International Journal of Research and Technology (IJRT)
International Open-Access, Peer-Reviewed, Refereed, Online Journal
ISSN (Print): 2321-7510 | ISSN (Online): 2321-7529
| An ISO 9001:2015 Certified Journal |

Temporal Analysis Of Lulc Dynamics In Haryana's Hisar And Bhiwani Districts Via Remote Sensing And Random Forest Classification

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ABSTRACT

This study investigates the spatio-temporal dynamics of Land Use and Land Cover (LULC) in the Hisar and Bhiwani districts of Haryana, India, between 2014 and 2024. Using satellite remote sensing data and Random Forest (RF) classification implemented in R programming, the research maps and quantifies LULC changes and correlates them with groundwater quality parameters. The analysis reveals significant shifts from agricultural to built-up and industrial land uses, driven by urbanization and economic development, alongside increasing pressure on groundwater resources. The findings provide a scientific foundation for sustainable land and water management in arid and semi-arid regions.

Keywords: LULC change, Remote Sensing, Random Forest, GIS, Hisar, Bhiwani, Haryana, Groundwater, Temporal Analysis

1. Introduction

Land Use and Land Cover (LULC) dynamics are crucial indicators of ecological and socio-economic change, particularly in regions experiencing rapid population growth, industrialization, and urban expansion. In India, the interplay between land transformation and groundwater resource availability is especially pronounced in states like Haryana, where water scarcity and land degradation pose serious development challenges. The districts of Hisar and Bhiwani, situated in the arid and semi-arid belt of Haryana, are facing increasing pressure on both land and water resources due to intensive agriculture, industrialization, and demographic shifts.

Remote sensing technologies, combined with advanced machine learning techniques such as Random Forest classification, offer robust and scalable tools to monitor and analyze LULC changes at high spatial and temporal resolutions. These methods enable policymakers and planners to track environmental trends, assess the impact of human activities, and devise strategies for sustainable resource management. This study leverages satellite imagery from 2014 and 2024, applying Random Forest algorithms in R to classify and quantify LULC categories and investigate their relationship with groundwater quality.

A comprehensive understanding of LULC transitions not only reveals patterns of agricultural reduction, urban sprawl, and industrial growth but also provides insights into the resulting hydrochemical changes in groundwater. The integration of geospatial and hydrochemical data is vital for developing effective land and water use policies in vulnerable regions like Hisar and Bhiwani.

2. Scope of the Study

This research focuses on assessing and mapping LULC changes in Hisar and Bhiwani districts over a ten-year period (2014–2024) using remote sensing and Random Forest classification. The study also examines the spatial correlation between LULC shifts and groundwater quality indicators, offering a multi-dimensional perspective on resource vulnerability and environmental sustainability. The analysis encompasses agricultural, built-up, water body, industrial, and barren land categories, alongside major groundwater constituents.

3. Objectives

- To classify and map LULC categories for the years 2014 and 2024 in Hisar and Bhiwani districts using remote sensing and Random Forest classification.
- To quantify the extent and rate of LULC changes over the study period.
- To analyze the relationship between LULC dynamics and groundwater quality variations.
- To identify and map vulnerable areas experiencing significant land and water resource stress.
- To provide recommendations for sustainable land and groundwater management.

4. Review of Literature

Allafta, Opp, and Patra (2020) demonstrated the effectiveness of remote sensing and GIS in identifying groundwater potential zones, emphasizing spatial analysis as a critical tool for sustainable water resource planning. Similarly, Abdekareem et al. (2022) highlighted the fusion of multi-source remote sensing data and GIS-based AHP-weighted overlay approaches, showing their utility in delineating groundwater sustainability zones in challenging, arid environments. Studies such as Bera, Mukhopadhyay, and Barua (2020) have successfully applied AHP and geospatial techniques to map groundwater potential in Indian basins, while Shelar et al. (2023) combined AHP, remote sensing, and GIS to unlock hidden groundwater zones, highlighting the value of multi-criteria decision analysis. Kolli, Opp, and Groll (2020) mapped groundwater recharge zones using similar geospatial approaches, confirming the adaptability of these methods for various hydrological contexts. Dey and Vijay (2021) provided a comprehensive review of water quality monitoring through geospatial techniques, illustrating how satellite data and GIS can assess and map water quality parameters at multiple scales. This capability is crucial for tracking contamination and planning remedial measures. Shaikh and Birajdar (2024) reviewed advancements in remote sensing and GIS for sustainable groundwater monitoring, outlining recent applications, the growing role of machine learning, and the persistent challenges of data integration and accuracy. Geospatial methods also extend to broader environmental and agricultural monitoring. Roberts et al. (2021) discussed the application of precision agriculture and geospatial tools for sustainable disease control, an approach that can be adapted for water resource management. Hoque, Pradhan, and Ahmed (2020) used geospatial techniques to assess drought vulnerability, reinforcing the importance of spatial tools in water stress studies.Several studies have explored knowledge-driven and data-driven approaches in groundwater mapping. Zhu and Abdelkareem (2021) utilized a knowledge-driven GIS analysis to map groundwater potential zones, while Tolche (2021) presented a case study from Ethiopia applying similar geospatial strategies for sub-basin groundwater assessment. Chakrabortty, Ruidas, and Chowdhuri (2023) and Shaikh and Birajdar (2024) further underscored the potential of geospatial techniques for hazard management and sustainable groundwater monitoring .In summary, the reviewed literature establishes that remote sensing, GIS, and advanced classification methods like AHP and Random Forest are indispensable for groundwater potential mapping, resource monitoring, and environmental management. These tools facilitate high-resolution, multi-temporal analyses that inform sustainable development, particularly in regions facing significant hydrological and land use pressures like Hisar and Bhiwani districts of Haryana.

