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Integrating Remote Sensing and GIS for LULC Studies in the Panchganga River Basin

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The lower Panchganga River Basin, located in the heart of Kolhapur District, is a vital ecological and socio-economic region known for its varied landscapes and evolving land use patterns. This

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study aims to analyze land use and land cover (LULC) changes in the basin for the years 1991, 2001, 2011, and 2021. Using remote sensing and GIS techniques, we assessed an area of 811.54 sq. km, creating LULC maps for the specified years through supervised classification in QGIS.

The accuracy of the classification was evaluated using the error matrix approach, with Kappa coefficients of 0.78, 0.79, 0.71, and 0.82 for 1991, 2001, 2011, and 2021, respectively, indicating satisfactory overall accuracy. The analysis revealed a decline in agricultural land (from 78.8% to 76.5%), water bodies (from 2.3% to 1.4%), barren land (from 4.9% to 3.9%), and forest areas (from 6.2% to 4.0%) over the 30-year period. Conversely, urban settlements increased significantly from 7.8% to 14.6% of the total area.

These findings highlight significant LULC changes in the basin, with agricultural land remaining predominant due to its economic importance. Understanding these changes is crucial for informed decision-making, sustainable resource management, and effective environmental planning in the Panchganga River Basin. Further study on LULC change detection in this important river basin in Kolhapur District, Maharashtra, is essential for addressing the region's evolving needs.

Keywords: RS; GIS; Q-GIS; Panchganga River basin; LULC; kappa coefficient.

1. INTRODUCTION

A vital ecological and socioeconomic hotspot distinguished by its varied landscapes and dynamic land use patterns; the Panchganga River Basin is tucked away in the centre of Kolhapur District. It is commonly known that there are just a few places on the planet that remain in their natural state and have not been influenced by human activities in some manner. These human activities result in significant land use changes at regional and local scales together with ecological, socio-economic and aesthetical impacts [1].

Lands are constantly changing as a result of a variety of manmade and natural causes. Land use land cover (LULC) is frequently associated with environmental issues; thus, land use land cover statistics are critical inputs for environmental management and future planning decisions. Increasing socioeconomic necessities with an increasing population creates enormous pressure on LULC [2]. LULC is to identify the social, economic, and cultural causes that lead to changes in land use patterns and can easily make proposals for the suitable use of land and its patterns of development [3-7].

Remote sensing (RS) and GIS have been recognized as essential and powerful tools in generating LULC at different spatial scales. RS and GIS have proved to be very useful for the detection of LULC patterns with the development of RS and GIS techniques, LULC mapping has become a detailed and useful way to advance the choice of areas for different uses (Sekela and Manfred, 2019).

Combining spatial data with multi-spectral images involves the integration of GIS and remote sensing for land use and land cover classification. GIS software such as QGIS facilitates this integration. Classification methods are used to group pixels into distinct land cover classes, either supervised or unsupervised. In order to ensure accuracy, classification findings must be validated [8-10]. This is typically done by using ground truth data to gauge how reliable the categorized maps are. The method of obtaining information classes from multiband remote sensing pictures, like land- cover categories, is known as image classification [11-14].

The Panchganga River basin is situated in the southwest of Maharashtra, India, well-known for its substantial impacts on the hydrology of the area. The Sanskrit term "Panchganga" means "five rivers," signifying the combination of the basin's five principal tributaries. The Panchganga River is formed by the convergence of these tributaries: Kasari, Kumbhi, Tulsi, Bhogavati, and Doodhganga [15-17].

The Panchganga River Basin is an agricultural heartland, supporting a wide range of crops and providing livelihoods for many communities. The reliance on the river for agricultural purposes also prompts questions about appropriate methods of managing water resources, particularly in light of shifting land-use patterns. The Panchganga River basin undergone through drastic changes in land use land cover past decades with increased population, increasing transportation facilities, increasing industrialization flooding prone conditions that occurs periodically. These changes arise new problems to the ecosystem of the basin area such as water quality is threatened by industrial discharges and runoff from agriculture Using cutting-edge RS and GIS techniques, the main goal of the study is to identify and analyse LULC in the Panchganga River Basin for the years 1991, 2001, 2011 and 2021. Monitoring LULC enables us to spot these trends and devise effective methods to mitigate their detrimental effects. The objectives of the study are to provide useful information and insights that will support evidence-based decision-making and promote harmony between ecological preservation and human development.

2. MATERIALS AND METHODS

This chapter discusses the approach used to achieve the objectives based on the ground data, study area location, characteristics and features as well as other relevant components of the study.

2.1 Study Area

2.1.1 Location

The lower Panchganga River basin covers an area about 811.54 sq. km., largely within the Kolhapur district. It is located between latitudes 16°31'22' N and 16°44'4' N and longitudes 74°14'33' E and 74°36'3' E. This Basin includes major cities such as Kolhapur, Hatkanangale, Ichalkaranji, Shirol & Kurundwad of state Maharashtra. The river gets confluences with Krishna River at Nrusinhwadi as one of major tributary of Krishna River. Fig. 1 shows the geographical location of study area.

