Monitoring Land Use and Land Cover change through earth observation datasets and metric analysis in the Barabanki District, Uttar Pradesh, India

Abstract

Land use and cover is the key environmental factors influencing the landscape. Changes in their composition are dynamic, widespread, and accelerating, driven primarily by natural phenomena and human activities. Timely and accurate information is a major challenge when assessing any landscape for future development. Remote sensing data, with its synoptic and multi-temporal characteristics, effectively bridges the gap by offering timely, accurate, and reliable information. The present study aimed to evaluate LULC change using Landsat satellite data within the Nindoora and Fatehpur blocks of Barabanki district, Lucknow, Uttar Pradesh. The study area covers approximately 59,498.78 ha. Landsat scenes recorded on November 10, 2013, and October 15, 2023, were acquired from the USGS website and subjected to geometric and radiometric corrections prior to analysis. The on-screen visual interpretation technique was employed to classify the satellite data into various land cover classes. The analysis identified five primary land use and land cover (LULC) classes: Water Bodies, Crops, Trees, Bare Ground, Rangeland, and Built-up Areas. In year 2013 Cropland emerged as the dominant land cover, occupying 88.34% of the total area followed by Built-up areas constitute 8.83% of the land. Whereas in year 2023 cropland occupy approximately 86.47% and Built-up areas constitute 10.70% of the land. This study underscores the complex interplay between agricultural productivity and urban expansion in Barabanki. These insights are essential for guiding future urban and environmental planning efforts in the region, offering a critical foundation for developing strategies that support both economic development and environmental sustainability.

Keywords: Land Use, landscape, LULC, Image Acquisitions

Introduction

Changes in land use and land cover (LULC) within any landscape result from a combination of natural processes, such as erosion and climate shifts along with human activities like urbanization, deforestation, and infrastructure development [1]. Together, these factors change the environment, altering its ecological balance and land characteristics over time.

These transformations can have significant environmental repercussions, including biodiversity loss, soil degradation, altered water cycles, and changes in greenhouse gas emissions [2]. For instance, urban sprawl can lead to habitat fragmentation and increased runoff, while deforestation contributes to carbon emissions and loss of biodiversity [3]. Thus, monitoring and analyzing these changes is critical for informing policy decisions, managing natural resources, and implementing effective conservation strategies [4].

Though, it is a great challenge to understand the natural as well as human impact of change in landscaper and its function. Though, there are many methods to understand the change in landscape and its function [5]. However, the use of geospatial technologies provides an excellent platform to collect, store and analyse the change in land use and land cover with a realistic way, low cost, and at time [6,7]. The Landsat program, operational since 1972, has provided an unparalleled continuous record of the Earth's surface, making it a valuable resource for long-term environmental monitoring and LULC studies [8]. The enhanced capabilities of Landsat 8 have made it a critical asset for LULC change detection, particularly in areas undergoing rapid urbanization, deforestation, and agricultural expansion [9]. Previous studies have demonstrated the significance of land use and land cover change and its impact [10,11,12,13].

The study area is characterized by a complex interplay of anthropogenic and natural factors, making it a significant challenge for scientific community to understand the human impact on the natural landscape. Although the study area lies in the doab region between the Ganga and Yamuna rivers, the inhabitants of the district have historically faced challenges with agricultural practices due to flooding, waterlogging, and soil salinity. Therefore, monitoring Land Use Land Cover (LULC) changes in these regions is essential for providing timely data on flood and drought occurrences, as well as for effective water resource management and optimization of agricultural practices. This article focuses on detecting and analyzing LULC changes in Nindoora and Fatehpur block of Barabanki District by utilizing Landsat satellite imagery to assess change over ten years.

