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RESEARCH ARTICLE

Characterization and sensitivity analysis of parameters for delineating groundwater potential zones in the Phakphokthum watershed, Ilam, eastern Nepal

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ABSTRACT

Groundwater potential (GWP) mapping is an important technique for the sustainable exploitation and management of water resources. Although GWP using Multi Criteria Decision Analysis (MCDA) is commonly assessed using multiple thematic layers, the sensitivity of individual parameters to the final GWP map remains poorly evaluated. This study assesses the sensitivity of nine thematic layers including slope, geology, Normalized Difference Vegetation Index (NDVI), Topographic Position Index (TPI), aspect, hydrogeomorphology, land use/land cover (LULC), drainage density (DD), and lineament density (LD) used to delineate GWP zones in the Phakphokthum watershed, Ilam, eastern Nepal. The GWP map was generated using the Analytic Hierarchy Process (AHP) within a Geographic Information System (GIS) environment, following the derivation of criteria weights for each thematic layer and its respective subclasses. The GWP map of the area, indicated 20% area as high potential zone and 55% as low potential zone and is validated against the spring inventory using the ROC/AUC method with an accuracy of 70.3 %. Sensitivity analysis was performed using a one-parameter-removal approach, in which each parameter was systematically excluded and the AHP recalculated using the remaining parameters, yielding nine distinct scenarios. The influence of each parameter on groundwater occurrence was evaluated through validation against 85 spring locations using the receiver operating characteristic–area under curve (ROC-AUC) method, with prediction accuracies ranging from 63.1% to 73.1%. TPI and LD were identified as the most influential parameters controlling groundwater occurrence in the study area. These parameters are considered critical and are recommended for the delineation of groundwater potential zone in similar geographic settings. The findings also highlight the importance of sensitivity analysis as a complementary approach to AHP for identifying influential paramenters, evaluating model robustness, and improving the reliability of GWP maps.

Keywords: ***Groundwater potential zones, Multi-criteria Decision Analysis (MCDA), Analytic Hierarchy Process (AHP), geospatial analysis, sensitivity analysis***

INTRODUCTION

Groundwater is the most widely distributed and, in many geographic settings, the most reliable source of fresh water available to rural communities (Patra et al., 2018). This dependence is especially pronounced in the mid-hill and mountain regions of the Nepal Himalaya, where groundwater emerges principally as springs and constitutes the primary domestic water source for many rural communities (Khadka and Pathak, 2021). Unlike alluvial aquifers, mountain aquifers are governed by fracture-controlled flow through weathered and jointed bedrock (Silwal and Pathak, 2018), making their exploration both technically challenging and, at a regional scale, prohibitively expensive using conventional hydrogeological survey methods. Identifying GWP zones in advance of costly field investigation is therefore essential, and a GWP map serves precisely this purpose (Silwal et al., 2023).

Geographic Information Systems (GIS) integrated with the Analytical Hierarchy Process (AHP) have become a standard and widely applied approach for delineating groundwater potential, whereby multiple thematic layers are combined using criteria weights derived from expert pairwise comparison (Bricker et al., 2014; Ghosh et al., 2016; Pathak and Gautam, 2019; Pathak and Shrestha, 2016; Khadka and Pathak, 2021; Melese and Belay, 2021; Silwal et al., 2023). Because these weights rest on subjective expert judgement rather than direct empirical measurement, the extent to which each thematic layer actually contributes to a GWP map's predictive accuracy is not self-evident from its AHP weight alone, and is rarely tested independently (Das, 2019; Fenta et al., 2015). Sensitivity analysis therefore plays a crucial role in identifying which factors genuinely control groundwater occurrence in a given setting, complementing AHP weighting rather than simply reaffirming it (Arulbalaji et al., 2019; Pathak et al., 2021; Sapkota et al., 2021). Pathak et al. (2021) evaluated parameter sensitivity in the comparable mountainous region (Khadadevi–Manthali) of Central Nepal and identified lineament density and hydrogeomorphology as the most influential factors, validated against well and spring data using ROC/AUC analysis. Whether the same factors govern groundwater occurrence elsewhere in the Nepal Himalaya, or whether parameter importance is instead strongly site-dependent, remains an open question: Most other research relied on a narrower set of terrain parameters (geology, drainage density, lineament density, slope, land use, and precipitation) without testing their relative sensitivity at all. Given the structurally and geologically delicate nature of mountain aquifers, this gap calls for a more comprehensive, site-specific approach.

The main objective of the present study is to determine and analyse the factors influencing groundwater occurrence in the Phakphokthum watershed, on the premise that sensitive factors responsible for groundwater occurrence should be given higher priority in GWP mapping. As the study area lies within mountainous terrain, validation is carried out using measured spring data from the field (Pathak et al., 2021). This study aims to advance the methodology of mountain groundwater exploration in the Nepal Himalaya. Its significance lies in its potential to inform decision-making around water management: the resulting groundwater map can serve as an essential tool for local authorities, planners, and policymakers in managing drought and groundwater depletion and in supporting sustainable water management. It further contributes to the broader discussion of groundwater resources in the context of Ilam and offers insights applicable to similar regions across Nepal.

STUDY AREA

The study was conducted in the Phakphokthum Rural Municipality, Ilam District, Koshi Province, covering an area of approximately 100 km^2(Fig. 1). The study area is well connected by the network of national highway and local roads. The accessibility to the upper reaches of the study area is facilitated by the Mechi Highway, while the Damak-Rabi-

Phalgunanda Highway provides access to the western part of the region. The Ghurbise-Panchami Bazar serves as a central location from which a major portion of the study area can be accessed. Additionally, the Saptami and Rabi Bazaar provide access to the southwest portion, while Gajurmukhi and Mangalbare Bazar are key points for accessing the eastern and southeast areas.

