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Geospatial Assessment Of Groundwater Vulnerability And Urbanization-Related Risks In Chamoli District

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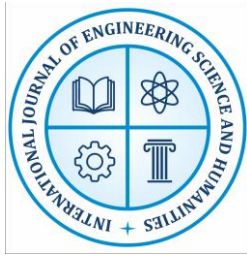
Abstract

Groundwater vulnerability is an important environmental concern in mountainous regions, where changing land-use patterns, urban expansion, and increasing human activities can affect groundwater quality, availability, and recharge processes. The present study aims to assess groundwater vulnerability and urbanization-related risks in Chamoli District, Uttarakhand, using geospatial techniques. The district's complex topography, geological diversity, variable rainfall patterns, and expanding settlements create distinct challenges for sustainable groundwater management. The study proposes the use of Remote Sensing and Geographic Information System (GIS) techniques to analyse land-use and land-cover changes, settlement expansion, drainage networks, slope, soil characteristics, geology, and rainfall distribution. These parameters can be integrated through a suitable multi-criteria decision analysis approach to identify areas with varying levels of groundwater vulnerability. The assessment also seeks to examine how increasing built-up areas, vegetation loss, surface runoff, and unplanned development may influence groundwater recharge and contamination risks. Spatial vulnerability maps can help identify environmentally sensitive zones and areas requiring priority intervention. The expected findings may support sustainable urban planning, groundwater conservation, and risk-informed land management in the Himalayan region. The study can provide valuable geospatial information for policymakers, planners, and environmental agencies to strengthen groundwater protection strategies and promote ecologically responsible development in Chamoli District.

Keywords: Groundwater Vulnerability, Urbanization, Geospatial Assessment, Remote Sensing, Geographic Information System (GIS)

1. Introduction

Groundwater vulnerability in mountain regions is shaped by the interaction of hydrogeology, terrain, land cover, climate and human activity. Unlike broad alluvial plains, Himalayan districts often contain fractured rocks, steep slopes, narrow valleys, talus deposits and spring-fed drainage



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systems. Water can move through complex subsurface pathways, making both resource assessment and hazard management challenging.

Chamoli District in Uttarakhand provides a relevant setting for examining this complexity. The supplied source document links urban growth, tourism, highway development and hydropower infrastructure with changing land cover and possible pressure on groundwater and spring systems. It also discusses Joshimath, where land subsidence and structural damage have heightened concern about the relationship between development, slope conditions, drainage and groundwater.

Groundwater vulnerability should not be interpreted as a single condition. It may refer to susceptibility to depletion, reduced recharge, contamination, spring-flow reduction or interaction with ground instability. These outcomes have different mechanisms and require different indicators. A geospatial framework can combine geological, geomorphological, slope, LULC and groundwater information to identify locations where multiple forms of risk overlap.

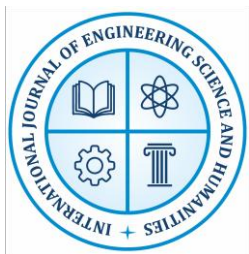
The source document proposes a mixed geospatial-hydrogeological approach involving remote sensing, GIS, monitoring records, analytical hierarchy process (AHP), and MODFLOW simulations. It also refers to interferometric synthetic aperture radar (InSAR) for subsidence analysis. This paper develops a distinct focus on vulnerability assessment, risk zoning and management options rather than concentrating primarily on LULC change rates.

The study treats urbanization as one pressure among several. Rainfall variability, geology, slope, extraction, drainage alteration and infrastructure activity can influence groundwater and ground stability. The aim is to establish a transparent method for identifying priority zones and clarifying what evidence is required before risks can be attributed to particular causes.

2. Review of Literature

Geospatial vulnerability assessment commonly combines several thematic layers into a spatial index. In groundwater studies, these layers may include geology, geomorphology, slope, land cover, drainage, rainfall, depth to water and abstraction pressure. In mountainous areas, fractured rock and slope materials can create localized recharge and flow conditions that are not represented well by district-wide averages. Consequently, vulnerability mapping should be interpreted at a scale appropriate to the available data.