2.1.2 Climate

With hot summers and moderate winters, the basin has tropical savanna climate. Temperatures range from 24°C to 28°C on average, with highs topping 40°C during the peak summer months (April-May). Monsoon rains, typically arrive in June and leave in September, which brings significant rainfall, averaging around 800 mm to 1000 mm makes a considerable contribution to the basin's water needs.

2.1.3 Physiography and relief

The Panchganga Basin has a rich ecology with a variety of flora and fauna. The Panchganga Basin is primarily located in the Deccan Plateau. The highest point in the basin is approximately 850 m above sea level, near the Sahyadri mountain range on its western side.

The Panchganga River, which passes through the river basin and defines its topography, serves as the basin's principal drainage feature. In its upper parts, the riverbed has mild gradients which change to extreme slopes as it flows into Kolhapur and beyond. The river is vital to agriculture, supplying irrigation for crops such as sugarcane, rice, wheat etc.

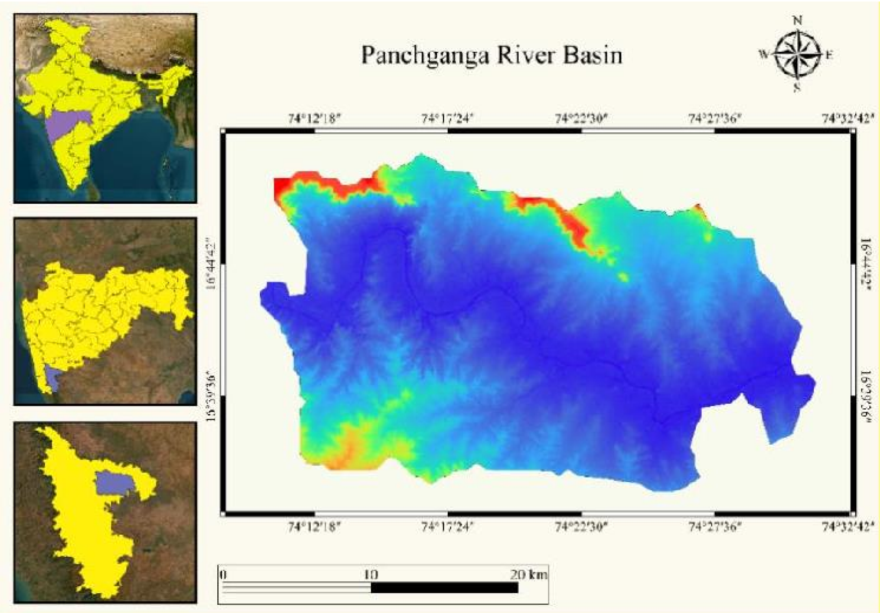


Fig. 1. Geographical Location of Lower Panchganga River Basin (study area)

2.1.4 Soil details and cropping pattern

The soils in the valleys have a heterogeneous character and range in color from brownish to reddish. Because of its undulating character, the eastern half has deep soils in low-lying areas and shallow soils on ridges. Reddish brown soils are productive and have a great granular structure. This soil is primarily generated from traps found in sloppy regions. The undulating uplands, slopes, and sloppy plains are covered in residual course, shallow soils. Medium black soils: It is located in the midst of the study region, near the river. This soil is suitable for paddy, sugarcane, soybean, and vegetable cultivation. Deep Black Soils are generated from the deposition of eroded materials, which are typically found on the eastern plain terrain. It has high proportion of clay and organic matter. This is useful for jowar, groundnuts, pulses, cotton, wheat, sugarcane, and soyabean [18].

2.2 Material Required

Variety of data is used in this manuscript which is gathered from multiple sources are enlisted in table 1 with its utility and sources and explained in further sub-sections.

2.2.1 Remote sensing data

2.2.1.1 Digital Elevation Model (DEM)

The study area's topographic features are obtained from the Digital Elevation Model (DEM). The DEM is generated using a QGIS plug-in called SRTM Downloader. The downloaded DEM is from the Shuttle Radar Topographic Mission (SRTM) and has a 1 arc-second (30m) resolution (Kulkarni and Kale, 2021).

2.2.1.2 Satellite imagery

Landsat satellites provide a distinct advantage for LULC studies. The Landsat satellites capture multispectral imagery with a spatial resolution ranging from 15 to 60 meters, depending on the sensors used. Landsat 5 provides multispectral imagery with a spatial resolution of 30 meters in the infrared bands. Because of their capacity to distinguish between diverse surface features based on their reflectance qualities, the infrared bands (Band 4 - Near Infrared and Band 5 - Mid-Infrared) delivered significant information for LULC classification. Landsat 7 has similar infrared band resolution to Landsat 5. With 30 meters spatial resolution, it continues to help with LULC change detection studies. Landsat 8 improved the ability to detect LULC change. Landsat 8's Operational Land Imager (OLI) sensor provides better radiometric and spatial resolution. The infrared bands (Bands 5 - Near Infrared and 6 - Shortwave Infrared) offer 30 meters spatial resolution.