Geologically, the area is underlain predominantly by metamorphic rocks comprising fine-grained dark grey to greenish-white quartz–biotite schist and coarse-grained, highly garnetiferous muscovite–biotite schist, as mapped by the Department of Mines and Geology (DMG) (2020). These lithological units exert a significant influence on groundwater occurrence by controlling weathering characteristics, secondary porosity, and fracture development.

METHODOLOGY

The groundwater potential (GWP) map was developed using a GIS-based MCDA framework integrated with the AHP. The methodology comprises six sequential steps, which includes the acquisition of spatial and field data, preparation of thematic layers contributing the occurrence of groundwater, derivation of weight of the thematic layers using AHP, generation of the GWP map using overlay analysis in GIS, sensitivity analysis using a one-factor-removal approach, and validation of the resulting maps using spring inventory data and ROC curve analysis (Fig. 2).

Data Sources and Preparation of Thematic Layers

Nine thematic layers representing the principal hydrogeological controls on groundwater occurrences were prepared within the GIS environment. These includes, hydrogeomorphology (HG), lineament density (LD), land use/land cover (LULC), slope, geology, Normalized Difference Vegetation Index (NDVI), drainage density (DD), Topographic Position Index (TPI), and aspect.

Topographic maps (Sheet Nos. 2687 04A, 2687 03D, 2787 15D, and 2687 03B) at a scale of 1:25,000 were used to generate a Digital Elevation Model (DEM). The DEM served as the basis for deriving slope, aspect, TPI, drainage density, and hillshade maps. Lineaments were manually interpreted from the hillshade images and subsequently converted into a lineament density map using spatial density analysis.

The geological map was extracted from the geological map of the Koshi Province (DMG, 2020). Hydrogeomorphological units were delineated through interpretation of terrain characteristics supported by field observations and slope analysis. Land use/land cover classes and NDVI layer were generated from satellite multispectral imagery using standard spectral band calculations.

All thematic layers were projected to a common coordinate system, rasterized, and resampled to identical spatial resolution prior to analysis to ensure compatibility during overlay operations

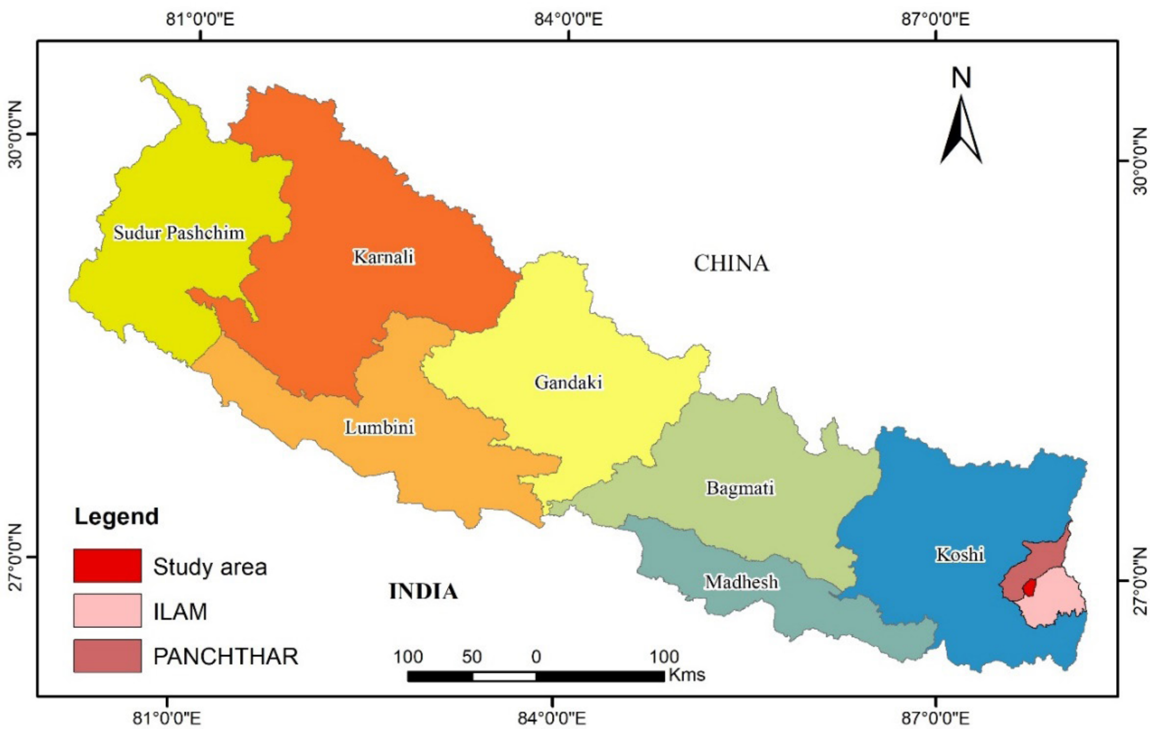


Fig. 1: Location Map of the study area.

