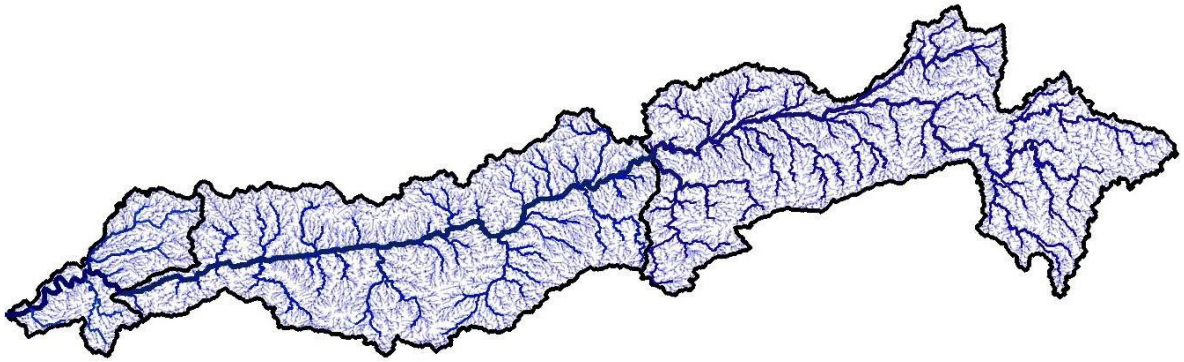




National River Conservation Directorate
Ministry of Jal Shakti, Department of Water
Resources,
River Development & Ganga Rejuvenation
Government of India

Narmada River Basin: Land Use and Land Cover (LULC) Analysis Report



March 2026

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Acknowledgment

This report is a comprehensive outcome of the project jointly executed by IIT Gandhinagar (Lead Institute) and IIT Indore (Fellow Institute) under the supervision of cGanga at IIT Kanpur. It was submitted to the National River Conservation Directorate (NRCD) in 2024. We gratefully acknowledge the individuals who provided information and photographs for this report.

Disclaimer

This report is a preliminary version prepared as part of the ongoing Condition Assessment and Management Plan (CAMP) project. The analyses, interpretations and data presented in the report are subject to further validation and revision. Certain datasets or assessments may contain provisional or incomplete information, which will be updated and refined in the final version of the report after comprehensive review and verification.

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PREFACE

The Narmada River Basin constitutes one of the most important river systems of central India, supporting diverse ecological functions, agricultural livelihoods, urban settlements, and industrial activities across multiple states. As a major west-flowing river, the Narmada plays a critical role in regional water security and socio-economic development. This report, titled "*Narmada River Basin: Land Use and Land Cover (LULC) Analysis*," presents a comprehensive assessment of land surface dynamics over the period 1995–2024, with detailed evaluation for the reference years 1995, 2005, 2015, and 2024. This analysis revealed significant changes in the LULC from 1995 to 2024. Understanding these changes was vital for identifying patterns and the dominant LULC classes within the catchment. LULC classification maps were created using Random Forest (RF) classification models, manually collected training data for the priority LULC classes, and Landsat satellite imagery for 1995, 2005, 2015, and 2024 on the Google Earth Engine (GEE) platform. Image classification accuracies were greater than 80%, and Kappa values were above 0.75 for each map. These maps showed an increasing trend in waterbodies, agriculture, and built-up areas from 1995 to 2024, while a decline in forest area was noted, primarily due to water resources development, agricultural intensification, and rapid population growth.

The study has been undertaken in alignment with the objectives of the National River Conservation Plan (NRCP) under the Ministry of Jal Shakti and reflects the basin-level management perspective promoted by cNarmada within the broader river basin knowledge framework of cGanga. The spatial organization of land use and land cover within the basin forms the primary interface through which human activities interact with hydrological and ecological processes, making its systematic assessment essential for integrated river basin management.

LULC, as addressed in this assessment, represents the integrated outcome of natural physiographic controls and human-induced transformations within the basin. Variations in forest cover, agricultural extent, surface water bodies, built-up areas, and fallow or barren land directly influence runoff generation, evapotranspiration, groundwater recharge, soil erosion, and sediment transport. In a river basin such as the Narmada, characterized by large reservoirs, expanding

irrigation infrastructure, and increasing urbanization, LULC patterns exert a first-order control on river health and water availability.

The Narmada Basin exhibits pronounced spatial heterogeneity, ranging from forest-dominated uplands in the upper catchment to intensively cultivated plains in the central basin and urban–industrial corridors in the lower reaches. These variations are closely linked to topography, rainfall gradients, and access to surface and groundwater resources. In this context, a basin-centric, spatially explicit assessment of LULC is essential to complement conventional administrative statistics and support hydrologically meaningful analysis.

To ensure methodological rigor and spatial consistency, the present assessment employs multi-temporal Landsat satellite data analyzed using a Random Forest machine learning classification framework implemented on the Google Earth Engine (GEE) platform. The approach integrates multispectral reflectance data with derived spectral indices to enhance class discrimination and mapping reliability. LULC patterns and changes have been examined at basin-, sub-basin-, and district-wise scales, and cartographic outputs have been prepared in ArcGIS and QGIS to ensure standardized visualization.

The assessment highlights broad patterns of land cover transformation across the basin, including expansion of agricultural and built-up areas, localized changes in forest cover, and land surface modifications associated with reservoir development. The identification of spatial concentrations of change provides critical insight into zones of intensified human–environment interaction, which are directly relevant to river basin planning and management. Overall, this report is intended to serve as a strategic spatial reference to support the objectives of NRCP and basin-level decision-making under the cNarmada and cGanga framework. By integrating long-term earth observation data with advanced geospatial analysis, the study establishes a robust baseline for subsequent investigations related to hydrology, soil erosion, climate variability, and sustainable land and water resource management in the Narmada River Basin.

Centre for Narmada River Basin Management Studies (cNarmada)

IIT Gandhinagar, IIT Indore

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1. INTRODUCTION

Land Use and Land Cover (LULC) change is a direct manifestation of human interaction with the natural environment and plays a fundamental role in regulating hydrological, ecological, and climatic processes. Alterations in land cover influence surface runoff, evapotranspiration, soil erosion, sediment transport, and groundwater recharge, particularly in large river basins undergoing rapid socio-economic transformation.

The Narmada River is one of India's major rivers, and the largest westward-flowing river, draining an area of 98,796 km². The Narmada River is a lifeline to states like Madhya Pradesh, Gujarat, and Maharashtra, serving millions of people in ecological, economic, and cultural ways. In terms of administrative expansion, the Narmada River Basin spans four Indian states: Chhattisgarh, Madhya Pradesh, Gujarat, and Maharashtra, covering vast parts of central and western India. Originating from Amarkantak, the 1,312 km long Narmada River flows westward, with 1,077 km in Madhya Pradesh, 74 km in Maharashtra, and 161 km in Gujarat, before draining into the Arabian Sea through the Gulf of Khambhat.

The basin supports over 20.8 million people across 33 districts, including 27 in Madhya Pradesh and 2 each in Chhattisgarh, Gujarat, and Maharashtra. It plays a crucial role in the region's ecology, economy, and society by providing water for drinking, agriculture, and hydropower. The districts within the basin exhibit wide variation in population density, economic structure, and terrain, ranging from fertile plains to hilly regions, shaping diverse development patterns and environmental challenges. The expansion of agriculture, urban and industrial growth, and the development of major water resource infrastructure, such as the Sardar Sarovar, Indira Sagar, and several other reservoirs, have altered the basin's hydrological regime and landscape patterns.

In this context, the present study investigates the spatial and temporal dynamics of LULC in the Narmada Basin at a decadal scale for 1995, 2005, 2015, and 2024, using Landsat satellite imagery and a Random Forest (RF) classification implemented in Google Earth Engine (GEE). The thematic maps were prepared in ArcGIS and QGIS. The analysis is reported for various spatial units, including basin-scale, sub-basin-level, and district-level.

2. NARMADA RIVER BASIN

The physiographic setting of the Narmada River Basin is defined by marked variations in elevation, relief, slope, soil development, and rainfall, which together form the basin's fundamental structural framework. Although advances in technology have partially reduced terrain-related constraints, physiography continues to exert primary control on land-use potential, hydrological behavior, and spatial organization across the basin. Elevation and relief, in particular, influence surface stability, runoff generation, soil depth, and accessibility, making them central to understanding basin-wide spatial differentiation. Figure 2.1 shows the physiographic features of the Narmada basin. Hydrologically, the Narmada basin is divided into three units: Upper Narmada basin (~44,850 km²), Middle Narmada basin (~42,193 km²), and Lower Narmada basin (~10,108 km²).

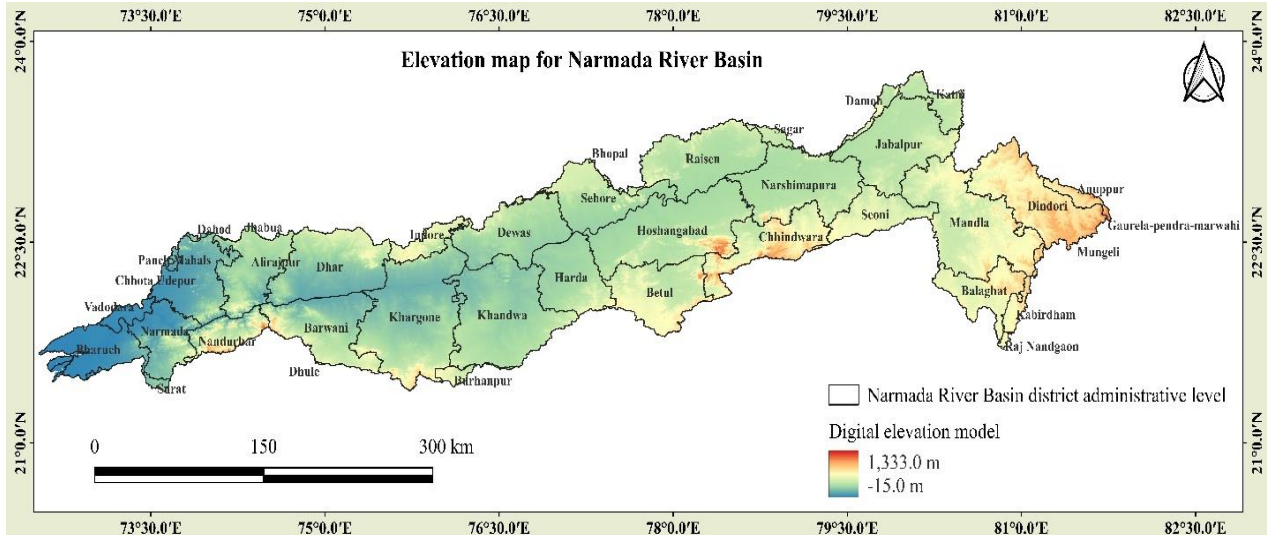


Figure 2.1: Physiography of the Narmada River Basin

The upper Narmada basin, including districts such as Anuppur, Dindori, Mandla, Balaghat, and Shahdol, is characterized by high relief, steep to very steep slopes, and deeply dissected terrain associated with the eastern highlands. These areas exhibit shallow to moderately developed soils and high runoff coefficients due to pronounced gradients. The rugged topography enhances erosion susceptibility, limits large contiguous land parcels, and constrains infrastructural expansion. Rapid

surface runoff during the monsoon and reduced moisture retention during dry periods reflect the strong geomorphic control on hydrological processes in this zone.

The middle Narmada basin forms a transitional physiographic corridor marked by moderate elevations, gently undulating terrain, and broad alluvial valleys, particularly across districts such as Narmadapuram, Narsinghpur, Jabalpur, and Damoh. Lower slope gradients promote better soil development, enhanced infiltration, and groundwater recharge, while the relatively stable terrain facilitates settlement concentration and surface-water regulation.

The Narmada lower basin, largely a part of the western plains, including Bharuch and the Narmada district of Gujarat, is dominated by very low relief and nearly level surfaces formed through long-term deposition. While the flat terrain favors hydraulic connectivity and infrastructure development, this region is climatically constrained by low, highly seasonal rainfall and high evapotranspiration, which increase dependence on regulated river flows.

3. DATA COLLECTION AND SOURCES

Land use and land cover (LULC) classification with a desired accuracy requires satellite data that are spatially consistent, temporally continuous, and radiometrically reliable. In the present study, multi-temporal satellite imagery was employed to capture long-term LULC dynamics across the Narmada River Basin over nearly three decades. The selection of data sources was guided by the need for uniform spatial resolution, consistent spectral characteristics, and adequate temporal coverage to support comparative analysis across different time slices.

