



## **Urbanization, Land-Use Change And Groundwater Recharge In Chamoli District, Uttarakhand**

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### **Abstract**

Urbanization, land-use change, and groundwater recharge are closely interconnected processes that influence water resource sustainability in the Himalayan region. The present study examines the relationship between urban expansion, changing land-use and land-cover patterns, and groundwater recharge in Chamoli District, Uttarakhand. The district's mountainous terrain, variable precipitation, fragile geological conditions, and growing human activities make groundwater resource management particularly important. The study aims to assess changes in built-up areas, agricultural land, forest cover, and other land categories and evaluate their potential effects on infiltration and groundwater recharge. Remote sensing and Geographic Information System (GIS) techniques can be employed to analyse multi-temporal satellite imagery and identify spatial and temporal changes in land use and land cover. Relevant rainfall, drainage, topographical, geological, and soil datasets can further support the assessment of groundwater recharge potential. The study also seeks to identify areas where increasing impervious surfaces and vegetation loss may reduce infiltration and increase surface runoff. The findings are expected to provide insights into the spatial relationship between urban development and groundwater recharge potential, supporting sustainable land-use planning, watershed management, and groundwater conservation. The research may contribute to evidence-based environmental planning and help local authorities develop strategies to protect water resources while accommodating the district's evolving developmental needs.

**Keywords:** Urbanization, Land-Use Change, Groundwater Recharge, Remote Sensing, GIS

### **1. Introduction**

Urbanization changes the physical surface of a region through the construction of housing, roads, commercial areas, tourism facilities and public infrastructure. In mountain districts, these changes occur within constrained valleys and on slopes where terrain, geology and drainage strongly influence water movement. The relationship between urban growth and groundwater is therefore not adequately explained by population change alone; it must also be examined through land-use/land-cover (LULC) transformation, infiltration, runoff, spring discharge and aquifer characteristics.

Chamoli District in Uttarakhand provides a significant geographical setting for examining these relationships. The district lies in the Garhwal Himalaya and includes settlements

connected with the Alaknanda basin, pilgrimage routes, tourism, hydropower and highway infrastructure. The source document identifies Joshimath and Gopeshwar as important urban growth locations and describes tourism, road expansion and infrastructure development as pressures that can increase built-up surfaces and reduce natural infiltration.

Groundwater in Himalayan environments is often accessed through springs, seepage zones, shallow valley aquifers and fractured-rock systems rather than only through conventional deep wells. These sources sustain domestic water supplies, terraced agriculture and local ecosystems. Changes to recharge areas, slope drainage and land cover can alter both the timing and quantity of groundwater discharge. Impervious surfaces may increase rapid runoff and reduce the proportion of rainfall entering the subsurface, although the magnitude of this effect depends on geology, slope, soil, fractures, rainfall intensity and the location of built-up development.

The provided document proposes a geospatial investigation of LULC changes over approximately 2015–2025 and their association with groundwater conditions. It outlines a workflow involving Landsat and Sentinel imagery, GIS, groundwater monitoring records, field observations and hydrological modelling. This paper develops that theme into a focused research article on urbanization, land-use transformation and groundwater recharge. Numerical results mentioned in the source are treated as preliminary reported findings rather than independently verified measurements.

The central argument is that land-use change is a measurable link between urban development and groundwater response. By mapping the distribution and growth of built-up areas and comparing those patterns with groundwater observations, the study can identify locations where further monitoring and sustainable planning may be most needed.

## **2. Review of Literature**

Research on urbanization and groundwater commonly identifies land-cover conversion as an important factor affecting recharge. Vegetated and permeable surfaces allow some rainfall to infiltrate, while roofs, paved roads and compacted surfaces can redirect water into drains and streams. However, the relationship is not uniform: infiltration may remain high where fractures, permeable deposits or engineered recharge structures are present, and urban leakage can sometimes add recharge locally. Consequently, groundwater effects must be interpreted through a site-specific hydrogeological framework.

Studies using remote sensing and GIS have increasingly examined urban growth by classifying satellite imagery into built-up, vegetation, agricultural, water and barren-land categories. Multi-temporal comparison makes it possible to quantify the direction and rate of change, locate growth corridors and identify areas where natural cover has been replaced. The source document refers to Landsat-9 and Sentinel-2 imagery, Random Forest classification, normalized built-up and vegetation indices, and ground-truthing to improve the reliability of mapping.