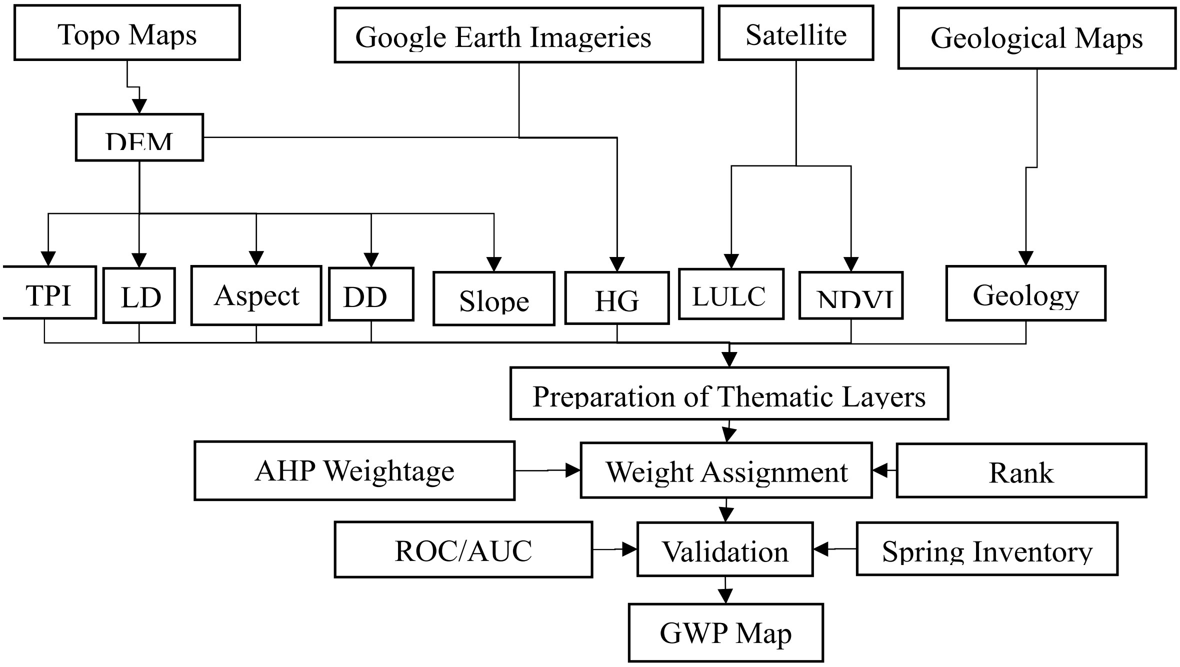


Fig. 2: Flowchart representation of Methodology

Slope

Slope exerts a first-order control on infiltration: steeper terrain accelerates surface runoff and reduces the residence time available for water to infiltrate the subsurface (Silwal and Pathak, 2018). Derived from the DEM, the slope layer was classified into three classes based on gradient: gentle (0–15°), moderate (15–35°), and steep (>35°) (Fig. 3a).

Hydrogeomorphology (HG)

Hydrogeomorphology characterizes landforms shaped by water-related surface processes, including drainage patterns and the interaction between surface water and terrain, and was prepared from field observations combined with the derived slope map. The study area was classified into five units: river channel, rock outcrop, and thin-, moderate-, and thick-soil zones (Fig. 3b). Major segment of the study area is characterized by moderate and thick soil which covers about 80% of the area and rock outcrop are seen in some portion of the study area.

Land use/land cover (LULC)

Land use/land cover (LULC) directly influences groundwater potential by governing surface infiltration, recharge, and flow paths (Silwal et al., 2023), and was digitized from Google Earth imagery. The study area was classified into five categories: cultivation covering about 56 %, vegetation (forest) covering 32 %, grass covering about 11 % of the area, sand bar and Barren land (1%) (Fig. 3c). There is a dominance of cultivation area and vegetation area.

Geology

Geology was extracted from the Geological map of Province 1, Nepal (DMG, 2020), which delineates three formations within the study area: the Sarung Khola Formation, the Shiprin Khola Formation, and the Himal Group (Fig. 3d). The Sarung Khola Formation comprises fine-grained, dark grey to greenish-white quartz-biotite schist along with this its member as CS (Calc silicates and marble bands), the Shiprin Khola Formation comprises coarse-grained, strongly garnetiferous muscovite-biotite schist; and the Himal Group comprises mica gneiss, granitic gneiss, and kyanite-bearing gneiss, together with migmatite and thin bands of marble. Lithology and structural fabric exert a first-order control on primary and secondary porosity, and hence on groundwater storage and movement. The study area is predominantly characterized by the Sharung Khola Fm and the Siprin Khola Fm consisting of crystalline metamorphic rocks.

Topographic Position Index (TPI)

TPI quantifies the elevation of a point relative to the mean elevation of its surrounding terrain and is correlated with distinct landform positions, including hilltops, ridges, valley bottoms, and flat or gently sloping terrain (Arulbalaji et al., 2019). Positive TPI values indicate a point situated above its surroundings, characteristic of ridges and hilltops, whereas negative values indicate a point situated below its surroundings, characteristic of valley bottoms. The TPI values of approximately 1–2 were taken to indicate flat terrain or mild slopes. On this basis, the study area was classified into hilltop/ridge, valley-bottom, and flat/gentle-slope classes (Fig. 3e).

Lineament Density (LD)

Lineament density reflects the density of linear structural features (e.g., fractures, joints, and faults) traced from the DEM-derived hillshade map and serves as a proxy for secondary permeability. The higher lineament density typically indicates greater potential for groundwater recharge, storage, and extraction, since such features can act as preferential pathways for water movement (Abdullah et al., 2015). The study area was classified into three lineament-density classes: low, medium, and high (Fig. 3f).

Aspect

Aspect represents the compass direction faced by a given slope, measured on a continuous scale from 0° to 360° and classified into eight cardinal and intercardinal directions (Fig. 3g). Majority of the hills are facing SW and SE direction which covers about 19 % and 18% respectively.