2. Materials and Methods

2.1 Study Area

District Barabanki lies between latitudes 26° 30′ North and 27° 19′ North and longitudes 80° 58′ East and 81° 55′ East. It is surrounded by Faizabad district in the east, Gonda and Bahraich districts in the northeast, Sitapur district in the northwest, Lucknow district in the west, Rae Bareli district in the south, and Amethi district in the southeast. The river Ghaghra forms the northeastern boundary, separating Barabanki from Bahraich and Gonda. The area of the district is 389,150 ha. This area may vary from year to year due to slight changes in the course of the river Ghaghra, which can noticeably affect the overall area of the district. Barabanki is well-fed by the rivers Ghaghra, Gomti, and Kalyani with their tributaries for most of the year, though some dry out during the summer and cause flooding during the rainy season, the district forms part of the Gangetic Plain, known for its predominantly flat terrain and high fertility.

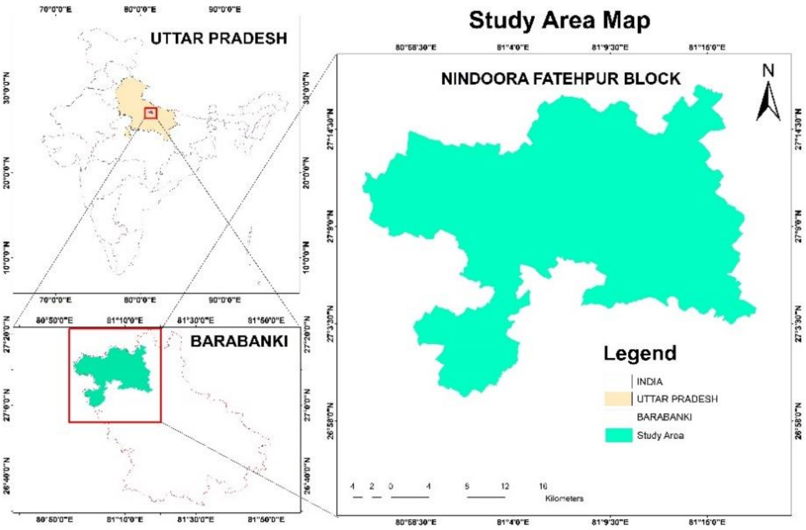

Fig1. Location map of the study area

This region is notably impacted by seasonal flooding due to its proximity to the Ganges River system, which includes the Ghaghara River a major tributary that traverses Barabanki and significantly enhances its agricultural productivity. The district experiences a humid subtropical climate, characterized by intense heat during the summer months with temperatures often surpassing 40°C, a pronounced monsoon season, and cooler winters with temperatures ranging between 5°C and 20°C. These climatic and hydrological conditions underscore the district's environmental dynamics, influencing its land use and socio-economic activities.

2.2 Image Acquisitions and pre-processing

Ortho-rectified Landsat satellite images of month/year: 21st October 2013, 30th October 2023, were down loaded from USGS web portal (USGS; http://www.usgs.gov/in) and detailed data sets specifications are given in Table 1. The image is already been geometrically corrected, however, Top of Atmospheric (TOA) calibration for both the image was performed using the Landsat 8 user handbook to get the data free from any atmospheric attenuations. The Conversion of DN to reflectance was carried out using the formula as follows

$$\rho\lambda' = M\rho Q_{cal} + A\rho \quad \ldots\ldots\ldots\ldots (1)$$

Where, $\rho\lambda'$ = TOA planetary reflectance, $M\rho$=Band-specific multiplicative rescaling factor, $A\rho$ = Band-specific additive rescaling factor and Qcal = Quantized and calibrated standard product pixel values (DN).

TOA reflectance with a correction for the sun angle is given as eqn. (2):

$$\rho\lambda = [\rho\lambda'/\cos(\theta SZ)] + [\rho\lambda'/\sin(\theta SE)] \quad \ldots\ldots\ldots (2)$$

Where, $\rho\lambda$ = TOA planetary reflectance, ϴSE = Local sun elevation angle. ϴSZ = Local solar zenith angle; ϴSZ = 90°- ϴSE. All the information is provided in the metadata.