The primary satellites utilized in this study were Landsat 5, 7, and 8, each equipped with its spectral bands and characteristics. Satellite images were obtained from Landsat 5 Thematic Mapper (TM) for the year 1991, Landsat 7 Enhanced Thematic Mapper Plus (ETM+) for the years 2001 and 2011, and Landsat 8 Operational Land Imager (OLI) for the year 2021. Table 2 provides details about the resolution and band composition of the satellite data used. *2.2.1.3 Soil data*

The soil map was obtained from the Food and Agricultural Organization (FAO) website *http://www.fao.org/geonetwork/srv/en/metadata.show* for the research area and evaluated

Table 1. Data Utility and its sources

Sr. No.	Data Type	Utility of data	Source of data
1.	Border Shapefiles	Preparation of Locality Map	GitHub
2.	Digital Elevation Model	LULC Maps	SRTM
3.	Satellite Data	LULC Maps	USGS Earth Explorer
4.	Soil Data	Validation of LULC	FAO
5.	Toposheets	Validation of LULC	Survey of India

Table 2. Remote Sensing/Satellite Data Utility

Sr. No.	Year	Satellite	Source	Resolution	Band Composition
1.	1991	Landsat 5	USGS Earth Explorer	30 m	4-3-2, 3-2-1
2.	2001	Landsat 7	USGS Earth Explorer	30m	4-3-2, 3-2-1, 5-3-1
3.	2011	Landsat 7	USGS Earth Explorer	30m	4-3-2, 3-2-1, 5-3-1
4.	2021	Landsat 8	USGS Earth Explorer	30 m	4-3-2, 3-2-1, 5-3-1

by using QGIS to identify the type of soil in the Panchganga River basin. Major soil types include sandy and clay, according to the Food and Agriculture Organization Soils Portal (FAOSOIL). (Kulkarni and Kale, 2021).

2.2.1.3 Toposheets

Topographic sheets for the Lower Panchganga River basin were obtained from the official website of the Survey of India (SOI), *https://onlinemaps.surveyofindia.gov.in/Home.aspxas.* These sheets are essential for creating and validating land use land cover (LULC) and are scaled at 1:50000.

2.2.2 Field data

Using a simple method of random sampling, the field samples i.e. ground data, were gathered from the study area. An information obtained from the ground truthing data will be used for evaluating and validating prepared LULC maps.

2.3 Methodology

2.3.1 Software used

The user-friendly interface of QGIS, as illustrated in Fig. 2, along with its comprehensive suite of geospatial analysis tools and plug-ins, made it easy to process, visualize, and validate the classification results seamlessly. The use of QGIS significantly improved the accuracy and efficiency of change detection analysis. Additionally, QGIS was used to define training polygons for different land cover classes, incorporating spectral signatures derived from satellite imagery and ground truth data. Then employed supervised classification algorithm, within QGIS to classify the entire image into distinct land cover classes. Identified and measured spatial and temporal changes in land cover categories using Change Detection wizard plug-in from QGIS.

2.3.2 Development of Land Use Land Cover (LULC) maps

In recent years, the analysis of land use and land cover (LULC) has become increasingly significant due to the advancements in remote sensing technology. The process involves the selection and acquisition of high-resolution satellite imagery covering the study area across multiple spectral bands, including the use of LANDSAT satellite data from the USGS platform.

Subsequently, a supervised classification technique was employed to categorize land use and land cover types for the years 1991, 2001, 2011 and 2021, with classifications including agricultural land, urban settlements, water bodies, barren land, and forest areas based on the Anderson LULC classification system. LULC maps of the Panchganga River basin were generated for these years, and the workflow for the development of these maps, their accuracy assessment and the creation of change detection maps is presented in Fig. 3.