Drainage Density (DD)

Drainage density, derived from the DEM-based stream network, reflects the degree of surface-channel development within a catchment and is inversely related to infiltration capacity: lower drainage density is generally associated with greater infiltration and, correspondingly, greater groundwater potential (Arulbalaji et al., 2019; Silwal and Pathak, 2018; Pathak et al., 2021). The study area was classified into low, medium, and high drainage-density classes (Fig. 3h).

Normalized Difference Vegetation Index (NDVI)

NDVI, derived from Landsat-8 imagery, characterizes the difference between visible and near-infrared reflectance of vegetation cover and serves as a proxy for vegetation density and, by extension, infiltration and recharge capacity (Parizi et al., 2020). NDVI values range from −1 to 1; positive values indicate the presence and relative density of vegetation, whereas negative values typically correspond to water bodies or sparsely vegetated/bare surfaces, though such values can also arise from data-processing artefacts (Figure 3i).

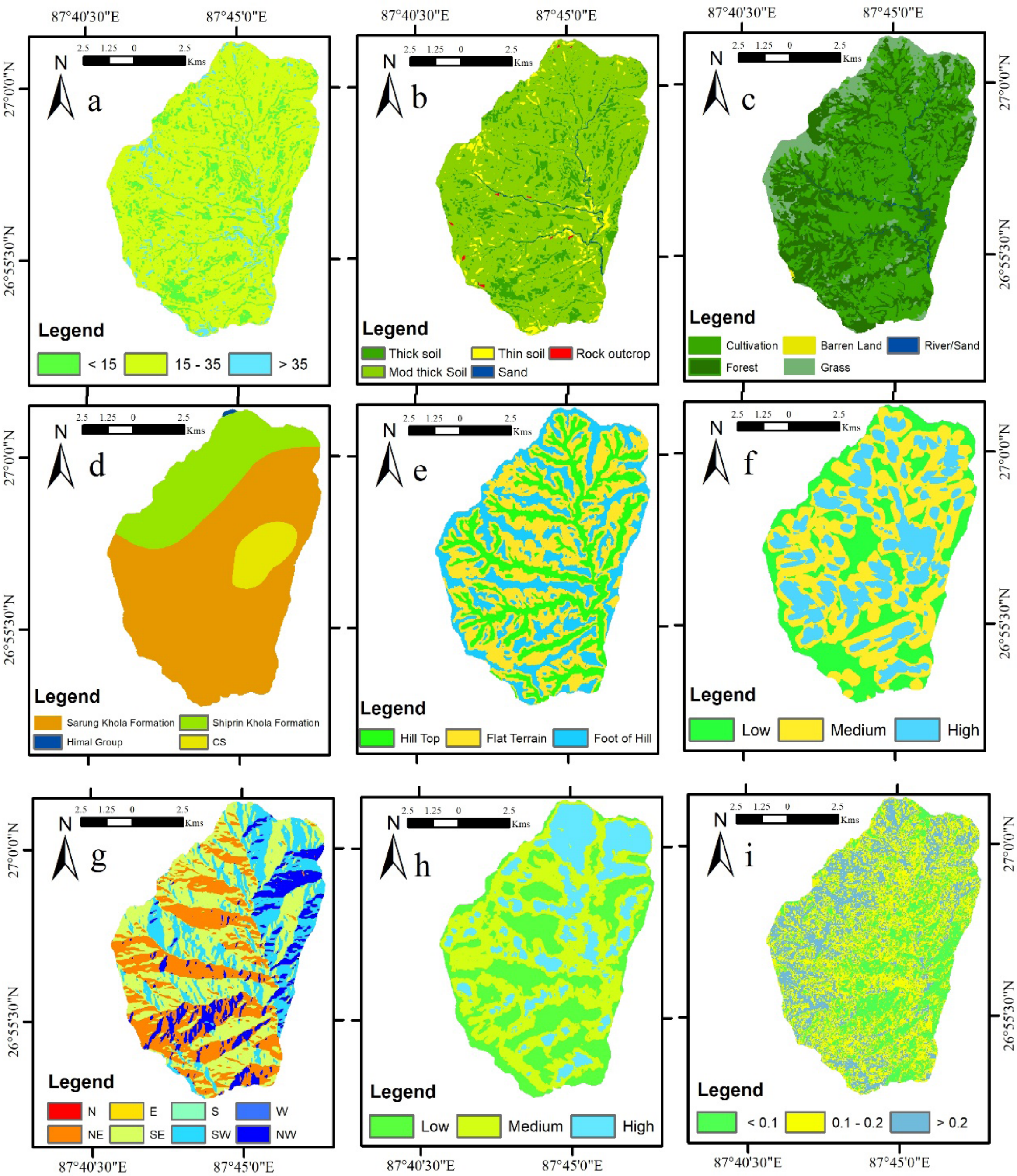


Fig. 3: Thematic maps used in delineating groundwater potential zone (a) Slope, (b) HG, (c) LULC, (d) Geology, (e) TPI, (f) LD, (g) Aspect, (h) DD, and (i) NDVI

Analytic Hierarchy Process (AHP)

The relative importance of the nine thematic layers was determined using the Analytic Hierarchy Process (AHP) proposed by Saaty (1980). Pairwise comparisons among all thematic layers were performed using Saaty's nine-point fundamental scale, where values range from 1 (equal importance) to 9 (extreme importance).