Multi-temporal Landsat surface reflectance imagery was used to generate LULC maps at a 30 m spatial resolution for 1995, 2005, 2015, and 2024, at a decadal scale. The Landsat archive was selected due to its unparalleled temporal continuity, global coverage, and proven suitability for basin-scale environmental and land-use studies. All satellite datasets were processed in surface reflectance form to reduce atmospheric effects and ensure spectral consistency across sensors and time periods. Using harmonized Landsat products enables reliable inter-temporal comparisons and minimizes classification bias arising from sensor differences. The multi-temporal Landsat dataset thus provides a robust and consistent foundation for analyzing long-term LULC changes and spatial patterns within the Narmada River Basin. Multi-temporal Landsat surface reflectance imagery was used to generate LULC maps at a 30 m spatial resolution, ensuring consistency across the study period. The Landsat archive was selected due to its long temporal continuity and suitability for basin-scale environmental analysis.

Table 3.1: Datasets for the classification

Year	Satellite Name	Resolution (m)	Sensor Type
1995	Landsat 5	30	TM
2005	Landsat 5	30	TM
2015	Landsat 8	30	OLI
2024	Landsat 8 / Landsat 9	30	OLI

4. METHODOLOGY AND DATA PROCESSING

4.1 Methodology Overview

The analysis begins with the acquisition of datasets within the Narmada Basin boundary, followed by multi-temporal Landsat imagery (Landsat-5 TM for 1995 and 2005; Landsat-8/9 OLI for 2015 and 2024). The images are pre-processed in Google Earth Engine using cloud and shadow masking, seasonal filtering, median compositing, and basin clipping to obtain the analysis-required datasets. Training and validation samples are prepared using class-wise and spatially distributed points, and a Random Forest algorithm is applied for multi-temporal LULC classification.

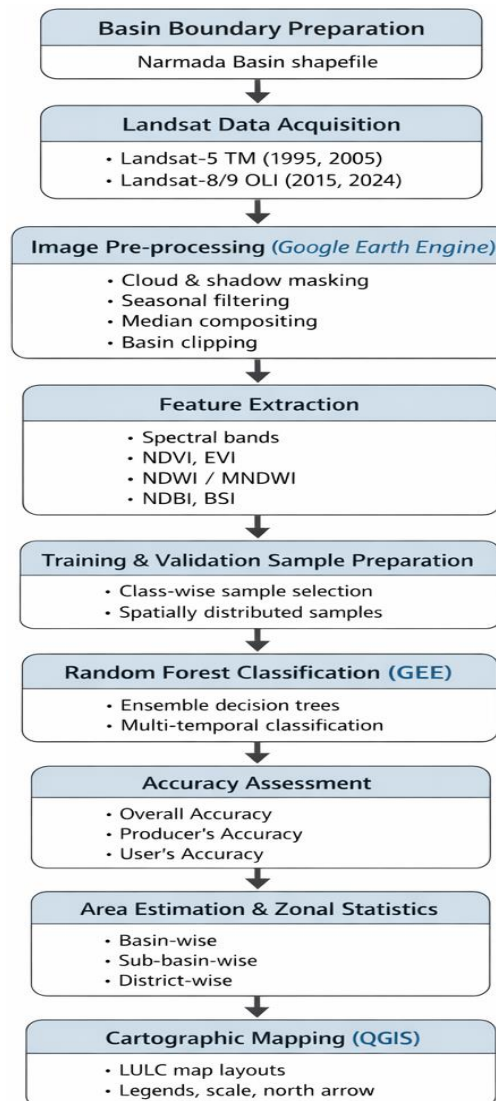


Figure 4.1: Overall methodology flowchart

The classification accuracy is evaluated using overall, producer's, and user's accuracy metrics. Finally, area estimation and zonal statistics are computed at basin, sub-basin, and district levels, and the results are presented through cartographic layouts in ArcGIS and QGIS. Figure 4.1 illustrates the overall methodology used for LULC classification.

4.2 Image Pre-processing

All Landsat imagery was pre-processed in Google Earth Engine to ensure uniform handling across sensors and years. The pre-processing workflow included cloud (10%) and cloud-shadow masking using quality-assessment bands, seasonal filtering to reduce phenological variability, median compositing to suppress noise, and clipping imagery to the basin boundary.

4.3 Spectral Features and Indices

To improve class separability, spectral indices were derived in addition to the original Landsat bands. These included NDVI (Normalized Difference Vegetation Index) for vegetation characterization, NDWI (Normalized Difference Water Index) and MNDWI (Modified Normalized Difference Water Index) for water body extraction, NDBI (Normalized Difference Built-up Index) for built-up area identification, and BSI (Bare Soil Index) for distinguishing bare and fallow land. The indices were stacked with spectral bands to form the final feature set used for classification.

Table 4.1: Spectral features of the Landsat 5

Spectral band	Name	Centre Wavelength (nm)	Band Width (nm)	Spatial Resolution (m)
B1	Blue	485	70	30
B2	Green	560	80	30
B3	Red	660	60	30
B4	Near Infrared (NIR)	830	140	30
B5	Shortwave Infrared 1 (SWIR-1)	1650	200	30
B6	Thermal Infrared	11450	2100	120
B7	Shortwave Infrared 2 (SWIR-2)	2215	270	30

Tables 4.1 and 4.2 present the spectral bands available for classification in Landsat 5 and Landsat 8/9, respectively, to better select sampling points by using them directly or by creating additional spectral indices, such as true-color and false-color composites.

Table 4.2: Spectral features of the Landsat 8/9

Spectral band	Name	Centre Wavelength (nm)	Band Width (nm)	Spatial Resolution (m)
B1	Coastal/Aerosol	443	20	30
B2	Blue	482	60	30
B3	Green	561	60	30
B4	Red	655	40	30
B5	Near Infrared (NIR)	865	30	30
B6	Shortwave Infrared 1 (SWIR-1)	1610	85	30
B7	Shortwave Infrared 2 (SWIR-2)	2200	180	30
B8	Panchromatic	590	180	15
B9	Cirrus	1375	30	30
B10	Thermal Infrared 1	10895	600	100

4.4 Random Forest Classification

The LULC classification maps were generated using the Random Forest machine learning algorithm implemented in Google Earth Engine. The RF algorithm, originally proposed by Leo Breiman (2001), is one of the most widely used supervised classification techniques in remote sensing due to its high classification accuracy, robustness to noise, and ability to handle large multidimensional datasets. Several studies have demonstrated the effectiveness of RF for LULC classification using satellite imagery (e.g., Pedro Rodríguez-Galiano et al., 2012). The RF algorithm is based on an ensemble learning approach in which multiple decision trees are constructed during the training phase, and their outputs are combined to produce a final classification result.

In this study, Landsat surface reflectance imagery was used to derive spectral bands and indices for classification. The spectral bands used include Blue (SR_B2), Green (SR_B3), Red (SR_B4),

Near Infrared (SR_B5), Shortwave Infrared 1 (SR_B6), and Shortwave Infrared 2 (SR_B7). These bands capture variations in vegetation, soil, water, and built-up features across the landscape.

To support the collection of reliable training samples, False Color Composite (FCC) imagery was generated using Landsat bands. In FCC images, the Near Infrared (NIR), Red, and Green bands are typically displayed in the red, green, and blue channels, respectively. This combination enhances vegetation signals and improves the visual differentiation of land cover types. In FCC imagery, healthy vegetation appears in bright red tones, water bodies appear dark or black, urban and built-up areas appear cyan or grey, and bare soil or barren land appears in light brown or yellowish tones. The use of FCC imagery significantly improves the identification of different land cover classes and facilitates the accurate selection of training samples for supervised classification.

Training samples representing six major LULC classes were digitized based on visual interpretation of FCC images, high-resolution imagery, and ancillary data. These samples were used to extract spectral values from the Landsat composite dataset using the `sampleRegions` function in GEE. In addition to the original spectral bands, several spectral indices were calculated to enhance the separability of different land cover types. These indices capture specific characteristics related to vegetation vigor, water presence, built-up areas, and bare soil conditions.

The Normalized Difference Vegetation Index (NDVI) was calculated to highlight vegetation density using the following equation:

$$NDVI = \frac{NIR-RED}{NIR+RED} \quad 4.1$$

where *NIR* represents the near-infrared band (SR_B5) and *RED* represents the red band (SR_B4).

The Normalized Difference Water Index (NDWI) was used to identify the water bodies and surface moisture at wetlands:

$$NDWI = \frac{GREEN-NIR}{GREEN+NIR} \quad 4.2$$

where *GREEN* corresponds to the green band (SR_B3) and *NIR* represents the near-infrared band (SR_B5).

The Modified Normalized Difference Water Index (MNDWI) was introduced by Hanqiu Xu (2006) to improve the detection of water bodies in satellite imagery. The index enhances open water features while suppressing noise from built-up areas, vegetation, and soil surfaces. Compared to the traditional NDWI, MNDWI replaces the near-infrared band with the shortwave infrared band, which significantly improves the discrimination of water bodies from urban land and soil surfaces. The MNDWI is calculated using the following equation:

$$MNDWI = \frac{GREEN - SWIR_1}{GREEN + SWIR_1} \quad 4.3$$

where *GREEN* represents the green band (SR_B3 in Landsat imagery) and *SWIR₁* represents the shortwave infrared band (SR_B6 in Landsat imagery)

Water bodies typically produce positive MNDWI values, while built-up areas, vegetation, and soil surfaces generally produce negative values. Therefore, this index is particularly effective in extracting surface water features from complex landscapes, especially in regions where urban areas and water bodies coexist. The Normalized Difference Built-up Index (NDBI) was used to identify urban and built-up areas:

$$NDBI = \frac{SWIR_1 - NIR}{SWIR_1 + NIR} \quad 4.4$$

where *SWIR₁* represents the shortwave infrared band (SR_B6) and *NIR* represents the near-infrared band (SR_B5).

The Bare Soil Index (BSI) was calculated to enhance exposed soil and barren land surfaces:

$$BSI = \frac{(SWIR_1 + RED) - (NIR + BLUE)}{(SWIR_1 + RED) + (NIR + BLUE)} \quad 4.5$$

where *SWIR₁* represents the shortwave infrared band (SR_B6), *RED* represents the red band (SR_B4), *NIR* represents the near-infrared band (SR_B5), and *BLUE* represents the blue band (SR_B2).

The spectral bands and derived indices were combined to create a multi-band composite dataset, which served as the input feature space for the RF classification model. The integration of spectral bands with derived indices improves the classifier's ability to distinguish between vegetation, water bodies, built-up areas, and bare soil surfaces.

For model development, the sample dataset was randomly split into training and test sets. In this study, 70% of the samples were used to train the RF classifier, while the remaining 30% were used for independent accuracy assessment. This train–test split ensures that the model is evaluated on unseen data and helps prevent overfitting. The RF classifier was implemented using the smileRandomForest algorithm in Google Earth Engine with 200 decision trees. Each tree in the forest is trained on a bootstrap sample of the training data, a process known as bagging (bootstrap aggregating). In this method, multiple decision trees are generated using different subsets of the training dataset, introducing randomness into the learning process and improving model generalization.

During classification, each decision tree independently predicts the class label of a pixel, and the final classification is determined through majority voting across all trees in the forest. This ensemble strategy reduces model variance, minimizes overfitting, and improves overall classification accuracy. Additional randomness is introduced during tree construction by selecting a subset of predictor variables at each node split, ensuring diversity among the decision trees. Using the trained RF classifier, the composite dataset was classified into six LULC categories across the Narmada River Basin. The final classified maps were produced at a 30 m spatial resolution and clipped to the basin boundary for further analysis. Separate RF models were developed for each study year to account for temporal variability and sensor-specific differences in spectral responses, ensuring consistent classification results across the entire study period.

Table 4.3: Classes adopted for the classification

Class no.	Class name	Description
1	Agriculture	These are areas used for farming and agricultural activities.
2	Barren	This refers to areas of land with little to no vegetation or human-made structures.
3	Built-up	These are areas with human-made structures and surfaces, including residential, commercial, and industrial buildings.
4	Fallow	Agricultural land intentionally left uncultivated for one or more growing seasons to regain fertility, manage moisture, and disrupt pest cycles
5	Forest	These are areas covered by indigenous trees and vegetation.
6	Waterbodies	This includes bodies of water such as dams, rivers, and estuaries.