The source document proposes an AHP-based multi-criteria assessment, assigning weights to geology, slope, LULC and extraction. AHP provides a structured way to compare criteria, but weights are partly judgment-based and should be supported by expert reasoning, pairwise-comparison consistency checks and sensitivity analysis. The resulting classes are relative priorities, not direct probabilities of groundwater failure.



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Groundwater monitoring is essential for interpreting vulnerability maps. CGWB bulletins document seasonal groundwater monitoring across Uttarakhand and distinguish the state's diverse hydrogeological units. The 2024 groundwater resource assessment for Uttarakhand reports statewide annual recharge and extraction estimates, while district-level interpretation requires the relevant district or assessment-unit data. The statewide status should not be substituted for measurements at a specific spring or settlement.

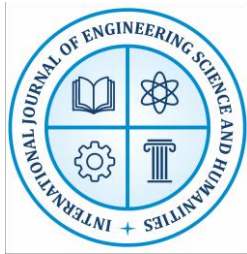
Remote sensing contributes information about surface change and land deformation. Multi-temporal optical imagery can identify urban expansion and vegetation loss, while InSAR can detect surface displacement when suitable radar data, processing methods and ground validation are available. Subsidence, however, can arise from several causes, including geological conditions, slope movement, construction loads, tunnelling, drainage changes and groundwater extraction. The presence of subsidence does not by itself prove groundwater over-extraction.

Hydrological models such as MODFLOW can simulate groundwater flow and test scenarios, but the reliability of predictions depends on conceptual-model quality, boundary conditions, aquifer geometry, hydraulic parameters and calibration data. In fractured mountain settings, model simplification is a major concern. Scenario results should therefore be presented with assumptions and uncertainty rather than as exact forecasts.

The literature and source material together point to a need for integrated assessment. A map of land-use change cannot alone explain groundwater vulnerability; a groundwater-level trend cannot alone explain subsidence; and an AHP index cannot replace field validation. A robust approach combines these evidence streams while preserving the distinction between observation, association and model-based scenario.

2.1 Conceptual and Analytical Framework

Component	Potential indicators	Role in assessment
Driving forces	Tourism, population, road and infrastructure growth	Identifies development pressure
Surface pressure	Built-up area, imperviousness, vegetation loss	Represents land-cover change
Hydrogeological setting	Lithology, fractures, aquifer type, springs	Controls subsurface flow and recharge
Terrain	Slope, elevation, geomorphology, drainage	Represents physical sensitivity
Observed state	Groundwater level, spring discharge, rainfall	Describes measured hydrological condition
Ground deformation	InSAR displacement, field	Identifies possible instability



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	cracks, slope instability	zones
Response	Zoning, recharge protection, monitoring, drainage management	Supports risk reduction

3. Objectives and scope of the research work

The study has three objectives:

- To develop a GIS-based groundwater vulnerability and urbanization-pressure framework for selected settlement corridors in Chamoli District.
- To integrate land-use/land-cover, hydrogeological, terrain and available groundwater or deformation observations to identify areas requiring priority monitoring.
- To evaluate scenario-based mitigation options and propose evidence-led recommendations for groundwater protection and risk-sensitive urban planning.

Scope. The study focuses on selected urban and peri-urban locations in Chamoli, particularly where the source document identifies urban expansion, groundwater monitoring needs or land-instability concerns. The analysis will use the most reliable available spatial and temporal datasets. The paper distinguishes groundwater depletion vulnerability from subsidence susceptibility, because these are related but not interchangeable processes.

4. Research Methodology / Experimental

4.1 Overall research approach

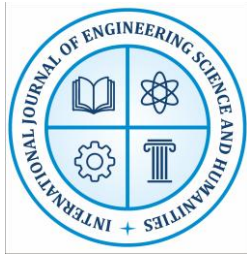
A mixed geospatial-hydrogeological design will be used. The workflow will compile thematic datasets, standardize their coordinate systems and spatial resolution, derive relevant indicators, develop a vulnerability index, compare the index with available observations and evaluate alternative management scenarios. Field validation and expert review will be used where feasible.

4.2 Study area characterization

The study area will be described in terms of administrative boundaries, settlement patterns, elevation, slope, geology, geomorphology, drainage, land cover and groundwater access. Particular attention will be given to the contrast between valley deposits and fractured mountain terrain. The boundaries of individual analysis zones will be recorded to ensure that results can be reproduced.