The normalized comparison matrix was used to calculate the weight of each thematic layer and its corresponding subclasses. The consistency of expert judgments was evaluated using the Consistency Index (CI) and Consistency Ratio (CR):

$$CI = \frac{\lambda max - n}{n-1}$$

For the consistency ratio (C.R.) = $\frac{CI}{RI}$

where λmax is the principal eigenvalue, n is the number of criteria, and RI represents Saaty's Random Index. Pairwise comparisons were considered acceptable only when CR < 0.10, indicating satisfactory consistency in the weighting process. This comparison helps gauge the degree of consistency in the matrix, ensuring the validity and reliability of the pairwise comparisons. All the thematic layer's weightage and their sub class weightage along with the consistency ratio is shown in Table 1.

Table 1: Weightage of the thematic layers and the respective classes calculated using AHP.

Thematic Layers	Weight	Class	Weight	CR
Hydrogeomorphology	0.23	River	0.46	0.05
		Thin soil	0.09	
		Moderate soil	0.16	
		Thick soil	0.25	
		Rock outcrop	0.04	
Lineament Density	0.12	Low	0.16	0.01
		Moderate	0.30	
		High	0.54	
LULC	0.10	Cultivation	0.35	0.05
		Vegetation (Forest)	0.28	
		Grass	0.15	
		Sand Bar	0.14	
		Barren Land	0.08	
Slope	0.04	Gentle	0.52	0.06
		Moderately Steep	0.30	
		Steep	0.18	
Geology	0.08	Pegmatite intrusion of calc-silicate	0.18	0.03
		Garnetiferous Schist	0.28	
		Mica gneisses, granitic gneisses, kyanite bearing gneisses	0.07	
		Quartzite, biotite schist	0.47	

NDVI	0.06	Low	0.10	0.04
		Medium	0.26	
		High	0.64	
Drainage Density	0.16	low	0.53	0.04
		Medium	0.29	
		High	0.18	
TPI	0.18	Foot of Hills	0.56	0.05
		Flat terrain	0.34	
		Hill top	0.10	
Aspect	0.03	N	0.05	0.04
		NE	0.11	
		E	0.03	
		SE	0.22	
		S	0.16	
		SW	0.34	
		W	0.02	
		NW	0.07	

Groundwater Potential Mapping

To calculate the groundwater potential index, 'overlay analysis' tool was used to compute groundwater potential index values using the following equation (Leake and Malczewski, 2000)

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

Where Wj is the normalized weight of the jth thematic layer, Xi is the normalized weight of the ith feature/ class of the thematic layer, m represents the total no. of thematic layers, and n is the total no. of the classes of the given thematic factor.

The resulting groundwater potential index was classified into three groundwater potential zones—low, moderate, and high—using natural break classification.

Sensitivity Analysis

To evaluate the influence of individual thematic layers on groundwater potential prediction, a one-factor-removal sensitivity analysis was conducted. Nine independent scenarios were generated by systematically excluding one thematic layer while retaining the remaining eight layers. For each scenario, thematic weights were recalculated using AHP before generating a new groundwater potential map.

The predictive performance of each scenario was compared with that of the complete nine-layer model to quantify the contribution of each thematic factor. This approach provides a direct assessment of parameter sensitivity and identifies the most influential factors governing groundwater occurrence in the study area.

Validation

Groundwater potential maps were validated using an inventory of 85 field-mapped perennial springs. The predictive performance of each model was assessed using Receiver Operating Characteristic (ROC) analysis and quantified by the Area Under the Curve (AUC) (Das., 2019; Naghibi et al., 2016; Pathak et al., 2021; Silwal et al., 2023).

The ROC curve evaluates the relationship between the True Positive Rate (TPR) and the False Positive Rate (FPR), while the AUC provides an overall measure of model discrimination. AUC values approaching 1 indicate excellent predictive performance, whereas values close to 0.5 indicate prediction no better than random chance. The validated AUC values were subsequently used to compare the predictive capability of the original model and each sensitivity-analysis scenario.

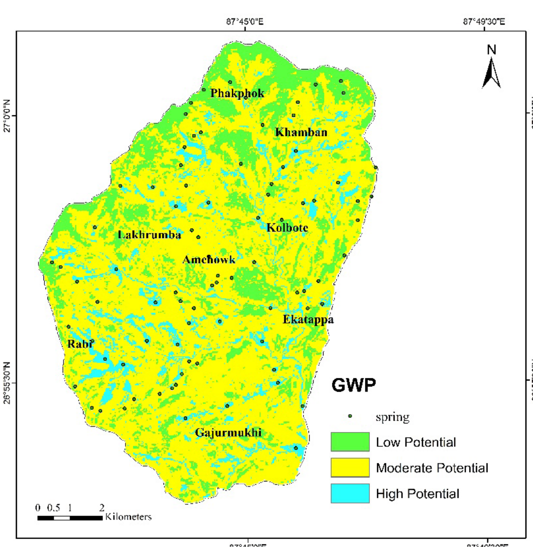
RESULTS

Groundwater Potential Map

The GWP map of the area, thus prepared suggests that 20% area is categorized as high potential zone and 55% area of low potential zone and is validated against the spring inventory using the ROC/AUC method which yields an accuracy of 70.3% (Fig. 4a and 4b), which follows the AUC-based quality classification of Yesilnacar and Topal (2005) and Naghibi et al. (2015). The Area Under the Curve (AUC) and predictive accuracy can also be categorized as poor (0.5-0.6), average (0.6-0.7), good (0.7-0.8), very good (0.8-0.9), and excellent from (0.9-1). The accuracy of (0.703) 70.3 % shows that the prediction falls in good category.