4.5 Accuracy Assessment

Classification accuracy was assessed using independent validation samples. Overall Accuracy (OA), Producer's Accuracy (PA), and User's Accuracy (UA) were computed for each classified map. Only accuracy-verified maps were used for subsequent analysis. The OA, Kappa statistic, UA, and PA were computed to assess the comprehensive accuracy of each RF model (for 1995, 2005, 2015, and 2024 models). Evaluating classification accuracy provides confidence in the outcomes and the subsequent identification of LULC changes (Cheng et al., 2021). The OA is the probability of a randomly selected point on the map being classified correctly, and it is calculated as follows:

$$OA = \frac{\text{Total correctly classified samples}}{\text{Total number of samples}} \quad 4.6$$

The Kappa statistic, introduced by Cohen (1960), is a popular metric for assessing the performance of RF models because it provides a more representative measure than OA. The Kappa statistic shows the difference between the observed agreement and the agreement expected by chance, and a higher Kappa value (> 0.75) indicates that the observed agreement is better than chance alone would predict. It is calculated as follows:

$$Kappa = \frac{\text{Total Observed accuracy} - \text{By chance accuracy}}{1 - \text{By chance accuracy}} \quad 4.7$$

The performance of each model was further assessed using confusion matrices for both the training and testing stages. The confusion matrix's diagonal elements represent the number of points for which the predicted class is equal to the reference class (correct classifications), while off-diagonal elements are those that are mislabeled by the classifier (misclassifications). From these confusion matrices, the UA and PA were computed. These metrics provide insights into the model's class-specific performance.

To reduce classification errors, the classified images were manually edited, and incorrectly classified pixels were corrected in the ArcGIS raster calculator. The goal of image postprocessing is to prevent error accumulation before classification.

5. LAND USE LAND COVER MAPPING

The classified maps represent six major classes: Agriculture, Forest, Fallow land, Built-up area, Barren land, and Waterbodies. Spatial patterns show strong physiographic control plains dominated by agriculture, plateau and hilly regions by forest, and urban growth concentrated along river corridors and district centers.

5.1 Lower Narmada Basin

The Lower Narmada Basin represents the downstream portion of the river system and extends mainly across the plains of Gujarat and parts of western Madhya Pradesh. This region is characterized by fertile alluvial soils, extensive irrigation infrastructure, and increasing industrial and urban development. The LULC maps for the Lower Narmada Basin for the years 1995, 2005, 2015, and 2024 are presented in Figures 5.1, 5.2, 5.3, and 5.4, respectively. These maps illustrate the spatial distribution and temporal evolution of major land-use categories in the basin's downstream region.

In 1995, the Lower Narmada Basin was predominantly characterized by agricultural landscapes and forest cover. Agricultural land occupied approximately 21,028.03 km², making it the dominant land use class in the region. The extensive presence of agriculture reflects the favorable climatic conditions, fertile soils, and irrigation facilities available in the lower basin. Forest cover accounted for approximately 19,179.20 km², representing a substantial proportion of the basin area. These forests were mainly distributed in hilly regions and in protected forest areas along the basin margins.

Fallow land constituted approximately 3,115.84 km², indicating that a significant portion of land remained temporarily uncultivated during this period. These areas were mainly distributed in agricultural zones where land was left fallow as part of crop rotation or soil fertility management practices. Built-up areas were relatively limited in 1995, covering only 283.10 km². Urban development was mainly concentrated around towns and cities such as Bharuch and peri-urban areas of the Vadodara district, which serve as important economic and administrative centers in the region. Water bodies covered 1,249.48 km², consisting primarily of rivers, natural water bodies,

and irrigation reservoirs. Barren land occupied approximately 62.49 km², representing a very small proportion of the landscape. Overall, the spatial pattern observed in Figure 5.1 indicates a landscape dominated by agriculture and forest ecosystems, with relatively limited urban development.

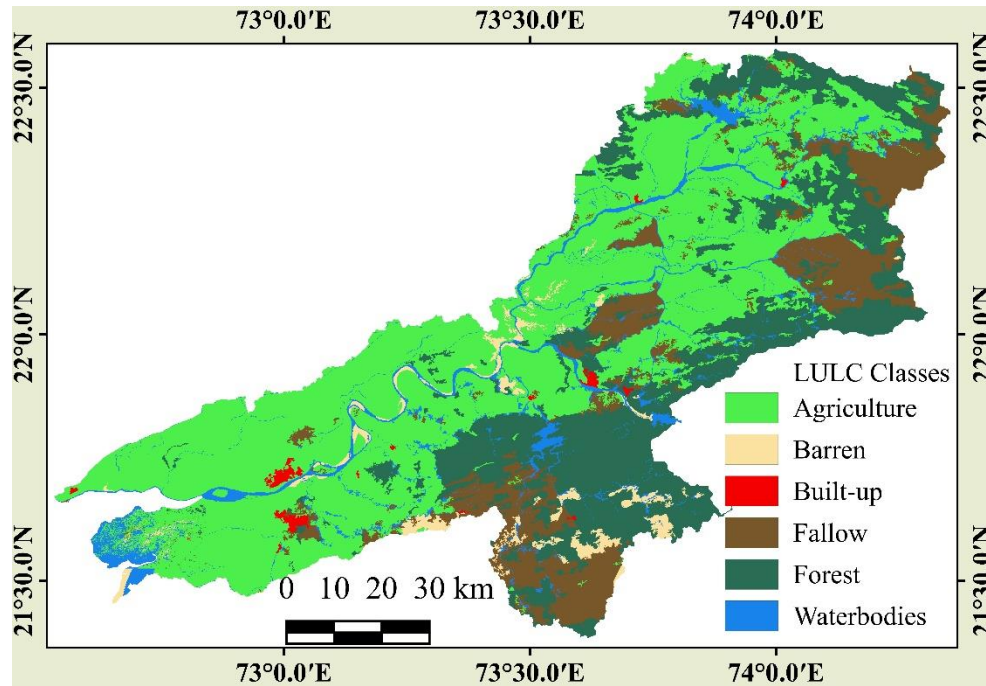


Figure 5.1: LULC map for the Lower Narmada basin for the year 1995

By 2005, several changes in land-use patterns had been observed in the Lower Narmada Basin. Agricultural land expanded significantly to 24,324.68 km², indicating increased agricultural activities and improved irrigation facilities (Figure 5.2). Forest cover decreased slightly to 18,065.99 km², suggesting that some forest areas may have been converted into agricultural land or other land uses. Fallow land declined dramatically to 915.86 km², indicating that many previously uncultivated lands were brought under active agricultural production. Built-up areas increased to 569.38 km², reflecting growing urbanization and infrastructure development in major towns and cities within the region. Water bodies decreased slightly to 1,036.75 km², which may be associated with seasonal hydrological variations or changes in water management practices. Barren land increased to 106.09 km², indicating localized land degradation in certain areas.

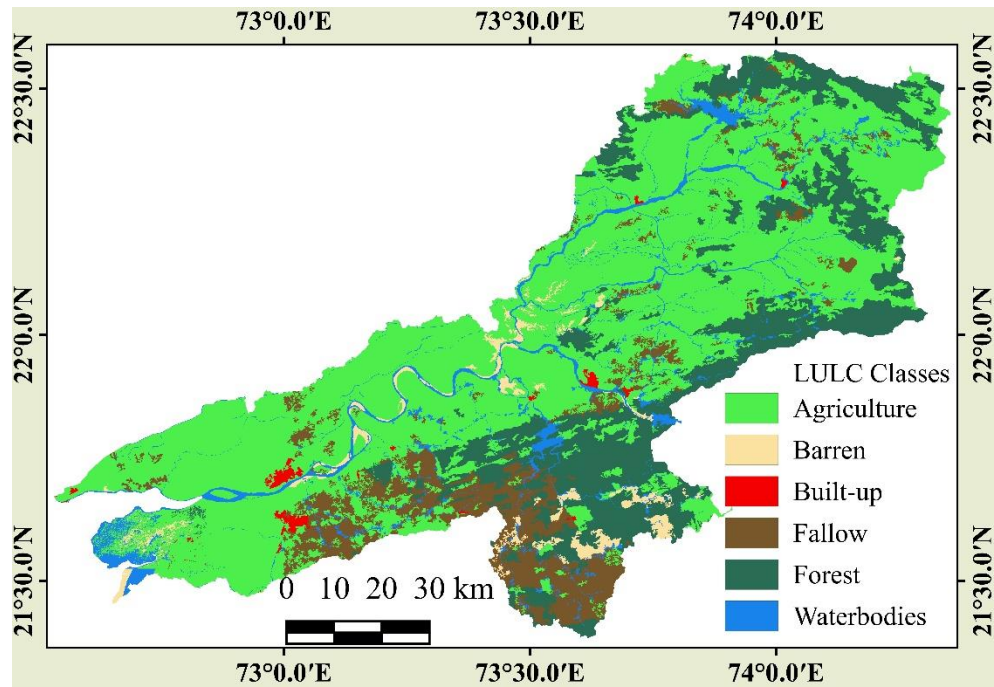


Figure 5.2: LULC map for the Lower Narmada basin for the year 2005

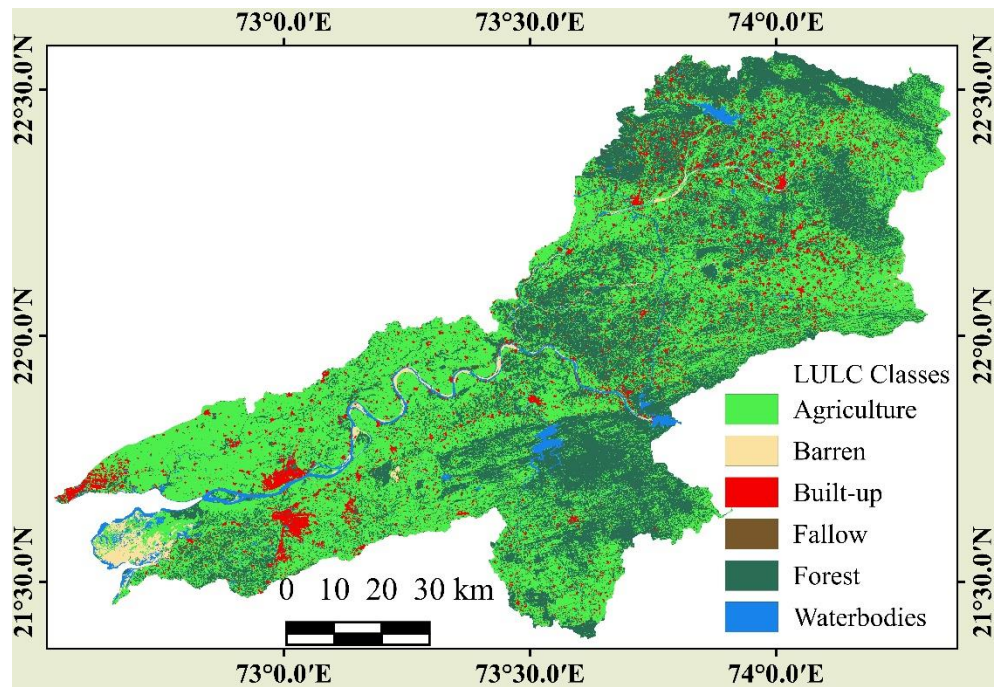


Figure 5.3: LULC map for the Lower Narmada basin for the year 2015

Figure 5.3 shows further transformations in land use patterns by 2015. Agricultural land decreased slightly to 23,032.14 km², although it remained the dominant land use category. Forest cover

increased to 19,617.15 km², suggesting partial forest regeneration or improved forest management practices. Built-up areas expanded further to 760.45 km², indicating continued urban growth in cities such as Vadodara and Bharuch, as well as in surrounding industrial areas. Fallow land declined sharply to 259.65 km², indicating continued conversion of fallow land into agricultural land. Water bodies remained relatively stable at 1,026.63 km², while barren land increased slightly to 124.21 km².