4.3 Data sources and inventory

Potential sources include CGWB groundwater-level bulletins and resource assessments, NRSC Bhuvan land-cover and elevation data, IMD rainfall records, CWC basin information, satellite imagery, planning documents and field observations. Data availability will be inventoried before modelling. Each layer will be assigned a date, scale, resolution, source and uncertainty note.



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4.4 Terrain and hydrogeological layers

A digital elevation model will be used to derive slope, elevation and selected terrain indices. Geological and geomorphological maps will be digitized or harmonized where permitted. Drainage density and distance to channels may be considered, while spring locations and monitoring stations will be georeferenced. The suitability of each variable will depend on spatial coverage and scale.

4.5 LULC and urban pressure indicators

LULC maps will be produced for comparable dates using satellite imagery and a consistent classification scheme. Built-up density, rate of expansion, vegetation cover and proximity to growth corridors may be used to characterize urbanization pressure. Change detection will help distinguish persistent built-up areas from recent conversion zones.

4.6 Groundwater observation layer

Available well and spring records will be assembled with dates, location, depth or discharge measure and measurement method. Seasonal comparability is important because groundwater levels respond to rainfall and snowmelt patterns. Data gaps will be explicitly mapped. A sparse monitoring network will limit the confidence of fine-scale conclusions.

4.7 AHP and multi-criteria evaluation

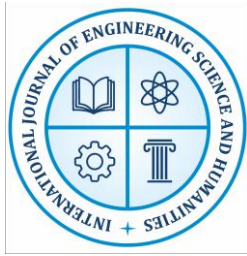
An Analytical Hierarchy Process may be used to weight geology, slope, LULC, extraction pressure and other justified criteria. Pairwise comparisons will be documented, and the consistency ratio will be checked. Alternative weighting schemes will be tested to determine whether the highest-priority zones remain stable. Index classes will be labelled as relative vulnerability categories rather than probabilities.

4.8 Groundwater modelling

MODFLOW or a comparable groundwater model may be used only if adequate hydrogeological data are available. The conceptual model will specify layers, boundaries, recharge, discharge and hydraulic parameters. Calibration will use observed groundwater levels or other suitable measurements. If these inputs are insufficient, the study will limit itself to a conceptual scenario analysis and clearly state that numerical predictions are exploratory.

4.9 Subsidence and deformation analysis

Where suitable radar imagery and processing capacity are available, InSAR may be used to examine surface displacement over selected periods. Results will be cross-checked against ground observations and published official assessments where available. Deformation will be analysed alongside geology, slope, construction activity and drainage information. It will not be attributed to groundwater extraction without corroborating evidence.



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4.10 Scenario construction

The study may compare a business-as-usual scenario with a sustainability-oriented scenario. The first represents continuation of observed land-cover trends, while the second explores measures such as protection of recharge zones, permeable surfaces, drainage improvements and spring-catchment restoration. Scenario parameters will be explicitly stated and outputs presented as conditional projections rather than guaranteed forecasts.

4.11 Validation and uncertainty

Validation will include ground-truthing, comparison with monitoring data, sensitivity analysis and review by subject experts. Map resolution, date mismatches, classification errors and uncertain AHP weights will be recorded. Where data are inadequate, the output will identify a monitoring priority instead of presenting a false sense of precision.

4.12 Ethical and safety considerations

Fieldwork in mountain terrain requires risk assessment and adherence to local safety instructions. Interviews, if conducted, will use informed consent and protect participant identity. The research will avoid exposing sensitive household or infrastructure information and will clearly distinguish scientific evidence from policy recommendations.

5. Hypothesis

The analysis will test three hypotheses:

H1: Locations combining rapid built-up expansion with sensitive geological or geomorphological conditions will receive higher relative groundwater-vulnerability scores than locations with lower development pressure and more favorable recharge conditions.

H2: Groundwater-level or spring-discharge observations will show meaningful spatial and seasonal variation associated with the combined influence of land cover, rainfall, slope and hydrogeological setting.

H3: A sustainability-oriented scenario that protects recharge areas and improves land-surface permeability will produce more favorable modelled or index-based outcomes than a continuation-of-trends scenario, subject to the assumptions and data quality of the model.