Sensitivity of parameters for groundwater potential mapping

The influence of each thematic layer was evaluated using a leave-one-out approach, in which the Groundwater Potential Index (GWPI) was recalculated after excluding one layer at a time, producing nine sensitivity scenarios validated against the 85 spring locations (Fig. 5 and 6; Table 2). Across all nine cases, high-potential-zone extent ranged from 17.99% (Case 3, without TPI) to 25.86% (Case 2, without Hydrogeomorphology), and low-potential-zone extent ranged from 39.87% (Case 6, without LULC) to 56.31% (Case 1, without Aspect). Exclusion of TPI (Case 3) and lineament density (Case 5) were the only two scenarios in which accuracy fell below the full nine-layer baseline of 70.3%, decreasing to 63.1% and 67.5%, respectively. Exclusion of every other layer instead maintained or increased accuracy relative to the baseline, with the highest accuracy (73.1%) achieved when drainage density was excluded (Case 4). This pattern indicates that TPI and lineament density are the two parameters most critical to the model's predictive performance, a finding examined further in the discussion.



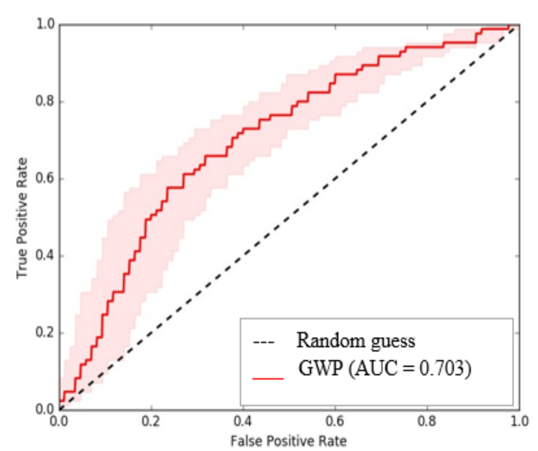


Fig. 4: a) GWP map of the study area and Validation of GWP map of the study area using ROC/ AUC curve.

Table 2: The outcomes of the sensitivity analysis of the GWP zones under different cases.

	Value	Class	Area	ROC Bound	(AUC)
Case 1: Without Aspect	1.24-2.62	Low Potential	56.31	0.644-0.763	0.705
	2.62-3.45	Moderate Potential	23.25		
	3.45-5.41	High Potential	20.25		
Case 2: Without HG	1.37-2.81	Low Potential	43.77	0.665-0.777	0.723
	2.81-3.81	Moderate Potential	29.94		
	3.81-5.46	High Potential	25.86		
Case 3: Without TPI	1.30-2.49	Low Potential	40.01	0.566-0.693	0.631
	2.49-3.06	Moderate Potential	41.49		
	3.06-4.87	High Potential	17.99		
Case4: Without DD	1.16-2.52	Low Potential	40.51	0.670-0.731	0.731
	2.52-3.26	Moderate Potential	34.73		
	3.26-5.22	High Potential	24.26		
Case 5: Without LD	1.20-2.40	Low Potential	41.24	0.614-0.732	0.675
	2.40-3.15	Moderate Potential	33.77		
	3.15-5.19	High Potential	24.49		
Case 6: Without LULC	1.22-2.01	Low Potential	39.87	0.653-0.762	0.711
	2.01-3.21	Moderate Potential	34.39		
	3.21-5.45	High Potential	23.24		
Case7: Without Geology	1.10-2.45	Low Potential	49.74	0.655-0.770	0.711
	2.45-3.27	Moderate Potential	27.10		
	3.27-5.34	High Potential	22.66		
Case 8: Without NDVI	1.12-2.35	Low Potential	54.33	0.671-0.796	0.729
	2.35-3.17	Moderate Potential	23.79		
	3.17-5.20	High Potential	21.27		
Case 9: Without Slope	1.23-2.45	Low Potential	52.20	0.661-0.780	0.716
	2.45-3.27	Moderate Potential	24.77		
	3.27-5.22	High Potential	22.52		

DISCUSSIONS

Mapping the groundwater potential of Phakphokthum watershed in Ilam, Nepal provides important insights into the spatial distribution and key influencing factors of groundwater resources in eastern Nepal Himalaya where the crystalline metamorphic rocks dominates the region. This study integrated nine thematic layers using GIS based multi-criteria decision analysis (MCDA), with AHP techniques to weight the thematic layers. The empirical and effective weights of each thematic layer would have different weights for similar layer depending on the geological, hydrogeological, local and regional conditions. Several studies (Fenta et al., 2015; Panahi et al., 2017; Anteneh et al., 2022) have relatively reported that parameter sensitivity depends strongly on the geological and hydrogeological conditions specific to each study area. Using a comparable leave-one-layer-out approach, Zewdie et al. (2024) identified rainfall and depth to groundwater as the most sensitive parameters for GWP mapping in an Ethiopian watershed, while Pathak et al. (2021) identified lineament density and hydrogeomorphology as the most influential parameters in the mountainous Khadadevi–Manthali region of central Nepal.

