Land use Land cover classification using Landsat satellite data of the Nani watershed, Maharashtra

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ABSTRACT

This paper investigates the land use and land cover (LULC) dynamics in the Nani watershed, Maharashtra, a semi-arid region within the Deccan trap. Understanding changes in land use and land cover (LULC) is pivotal for effective environmental conservation, sustainable resource management, and informed land use planning. Leveraging Landsat 4-5, 7, and 8 satellite imagery spanning 1991, 2001, 2014, and 2021, this study delves into the evolution of LULC in the area. Remote sensing and GIS technologies play a crucial role in spatial analysis, enabling precise monitoring of land cover changes. Utilizing a supervised approach employing maximum likelihood classification, LULC maps were generated through the use of training samples. The study area was segmented into four primary land cover types: settlement, vegetation/agricultural area, barren land, and water body. Over the last three decades, notable shifts in LULC have been observed. Settlements, vegetation/agricultural areas, and water bodies exhibited an increase, while barren land saw a decline. These findings underscore the dynamic nature of land use patterns and highlight the importance of continual monitoring for informed decision-making in land management strategies.

Keywords: LULC, Landsat images, Supervised classification, Remote sensing, GIS.

INTRODUCTION

Understanding the dynamics of land use and land cover (LULC) is fundamental for comprehending the complex interactions between human activities and the natural environment. Land use encompasses the activities conducted on and around land, while land cover pertains to physical features such as vegetation and artificial constructions. Satellite data has emerged as a powerful tool for providing accurate, real-time insights into the spatial characteristics of the Earth's surface (Lo, 1986; Burley, 1961; P. S. Roy et al., 2008).

Remote sensing and Geographic Information Systems (GIS) offer rapid and efficient means to classify and map LULC changes across temporal and spatial scales. The integration of temporal and spatial data within GIS facilitates the quantification of these changes, crucial for understanding the interplay between natural processes and human interventions. Digital classification techniques, particularly supervised and unsupervised methods, are widely utilized for mapping land cover categories and their distributions (Loveland et al., 2006).

LULC change analysis aims to elucidate the spatial distribution, rate, and drivers of changes occurring in land cover types. It also endeavors to forecast future patterns through simulation modeling, often extrapolating historical data to predict future scenarios (Brown et al., 2000).

The advent of remote sensing technology has revolutionized the field of land use and land cover (LULC) monitoring by providing continuous observations and synoptic views of the Earth's surface from space. This capability has significantly enhanced our ability to detect and analyze changes in land cover patterns over time. Among the various remote sensing platforms, Landsat imagery has emerged as a cornerstone in LULC monitoring efforts.

Since its inception in 1972, Landsat satellites have been instrumental in providing a wealth of optical remote sensing data, making them indispensable tools for monitoring LULC changes. Numerous studies have underscored the pivotal role of Landsat imagery in this regard, with researchers across various disciplines leveraging its capabilities for comprehensive LULC assessments (Helmer et al., 2000; Gao and Zhang, 2009; Gumma et al., 2011; Jia et al., 2014; Kumar et al., 2016).

The Landsat series of satellites, including Landsat TM (Thematic Mapper), Landsat ETM+ (Enhanced Thematic Mapper Plus), and Landsat OLI (Operational Land Imager), have collectively provided a wealth of data characterized by moderate spatial resolution ranging from 15 meters to 60 meters. This moderate spatial resolution strikes a balance between detail and coverage, enabling the detection and analysis of LULC changes at both regional and local scales.

The extensive utilization of Landsat TM/ETM+/OLI data underscores its versatility and reliability in detecting and analyzing LULC changes across diverse landscapes and ecosystems. Whether it's monitoring deforestation, assessing urban expansion, or evaluating agricultural dynamics, Landsat imagery continues to serve as a cornerstone in our efforts to understand and manage Earth's changing land cover.

The Nani watershed in Maharashtra, India, situated within the semi-arid Deccan trap region, has been subject to remote sensing monitoring to assess various land characteristics, including barren land, cropping patterns, settlement, vegetation, and water resources. This study utilizes Landsat data spanning 1991, 2001, 2014, and 2021, employing a post-classification method to quantify LULC changes. However, it excludes the year 2011 data (Landsat 7 ETM) due to line stripping errors.

OBJECTIVE

The primary objective of this research is to analyze and identify the patterns of land use and land cover changes in the Nani watershed during the specified period.

STUDY AREA

The study area encompasses the watershed of the Nani River, spanning approximately 489.82 square kilometers. Situated across two districts, Satara and Sangli, the Nani River serves as a right-bank tributary of the Yerla River. Originating from the Shambhu Mahadeo hill range near Aundh town in Satara, the Nani River flows in a north to south-east direction before converging with the Yerla River at Shivani village in Kadegaon Taluka, Sangli District.