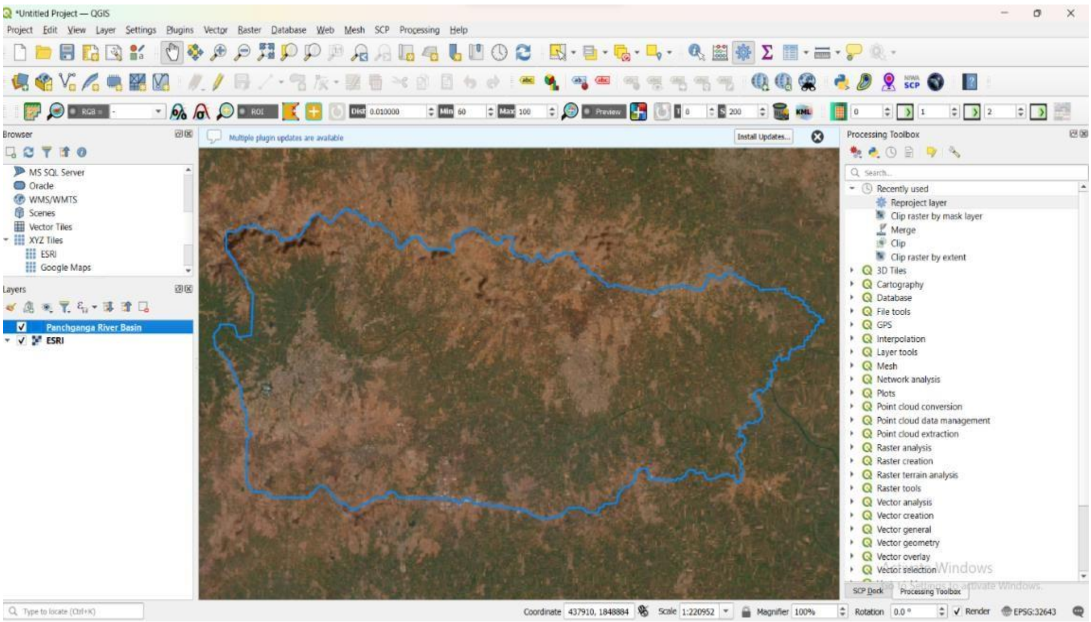


Fig. 2. The User Interface of Quantum GIS (QGIS)

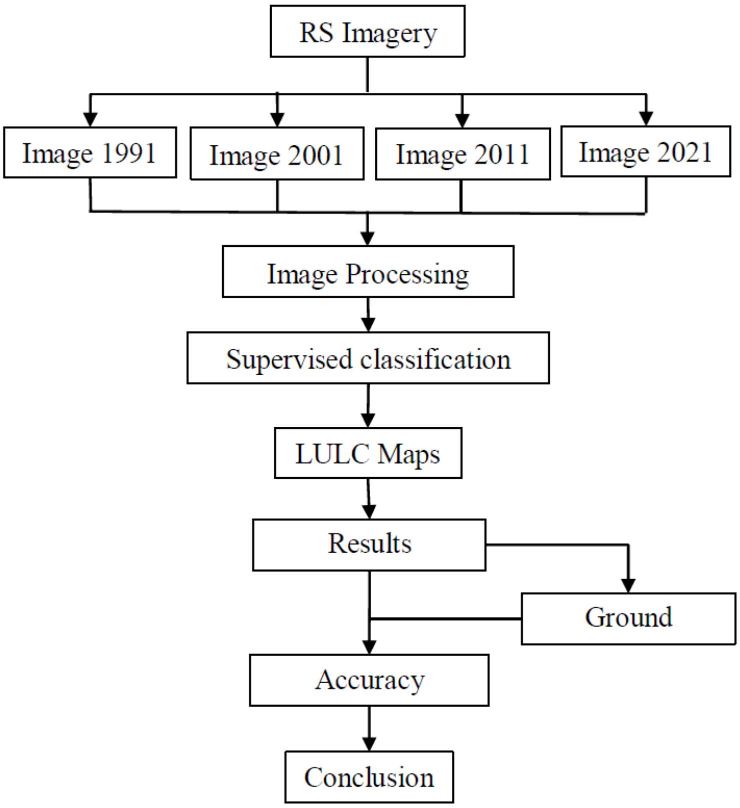


Fig. 3. Framework for Change Detection in LULC using QGIS

2.3.2.1 Supervised classification

To classify unidentified pixels, supervised classification relies on the utilization of training areas or samples containing known identity pixels. In the context of the Panchganga basin, training samples representing various land cover classes were meticulously selected using spectral data from LANDSAT. These selected samples were categorized based on color combinations, complexity and familiarity with the study area. Subsequently, the entire image underwent classification into multiple land cover categories utilizing the Maximum Likelihood Classifier (MLC) algorithm. Through the analysis of their spectral information, pixels in the images were then classified into the most probable Land Use and Land Cover (LULC) classes based on the training data. Overall, incorporating supervised image classification proved beneficial in development of accurate and reliable LULC maps.

2.3.2.2 Accuracy assessment

Finally, accuracy assessment validated to attest dependability of image classification results, ensuring resilience and precision in the resulting LULC. The error matrix is the most common approach for measuring image classification accuracy. It is used to compute a variety of descriptive and analytical statistics, such as overall accuracy and the Kappa coefficient.

Assessing classification accuracy has come to include Kappa statistics as a common component. Kappa coefficient calculated using Eq.1.

$$\widehat{K} = \frac{(Total\ sample\ x\ Total\ correct\ sample) - \sum(Column\ Total\ x\ Row\ Total)}{(Total\ sample\ x\ Total\ Sample) - \sum(Column\ Total\ x\ Row\ Total)} \quad \text{...Eq.1}$$

This statistic shows % for right values of error matrices are attributable to "true" agreement as opposed to "chance" agreement. K approaches 1 as genuine agreement, observed approaches 1 and chance agreement approaches 0. Actually, k typically falls between 0 and 1.