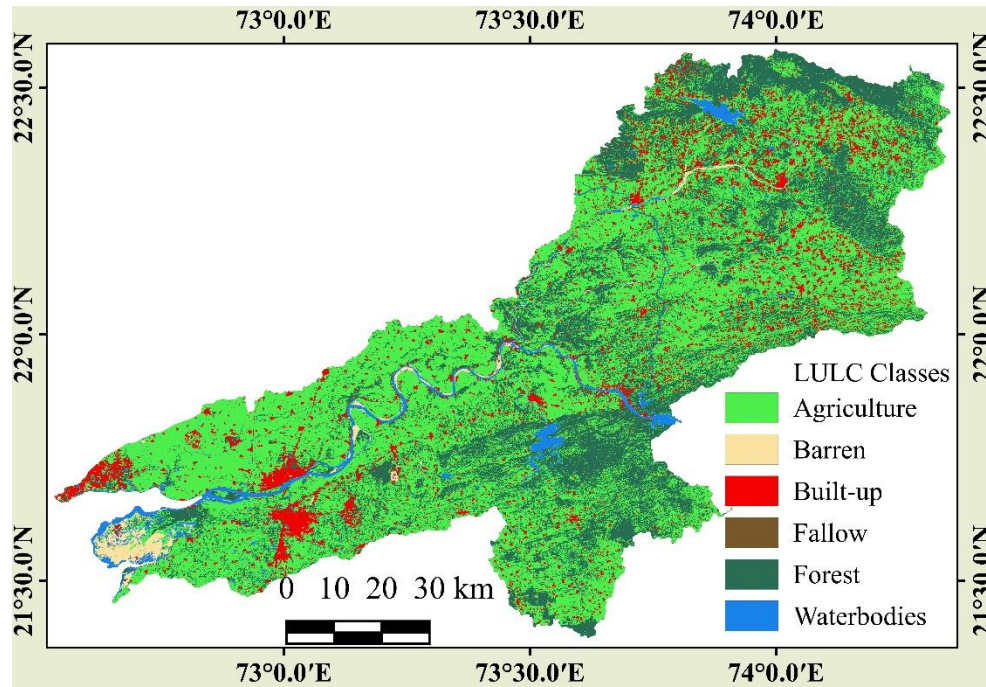


Figure 5.4: LULC map for the Lower Narmada basin for the year 2024

Figure 5.4 shows land-use distribution for the year 2024. Agricultural land covers 22,921.27 km², indicating a slight decline compared to earlier years but still representing the dominant land use category. Forest cover remains relatively stable at 19,386.03 km², indicating the persistence of forest landscapes in this region. Built-up areas expanded dramatically to 1,236.74 km², reflecting rapid urbanization and industrial expansion in the lower basin. Water bodies increased to 1,090.12 km², partly due to reservoir expansion and improved irrigation infrastructure. Fallow land declined further to 114.12 km², indicating that almost all previously unused agricultural land has been brought under cultivation. Overall, the lower basin shows a clear trend toward urban expansion and agricultural intensification over the tree decades.

5.2 Middle Narmada Basin

The Middle Narmada Basin is the central part of the Narmada River system and serves as a transitional zone between the forest-dominated upper basin and the agriculturally intensive lower basin. This region includes several important districts, including Hoshangabad (Narmadapuram), Sehore, Raisen, Dewas, Dhar, Khandwa, and Khargone, characterized by fertile agricultural plains, growing urban centers, and significant hydrological infrastructure. The LULC maps for the Middle Narmada Basin for the years 1995, 2005, 2015, and 2024 are presented in Figures 5.5, 5.6, 5.7, and 5.8, respectively.

The 1995 LULC map serves as the baseline land-use distribution for the Middle Narmada Basin. During this period, the landscape was characterized by a balanced distribution between agricultural land and forest cover. Agriculture occupied approximately 19,721.06 km², representing the region's dominant land use category. Agricultural areas were mainly concentrated in the fertile plains along the Narmada River and its tributaries, where favorable soil conditions and moderate climatic conditions supported extensive crop cultivation. Forest cover was the second most dominant land-use category, covering 15,950.87 km². These forests were mainly distributed along the Vindhyan and Satpura Ranges, forming an important ecological corridor that supports biodiversity and regulates hydrological processes in the basin. Fallow land covered 4,968.49 km², representing a significant portion of the landscape. These areas were primarily associated with agricultural lands that were temporarily left uncultivated due to seasonal cropping patterns, soil fertility management, or water availability constraints.

Built-up areas were relatively limited in 1995, covering only 140.08 km². Urban settlements were mainly confined to major towns such as Narmadapuram, Dewas, and Sehore, while most of the region remained rural. Water bodies covered 1,093.95 km², consisting mainly of rivers, natural lakes, and smaller irrigation reservoirs. Barren land occupied 244.67 km², representing degraded lands with limited vegetation cover. Overall, the spatial pattern observed in Figure 5.5 indicates that the Middle Narmada Basin was largely characterized by agriculture–forest mosaics, with relatively limited urban development.

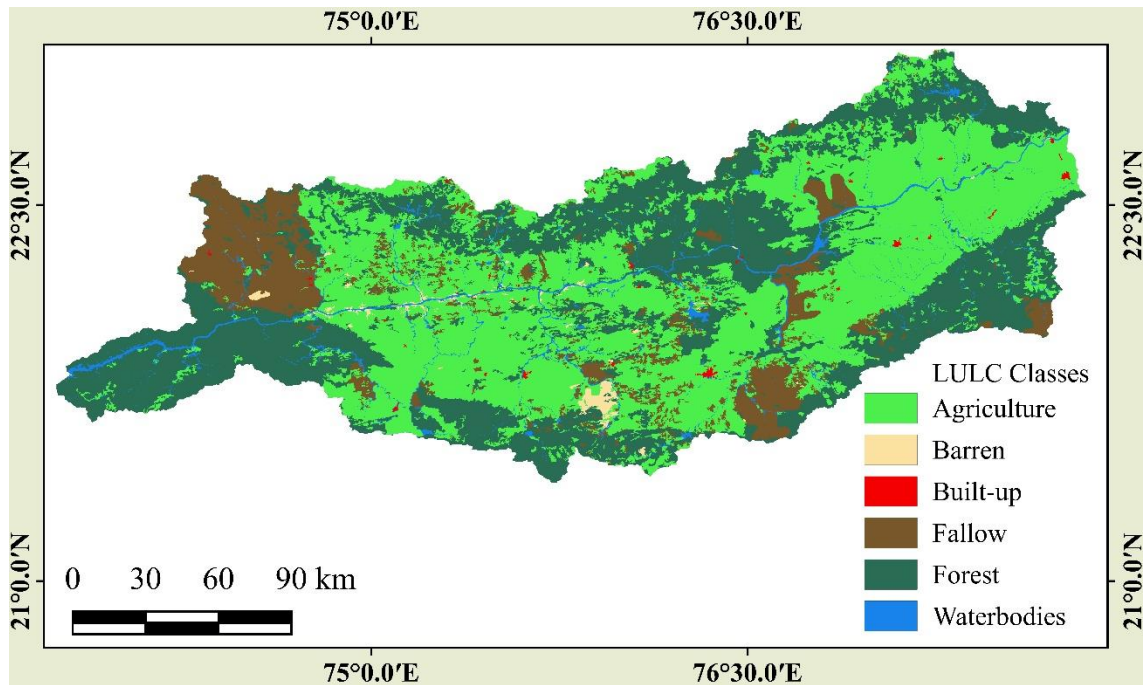


Figure 5.5: LULC map for the Middle Narmada basin for the year 1995

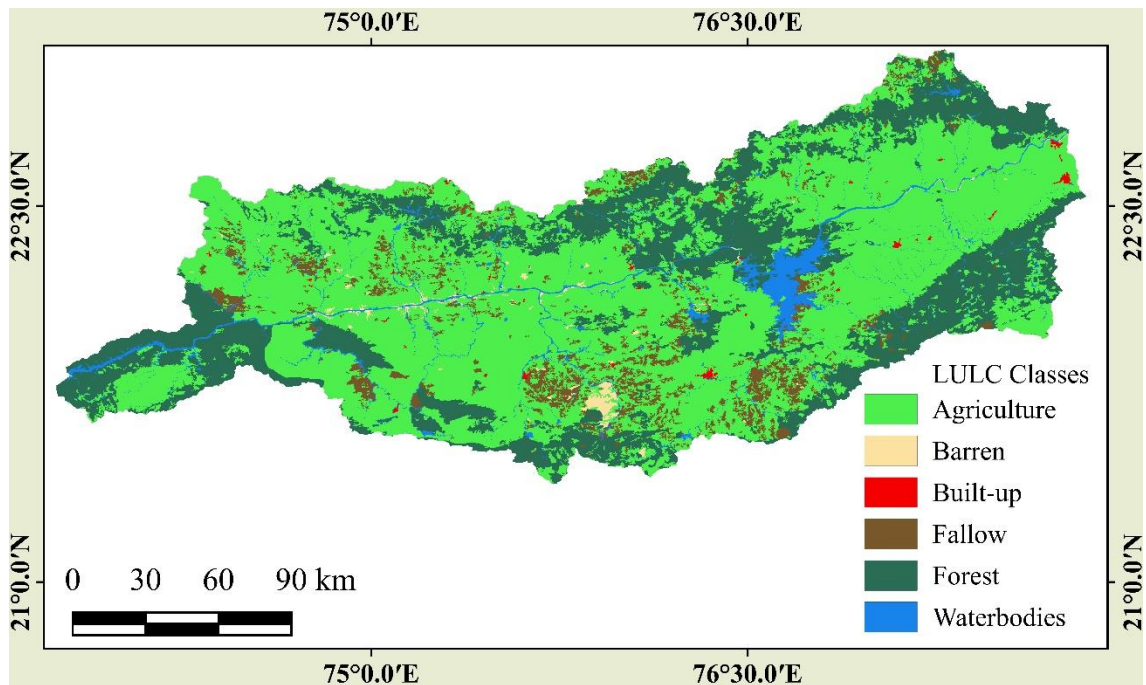


Figure 5.6: LULC map for the Middle Narmada basin for the year 2005

The 2005 LULC map reveals significant changes in land-use patterns compared to the baseline conditions observed in 1995. The most prominent change during this period is the expansion of

agricultural land. Agriculture increased substantially to 25,918.98 km², representing a gain of more than 6,000 km² over the past decade. This rapid agricultural expansion can be attributed to several factors, including expanded irrigation infrastructure, agricultural development programs, rising demand for food production, and the conversion of forest and fallow land into agricultural fields.

At the same time, forest cover declined sharply to 11,538.94 km², indicating a loss of more than 4,400 km² of forest area between 1995 and 2005. This suggests that a significant portion of forest land was converted to agricultural or other land uses. Fallow land decreased to 2,507.99 km², indicating that many previously unused agricultural lands were brought under cultivation. Built-up areas expanded to 320.91 km², reflecting increasing urbanization and infrastructure development in major towns and cities. Water bodies increased significantly to 1,409.57 km², mainly due to the development of large reservoirs associated with major dam projects such as Indira Sagar and Omkareshwar reservoirs.

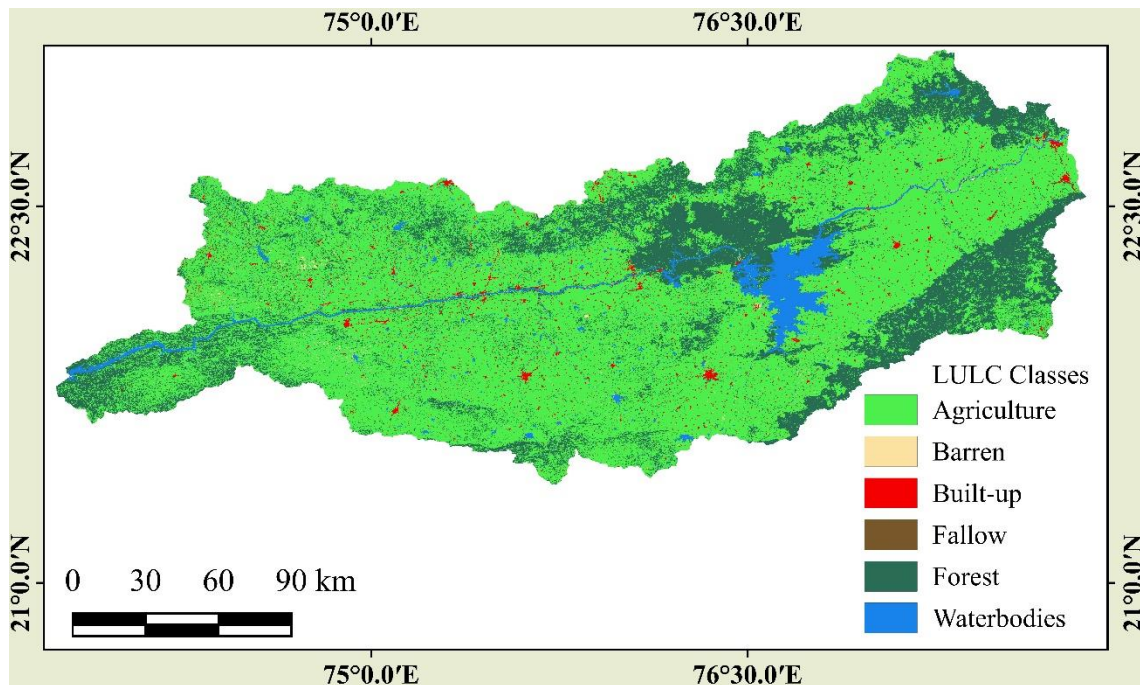


Figure 5.7: LULC map for the Middle Narmada basin for the year 2015

The spatial distribution shown in Figure 5.6 highlights the beginning of a major landscape transformation driven by agricultural intensification and reservoir development. The 2015 LULC

map shows further transformations in land-use patterns across the Middle Narmada Basin. Agricultural land increased further to 29,027.67 km², indicating continued expansion of agriculture across the region. This increase reflects the growing importance of the Middle Narmada Basin as a major agricultural production zone. Forest cover declined further to 10,163.42 km², representing a continued reduction in forest area over time. The decline in forest cover during this period may be attributed to agricultural encroachment, infrastructure development, and land conversion associated with reservoir expansion.