The geological composition of the study area is primarily basaltic. Geographically, the watershed extends from 17°10' N to 17°35' N latitude and 74°10' E to 74°25' E longitude (refer to Figure 1). With an annual rainfall ranging between 300-400mm, the region experiences a semi-arid climate. Agriculture serves as the primary occupation within the basin area, engaging over 70 percent of the local population.

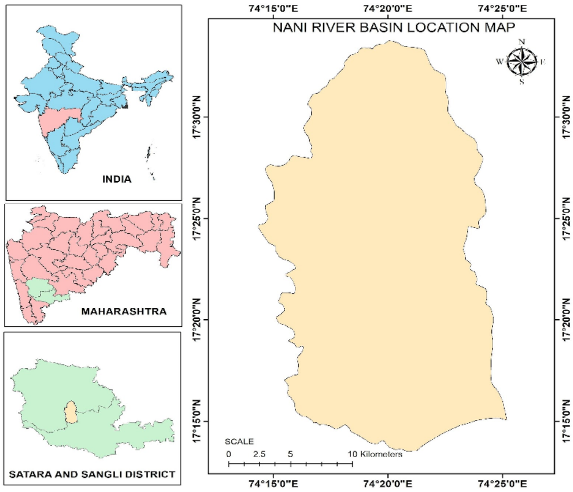

Figure 1. Location Map of the Nani watershed.

MATERIALS AND METHODOLOGY

For the evaluation of land use and land cover (LULC) changes, it is imperative to obtain data from at least two different periods for comparative analysis. In this study, Landsat 4-5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper (ETM), and Landsat 8 Operational Land Imager (OLI) data in GeoTIFF (Level-2) format were acquired from the USGS Earth Explorer platform http://earthexplorer.usgs.gov/ (refer to Table 1). The acquired images underwent further processing, including rectification and assignment of Universal Transverse Mercator (UTM) Zone 43N projection with the WGS-84 datum. ArcGIS 10.4 software was employed for image processing and statistical spatial analysis.

Supervised classification was utilized to detect changes in LULC patterns within the study area. The Maximum Likelihood Classifier (MLC) was employed, which operates on the principle that pixels of unknown class membership are assigned to the class with the highest likelihood of membership. This classification method relies on information derived from a set of signature files and is widely used for remotely sensed data classification.

LANDSAT DATA

Four scenes of Landsat data (Table 1) were used for LULC classification. The swath width of Landsat data is 185 km (30M resolution) and the revisit time of 16 days time interval.

Scene No.	Year	Satellite Series	Sensor	Date of Acquisition (yyyy-mm-dd)	Path No.	Row No.	Band Numbers
1	1991	Landsat 4-5	TM	1991-12-02	147	048	Band 1-7
2	2001	Landsat 7	ETM	2001-11-03	147	048	Band 1-8
3	2014	Landsat 8	OLI	2014-10-14	147	048	Band 1-11
4	2021	Landsat 8	OLI	2021-10-30	147	048	Band 1-11

Table 1. Landsat data specification.

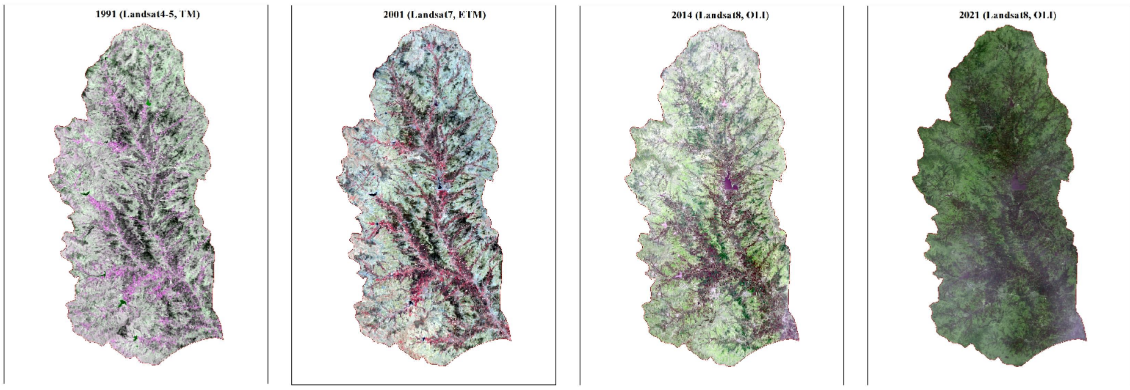

Figure 2. The Landsat images (FCC) are used for Land use and land cover classification.