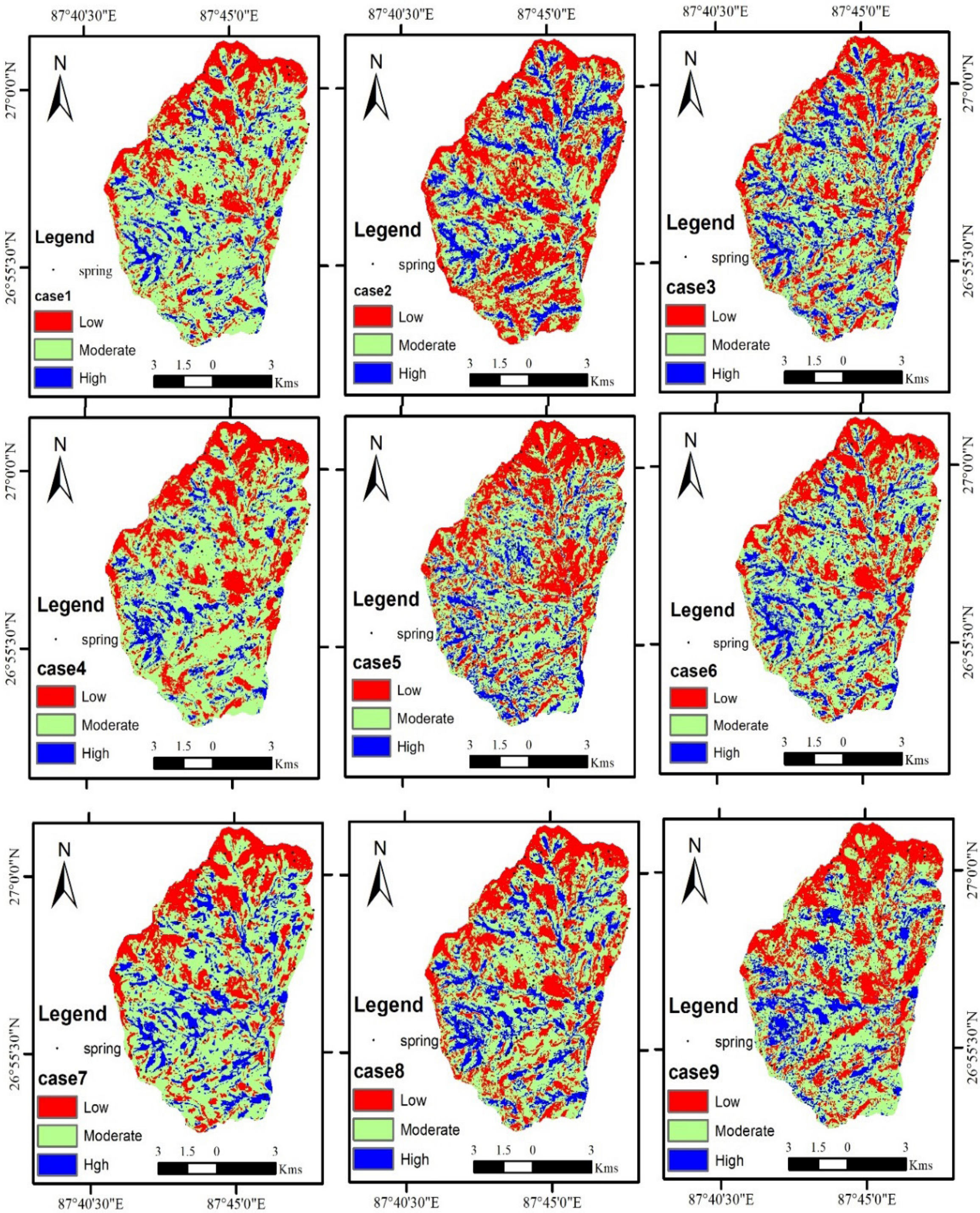


Fig. 5: Sensitivity analysis of the GWP zones under different case scenarios (see Table 2).