Built-up areas expanded considerably to 981.72 km², indicating rapid urban growth. Cities such as Indore, Dewas, and Narmadapuram experienced significant urban expansion during this period. Water bodies increased to 1,739.56 km², reflecting the increasing influence of large reservoirs in the basin. Reservoirs such as Indira Sagar and Omkareshwar significantly altered the region's hydrological landscape. Fallow land declined drastically to 93.84 km², indicating that almost all previously unused agricultural land had been brought under seasonal cultivation. The spatial pattern observed in Figure 5.7 illustrates a landscape increasingly dominated by intensive agriculture and expanding urban settlements.

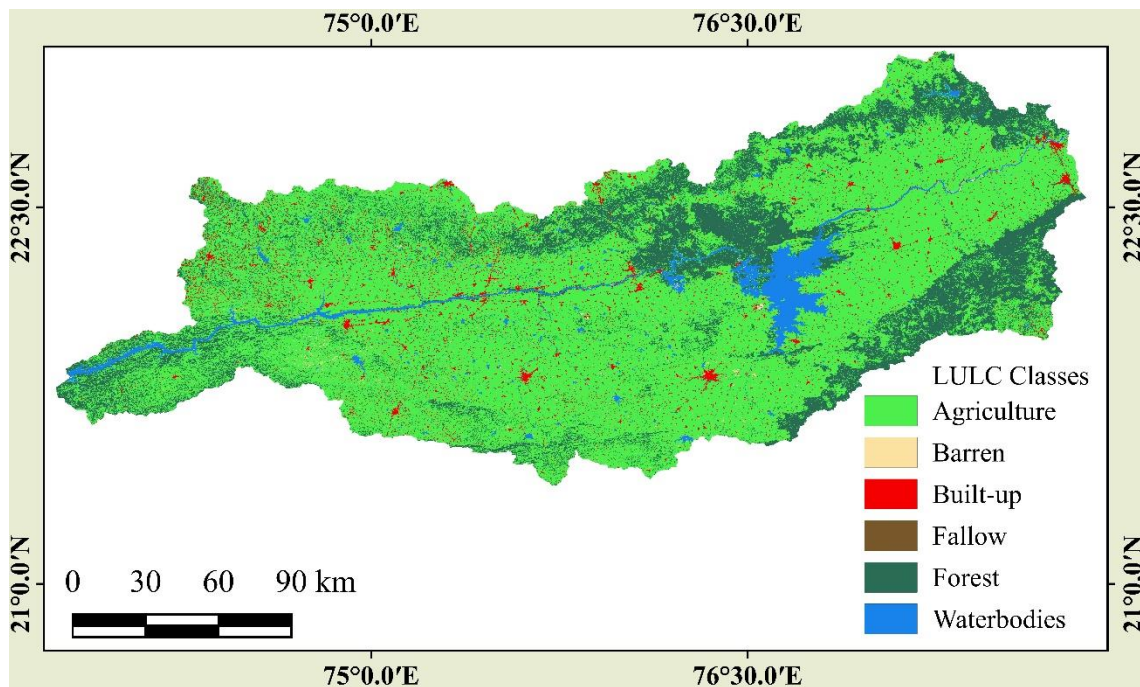


Figure 5.8: LULC map for the Middle Narmada basin for the year 2024

The most recent LULC map for the Middle Narmada Basin is shown in Figure 5.8 and depicts land use conditions in 2024. Agricultural land increased further to 29,713.97 km², confirming the dominance of agriculture in the middle basin. Forest cover declined to 8,878.89 km², the lowest level observed during the study period. This indicates long-term pressure on forest ecosystems due to land conversion. Built-up areas expanded significantly to 1,523.03 km², reflecting continued urban growth and infrastructure development. Water bodies increased further to 1,913.96 km², highlighting the significant impact of reservoir construction and water management projects. Overall, the Middle Narmada Basin has experienced the most dramatic land-use transformations, primarily driven by agricultural expansion and urbanization. Overall, substantial land transformation in the Middle Narmada basin over the past three decades has been driven by agricultural expansion, reservoir construction, and urbanization.

5.3 Upper Narmada Basin

The Upper Narmada Basin represents the upstream mountainous headwater region of the river system, extending across the Amarkantak Plateau and surrounding forested landscapes. This region is characterized by rugged terrain, dense forests, and relatively low population density compared to the middle and lower basin regions. The LULC maps for the Upper Narmada Basin for the years 1995, 2005, 2015, and 2024 are presented in Figures 5.9, 5.10, 5.11, and 5.12, respectively.

In 1995, the Upper Narmada Basin was primarily characterized by forest ecosystems and moderate agricultural activity. Agricultural land covered 5,395.63 km², representing the region's dominant land use category. These agricultural areas were mainly concentrated in valleys and relatively flat areas where cultivation was feasible. Fallow land occupied 1,383.07 km², indicating that a substantial portion of agricultural land remained temporarily uncultivated. Built-up areas were minimal, covering only 90.49 km², reflecting the upper basin's rural nature. Water bodies covered 562.55 km², consisting mainly of rivers, natural lakes, and small reservoirs. Overall, the spatial distribution shown in Figure 5.9 indicates a landscape dominated by forests and small-scale agriculture. Forest cover accounted for 2,479.26 km², forming an important ecological component

of the upper basin. These forests are part of the Satpura and Maikal Ranges, which support rich biodiversity and play a crucial role in maintaining watershed stability.

By 2005, several changes in land-use patterns had been observed in the Upper Narmada Basin. Agricultural land increased slightly to 6,193.59 km², indicating moderate agricultural expansion in the region. Forest cover declined to 2,032.51 km², suggesting that some forest areas may have been converted into agricultural land or other land uses. Fallow land decreased to 984.43 km², reflecting increasing utilization of agricultural land. Built-up areas increased to 183 km², indicating gradual urban expansion in towns such as Jabalpur and Mandla. Water bodies decreased slightly to 492.87 km², possibly due to seasonal hydrological variations.

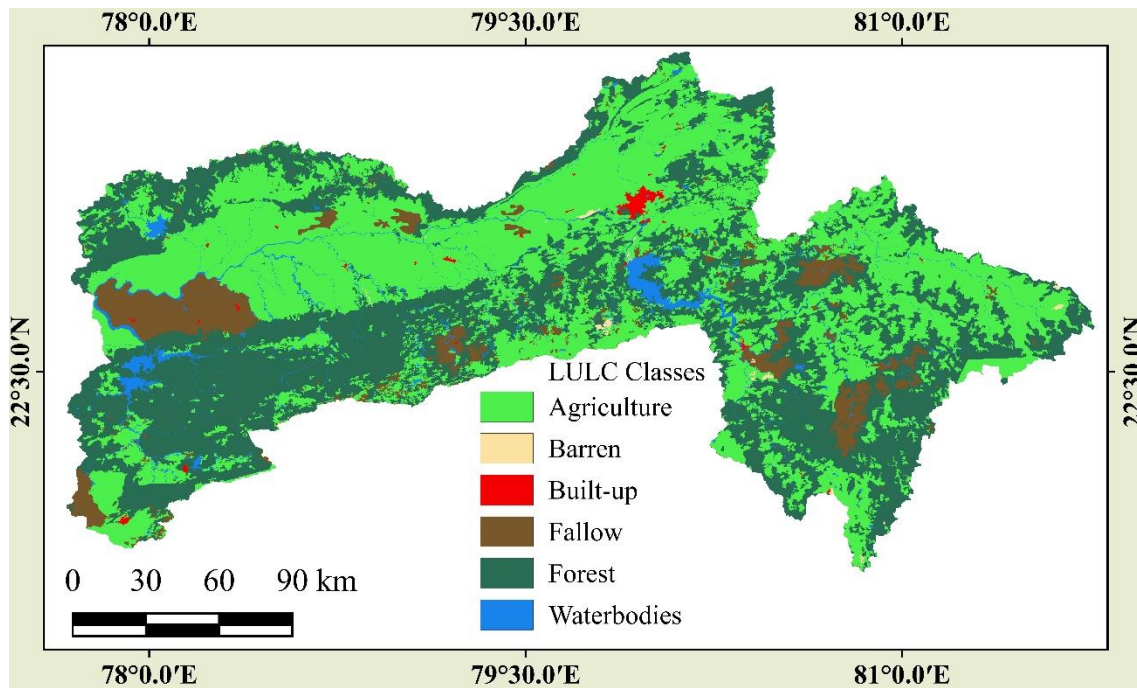


Figure 5.9: LULC map for the Upper Narmada basin for the year 1995

The 2015 LULC map shows a significant increase in forest cover, reaching 3,867.50 km². This increase may be associated with forest regeneration, afforestation programs, or improved forest classification techniques. Agricultural land decreased slightly to 5,206.76 km², suggesting shifts in land-use patterns. Built-up areas increased dramatically to 588.91 km², reflecting rapid urban

expansion in the upper basin. Water bodies declined to 282.57 km², indicating possible hydrological variability.

The most recent LULC map for the Upper Narmada Basin is shown in Figure 5.12 and depicts land use conditions in 2024. Agricultural land increased again to 5,723.56 km², reflecting renewed agricultural expansion. Forest cover declined slightly to 3,046.80 km², although forests still represent an important component of the landscape. Built-up areas increased significantly to 829.40 km², indicating ongoing urban development in the upper basin. Water bodies increased slightly to 354.32 km², possibly due to watershed management projects and the construction of small reservoirs. Overall, the Upper Narmada Basin continues to maintain relatively higher forest cover compared to other parts of the basin, although gradual urbanization and agricultural expansion are becoming increasingly.