Table 3. Rating Criteria for Kappa Statistics *(Islami, 2022)*

Sr. No.	Range of Kappa Coefficient K	Strength of Agreement
1	<0.00	Poor
2	0.00 – 0.20	Slight
3	0.21 – 0.40	Fair
4	0.41 – 0.60	Moderate
5	0.61 – 0.80	Substantial
6	0.81 – 1.00	Almost Perfect

Along with Kappa statistics overall accuracy is also used to know the strength of accuracy of the map. Overall accuracy interprets total accuracy of the classification maps. Calculation of overall accuracy is simple and performed using Eq. 2,

$$Overall\ Accuracy = (Total\ correct\ sample\ (diagonally)\ /\ Column\ Total)\ X\ 100 \quad \text{...Eq. 2.}$$

3. RESULTS AND DISCUSSION

The study "Preparation of Land Use Land Cover (LULC) for Panchganga River Basin using Remote Sensing and GIS" aimed to examine the changes in LULC due to urbanization, industrialization, improved agricultural practices, and deforestation in the Panchganga River basin. The study evaluated the land use and land cover for the years 1991, 2001, 2011, and 2021 using remote sensing data and GIS techniques. The results obtained were found to be significant over the chosen period and are presented and discussed in this chapter in chronological order of the study objectives.

3.1`Preparation of Land Use Land Cover (LULC) Maps

The LULC map was created using multispectral satellite images taken from Landsat. To make sure the input data was accurate and of high quality, pre-processing procedures such geometry rectification, image correction, and enhancement were performed.

In this research, a supervised classification strategy is used because of its ability to incorporate existing knowledge and maximum classification accuracy. The satellite images have been categorized into different land cover classes, such as urban areas, agricultural land, forests, water bodies, and barren land. Fig. 4 shows the land use and land cover maps of the lower Panchganga River basin for the years 1991, 2001, 2011 and 2021, respectively. The land use and land cover (LULC) maps developed in this study provide a comprehensive understanding of land use changes and landscape patterns. These maps can be utilized for environmental monitoring, land management and urban planning purposes.

From Fig. 4 and Table 4, it is observed that agricultural land covers 653.2, 647.6, 639.1 and 634.4 sq. km. area which is 78.8%, 78.1%, 77.1% and 76.5% of the total study area. Similarly, settlement covers 64.4, 79.4, 703.4, 121.3 sq. km. which is 7.8%, 9.6%, 12.5% and 14.6% of the total study area. Water bodies covers 19.4, 15.5, 13.7 and 11.3 sq. km. area which is 2.3%, 1.9%, 1.7% and 1.4% of the total study area. Barren land covers 40.4, 37.9, 32.5 and 29.1 sq. km. area which is 4.9%, 4.6%, 3.9% and 3.5% of total study area. Forest covers 51.6, 48.7, 40.4 and 32.9 sq. km. area which is 6.2%, 5.9%, 4.9% and 4.0% of the total study area. This area coverage of each class mentioned for the years 1991, 2001, 2011 and 2021, respectively of Panchganga River basin.