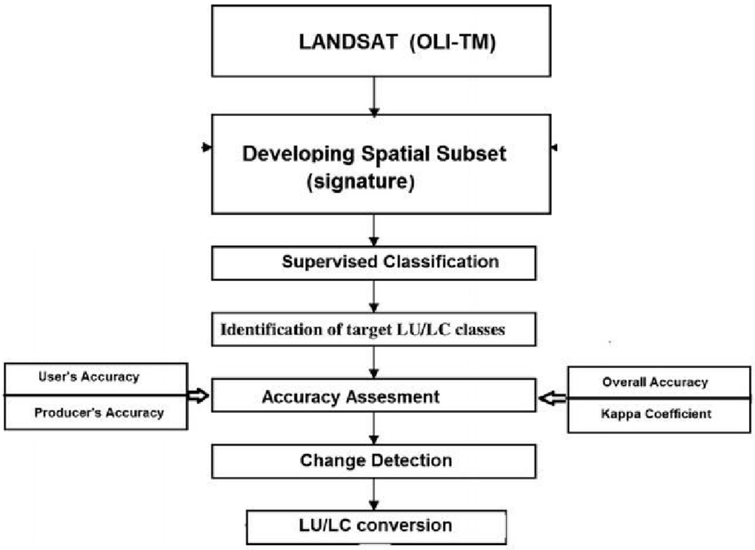

Figure 3: Methodology Chart

METHODS

In this study, a supervised classification approach was employed for remote sensing image classification, utilizing both spectral and texture features. The classification process utilized the maximum likelihood method to categorize land use and land cover (LULC) types into five distinct categories. The classification scheme encompassed settlement areas, agriculture/vegetation areas, barren land, and water bodies. To generate accurate classification results, training and validation samples were collected through visual interpretation.

Ensuring the reliability of classification outcomes necessitates an accuracy assessment step. This assessment involved the utilization of an error matrix, which serves as a comparison array depicting the pixel numbers of specific categories and their corresponding ground-truth values.

Various accuracy indicators were computed from the error matrix to evaluate the classification performance. These indicators included overall accuracy, product accuracy, customer accuracy, and Kappa statistics, calculated for each classification result. Following the accuracy assessment, a change detection procedure was implemented based on the classification results obtained at three different time steps. This procedure facilitated the identification of temporal changes in LULC patterns. ArcGIS 10.4 software was utilized for exporting classification maps and calculating change statistics, providing a comprehensive platform for the analysis and interpretation of LULC dynamics over time.

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RESULTS AND DISCUSSION

The classification outcomes for the years 1991, 2001, 2014, and 2021 are visually depicted in Figures 2 and 4, showcasing the spatial distribution of various land use and land cover (LULC) categories across the study area. To ensure the reliability and accuracy of these classification results, a rigorous accuracy assessment procedure was conducted. Random sampling methodology was employed to systematically select representative areas within each classification image for evaluation. These sampled areas were then visually inspected and compared against ground-truth data to determine the accuracy of the classification outcomes.

The accuracy assessment results, derived from this meticulous process, provide valuable insights into the reliability of each classification image. The overall classification accuracy, which serves as a comprehensive measure of the classification performance, was found to be exceptionally high across all examined years. Specifically, the overall classification accuracy for the 1991 image stood at an impressive 91.79%, indicating a high degree of fidelity in delineating LULC categories. Similarly, the classification accuracies for the subsequent years were 90.11% in 2001, 87.57% in 2014, and 92.12% in 2021, further attesting to the robustness and consistency of the classification outcomes.

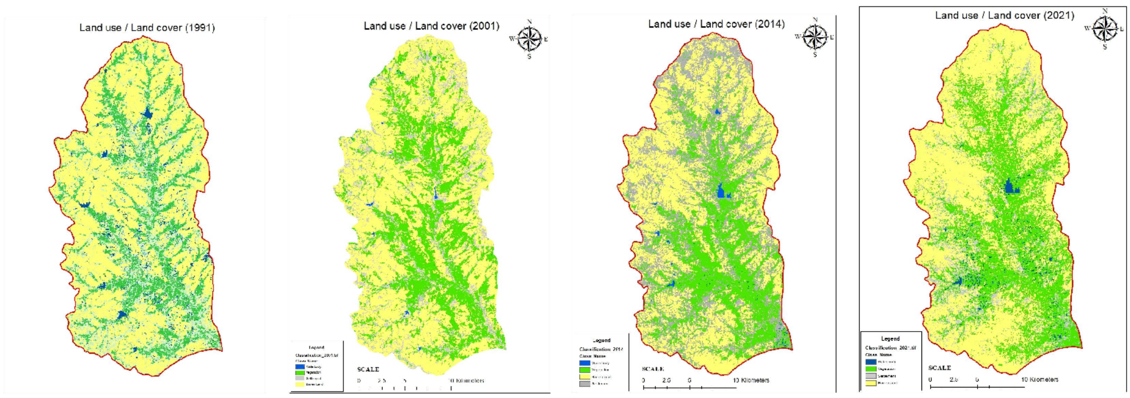

Figure 4. The land use and land cover classification result in 1991, 2001, 2014, and 2021.