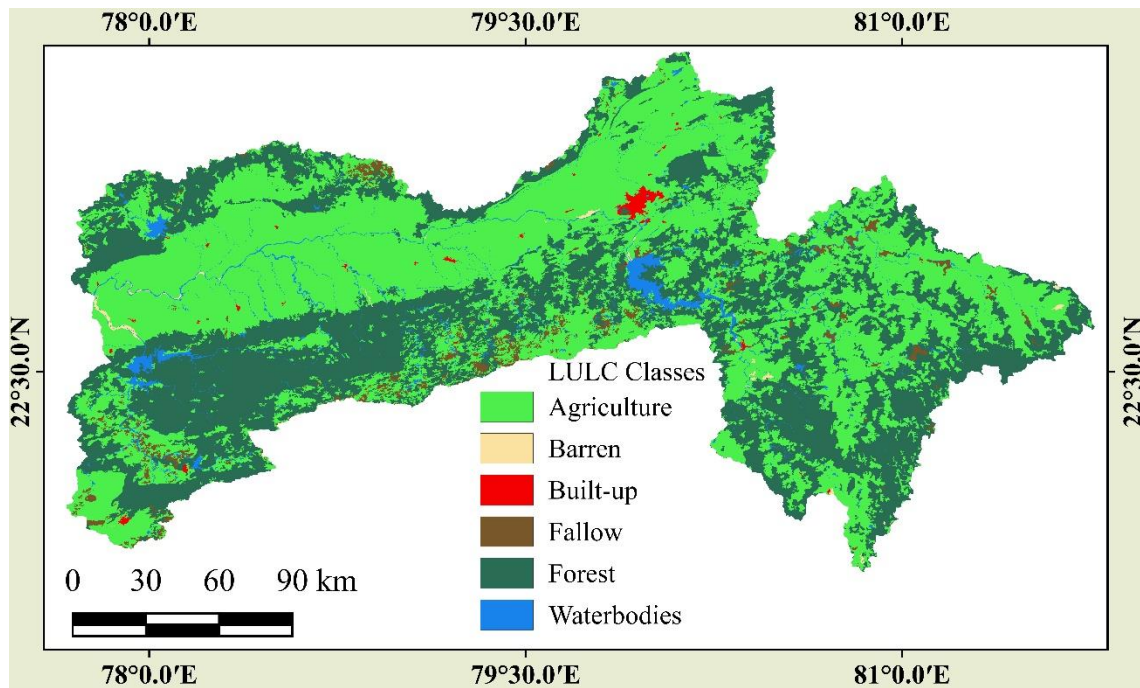


Figure 5.10: LULC map for the Upper Narmada basin for the year 2005

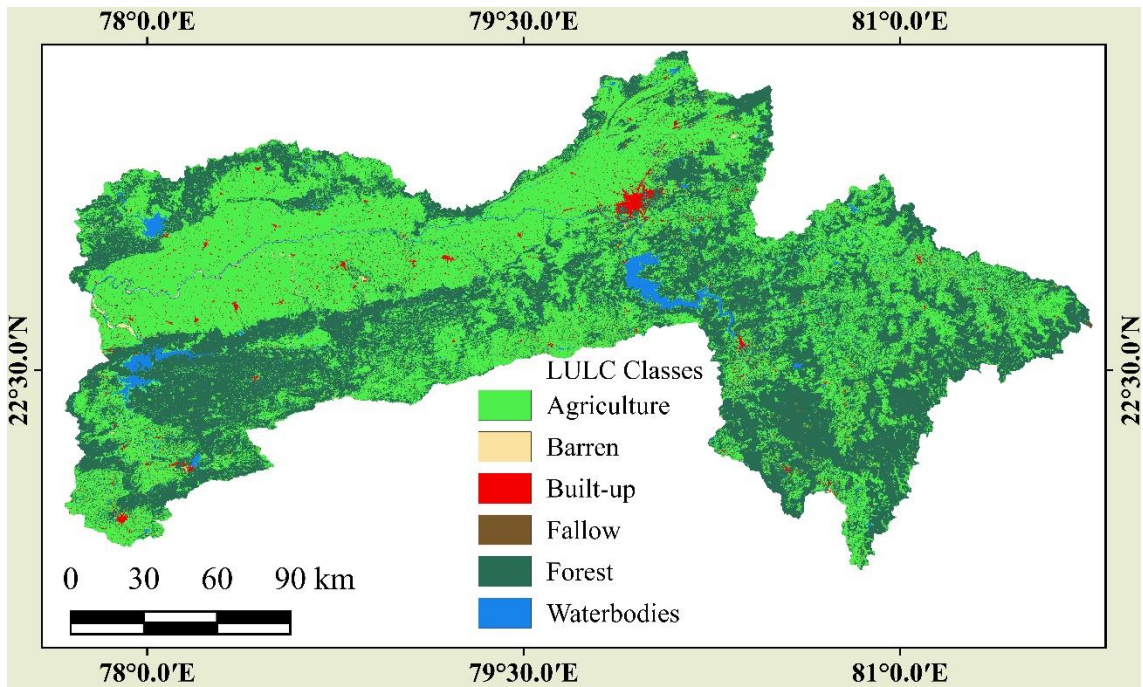


Figure 5.11: LULC map for the Upper Narmada basin for the year 2015

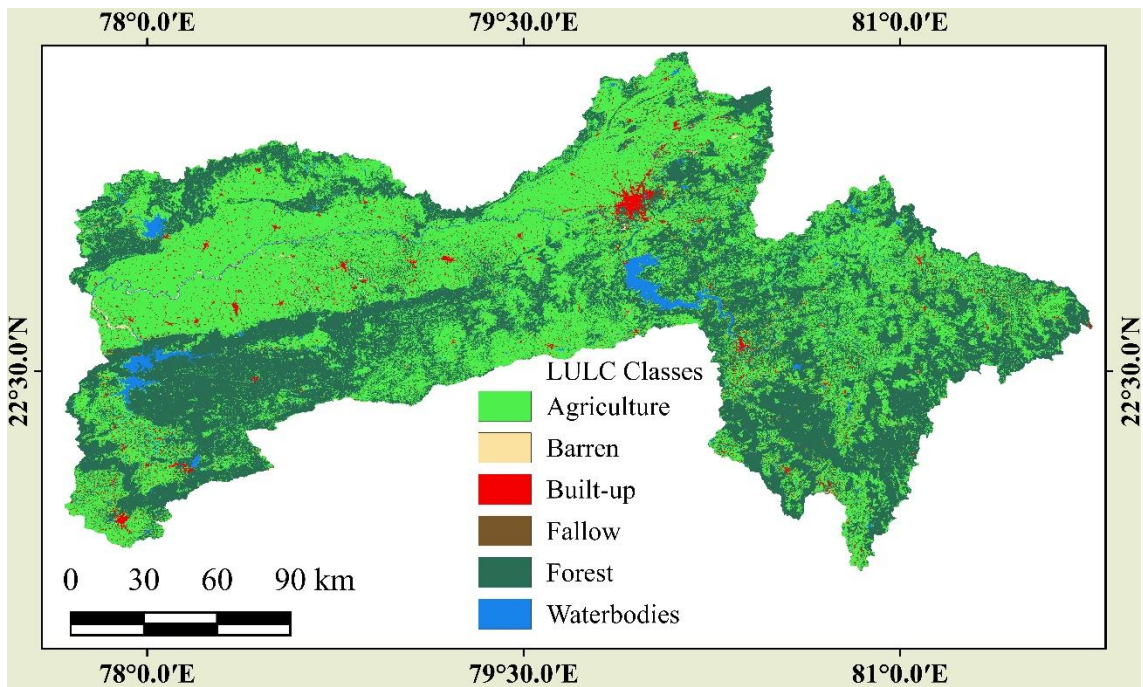


Figure 5.12: LULC map for the Upper Narmada basin for the year 2024

5.4 Entire Narmada River Basin

An exhaustive analysis of the LULC distribution for 1995, 2005, 2015, and 2024 across the entire Narmada River Basin is presented in the following section. Figure 5.13 illustrates the LULC distribution across the Narmada Basin in 1995, representing the baseline land use conditions before large-scale infrastructure expansion in the basin. The statistics indicate that agriculture was the dominant land-use category, occupying approximately 46,144.81 km², corresponding to 47.50% of the total basin area. Agricultural land was mainly concentrated in the middle and lower regions of the basin, where fertile soils and relatively gentle topography support extensive cultivation.

The second most dominant land-use category was forests, occupying 37,609.40 km², representing 38.71% of the basin area. Forests were primarily concentrated in the upper basin districts, particularly in Mandla, Dindori, Betul, and Chhindwara. These forested areas play an essential role in maintaining ecological balance, supporting biodiversity, and regulating hydrological processes. Fallow land accounted for 9,467.38 km², representing 9.74% of the basin area. These areas were largely distributed in agricultural regions where land was temporarily left uncultivated due to soil recovery requirements or agricultural management practices. Water bodies covered 2,905.99 km², representing 2.99% of the basin area.

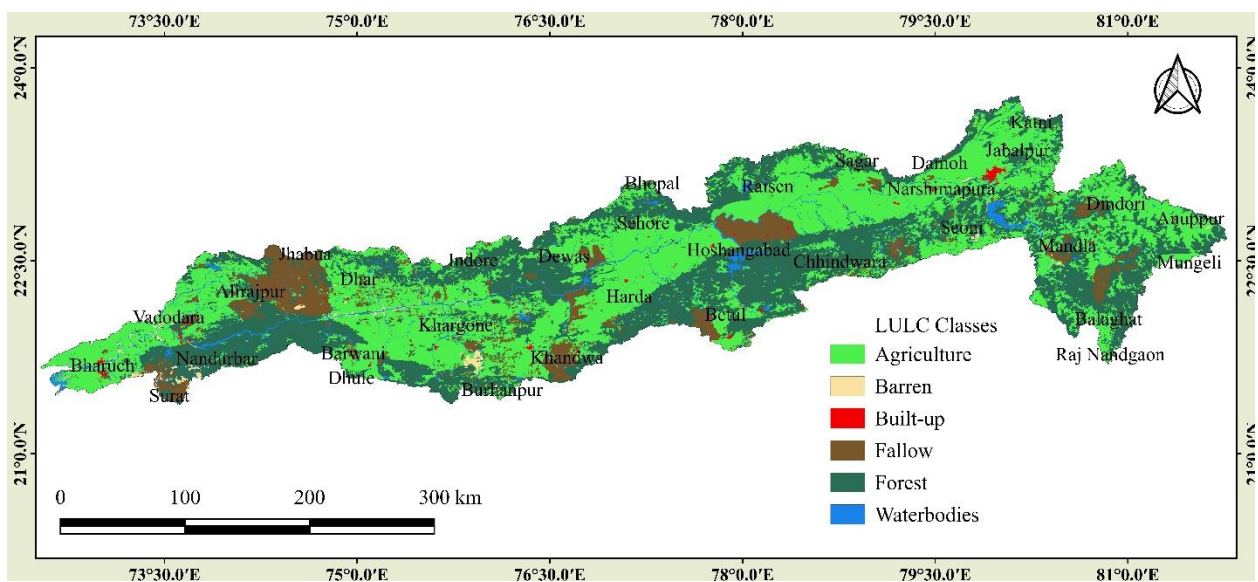


Figure 5.13: LULC map for the Entire Narmada basin for the year 1995

These water bodies included natural rivers, lakes, and existing reservoirs. The built-up area in 1995 was relatively small, covering only 513.60 km², or 0.53% of the basin area. Urban settlements were mainly confined to major cities such as Jabalpur, Indore, and Bhopal, while most of the basin remained rural. Barren land constituted 511.01 km², accounting for 0.53% of the basin area. Overall, the LULC pattern in 1995 indicates a basin dominated by natural forest ecosystems and agricultural landscapes, with relatively limited urban development.

The LULC in the Narmada Basin in 2005 highlights significant changes from baseline conditions observed in 1995 (Figure 5.14). The most prominent change during this period is the expansion of agricultural land. Agricultural area increased from 46,144.81 km² in 1995 to 56,437.46 km² in 2005, representing 58.09% of the basin area. This indicates an increase of more than 10,000 km² of agricultural land within a decade. This expansion reflects increasing agricultural intensification driven by population growth, government agricultural programs, and improvements in irrigation infrastructure. At the same time, forest cover declined substantially from 37,609.40 km² in 1995 to 31,637.50 km² in 2005, representing 32.56% of the basin area. This reduction suggests that a significant portion of forest land was converted to agricultural land. Fallow land also declined dramatically from 9,467.38 km² to 4,408.42 km², indicating that previously uncultivated lands were increasingly brought under cultivation. Built-up areas increased from 513.60 km² in 1995 to 1,073.46 km² in 2005, reflecting early stages of urban expansion in the basin.