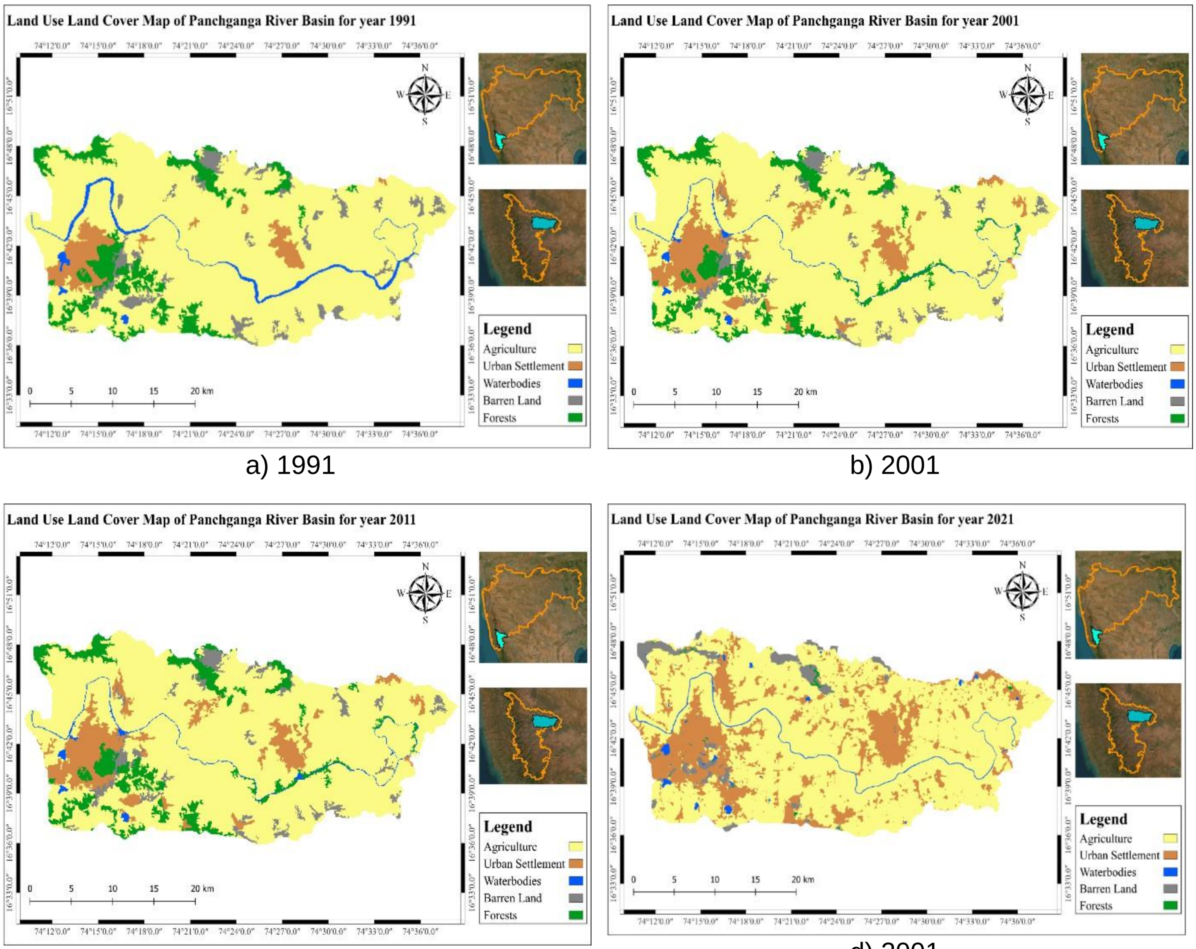
3.1.1 Accuracy assessment

Accuracy assessment was done to determine accuracy of LULC classification. Ground truthing was done by visiting nearly 18 places which were selected by random sampling method. These points were selected using random sample method as mentioned in methodology. The table of latitudes and longitudes of visited places were given in Appendix I. Moreover, assessment was incorporated with calculating overall accuracy and Kappa coefficient. Detailed accuracy assessment calculation and results for 1991 and 2021 are presented in Appendix II.

Table 5 represents the values for overall efficiency and accuracy assessment for each of the maps prepared for study period i.e. 1991 - 2021. Considering the overall accuracy and Kappa coefficient of the LULC map prepared, it is found to be 82.21% and 0.78 for the year 1991, 83.34% and 0.79 for the year 2001, 76.66% and 0.71 for the year 2011 and 85.71% and 0.82 for the year 2021, respectively. The results also explains that, an overall accuracy and Kappa coefficient are satisfactory and shows substantial strength of agreement.

Table 4. Area under different LULC Classes from 1991 to 2021

Land Cover Type	Area Coverage (sq. km)				Area Coverage (%)			
	1991	2001	2011	2021	1991	2001	2011	2021
Agriculture	653.2	647.6	639.1	634.4	78.8%	78.1%	77.1%	76.5%
Settlement	64.4	79.4	103.4	121.3	7.8%	9.6%	12.5%	14.6%
Water Body	19.4	15.5	13.7	11.3	2.3%	1.9%	1.7%	1.4%
Barren Land	40.4	37.9	32.5	29.1	4.9%	4.6%	3.9%	3.5%
Forest	51.6	48.7	40.4	32.9	6.2%	5.9%	4.9%	4.0%



a) 1991 b) 2001

c) 1991 d) 2001

Fig. 4. Land Use Land Cover Map of lower Panchganga River basin for years 1991, 2001, 2011 and 2021

Table 5. Accuracy Assessment Summary (Appendix II)

Sr. No.	Year	Overall Accuracy	Kappa Coefficient	Strength of Agreement
1	1991	82.21	0.78	Substantial
2	2001	83.34	0.79	Substantial
3	2011	76.66	0.71	Substantial
4	2021	85.71	0.82	Substantial

3.2 Discussion

GIS analysis has shown the capabilities of GIS to solving spatial problems and to providing information that aid decision making [19]. This study investigated LULC in the lower Panchganga River basin for the years 1991, 2001, 2011 and 2021 using remote sensing (RS) and geographic information systems (GIS) techniques. The main source of data was Landsat TM, ETM+ and OLI images of years 1991, 2001, 2011 and 2021, which gave a consistent and similar perspective of the study area. It was discovered that greater training sample selection results correlate with higher accuracy. Knowledge and familiarity with the study area of the researcher are crucial for the selection of training samples to ease the selection. Hereby, better training sample selection results tend towards more accuracy.

After classification, for checking the reliability, accuracy assessment was conducted out by ground truthing and calculating Kappa coefficient. An overall accuracy found satisfactory as results are showing substantial strength of agreement. Over the period of 30 years, transformation of LULC shifts has been noticed in the study area.

4. SUMMARY AND CONCLUSIONS

The changes in Land Use and Land Cover (LULC) have been better understood with the help of Remote Sensing (RS) and Geographic Information Systems (GIS). This study analyzes the LULC for the years 1991, 2001, 2011 and 2021 using RS and GIS methods. The results obtained from the study are summarized and discussed in relation to the objectives outlined in this chapter.

4.1 Summary

The objective of this research was to use remote sensing methods to analyze and comprehend the changes in land use and land cover (LULC) from 1991 to 2021. The study utilized satellite images from Landsat 5 Thematic Mapper (TM) for 1991, Landsat 7 Enhanced Thematic Mapper Plus (ETM+) for 2001 and 2011, and Landsat 8 Operational Land Imager (OLI) for 2021. Employing the supervised classification technique, the research focused on the Panchganga River basin to identify significant variations in LULC patterns.