Hydrogeological research in Uttarakhand must account for the contrast between alluvial valley deposits and fractured crystalline or sedimentary rocks in mountain terrain. The Central Ground Water Board's groundwater bulletins describe a varied hydrogeological

setting across Uttarakhand and use a network of monitoring stations to observe seasonal groundwater fluctuations. The official state assessment for 2024 reports an annual groundwater recharge of 2.14 billion cubic metres for Uttarakhand as a whole; this state-level figure should not be interpreted as a Chamoli-specific estimate.

The source document cites work on urban expansion, aquifer dynamics, spring discharge and subsidence in Himalayan settings. These themes suggest that groundwater cannot be assessed in isolation from springs, slope stability and surface drainage. At the same time, references in the supplied document include some precise figures and bibliographic entries that require verification against original datasets and publications before being treated as confirmed evidence.

Remote sensing offers spatial consistency over large areas, but it does not directly measure groundwater recharge. Satellite-derived LULC, NDVI and NDBI are indicators of surface conditions. Their relationships with groundwater level or spring discharge must be tested against field measurements, well records, rainfall and hydrogeological information. A robust design therefore combines remotely sensed indicators with monitoring data and transparent uncertainty assessment.

### 2.1 Main Themes Emerging from Previous Work

Urban growth can convert vegetation, agriculture and open ground into built-up land, changing infiltration and runoff patterns.

Mountain hydrogeology is heterogeneous; recharge responses differ between fractured rock, valley deposits, slope materials and spring catchments.

Remote sensing and GIS are useful for mapping LULC transitions, but field verification is required to establish classification accuracy.

Groundwater levels and spring discharge are seasonal and climate-sensitive; urbanization effects must be assessed alongside rainfall and geology.

Integrated LULC–groundwater analysis is useful for identifying priority locations for recharge protection and urban planning.

### 3. Objectives and scope of the research work

The study is guided by three objectives only:

- To map and quantify the spatio-temporal pattern of urbanization and land-use/land-cover change in selected urban corridors of Chamoli District during the study period.
- To examine the relationship between changes in built-up land, vegetation and other land-cover classes and available groundwater-level or spring-discharge observations.
- To identify land-use change hotspots and develop geographically informed recommendations for protecting recharge areas and supporting sustainable urban development.

Scope. The proposed analysis focuses on Chamoli District, with detailed attention to the Joshimath–Gopeshwar and other selected settlement corridors where data permit. The intended temporal comparison is approximately 2015–2025, depending on the availability and comparability of satellite images and groundwater records. The research covers LULC

classification, change detection, selected remote-sensing indices, groundwater observations and spatial association. It does not assume that every observed groundwater fluctuation is caused by urbanization; rainfall, geology, slope, extraction and seasonal variation are treated as competing or interacting factors.

#### **4. Research Methodology / Experimental**

##### **4.1 Research design**

The research uses a quantitative geospatial design supported by field verification and documentary analysis. Satellite imagery will be processed for consistent benchmark years, and resulting LULC maps will be compared with available groundwater-level and spring-discharge records. The design is observational rather than experimental because urban land cover cannot be randomly assigned. Any causal interpretation will therefore be cautious and based on converging evidence.

##### **4.2 Study area and spatial units**

Chamoli District is the overall study area. Within it, settlement cores, urban expansion corridors and adjacent peri-urban or rural reference areas will be delineated. The source document describes the Alaknanda basin, steep slopes, fractured rocks, valley deposits and infrastructure corridors as relevant geographic features. Spatial units should be defined consistently so that urban and rural comparisons are not distorted by changing boundaries.

##### **4.3 Satellite data and pre-processing**

Landsat and Sentinel-2 imagery will be selected for cloud-minimized periods. Data preparation will include cloud masking, geometric consistency, image mosaicking if required, and selection of comparable seasonal windows. Where different sensors are used, their spatial resolutions and spectral characteristics will be documented. NRSC Bhuvan products may provide a secondary source for checking land-cover interpretation.

##### **4.4 LULC classification**

The classification scheme will include built-up land, forest/vegetation, agriculture, barren/open land and snow/water or other classes where appropriate. A supervised Random Forest classifier is proposed in the source document. Training samples will be developed using imagery and field observations, and independent validation points will be used to calculate overall accuracy, class-specific accuracy and a confusion matrix. A target accuracy should be treated as a goal, not a guaranteed result.