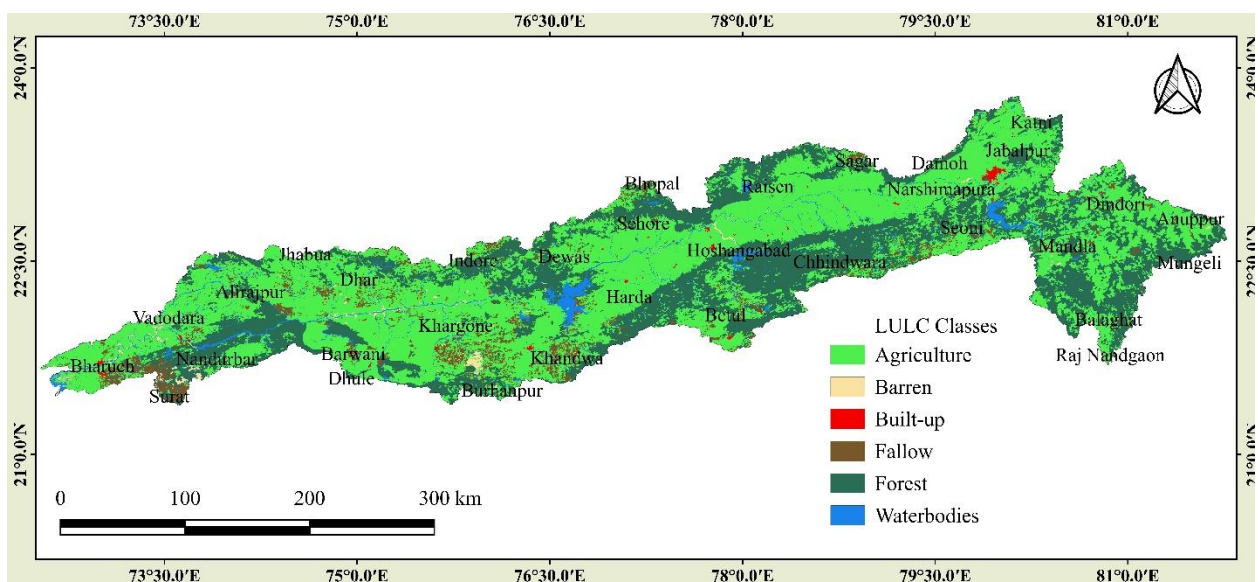


Figure 5.14: LULC map for the Entire Narmada basin for the year 2005

Water bodies increased slightly to 2,939.03 km², partly due to the development of reservoir infrastructure. Built-up areas remain minimal and largely confined to major urban centers such as Jabalpur and Bharuch. Water bodies are primarily limited to the main river channel and a few small reservoirs. Fallow land appears scattered across rain-fed agricultural regions, indicating seasonal cultivation practices. The overall spatial organization suggests a largely agrarian basin with moderate human pressure and strong natural land cover continuity.

Figure 5.15 illustrates the LULC distribution for the Narmada Basin in 2015, showing further landscape transformations. Agricultural land continued to expand, reaching 57,266.59 km², representing 58.95% of the basin area. The increase in agricultural land during this period reflects continued agricultural intensification across the basin. The most significant change during this period is the sharp decline in fallow land, which decreased to 400.23 km², representing only 0.41% of the basin area. This indicates that most fallow land was converted into productive agricultural land. Built-up areas expanded significantly to 2,331.08 km², representing 2.40% of the basin area. Forest cover increased slightly to 33,647.98 km², accounting for 34.63% of the basin area. This temporary increase may be attributed to forest regeneration or afforestation initiatives. Rapid urbanization during this period was driven by population growth, industrial development, and infrastructure expansion. Water bodies increased to 3,048.83 km², reflecting the growing influence of large reservoirs in the basin.

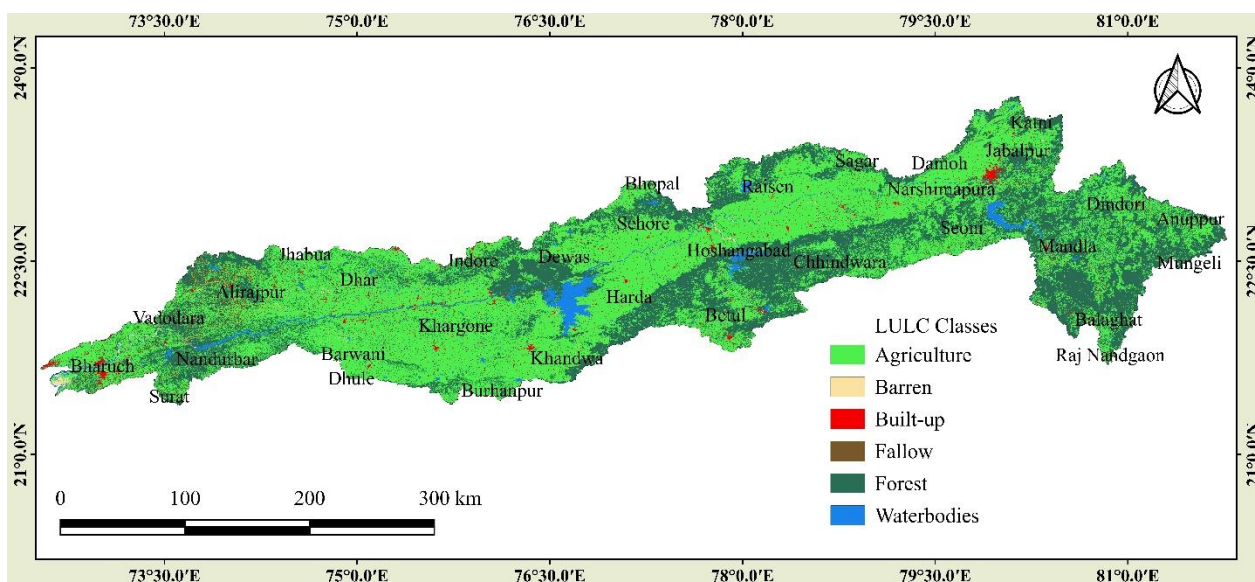


Figure 5.15: LULC map for the Entire Narmada basin for the year 2015

6. BASIN TO DISTRICT-LEVEL LULC DISTRIBUTION

This study provides a comprehensive multi-temporal assessment of LULC dynamics in the Narmada Basin for the period 1995–2024 using Landsat data and Random Forest classification. The basin-, sub-basin-, and district-wise analyses, together with robust change detection and statistical evaluation, provide a reliable spatial framework for future environmental and hydrological investigations. The LULC statistics derived from multi-temporal classification reveal significant spatial and temporal transformations across the Narmada River Basin during the period 1995–2024. Tables 7.1, 7.2, 7.3, 7.4, and 7.5 present the basin-class-wise area statistics for the entire basin, lower basin, middle basin, upper basin, and district level, respectively.

Table 7.1 presents aggregated area statistics for the six major Land Use Land Cover (LULC) classes across the entire Narmada River Basin for the years 1995, 2005, 2015, and 2024. The results illustrate the long-term evolution of landscape structure across the basin over nearly three decades. While the total basin area remains approximately 97,152 km² (as per the shapefile), the proportional distribution of land-use categories has undergone considerable change, reflecting the growing influence of anthropogenic activities, agricultural intensification, infrastructure development, and hydrological regulation across the basin.

Agriculture remained the dominant land-use category throughout the study period. The agricultural area increased steadily from 46,144.81 km² (47.50%) in 1995 to 58,358.59 km² (60.07%) in 2024, representing an overall increase of approximately 12,213 km² over the three decades. This substantial expansion highlights the growing importance of agricultural production in the basin and reflects the ongoing conversion of fallow and forest lands into cultivated areas. The most pronounced expansion occurred between 1995 and 2005, when agricultural land increased considerably, suggesting rapid agricultural intensification supported by irrigation development and improved agricultural practices.

Forest cover represents the second most dominant land-use category in the basin; however, the statistics reveal a gradual long-term decline. Forest area decreased from 37,609.40 km² (38.71%) in 1995 to 31,311.63 km² (32.23%) in 2024, resulting in a net loss of approximately 6,298 km²

over the study period. Although a nominal increase was observed in 2015 (33,647.98 km²), the overall trend suggests increasing pressure on forest ecosystems from agricultural expansion, infrastructure development, and land conversion. Evidence from district-level forest monitoring further supports this observation.

Satellite-based assessments from Global Forest Watch (<https://www.globalforestwatch.org>) indicated nearly 19% of tree cover loss between 2001 and 2024 in Dindori district, located in the Upper Narmada Basin, which occurred in areas associated with permanent deforestation drivers, primarily related to agricultural expansion. In addition, temporary disturbances, such as logging (approximately 400 ha) and wildfires (approximately 31 ha), were identified as contributing factors to forest degradation. These findings suggest that forest loss within the basin is largely driven by localized anthropogenic disturbances rather than large-scale clear-cutting.

A notable reduction in fallow land is also observed (Table 7.1). The fallow area declined sharply from 9,467.38 km² (9.74%) in 1995 to 127.51 km² (0.13%) in 2024, representing a reduction of more than 9,300 km² over the study period. This substantial decline indicates that a large portion of previously unused or temporarily uncultivated land has been progressively brought under agricultural production. Consequently, the reduction in fallow land represents a major contributor to the expansion of agricultural areas observed across the basin.

Urbanization also emerged as an important component of landscape transformation. Built-up areas increased significantly from 513.60 km² (0.53%) in 1995 to 3,589.13 km² (3.69%) in 2024, representing nearly a sevenfold increase. This rapid growth reflects the expansion of urban settlements, transportation networks, and industrial infrastructure across major urban centers, including Jabalpur, Dindori, Mandla, Narmadapuram, and Bharuch. The increase in built-up land demonstrates the basin's growing socio-economic development over the past three decades.

Water bodies showed a moderate yet consistent increase over the study period. The total area of water bodies expanded from 2,905.99 km² (2.99%) in 1995 to 3,358.42 km² (3.46%) in 2024. This expansion is primarily associated with the construction and expansion of large reservoirs, such as Indira Sagar, Omkareshwar, Bargi, and Sardar Sarovar, which have significantly altered the basin's

hydrological landscape. The increase in water surface area reflects enhanced water storage capacity and improved irrigation potential across the basin.

In contrast, barren land accounts for only a small proportion of the basin and shows only minor fluctuations over time. The barren land area increased slightly between 1995 and 2005, reaching 656.32 km², but subsequently declined to 406.92 km² by 2024. Overall, barren land accounts for less than 1% of the total basin area, indicating that most landscapes within the basin are actively utilized for agriculture, forestry, settlements, or water storage.

Overall, the statistics presented in Table 7.1 demonstrate that the Narmada River Basin has undergone substantial land-use transformation over the past three decades. The dominant trends include agricultural expansion, reduction of fallow land, gradual decline in forest cover, and rapid growth of built-up areas, accompanied by moderate increases in water bodies associated with reservoir development. These changes reflect the combined effects of population growth, agricultural intensification, urban expansion, and hydrological infrastructure development across the basin.

Table 6.1: LULC class area distribution for the entire Narmada River Basin (1995–2024)

Year → /LULC class ↓	1995		2005		2015		2024	
	Total area (km ²)	% of basin area	Total area (km ²)	% of basin area	Total area (km ²)	% of basin area	Total area (km ²)	% of basin area
Agriculture	46144.81	47.50	56437.46	58.09	57266.59	58.95	58358.59	60.07
Barren	511.01	0.53	656.32	0.68	457.48	0.47	406.92	0.42
Built-up	513.60	0.53	1073.46	1.10	2331.08	2.40	3589.13	3.69
Fallow	9467.38	9.74	4408.42	4.54	400.23	0.41	127.51	0.13
Forest	37609.40	38.71	31637.50	32.56	33647.98	34.63	31311.63	32.23
Water	2905.99	2.99	2939.03	3.03	3048.83	3.14	3358.42	3.46
Total	97152.1	100.0	97152.0	100.0	97152.0	100.0	97152.1	100.0

Table 7.2 presents the aggregated area statistics of the six major LULC classes for the Upper Narmada Basin for the years 1995, 2005, 2015, and 2024. The results reveal notable spatio-temporal transformations in land-use structure across the upstream portion of the basin over the

past three decades. Although the total geographical extent of the lower basin remains relatively constant at approximately 10,100 km², the proportional distribution of land-use categories has undergone considerable change, reflecting evolving land management practices, agricultural expansion, and increasing anthropogenic influence in this mountainous watershed.

Agriculture represents the dominant land-use category within the Upper Narmada Basin throughout the study period. Agricultural land increased from 5,395.63 km² (53.34%) in 1995 to 6,193.59 km² (61.10%) in 2005, indicating a substantial expansion of cultivated land during the early part of the study period. This growth reflects the increasing utilization of valley bottoms and relatively flat terrain for agricultural activities. However, the agricultural area declined to 5,206.76 km² (51.32%) in 2015, possibly due to changes in land classification, forest regeneration, or shifts in local land-use practices. By 2024, agricultural land again increased to 5,723.56 km² (56.62%), indicating renewed agricultural expansion in the region. Overall, agriculture continues to dominate the land-use structure of the upper basin, though observed fluctuations suggest a dynamic interaction among agricultural land, forest cover, and other land-use categories.

Forest cover forms the second most significant land-use class within the Lower Narmada Basin and plays a critical role in maintaining watershed stability and ecological balance. The forest area declined from 2,479.26 km² (24.51%) in 1995 to 2,032.51 km² (20.05%) in 2005, indicating early pressure on forest ecosystems due to land conversion and resource utilization. However, a substantial increase in forest cover was observed in 2015, when forest area expanded to 3,867.50 km² (38.12%), representing the highest forest coverage recorded during the study period.