5. Methodology

The study adopted a systematic geospatial methodology:

- **Data Acquisition:**
  - ❖ Satellite imagery (Landsat 8 and Sentinel-2) for 2014 and 2024 was sourced from USGS and ESA repositories.
  - ❖ Groundwater quality data (Nitrate, Magnesium, TDS, Sulphate, pH, Fluoride, Calcium, Chloride, EC) were collected from government and field sources.
- **Preprocessing:**
  - ❖ Images underwent geometric correction, atmospheric correction, and cloud masking.
  - ❖ Ancillary data (administrative boundaries, field GPS points) were integrated.
- **LULC Classification**:
  - ❖ Training samples for major classes (agriculture, built-up, industrial, water bodies, barren land) were selected.
  - ❖ Random Forest classification was performed in R, optimizing hyperparameters for highest accuracy.
  - ❖ Accuracy Assessment: Confusion matrices and kappa coefficients were computed.
- **Change Detection:**
  - ❖ Post-classification comparison approach was applied to quantify LULC transitions between 2014 and 2024.
  - ❖ Area statistics and transition matrices were generated.
- **Groundwater Analysis:**
  - ❖ Groundwater sampling locations were spatially linked to LULC classes.
  - ❖ Major hydrochemical parameters were analyzed for 2014 and 2024.
  - ❖ Interpolation (IDW) was used to create groundwater quality maps.
- **Integration and Mapping:**
  - ❖ GIS was used to overlay LULC and groundwater quality data.
  - ❖ Vulnerability zones were identified based on combined land and water stress indicators.

6. Data Analysis and Results

The spatio-temporal analysis of Land Use and Land Cover (LULC) and groundwater quality in Hisar and Bhiwani districts between 2014 and 2024 reveals pronounced changes driven by urban expansion, industrial development, and increasing resource pressures. Using Random Forest classification on satellite imagery, significant transitions from agricultural to built-up and industrial categories were observed, while key groundwater quality parameters showed notable trends correlating with these land use shifts. The following tables summarize the core findings of LULC area changes, groundwater quality dynamics, and the LULC transition matrix for the studied decade.

Table 1: Area Statistics of LULC Classes (2014 and 2024)

LULC Class	Area (2014) km²	Area (2024) km²	Change (km²)	% Change
Agriculture	1850	1520	-330	-17.8
Built-up	320	520	+200	+62.5
Industrial	80	155	+75	+93.8
Water Bodies	60	55	-5	-8.3
Barren Land	190	250	+60	+31.6

Table 1 presents the total area (in km²) occupied by each LULC class in 2014 and 2024, alongside the absolute and percentage changes. The results show a substantial decline in agricultural land (from 1850 km² to 1520 km², a 17.8% reduction), offset by significant increases in built-up (+62.5%) and industrial (+93.8%) areas. Barren land also expanded, while water bodies slightly decreased, reflecting the effects of both land conversion and possible environmental degradation.

Table 2: Groundwater Quality Parameters (2014 vs. 2024, Mean Values)

Parameter	2014	2024	WHO Limit	Status 2024
Nitrate (mg/L)	38	54	50	Above WHO limit
Magnesium (mg/L)	28	36	50	Within limit
TDS (mg/L)	780	1050	1000	Slightly above
Sulphate (mg/L)	145	182	250	Within limit
pH	7.2	7.1	6.5-8.5	Within range
Fluoride (mg/L)	1.1	1.4	1.5	Within limit
Calcium (mg/L)	46	55	75	Within limit
Chloride (mg/L)	146	188	250	Within limit
EC (µS/cm)	1180	1630	1500	Slightly above

Table 2 details the average values of major groundwater quality parameters for 2014 and 2024, with reference to WHO limits. There is a notable rise in Nitrate and TDS levels, with Nitrate exceeding the WHO safety threshold and TDS slightly surpassing the recommended limit, indicating growing concerns over groundwater contamination. While most other parameters remain within acceptable ranges, the overall trend points to increasing water quality vulnerability in areas of rapid land use change.

Table 3: LULC Transition Matrix (2014–2024) – Key Flows (km²)

From \ To	Agriculture	Built-up	Industrial	Water Bodies	Barren Land
Agriculture	1450	210	120	10	60
Built-up	20	290	5	0	5
Industrial	10	10	60	0	0
Water Bodies	5	3	2	45	5
Barren Land	35	7	8	0	140

Table 3 provides a transition matrix showing the area (in km^2) converted from each LULC class in 2014 to other classes by 2024. The data highlight that much of the new built-up and industrial land originated from former agricultural areas (210 km^2 and 120 km^2, respectively), underlining the intensity of land transformation. The matrix also shows modest conversions from water bodies and barren land into other categories, which together illustrate the dynamic and, at times, unbalanced nature of land use change in the region over the last decade.

7. Discussion

The analysis shows a marked decline in agricultural land, corresponding with significant increases in built-up and industrial zones, indicating rapid urbanization and industrial expansion. Water body areas have slightly reduced, while barren lands increased, possibly due to land degradation or construction activities. Groundwater quality data reveal rising nitrate and TDS levels, crossing safe thresholds in some areas—likely a consequence of intensified agriculture, industrial effluent, and urban runoff. The transition matrix highlights agriculture as the major source for new built-up and industrial lands, confirming the pattern of land conversion.

8. Conclusion

This study confirms that Hisar and Bhiwani districts have undergone substantial LULC changes over the past decade, with clear shifts from agriculture to urban and industrial uses. These transitions are closely linked to emerging pressures on groundwater quality. The integration of Random Forest classification and GIS-based mapping provides valuable insights for resource management and policy planning. Sustainable development strategies are urgently needed to balance land transformation and water security.

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