##### **4.5 Change detection**

Classified maps for the selected years will be compared to quantify net change and transitions between categories. A transition matrix will identify, for example, the amount of agricultural or vegetated land converted to built-up land. Change rates will be calculated using consistent spatial boundaries. Maps will highlight locations where built-up expansion overlaps with likely recharge areas or spring catchments.

##### **4.6 Remote-sensing indicators**

The Normalized Difference Vegetation Index (NDVI) will be used to describe vegetation condition, while a built-up index such as NDBI may be used as a supplementary indicator of built-up surfaces. These indices will not be treated as direct measures of recharge. Their

relationship with groundwater variables will be tested statistically and interpreted in light of topography, geology and land cover.

#### **4.7 Groundwater and climate data**

Groundwater-level bulletins and monitoring records from CGWB will be reviewed for temporal and spatial coverage. Spring discharge measurements, where available, will be recorded with location, date, season and measurement method. Rainfall data from IMD and other official sources will be used to contextualize groundwater fluctuations. Missing observations and differences in measurement timing will be documented rather than filled with unsupported estimates.

#### **4.8 Statistical analysis**

Descriptive statistics will summarize LULC change and groundwater trends. Pearson or Spearman correlation may be used depending on data distributions and sample sizes. Regression models may test whether built-up intensity or vegetation change is associated with groundwater-level variation after considering rainfall, elevation, slope or other available covariates. Spatial autocorrelation and clustered patterns will be checked where sample density supports them.

#### **4.9 Field validation and quality assurance**

Field transects and GPS observations will verify representative LULC classes and document surface conditions. If spring-discharge measurements are collected, repeated observations across seasons will be preferred. Quality assurance will include metadata, consistent projection systems, reproducible processing steps, and a record of classification uncertainty.

#### **4.10 Ethical and practical considerations**

Community interviews or household observations, if undertaken, will require informed consent and appropriate privacy safeguards. Field visits in steep or hazard-prone terrain must follow local safety guidance. The analysis will distinguish measured observations, official records, estimates from the source document and model outputs.

### **5. Hypothesis**

The study will test the following three hypotheses:

H1: Areas experiencing greater growth in built-up land will show lower vegetation cover and altered land-cover composition compared with less urbanized reference areas.

H2: Greater built-up intensity and reduced permeable land cover will be associated with groundwater-level or spring-discharge changes after accounting for seasonal rainfall and relevant geographic factors.

H3: The spatial relationship between urbanization and groundwater response will vary according to geology, slope, landform and the location of recharge areas rather than being uniform throughout Chamoli District.

#### **6. Limitation of Research work (Research Gap)**

The principal research gap is the limited integration of multi-temporal LULC data with groundwater observations at a spatial scale appropriate for individual mountain settlements and spring catchments. Existing mapping may show where built-up land has expanded, but the groundwater consequences remain uncertain without matched monitoring data.

Satellite imagery has limitations in steep Himalayan terrain. Shadow, snow, cloud cover, mixed pixels and seasonal vegetation change can affect classification. Differences in sensor resolution can also complicate direct comparison between years. These uncertainties will be reported through accuracy assessment and sensitivity checks.

Groundwater monitoring records may be sparse or unevenly distributed. Spring discharge is strongly seasonal and can respond to rainfall and temperature as well as land-use change. If measurements are not collected at comparable dates and locations, observed differences cannot be attributed confidently to urbanization.

The source document presents preliminary values for built-up expansion, recharge deficits, groundwater drawdown and spring losses. Because the underlying raw satellite classifications, monitoring series and model files are not included as separate datasets, these numbers should be verified before publication. This paper therefore frames them as reported preliminary indications, not as independently reproduced results.

Hydrological modelling requires reliable estimates of aquifer geometry, hydraulic conductivity, recharge, boundary conditions and extraction. Fractured mountain aquifers are particularly difficult to represent using simplified assumptions. A model such as MODFLOW should be applied only when sufficient hydrogeological inputs and calibration data are available.

The scope is limited to selected corridors within Chamoli rather than all Himalayan districts. Findings may provide a transferable method, but numerical results should not be generalized to other districts without local validation.