6. Limitation of Research work (Research Gap)

The main gap is the limited availability of a unified, validated dataset that simultaneously represents land-use change, groundwater conditions, spring discharge, terrain, geology and surface deformation at the scale of individual settlements. These variables are often collected by different agencies at different spatial and temporal resolutions.

An AHP-based vulnerability map is sensitive to the choice of criteria and weights. Expert judgement can introduce subjectivity, while correlated indicators may inadvertently count the



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same process more than once. Sensitivity analysis and transparent documentation are therefore necessary.

Groundwater monitoring stations may not represent all spring catchments or fractured-rock systems. Data from a small number of wells cannot be assumed to describe the entire district. Seasonal rainfall, snowmelt and local abstraction can complicate trend interpretation.

InSAR is affected by vegetation, atmospheric conditions, temporal decorrelation, viewing geometry and processing choices. Displacement detected from satellite radar requires careful interpretation and ground validation. A deformation signal alone cannot identify its cause.

MODFLOW modelling of fractured mountain aquifers may require simplifications that are not fully representative of real flow paths. If calibration data are inadequate, model outputs should be presented as exploratory scenarios rather than precise forecasts.

The source document contains preliminary quantitative claims about recharge deficits, drawdown, spring loss and risk-zone percentages. The underlying data and model files are not supplied separately. These values require independent verification, and this paper does not present them as independently reproduced findings.

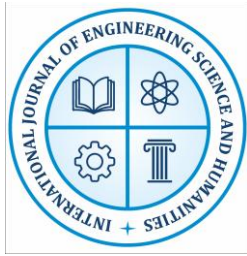
Some bibliographic entries in the source document may need confirmation against the original publications. Prior to formal submission, authorship, title, journal, volume, page range and DOI should be checked in authoritative databases.

8. Results and Discussion

8.1 Vulnerability zoning approach

The source document proposes an AHP vulnerability assessment using geology, slope, LULC and extraction-related criteria. It reports relative zones of high, medium and low risk. Such a map can be useful for prioritizing monitoring, but its interpretation depends on the criteria, weights, normalization and validation method. The categories should therefore be understood as relative spatial priorities rather than absolute forecasts of failure.

Criterion listed in source	Illustrative weight reported	Interpretive caution
Geology	30%	Weight needs expert justification and consistency testing
Slope	25%	Slope alone does not establish groundwater vulnerability
LULC	20%	Classification date and accuracy affect the result
Extraction pressure	25%	Requires reliable local extraction data



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8.2 Interpretation of groundwater indicators

The source document reports groundwater-level drawdown in selected urban hotspots and a preliminary association between built-up intensity and water-level conditions. The reported correlation is a useful hypothesis-generating result, but the sign and magnitude of a correlation depend on how variables are defined—for example, groundwater elevation versus depth to water. The analysis must specify units, station selection, observation dates and seasonal treatment before the coefficient can be interpreted.

8.3 Subsidence and groundwater: avoiding a single-cause explanation

The source document discusses Joshimath and reports subsidence-related observations. The broader interpretation must recognize that ground deformation in mountain towns may reflect multiple interacting causes: geological materials, slope movement, drainage alteration, construction loads, tunnelling, rainfall and groundwater conditions. Groundwater extraction may be relevant in some settings, but attribution requires a clear causal model and corroborating evidence. The research should therefore compare deformation patterns with hydrogeology and land-use change without assuming that one factor explains all observed movement.

8.4 Scenario analysis

The supplied document outlines contrasting 2030 scenarios, including a business-as-usual pathway and a sustainability-oriented pathway. These projections should be treated as conditional model outputs. A valid comparison requires consistent starting conditions, explicit assumptions about future built-up growth and abstraction, and calibration against observed data. The most useful output may be the relative direction of change and the identification of sensitive zones rather than a single district-wide recharge number.

8.5 Management priorities

Protect mapped spring catchments and potential recharge areas from unassessed land conversion. Use local hydrogeological and slope evidence when reviewing development in sensitive zones. Maintain a monitoring network that includes springs as well as wells, with repeated seasonal measurements.

Use drainage design, permeable surfaces and rainwater management where technically appropriate and safe.