Table-1 Details of satellite images

Satellite and Sensor	Date/year	Path/row	Band used	Spatial Resolution (m)
Landsat 8/OLI	21th October 2013 & 30th October 2023	143/41,144/41	2,3,4,5,6,7	30

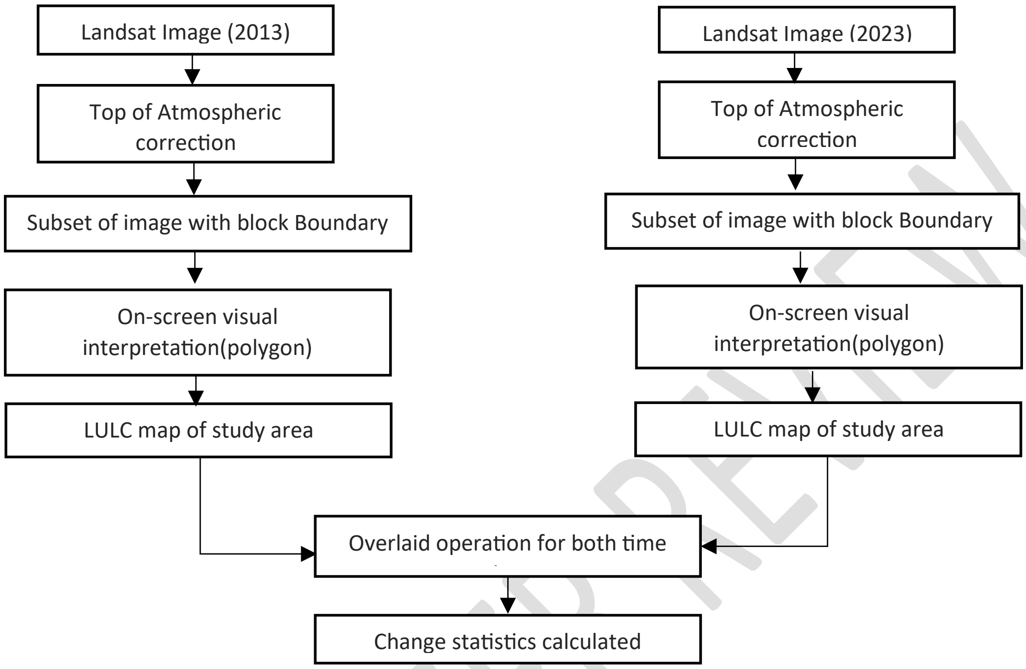

Fig.2 Flow diagram of methodology

2.3 Classification of Land Use Land Cover

The LULC maps were prepared by using on-screen visual interpretation techniques based on interpretation key i.e. shape, size, tone, pattern, texture, association, and shadow. Interpretation key of different land cover classes of the study area has been shown in the Table 2. The interpreted polygon layers representing land cover classes for both time periods were overlaid to identify changes in land cover. This process involved comparing the spatial extent and boundaries of each class between the two periods. By overlaying these layers, areas of change were identified, and change statistics were calculated. This technique was found more efficient, convenient and reliable for mapping and detecting changes in small areas. The entire process was carried out using ArcGIS Pro software and flow diagram of shown in the Fig.2. Field visit has been conducted on 11th December 2022 and 23th June 2023 to understand the study area whereas 23th October 2023 field visit has been conducted to check the accuracy of the classified image (Fig.3).