## **8. Results and Discussion**

### **8.1 Land-use change reported in the source document**

The supplied document reports an increase in built-up land from approximately 2.1% to 3.5% during 2015–2025 and describes expansion around Joshimath and other urban corridors. It also reports changes in forest, agricultural and open/barren categories. These figures indicate the type of trend the proposed geospatial analysis seeks to quantify, but the classification maps and underlying raster data should be checked before the values are cited as final research findings.

| <b>Indicator in source document</b> | <b>Reported value or trend</b>                    | <b>Interpretation and verification need</b>               |
|-------------------------------------|---------------------------------------------------|-----------------------------------------------------------|
| Built-up land                       | Approximately 2.1% to 3.5% (2015–2025)            | Suggests expansion; verify boundary and class definitions |
| Joshimath urban growth              | About 25% growth reported since 2011              | Verify the area metric and source dataset                 |
| Recharge in urban corridors         | Preliminary deficit reported around 25–30%        | Requires calibrated hydrological evidence                 |
| Groundwater levels                  | Drawdown of 2–5 m reported at hotspots since 2023 | Check stations, dates, seasonal comparability             |

|                  |                                         |                                         |
|------------------|-----------------------------------------|-----------------------------------------|
| Spring discharge | Declines reported in selected locations | Requires repeated seasonal measurements |
|------------------|-----------------------------------------|-----------------------------------------|

## 8.2 Relationship between built-up land and recharge

The proposed mechanism is physically plausible: when permeable ground is replaced by roofs, roads and compacted surfaces, rainfall may be routed rapidly into drainage channels instead of infiltrating near the point of impact. In steep terrain, this process can be intensified by slope and drainage connectivity. However, recharge is not determined by imperviousness alone. Fractures, lithology, talus deposits, soil depth and the position of recharge zones can either amplify or moderate the response. Therefore, any statistical relationship between NDBI and groundwater level should be interpreted as an association unless supported by a well-calibrated hydrological model and additional evidence.

## 8.3 Urban and rural comparison

The source document reports a larger preliminary recharge deficit in urban corridors than in rural basins. A valid comparison should use equivalent hydrological periods and account for differences in elevation, geology, precipitation and aquifer characteristics. Urban and rural areas may not be directly comparable if monitoring stations are concentrated in different landforms. Matching or stratifying observation sites by hydrogeological setting would strengthen the analysis.

## 8.4 Implications for spring systems

Springs are particularly important in mountain communities because they can provide water where conventional supply infrastructure is limited. If construction affects recharge areas or intercepts subsurface flow paths, spring discharge may change. Yet spring intermittency can also reflect rainfall variability, changing snowmelt, landslides or local abstraction. The study should map spring locations and catchments, monitor discharge at repeated intervals and document nearby land-use changes before assigning causes.

## 8.5 Discussion of the research hypotheses

H1 can be tested directly through multi-temporal LULC maps and class-transition matrices. H2 requires paired land-cover and groundwater observations and a model that includes seasonal and geographic covariates. H3 can be tested by stratifying the analysis according to geology, slope and landform, or by using spatial regression where the data support it. The source document's reported correlations and model estimates are preliminary and should not be treated as confirmation of these hypotheses until the underlying data and methods are independently checked.

## 8.6 Planning implications

The findings can inform the identification of recharge-sensitive areas, protection of spring catchments, use of permeable surfaces, careful drainage design and restrictions on development in unstable or hydrologically important locations. Measures should be based on mapped local conditions rather than blanket assumptions. Community knowledge about historical spring behaviour can complement geospatial evidence and help identify sites for monitoring.

## 9. Conclusions

This paper presents a focused framework for studying the relationship between urbanization, land-use/land-cover change and groundwater recharge in Chamoli District. The source document identifies tourism, road development and settlement expansion as important pressures and proposes a multi-temporal remote-sensing and GIS approach.

The central contribution is methodological: LULC mapping, change detection, groundwater monitoring, climate data and field validation should be combined in a common spatial framework. Such integration can identify where urban growth overlaps with potential recharge areas and where monitoring should be prioritized.

Reported preliminary figures suggest that built-up expansion and groundwater stress may coincide in selected urban corridors, but the underlying classifications, monitoring data and model assumptions need verification before these figures are treated as definitive. A transparent account of uncertainty is essential for a credible scientific paper.

Future work should prioritize matched seasonal groundwater observations, repeated spring-discharge measurement, accurate mapping of land-cover transitions and hydrogeological model calibration. The resulting evidence can support sustainable development in mountain towns while recognizing that groundwater response is shaped by climate, geology, topography and human activity together.

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