These accuracy assessment results not only validate the reliability of the classification methodology employed but also provide valuable insights into the temporal dynamics of LULC patterns within the study area. Such high accuracy levels underscore the utility of remote sensing data and classification techniques in effectively monitoring and analyzing land cover changes over time, thereby facilitating informed decision-making in land management and resource planning endeavors.

Land use / Land cover Class	1991	2001	2014	2021
Waterbody	2.38	3.12	4.01	4.41
Vegetation	23.09	28.86	29.87	30.13
Settlement	7.40	8.26	9.57	10.98
Barren land	67.13	59.76	56.55	54.49

Table 2. Summary of Landsat classification area in percentage.

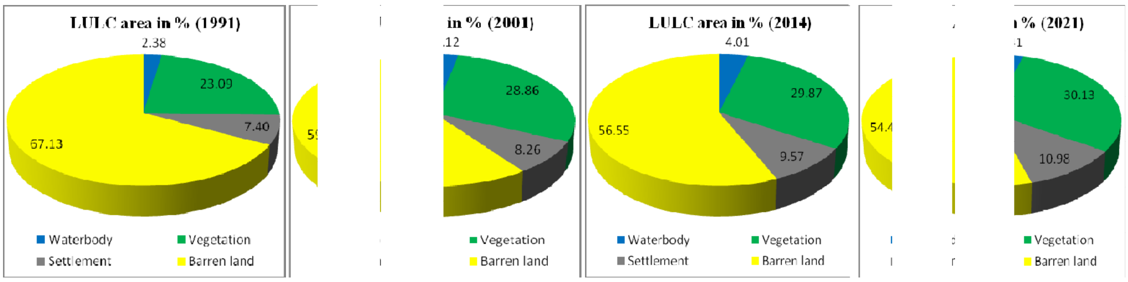

Figure 5. The land use and land cover classification area in % (1991, 2001, 2014, and 2021).

The LULC changes in the Nani watershed are illustrated in Figure 5. The areas of vegetation/agriculture and built-up have been increasing since 1991, whereas areas of barren land have been decreasing. The area of the water body changes over time due to monsoon rainfall in the study area. Corresponding statistic values of waterbodies are listed in Table 2.

It can be seen that the vegetation/agricultural land area has increased from 23.09 % in 1991 to 30.13 % in 2014 showing that 7.04% area increase under agriculture/vegetation. In contrast, there is little change in the area of water bodies (2.38% to 4.41%) due to increased soil and water conservation structures in the study area under various government schemes like drought-prone area program, Jalyukta Shivar yojna, samrudha gav yojna, MANAREGA, etc.. The area of barren land decreases due to increasing area under agricultural land.

CONCLUSION

Based on the comprehensive analysis of the classification results and the dynamic changes observed from 1991 to 2021, several significant conclusions emerge, shedding light on the evolving landscape of the study area. Firstly, the expansion of vegetation/agricultural areas stands out prominently, attributable to advancements in irrigation facilities within the region. This expansion underscores the proactive measures undertaken to enhance agricultural productivity and meet the growing demands of the burgeoning population. Moreover, the gradual decline in barren land areas over the past few decades is noteworthy, mirroring the concerted efforts aimed at land reclamation and rehabilitation. This trend aligns with sustainable land management practices aimed at mitigating soil degradation and promoting ecological resilience. Simultaneously, the expansion of settlement areas over both space and time signifies the demographic shifts and urbanization trends witnessed in the study area. The burgeoning population, coupled with socio-economic factors, has led to the proliferation of residential clusters and infrastructural developments. Furthermore, the notable changes observed in the water body areas signify significant improvements, largely attributed to the implementation of various soil and water conservation structures. Government schemes and programs aimed at enhancing water resource management have played a pivotal role in augmenting the availability and sustainability of water bodies within the study area. Overall, these findings underscore the dynamic interplay between natural processes and anthropogenic interventions, emphasizing the need for proactive land use planning and sustainable resource management strategies to ensure the long-term environmental and socio-economic viability of the region.

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