Table 2: Interpretation key used in this study

S. N	LU/LC Category	Tone	Size	Shape	Texture	Pattern	Association
1	Built up Land	bluish green	Small to big	Irregular	Coarse & mottled	Clustered to scattered	Surrounded by agricultural lands, forest cover, wastelands, rivers, roads, rail, etc.
2	Waterbody	Bright red dull red	Small to big	Regular to irregular	Medium to smooth	Contiguous to noncontiguous	Proximity to rivers/canals/streams and settlements and lowland areas
3	Bare ground	Greenish blue	Small to big	Regular to irregular	Medium to smooth	Contiguous to noncontiguous	Amidst or near cropland
4	Cropland	Different tones of red	Varying in size	Irregular	Smooth to medium depending on crown	Contiguous to noncontiguous	With different agriculture types and species in undulating areas
5	Rangeland	Red to Dark red	Varying in size	Regular to irregular	coarse	Contiguous to noncontiguous	Forest fringes and amidst forest areas
6	Tree clad areas	Red to Dark red	Varying in size	Regular to irregular	coarse	Contiguous to noncontiguous	Near villages and Forest areas

Fig 3. Field visit of study area

3. Result and discussion

The research conducted focused on detecting LULC changes in Barabanki district using GIS techniques to understand land cover patterns in the last ten years. The study aimed to understand the evolution of urban environments within the district over the decade. The findings revealed significant urban expansion along the district's peripheries, leading to substantial shifts in LULC patterns. This urban development has introduced notable diversity in land cover types, reflecting the impact of urbanization on the region's landscape.

3.1 Spatiotemporal analysis of land use and Land Cover Changes

The analysis highlights the region's LULC change over the past ten years, from 2013 to 2023. The LULC maps for both the years have been visually classified into six broad land use categories that is water bodies, crops, trees, bare ground, rangeland, and built-up areas.