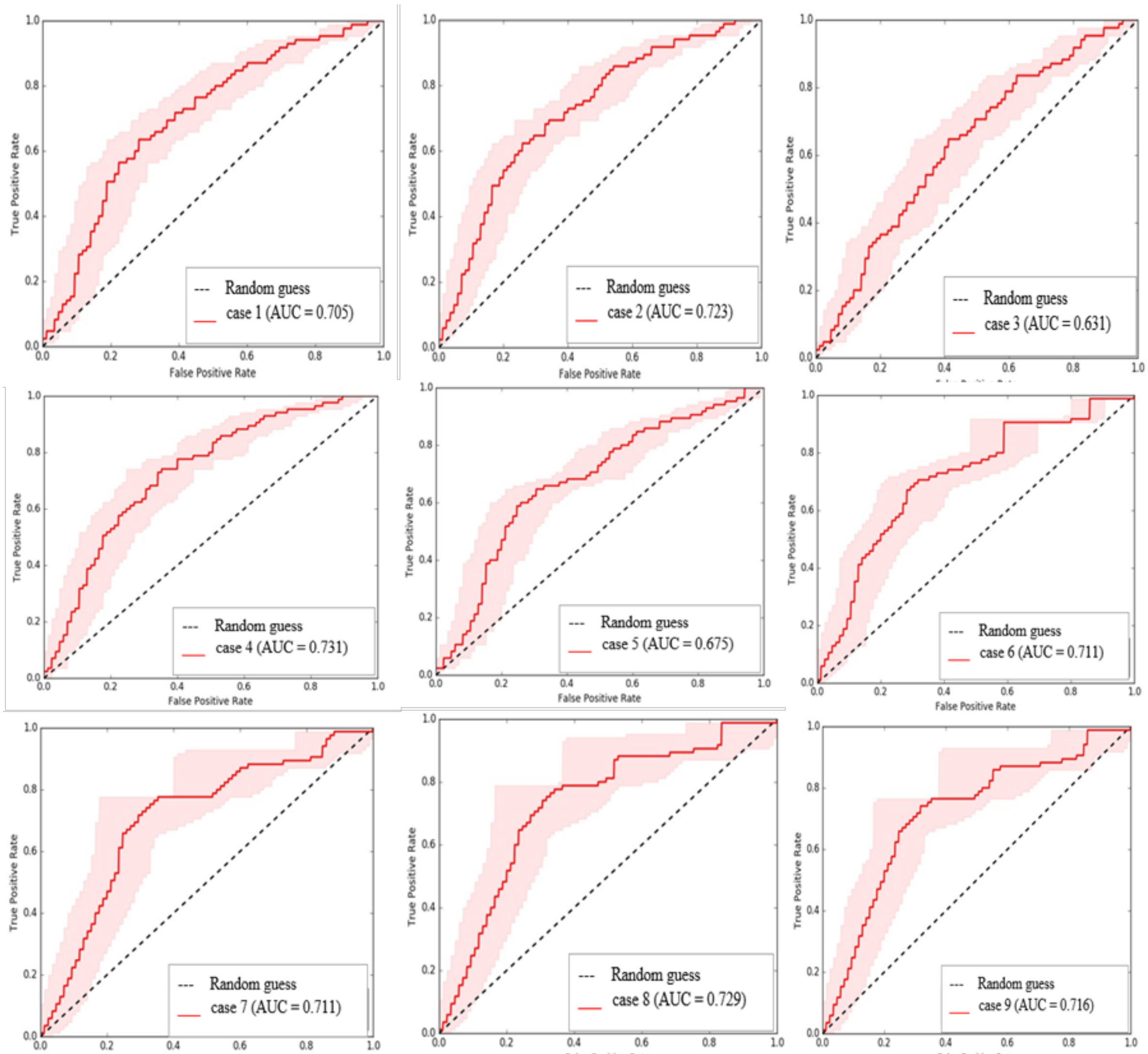


Fig. 6: ROC/AUC curve for the GWP map prepared for different case scenarios (Case 1 - 9) and validated against the spring inventory of the area.

The present study's sensitivity analysis identifies TPI and lineament density as the parameters whose exclusion most reduced predictive accuracy to 63.1% and 67.5%, respectively, against a full-model accuracy of 70.3% and is therefore consistent with Pathak et al. (2021) with respect to lineament density. However, exclusion of hydrogeomorphology, despite it carrying the highest AHP-derived weight (0.23) of the nine layers, increased model accuracy to 72.3%, as did exclusion of drainage density (0.16 weight; accuracy increased to 73.1%, the highest of any single-removal case). This divergence between AHP-derived weight (expert pairwise judgement) and leave-one-out sensitivity (empirical validation against spring data) suggests the two measures capture different aspects of parameter importance, and that reporting both (rather than AHP weight alone) gives a more complete picture of which factors genuinely drive predictive performance in this terrain.

NDVI and LULC results indicate that denser vegetation cover is associated with greater infiltration, whereas barren or sparsely vegetated slopes are associated with more rapid runoff, consistent with Kumar et al. (2023). The model classified 17–26% of the watershed as high-potential zones across the nine sensitivity cases, concentrated in areas of gentle slope, valley floors, and high lineament density (Arulbalaji et al., 2019). The findings collectively support the need for micro-watershed-scale management to address spatial variability in water availability. The proposed methodology offers a cost-effective, reproducible framework for GWP mapping in the Nepal Himalaya, particularly where spring inventory data are limited, and bridges theoretical hydrogeology with practical water resource planning by integrating remote sensing, geospatial analysis, and field validation (Bricker et al., 2014).

CONCLUSIONS

Groundwater appears in terms of spring in mountainous regions. The exploitation of groundwater in these regions is very difficult so groundwater potential map play a crucial role in identifying the water rich zone and the factors that are used to delineate the potential zone are key resources. Nine different thematic layers namely -hydrogeomorphology, slope, aspect, DD, LD, LULC, NDVI, TPI, and geology were used for the preparation of the GWP map. ROC/AUC validation with the collected data from spring inventory shows accuracy percentage from 63.1 % to 73.1 %. It suggests and topographic position index (TPI), lineament density (LD) as an most influential factor.

An important finding is the difference between expert-derived AHP weights and empirically evaluated parameter sensitivity. Although hydrogeomorphology received the highest AHP weight, its removal improved model performance, whereas TPI and lineament density showed greater sensitivity despite having lower AHP weights. This highlights the value of sensitivity analysis as a complementary approach for evaluating the robustness of AHP based groundwater potential models.

Despite the removal of individual factors, the accuracy of the GWPI maps relatively high across all cases, this suggests that the combined influence of the remaining factors still effectively predicts groundwater potential. Across all cases, a notable proportion of the study area was identified as high potential zones for groundwater occurrence, ranging from 17% to 25%. This information is crucial for water resource management and planning in the region. Seasonal spring dominance in Lakhrumba and Amchok, indicates water scarcity in the area. This methodology can be reproduced to generate a GWP map for groundwater assessment in the mountainous region of Nepal Himalaya, particularly in the absence of detailed spring inventory data. Implementing this approach has the potential to significantly improve groundwater exploration, fostering sustainable exploitation of groundwater resources in the Himalayan mountainous region.

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AUTHORS CONTRIBUTION

Authors 1, 2, and 5 conceived and design the study. Author 1 conducted the field investigation, collected and analyzed the data, and prepared the original draft of the manuscript. Authors 3 and 4 contributed to fieldwork, data collection, and interpretation of the results. Author 2 and 5 provided overall supervision, contributed to the interpretation of the results, critically reviewed the manuscript, and guided its final revision. All authors contributed to the study, proof read and approved the final version of the manuscript.

CONFLICT OF INTEREST

The authors declare no competing interests for this work.

DATA AVAILABILITY

The datasets generated and/or analyzed during the current study are available from the corresponding author and can be obtained through direct email communication upon reasonable request.

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