The most popular method for assess the accuracy of image classification, error matrices was used to calculate overall accuracy and Kappa coefficient. The link between the reference field data and the relevant categorization results were compared using error matrices. The categorization results' dependability was attested by overall accuracy of LULC classification which found 82.21%, 83.34%, 76.66% and 85.71% for the years 1991, 2001, 2011 and 2021, respectively. As well as these results were validated by calculating Kappa coefficient, which found 0.78, 0.79, 0.71 and 0.82 for the years 1991, 2001, 2011 and 2021, respectively. These results gave substantial strength of agreement with field conditions and found satisfactory.

4.2 Conclusions

The research work entitled "Preparation of Land Use Land Cover (LULC) for Panchganga River Basin using Remote Sensing and GIS" has been performed to understand the trend of LULC scenario in the basin area. To summarize all the results, below findings are listed:

1. The study employed satellite imagery and spatial analytic approaches to examine land use patterns over a 30-year period. It emphasized the combination of RS and GIS technologies for efficient land resources management and monitoring.
2. Supervised classification technique found best for preparing LULC maps with different classes such as agriculture, barren land, urban settlements, water bodies and forest land.
3. Accuracy assessment was done using error matrices method and calculating Kappa coefficient along with ground truthing. An overall accuracy of LULC classification found 82.21%, 83.34%, 76.66% and 85.71% for the years 1991, 2001, 2011 and 2021, respectively.

As well as, the Kappa coefficient found 0.78, 0.79, 0.71 and 0.82 for the years 1991, 2001, 2011 and 2021, respectively. These results found satisfactory with substantial strength of agreement with field conditions.

1. Considering LULC change over the period of 30 years, agricultural land found dominant as it is the main source of economy in the basin.
2. The notable LULC scenario in the study area for different years, underscored the effects of environmental factors, natural processes and the effect of human activity on the land use dynamics. The extended degree of evaluation provided a base for sustainable land management practices and well-informed decision-making.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX I

Ground Truthing Points and Photographs

1. Ground Truthing

Table 1 Latitude and longitude of ground truthing points

Name	Description	Latitude	Longitude
Point 1	Forest	74° 11' 29.49"	16° 47' 38.46"
Point 2	Agriculture	74° 16' 31.01"	16° 47' 46.52"
Point 3	Water body	74° 18' 15.64"	16° 46' 24.51"
Point 4	Agriculture	74° 15' 33.85"	16° 45' 33.24"
Point 5	Settlement	74° 11' 44.40"	16° 46' 00.50"
Point 6	Water Body	74° 12' 51.76"	16° 44' 00.22"
Point 7	Settlement	74° 16' 53.41"	16° 42' 28.93"
Point 8	Barren Land	74° 16' 11.26"	16° 40' 51.59"
Point 9	Water body	74° 12' 38.59"	16° 41' 32.57"
Point 10	Forest	74° 12' 52.38"	16° 38' 05.87"
Point 11	Barren land	74° 16' 04.04"	16° 37' 53.22"
Point 12	Settlement	74° 20' 48.47"	16° 37' 26.34"
Point 13	Settlement	74° 25' 11.41"	16° 37' 20.96"
Point 14	Agriculture	74° 22' 42.70"	16° 38' 56.26"
Point 15	Barren land	74° 20' 45.67"	16° 40' 24.02"
Point 16	Agriculture	74° 23' 38.96"	16° 40' 48.19"
Point 17	Settlement	74° 24' 33.80"	16° 42' 46.16"
Point 18	Water body	74° 22' 05.62"	16° 44' 23.64"

2. Field Photographs

Point 1

Point 2

Point 3

Point 4

Point 5

Point 6

Point 7

Point 8

Point 9

Point 10

Point 11

Point 12

Point 13

Point 14

Point 15

Point 16

Point 17

Point 18

APPENDIX II

Table 2. Accuracy assessment calculation of land use change analysis for 1991

	Agriculture	Urban Settlement	Water Bodies	Barren Land	Forest	Total
Agriculture	4	1	0	0	0	5
Urban Settlement	0	7	0	0	0	7
Waterbodies	0	0	3	0	0	3
Barren Land	0	1	2	4	0	7
Forest	0	0	0	1	5	6
Total	4	9	5	5	5	28

1. Overall Accuracy

$$Overall\ Accuracy = \frac{Total\ correct\ sample\ (diagonally)}{Column\ Total}\ X\ 100$$

$$Overall\ Accuracy = \frac{(4+7+3+4+5)}{28}\ X\ 100$$

$$Overall\ Accuracy = 82.21\%$$

2. Kappa Coefficient

$$\hat{K} = \frac{(Total\ sample\ x\ Total\ correct\ sample) - \sum(Column\ Total\ x\ Row\ Total)}{(Total\ sample\ x\ Total\ Sample) - \sum(Column\ Total\ x\ Row\ Total)}$$

$$\hat{K} = \frac{(28\ x\ 23) - ((5\ x\ 4) + (9\ x\ 7) + (5\ x\ 3) + (5\ x\ 3) + (5\ x\ 6))}{(86\ x\ 86) - ((5\ x\ 4) + (9\ x\ 7) + (5\ x\ 3) + (5\ x\ 3) + (5\ x\ 6))}$$

$$\hat{K} = 0.78$$

As Kappa coefficient for LULC map 1991 is 0.78 which is substantial as mentioned in Table 2.

