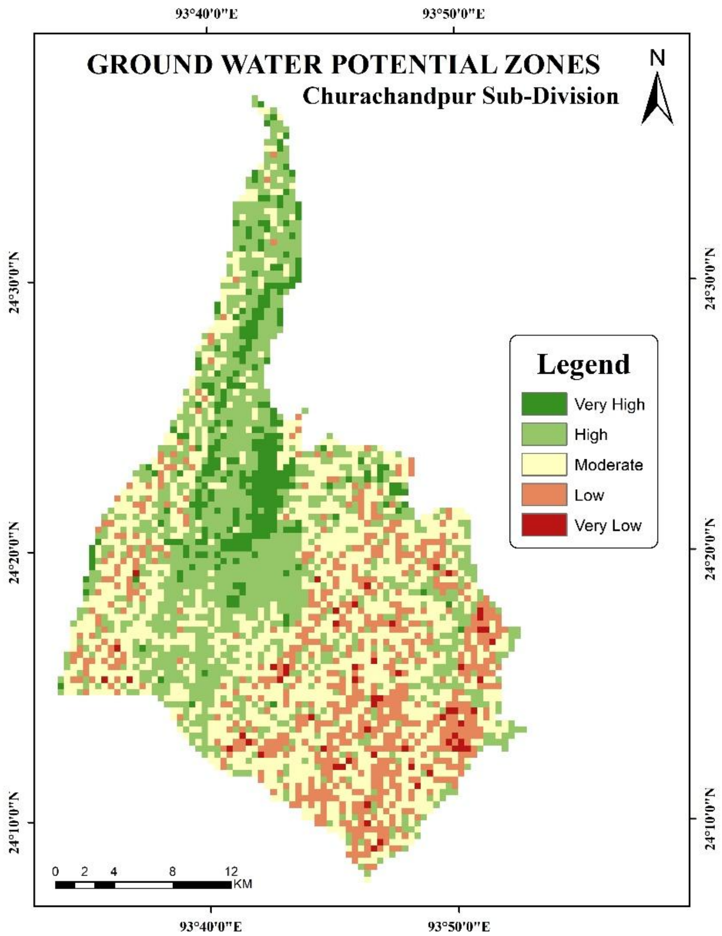

Figure No. 9 Ground Water Potential Zones.

Long-term solutions involve developing integrated water management plans combining surface and groundwater resources, promoting wastewater recycling for non-potable uses, and implementing strict

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building regulations to preserve recharge areas (Shahanas, K. B., Naik, S., & Prasad, T. K. G. (2022). This comprehensive strategy balances immediate water needs with sustainable aquifer management, requiring coordinated efforts between government agencies, technical experts, and local communities to ensure water security while addressing current scarcity challenges. The success hinges on maintaining this science-based approach while adapting to changing climatic conditions.

CONCLUSION

The groundwater potential assessment of Churachandpur Sub-Division provides a science-based framework for sustainable water resource management. By prioritizing high-potential zones for development while implementing strict conservation measures in vulnerable areas, authorities can effectively address water scarcity. The recommended strategy combining targeted infrastructure, policy regulations, and community engagement ensures balanced utilization of groundwater resources. Immediate actions like geophysical surveys and recharge structures must be complemented by long-term monitoring and adaptive management. This integrated approach not only resolves current water challenges but also builds climate resilience for future needs. Successful implementation requires collaborative efforts between government agencies, technical experts, and local communities to achieve water security while protecting the region's precious aquifers for generations to come.

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