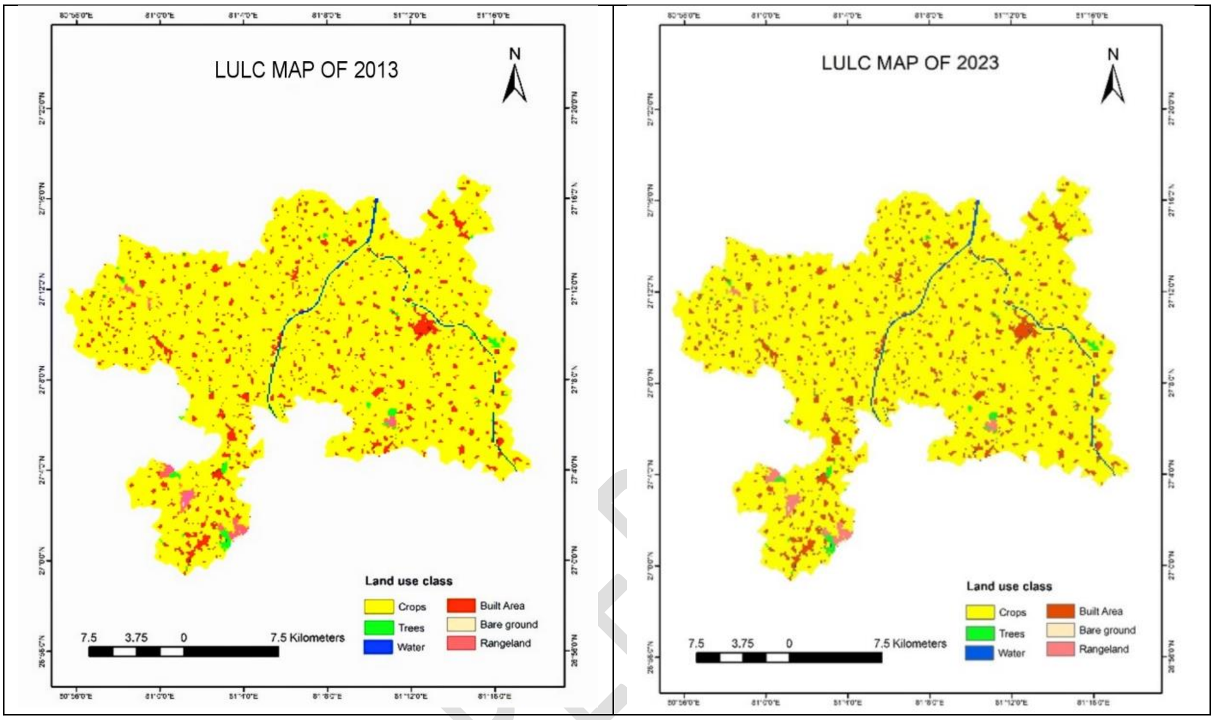

Fig. 4 LULC maps of 2013 and 2023

In 2013, the area was predominantly agriculture land occupying 88.34% of the land, indicating significant agricultural activity and potential for further development. Built-up areas accounted 8.83% of the study area which reflect moderate urbanization and ongoing infrastructural development. Rangeland and water bodies covered 1.01% and 0.98% of the area, respectively, supporting livestock and contributing to water resources. Tree cover and bare ground were minimal, representing 0.80% and 0.05% of the total area, indicating limited forested regions and stable land conditions.

In year 2023, the land use distribution has shifted slightly, with agricultural activities still dominant covering 86.47% of the land. Built-up areas increased to 10.70%, signifying significant urbanization and infrastructural growth. Tree cover expanded slightly to 1.05%, while rangeland and water bodies accounted for 0.76% and 1.02%, respectively, continuing to play crucial roles in biodiversity, livestock support, and water resource provision. The bare ground remained minimal, decreasing to just 0.01%, suggesting stable and well-managed land conditions. The area statistics for 2013 and 2023 are presented in Table 3 and classified maps were shown in Fig.4.

Table 3: Area statistics of different land use/land cover classes of different years.

Land use	2013		2023	
	Area (ha)	**Area (%)**	**Area (ha)**	**Area (%)**
Crop	52559.30	88.34	51449.9	86.47
Tree	474.35	0.80	622.22	1.05
Range land	601.50	1.01	449.35	0.76
Water	582.14	0.98	605.53	1.02
Bare Ground	30.43	0.05	3.86	0.01
Built Area	5251.06	8.83	6367.93	10.70
Total	59498.78	100	59498.78	100

Table 4: Change matrix on land cover class between the years 2013 and 2023

		2023						
		Crop	Tree	Rangeland	Water	Bare Ground	Built Area	Total
2013	Crop	49877.51	242.435	228.3453	206.8745	0.550896	2791.525	53347.24067
	Tree	100.286	275.6649	11.03351	2.155372	0.020097	41.20949	430.369364
	Range land	245.2482	82.5202	175.9332	5.961516	2.96264	76.60007	589.225826
	Water	151.5952	1.14915	0.290364	359.3065	0	17.75478	530.095994
	Bare Ground	12.17057	0	1.901985	4.46338	0.323112	8.507906	27.366953
	Built Area	885.8549	17.74094	26.05635	25.26087	0	3619.092	4574.005055
	Total	51272.66487	619.5102	443.5607	604.0221	3.856745	6554.689246	59498.78386

Table 4 presents the land cover change matrix based on the classified data for the years 2013 and 2023, emphasizing the transitions and stability across various land use categories during this study period. The total area initially classified as cropland class (53,347.24 ha) underwent significant transformations over the decade. Specifically, 242.43ha transitioned to tree land, 228.34ha to rangeland, 206.87ha to water bodies, 0.55ha to bare ground, and 2,791.52ha to built-up areas. Consequently, the cropland area decreased to 49,877.51ha. Tree land class, originally covering 430.36 ha, also experienced considerable changes. Of this, 100.29ha were converted to cropland, 11.03ha to rangeland, 2.15ha to water bodies, 0.02ha to bare ground, and 41.21ha to built-up areas, reducing the tree land area to 275.66 ha. In Range land class, which initially covered 589.22ha, saw notable transitions. A total of 245.24ha was converted to cropland, 82.52ha to tree land, 5.96ha to water bodies, 2.96 ha to bare ground, and 76.60 ha to built-up areas, resulting in a reduced rangeland area of 175.93ha. Similarly, water bodies class, originally encompassing 530.09ha, underwent significant changes. Of this, 151.59 ha were converted to cropland, 1.14 ha to tree land, 0.29 ha to rangeland, and 17.75ha to built-up areas. As a result, the area designated as water bodies decreased to 359.31ha. Bare ground class, initially covering 27.36 ha, experienced marked transitions. Specifically, 12.10ha were converted to cropland, 1.90 ha to rangeland, 4.46 ha to water bodies, and 8.50 ha to built-up areas, leaving only 0.32 hectares as bare ground. Finally, the built-up area class, which originally spanned 4,574.00ha, also underwent substantial changes. A total of 885.85ha was converted to cropland, 17.74ha to tree land, 26.05 ha to rangeland, and 25.26ha to water bodies, leading to a reduction of the built-up area to 3,619.09 ha.