Table 3. Accuracy assessment calculation of land use change analysis for 2001

	Agriculture	Urban Settlement	Water bodies	Barren Land	Forest	Total
Agriculture	7	0	0	0	1	8
Urban Settlement	0	6	0	0	0	6
Waterbodies	0	0	3	0	0	3
Barren Land	0	1	2	5	0	8
Forest	0	0	0	1	4	5
Total	7	7	5	6	5	30

1. Overall Accuracy

$$Overall\ Accuracy = \frac{Total\ correct\ sample\ (diagonally)}{Column\ Total}\ X\ 100$$

$$Overall\ Accuracy = \frac{(7+6+3+5+4)}{30}\ X\ 100$$

$$Overall\ Accuracy = 83.34\%$$

2. Kappa Coefficient

$$\hat{K} = \frac{(Total\ sample\ x\ Total\ correct\ sample) - \sum(Column\ Total\ x\ Row\ Total)}{(Total\ sample\ x\ Total\ Sample) - \sum(Column\ Total\ x\ Row\ Total)}$$

$$\hat{K} = \frac{(30\ x\ 25) - ((7\ x\ 8) + (7\ x\ 6) + (5\ x\ 3) + (6\ x\ 8) + (5\ x\ 5))}{(30\ x\ 30) - ((7\ x\ 8) + (7\ x\ 6) + (5\ x\ 3) + (6\ x\ 8) + (5\ x\ 5))}$$

$$\hat{K} = 0.79$$

As Kappa coefficient for LULC map 2001 is 0.79 which is substantial as mentioned in Table 3.

Table 4. Accuracy assessment calculation of land use change analysis for 2011

	Agriculture	Urban Settlement	Water bodies	Barren Land	Forest	Total
Agriculture	4	1	0	0	0	5
Urban Settlement	0	7	0	0	0	7
Waterbodies	0	0	5	1	1	7
Barren Land	0	1	2	3	0	6
Forest	0	0	0	1	4	5
Total	4	9	7	5	5	30

1. Overall Accuracy

$$Overall\ Accuracy = \frac{Total\ correct\ sample\ (diagonally)}{Column\ Total}\ X\ 100$$

$$Overall\ Accuracy = \frac{(4+7+5+3+4)}{30}\ X\ 100$$

$$Overall\ Accuracy = 76.66\%$$

2. Kappa Coefficient

$$\hat{K} = \frac{(Total\ sample\ x\ Total\ correct\ sample) - \sum(Column\ Total\ x\ Row\ Total)}{(Total\ sample\ x\ Total\ Sample) - \sum(Column\ Total\ x\ Row\ Total)}$$

$$\hat{K} = \frac{(30\ x\ 23) - ((4\ x\ 5) + (9\ x\ 7) + (7\ x\ 7) + (5\ x\ 6) + (5\ x\ 5))}{(30\ x\ 30) - ((4\ x\ 5) + (9\ x\ 7) + (7\ x\ 7) + (5\ x\ 6) + (5\ x\ 5))}$$

$$\hat{K} = 0.71$$

As Kappa coefficient for LULC map 2011 is 0.71 which is substantial as mentioned in Table 4.

Table 5. Accuracy assessment calculation of land use change analysis for 2021.

	Agriculture	Urban Settlement	Water bodies	Barren Land	Forest	Total
Agriculture	8	1	0	0	0	9
Urban Settlement	0	7	0	0	0	7
Waterbodies	0	0	5	0	0	5
Barren Land	0	1	2	6	0	9
Forest	0	0	0	1	4	5
Total	8	9	7	7	4	35

1. Overall Accuracy

$$Overall\ Accuracy = \frac{Total\ correct\ sample\ (diagonally)}{Column\ Total}\ X\ 100$$

$$Overall\ Accuracy = \frac{(8+7+5+6+4)}{35}\ X\ 100$$

$$Overall\ Accuracy = 85.71\%$$

2. Kappa Coefficient

$$\hat{K} = \frac{(Total\ sample\ x\ Total\ correct\ sample) - \sum(Column\ Total\ x\ Row\ Total)}{(Total\ sample\ x\ Total\ Sample) - \sum(Column\ Total\ x\ Row\ Total)}$$

$$\hat{K} = \frac{(35\ x\ 30) - ((8\ x\ 9) + (9\ x\ 7) + (7\ x\ 5) + (7\ x\ 9) + (4\ x\ 5))}{(35\ x\ 35) - ((8\ x\ 9) + (9\ x\ 7) + (7\ x\ 5) + (7\ x\ 9) + (4\ x\ 5))}$$

$$\hat{K} = 0.82$$

As Kappa coefficient for LULC map 2021 is 0.82 which is substantial as mentioned in Table 1.

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