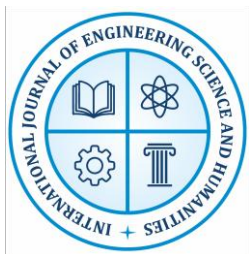
Require transparent reporting of uncertainty in vulnerability maps and scenario forecasts.

Coordinate groundwater, urban planning, road, disaster-management and community institutions.

8.6 Hypothesis assessment

H1 can be assessed by comparing vulnerability scores across land-use and geological settings.

H2 requires sufficiently long, seasonally matched groundwater and spring records, with rainfall



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and terrain covariates. H3 can be assessed through sensitivity-tested scenario modelling or a transparent indicator framework. Because the source file does not include all raw data, the hypotheses remain testable propositions rather than conclusions proven by this paper.

9. Conclusions

This paper presents an integrated geospatial framework for examining groundwater vulnerability and urbanization-related risks in Chamoli District. Its distinctive contribution is the combined consideration of land cover, hydrogeology, terrain, groundwater observations and possible ground deformation.

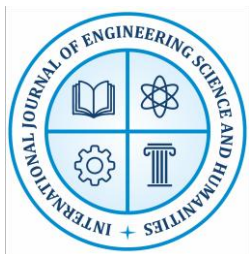
The research design emphasizes that a vulnerability map is a decision-support tool, not a substitute for direct monitoring. Criteria and weights must be justified, observations should be seasonally comparable, and model outputs should be validated against field evidence wherever possible.

The source document identifies urban corridors and Joshimath as areas of concern and proposes AHP zoning, groundwater modelling and geospatial scenario analysis. The quantitative claims supplied in that document require verification against original monitoring records, satellite products and model files before they can be used as definitive evidence.

Future work should prioritize integrated monitoring, spring-catchment mapping, field verification, transparent model calibration and coordination among planning and water-management agencies. Such a framework can support risk-sensitive development while avoiding oversimplified claims about the causes of groundwater change or subsidence.

10. References

- Central Ground Water Board (CGWB). (2024). Ground Water Year Book of Uttarakhand 2023–24. Ministry of Jal Shakti, Government of India.
- Central Ground Water Board (CGWB). (2024). Summary on Status of Dynamic Ground Water Resources of Uttarakhand (as on 2023). Government of India.
- National Remote Sensing Centre (NRSC). (2025). Bhuvan Geoportal and thematic services for land use/land cover. ISRO.
- India Meteorological Department (IMD). (2025). Monsoon and climate bulletins for Uttarakhand. Government of India.
- Central Water Commission (CWC). (2024). Alaknanda and Bhagirathi River Atlas.
- United Nations Department of Economic and Social Affairs. (2022). World Urbanization Prospects: The 2022 Revision.
- Bhardwaj, A., et al. (2022). Urban expansion and its impact on groundwater recharge in Himalayan regions: A GIS-based study. *Journal of Environmental Management*, 310,



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114765. (Reference as listed in the source document; verify bibliographic details before submission.)

- Ranjan, R., et al. (2024). Sentinel-2 based assessment of urban sprawl and aquifer dynamics in Uttarakhand. Remote Sensing Applications: Society and Environment. (Reference as listed in the source document; verify bibliographic details before submission.)
- Rawat, K. S., & Rawat, K. S. (2024). InSAR analysis of subsidence in Joshimath: Linking to groundwater overexploitation. Natural Hazards. (Reference as listed in the source document; verify bibliographic details before submission.)
- Sultan, M., et al. (2022). Spring discharge variability in the Garhwal Himalayas: Role of land use changes. Hydrogeology Journal. (Reference as listed in the source document; verify bibliographic details before submission.)
- United Nations. (2015). Transforming Our World: The 2030 Agenda for Sustainable Development.
- Government of India. (2012). National Water Policy. Ministry of Water Resources.
- European Environment Agency. (2005). EEA Core Set of Indicators: Technical Report No. 1/2005.
- US Geological Survey. (2024). MODFLOW 6 groundwater modelling system documentation.
- Google Earth Engine. (2025). Earth Engine data catalog and geospatial processing platform documentation.
- National Remote Sensing Centre (NRSC). (2024–2025). Land use/land cover thematic data and Bhuvan geospatial services.