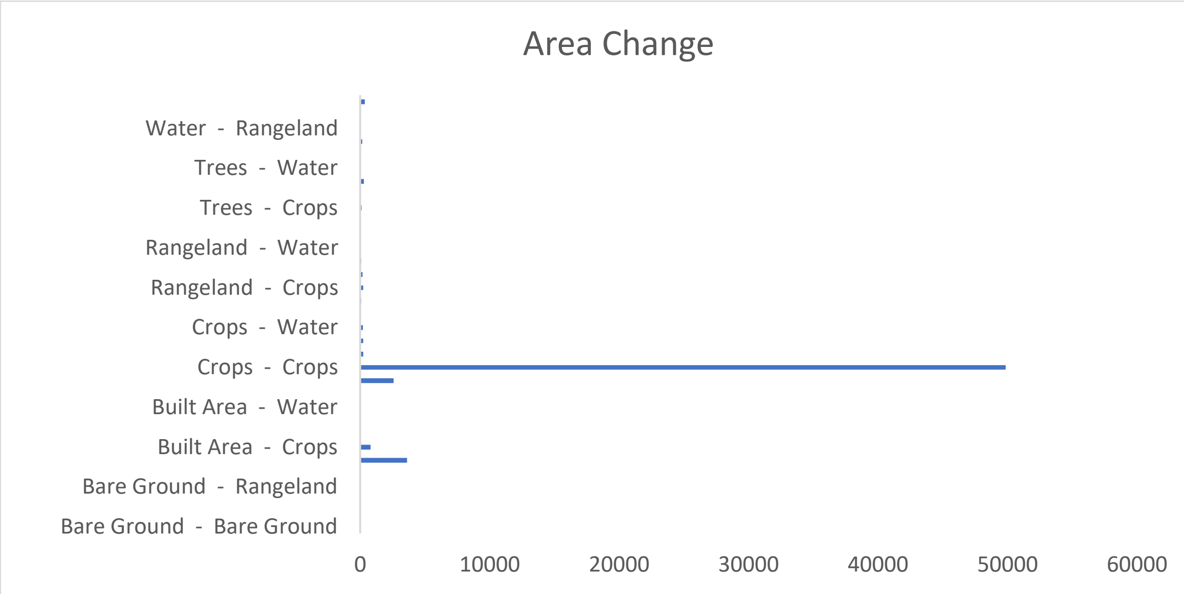

Fig. 5 Bar chart of statistical results of LULC classification of 2013 and 2023.

The bar chart (Fig 5) displays the statistical results of the LULC classification for the years 2013 and 2023. This visual representation highlights the distribution and changes in different land cover categories over the ten years. Each bar represents a specific LULC category, showing the total area covered by that category in both 2013 and 2023. This chart illustrates the magnitude of land cover transitions, emphasizing which transitions involve significant changes in area. For instance, the "Crops to Crops" transition shows a substantial increase, indicating that the crop area has either remained stable or expanded significantly over time. Other transitions, such as "Built Area - Water" and "Bare Ground - Rangeland," exhibit minimal changes. This type of analysis can be integral to a broader study on land use dynamics, environmental changes, or agricultural expansion. By focusing on specific land cover changes, the chart provides insights into the evolving patterns of land use, which is essential for effective planning and policy-making in areas like agriculture, urban development, and conservation.

4. Conclusion

The study reported that landscape predominantly characterized by extensive agricultural activity, with crop production covering more than 86% of the area across both datasets. The results reveal that Landsat data using on screen visual interpretation with extensive field visit produce acceptable classified maps. The minimal coverage of rangeland, water bodies, and tree cover points to a landscape that is heavily utilized for agriculture, with limited natural areas remaining. The presence of these natural features is insufficient to support substantial biodiversity or to provide ample ecological services. This observation underscores the need for integrating sustainable land management practices to balance agricultural expansion with ecological preservation. Ensuring that environmental considerations are incorporated into land use planning will be essential for maintaining ecological health and resource sustainability. Understanding these distributions is crucial for planning and managing land resources effectively, ensuring that agricultural expansion does not come at the expense of environmental sustainability.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1.

2.

3.

Note: No any AI technologies has been used in this manuscript.

References:

1. Song, X. P., Hansen, M. C., Stehman, S. V., & Tucker, C. J. Characterizing recent trends in global forest loss. Earth's Future, 2018, 6(1), 120-136.
2. Turner, B. L., Lambin, E. F., & Reenberg, A. The Emergence of Land Change Science for Global Environmental Change and Sustainability. Proceedings of the National Academy of Sciences, 2010, 104(52), 20666-20671.
3. DeFries, R. S., & Eshleman, K. N. Land-use change and hydrologic processes: a major focus for the future. Hydrological Processes, 2004, 18(11), 2183-2186.
4. Pettorelli, N., Jenkins, C. N., & Carranza, M. L. The Role of Remote Sensing in Monitoring Land Cover Change. Ecological Indicators, 2014, 38, 66-74.
5. Lillesand, T., Kiefer, R. W., & Chipman, J. Remote Sensing and Image Interpretation (7th ed.). Wiley, 2015.

6. Jensen, J. R. Introductory digital image processing: A remote sensing perspective. Pearson Education, 2015.
7. Cohen, W. B., & Goward, S. N. Landsat's role in ecological applications of remote sensing. BioScience, 2004, 54(6), 535-545.
8. Roy, D. P., Wulder, M. A., Loveland, T. R., Woodcock, C. E., Allen, R. G., Anderson, M. C., & Zhu, Z. Landsat-8: Science and product vision for terrestrial global change research. Remote Sensing of Environment, 2014, 145, 154-172.
9. Sharma, S., & Singh, A. Impact of Agricultural Expansion on Land Use and Soil Quality in Uttar Pradesh. Journal of Environmental Management, 2020, 260, 110156.
10. Kumar, M., Denis, D. M., Singh, S. K., Szabó, S., & Suryavanshi, S. Landscape metrics for assessment of land cover change and fragmentation of a heterogeneous watershed. Remote Sensing Applications: Society and Environment, 2018, 10, 1-12. https://doi.org/10.1016/j.rsase.2018.04.002.
11. Patra, T., Dutta, D., Kundu, A., Kumar, M., Hossain, S. S., & Chattoraje, K. K. Evolution of Opencast Mines in the Raniganj Coalfield (India): An Assessment through Multi-temporal Satellite Data. Journal of the Geological Society of India, 2022, 98(3), 387-394. https://doi.org/10.1007/s12594-022-1990-5.
12. Kulkarni, K., & Vijaya, P. A. Mapping Forests Using an Imbalanced Dataset. J. Inst. Eng. India Ser. B, 2022, 103(6), 1987–1994. https://doi.org/10.1007/s40031-022-00790-y.
13. Kulkarni, K., & Vijaya, P. A. A Majority Voting Ensemble Approach for LULC Classification of Satellite Images. J. Inst. Eng. India Ser. B, 2023, 104(2), 327–333. https://doi.org/10.1007/s40031-023-00865-4