This increase may be attributed to forest regeneration, improved forest conservation efforts, or enhanced classification accuracy in satellite imagery. By 2024, forest cover decreased slightly to 3,046.80 km² (30.14%), although it remained significantly higher than levels observed during the early 2000s. These trends suggest that forest dynamics in the Lower Narmada Basin are influenced by a combination of natural regeneration processes and anthropogenic disturbances. One of the most prominent transformations in the upper basin is the drastic decline in fallow land. The fallow area decreased sharply from 1,383.07 km² (13.67%) in 1995 to 984.43 km² (9.71%) in 2005 and further declined dramatically to 46.75 km² (0.46%) in 2015 and 4.92 km² (0.05%) in 2024. This

reduction indicates that nearly all previously uncultivated or temporarily unused agricultural lands have been brought under active cultivation or converted to other land-use categories. The reduction of fallow land, therefore, appears to be a major contributor to the expansion of agricultural land in the upper basin. Urban expansion is another important trend observed in the Lower Narmada Basin. Built-up areas increased steadily from 90.49 km² (0.89%) in 1995 to 183.00 km² (1.81%) in 2005, then rose sharply to 588.91 km² (5.81%) in 2015 and 829.40 km² (8.21%) in 2024.

Table 6.2: LULC class area distribution for the Lower Narmada River Basin (1995–2024)

Year → /LULC class ↓	1995		2005		2015		2024	
	Total area (km ²)	% of basin area	Total area (km ²)	% of basin area	Total area (km ²)	% of basin area	Total area (km ²)	% of basin area
Agriculture	5395.63	53.34	6193.59	61.10	5206.76	51.32	5723.56	56.62
Barren	203.82	2.02	251.03	2.48	152.33	1.50	149.30	1.48
Built-up	90.49	0.89	183.00	1.81	588.91	5.81	829.40	8.21
Fallow	1383.07	13.67	984.43	9.71	46.75	0.46	4.92	0.05
Forest	2479.26	24.51	2032.51	20.05	3867.50	38.12	3046.80	30.14
Water	562.55	5.56	492.87	4.86	282.57	2.79	354.32	3.51

Waterbodies show moderate fluctuations during the study period. The area covered by water bodies declined from 562.55 km² (5.56%) in 1995 to 492.87 km² (4.86%) in 2005 and further decreased to 282.57 km² (2.79%) in 2015. This reduction may be associated with hydrological variability, reservoir management, or seasonal differences in satellite imagery. However, water bodies increased again to 354.32 km² (3.51%) in 2024, indicating partial recovery or expansion of water storage areas through watershed development and small reservoir construction. Barren land occupies a relatively small proportion of the lower basin and exhibits only minor fluctuations over time. The barren land area increased slightly from 203.82 km² (2.02%) in 1995 to 251.03 km² (2.48%) in 2005, but subsequently declined to 152.33 km² (1.50%) in 2015 and 149.30 km² (1.48%) in 2024. The overall decline in barren land suggests improved land utilization and vegetation recovery in certain parts of the basin. The observed transformations have important implications for watershed hydrology, soil erosion, and ecosystem sustainability in the lower reaches of the Narmada Basin.

Table 7.3 presents the aggregated area statistics for the six major Land Use Land Cover (LULC) classes in the Middle Narmada Basin for 1995, 2005, 2015, and 2024. The statistics reveal substantial changes in the land-use structure of the basin's central portion over nearly three decades. Although the total geographical extent of the Middle Narmada Basin remains relatively stable at approximately 42,100 km², the proportional distribution of land-use categories has changed significantly, reflecting increasing agricultural intensification, urban expansion, and hydrological infrastructure development in the region.

Agriculture is the most dominant land-use category in the Middle Narmada Basin and exhibits a strong upward trend during the study period. Agricultural land increased from 19,721.06 km² (46.82%) in 1995 to 25,918.98 km² (61.72%) in 2005, representing a substantial expansion of cultivated land within the basin. This rapid increase indicates extensive conversion of other land-use categories, particularly fallow land and forest areas, into agricultural fields during the early stages of the study period. Agricultural expansion continued steadily in the following years, reaching 29,027.67 km² (68.81%) in 2015 and further increasing to 29,713.97 km² (70.42%) in 2024. Overall, agricultural land increased by nearly 10,000 km² between 1995 and 2024, highlighting the growing importance of agricultural production in the middle basin and reflecting the expansion of irrigation infrastructure and improved farming practices.

In contrast to the expansion of agriculture, forest cover shows a continuous declining trend throughout the study period. Forest area decreased significantly from 15,950.87 km² (37.87%) in 1995 to 11,538.94 km² (27.48%) in 2005, indicating substantial forest conversion during this decade. The decline continued in subsequent years, with forest cover reducing further to 10,163.42 km² (24.09%) in 2015 and 8,878.89 km² (21.04%) in 2024. Overall, the Middle Narmada Basin experienced a net loss of more than 7,000 km² of forest area over the study period. This persistent reduction in forest cover reflects increasing anthropogenic pressure associated with agricultural expansion, settlement growth, and infrastructure development within the basin.

One of the most dramatic transformations observed in the Middle Narmada Basin is the sharp reduction in fallow land. The fallow area declined from 4,968.49 km² (11.80%) in 1995 to 2,507.99 km² (5.97%) in 2005, indicating a rapid conversion of previously uncultivated land into productive

agricultural fields. The decline became even more pronounced in later years, with fallow land decreasing drastically to 93.84 km² (0.22%) in 2015 and 8.47 km² (0.02%) in 2024. This near-complete disappearance of fallow land indicates intensive agricultural use of available land resources and reflects the increasing demand for agricultural production within the basin.

Urbanization represents another major driver of land-use change in the Middle Narmada Basin. Built-up areas increased substantially from 140.08 km² (0.33%) in 1995 to 320.91 km² (0.76%) in 2005, reflecting the early stages of urban growth. However, the rate of urban expansion accelerated significantly in later years, with built-up land increasing to 981.72 km² (2.33%) in 2015 and further expanding to 1,523.03 km² (3.61%) in 2024. This five- to seven-fold increase in built-up area highlights the rapid development of urban centers and infrastructure in cities such as Jabalpur and Narmadapuram, as well as surrounding urban regions. The growth of transportation networks, industrial zones, and residential settlements has increased the footprint of built-up land across the middle basin.

Water bodies also show a gradual increase during the study period, reflecting the influence of major hydrological infrastructure projects in the basin. The area covered by water bodies increased from 1,093.95 km² (2.60%) in 1995 to 1,409.57 km² (3.36%) in 2005, then further expanded to 1,739.56 km² (4.12%) in 2015 and 1,913.96 km² (4.54%) in 2024. This increase is largely associated with the construction and expansion of large reservoirs such as Indira Sagar and Omkareshwar, which have significantly altered the hydrological regime of the Middle Narmada Basin and enhanced irrigation potential across the region.

Barren land occupies a relatively small proportion of the basin and shows only minor fluctuations over time. The barren land area increased slightly from 244.67 km² (0.58%) in 1995 to 299.19 km² (0.71%) in 2005 but subsequently declined to 180.94 km² (0.43%) in 2015 and 155.60 km² (0.37%) in 2024. The overall decline in barren land suggests improved land utilization and vegetation recovery in some areas. Overall, the Middle Narmada Basin has undergone significant land-use transformation over the past three decades. The dominant trends include large-scale agricultural expansion, continuous decline in forest cover, near elimination of fallow land, and rapid growth of

built-up areas, accompanied by moderate increases in water bodies associated with reservoir development.

Table 6.3: LULC class area distribution for the Middle Narmada River Basin (1995–2024)

Year → /LULC class ↓	1995		2005		2015		2024	
	Total area (km ²)	% of basin area	Total area (km ²)	% of basin area	Total area (km ²)	% of basin area	Total area (km ²)	% of basin area
Agriculture	19721.06	46.82	25918.98	61.72	29027.67	68.81	29713.97	70.42
Barren	244.67	0.58	299.19	0.71	180.94	0.43	155.60	0.37
Built-up	140.08	0.33	320.91	0.76	981.72	2.33	1523.03	3.61
Fallow	4968.49	11.80	2507.99	5.97	93.84	0.22	8.47	0.02
Forest	15950.87	37.87	11538.94	27.48	10163.42	24.09	8878.89	21.04
Water	1093.95	2.60	1409.57	3.36	1739.56	4.12	1913.96	4.54

Table 7.4 presents the aggregated area statistics for the six major Land Use Land Cover (LULC) classes in the Lower Narmada Basin for the years 1995, 2005, 2015, and 2024. The statistics highlight the temporal evolution of land-use patterns in the downstream portion of the basin over nearly three decades. Although the total geographical area of the Lower Narmada Basin remains relatively stable at approximately 44,900 km², noticeable changes are observed in the proportional distribution of different land-use categories, reflecting increasing agricultural development, urban expansion, and changing land management practices across the region.

Agriculture represents the dominant land-use class within the Lower Narmada Basin throughout the study period. Agricultural land covered 21,028.03 km² (46.81%) in 1995, indicating the region's strong agrarian character. The agricultural area increased significantly to 24,324.68 km² (54.03%) in 2005, suggesting an early period of agricultural expansion during the study period. However, in subsequent years, agricultural land showed a slight decline, decreasing to 23,032.14 km² (51.39%) in 2015 and further to 22,921.27 km² (51.11%) in 2024. Despite this minor reduction, agriculture continues to dominate the lower basin, accounting for more than half of the total area. The slight decline after 2005 may be associated with the expansion of urban settlements and infrastructural development in certain parts of the region.

Forest cover represents the second most prominent land-use category in the Lower Narmada Basin and exhibits relatively stable trends during the study period. Forest area decreased slightly from 19,179.20 km² (42.70%) in 1995 to 18,065.99 km² (40.13%) in 2005, indicating moderate forest loss during the early phase of the study period. However, forest cover increased again to 19,617.15 km² (43.77%) in 2015, suggesting possible forest regeneration, improved conservation measures, or variations in classification accuracy. By 2024, forest cover slightly declined to 19,386.03 km² (43.22%) but remains comparable to the baseline levels observed in 1995. Overall, forest ecosystems remain an important component of the lower basin landscape.

Fallow land shows a pronounced decline over the study period. The fallow area decreased dramatically from 3,115.84 km² (6.94%) in 1995 to 915.86 km² (2.03%) in 2005, indicating the conversion of previously unused land into active agricultural fields. The reduction continued in later years, with fallow land declining to 259.65 km² (0.58%) in 2015 and 114.12 km² (0.25%) in 2024. This significant reduction reflects increasing land utilization and agricultural intensification across the lower basin.

Urban expansion is another notable trend in the Lower Narmada Basin. Built-up areas increased steadily from 283.10 km² (0.63%) in 1995 to 569.38 km² (1.26%) in 2005, indicating the early stages of urban growth. The expansion accelerated further in subsequent years, with built-up land increasing to 760.45 km² (1.70%) in 2015 and reaching 1,236.74 km² (2.76%) in 2024. This more than fourfold increase in built-up areas reflects the expansion of urban centers, transportation networks, and industrial development in cities such as Vadodara, Bharuch, and surrounding urban regions.

Water bodies show moderate fluctuations over time. The area covered by water bodies declined from 1,249.48 km² (2.78%) in 1995 to 1,036.75 km² (2.30%) in 2005, possibly due to seasonal hydrological variations or changes in water storage patterns. Water area remained relatively stable during the following decade, measuring 1,026.63 km² (2.29%) in 2015, before increasing slightly to 1,090.12 km² (2.43%) in 2024. These variations may be associated with reservoir management, irrigation infrastructure, and hydrological variability within the basin.

Table 6.4: LULC class area distribution for the Upper Narmada River Basin (1995–2024)

Year → /LULC class ↓	1995		2005		2015		2024	
	Total area (km ²)	% of basin area	Total area (km ²)	% of basin area	Total area (km ²)	% of basin area	Total area (km ²)	% of basin area
Agriculture	21028.03	46.81	24324.68	54.03	23032.14	51.39	22921.27	51.11
Barren	62.49	0.14	106.09	0.24	124.21	0.28	102.01	0.23
Built-up	283.10	0.63	569.38	1.26	760.45	1.70	1236.74	2.76
Fallow	3115.84	6.94	915.86	2.03	259.65	0.58	114.12	0.25
Forest	19179.20	42.70	18065.99	40.13	19617.15	43.77	19386.03	43.22
Water	1249.48	2.78	1036.75	2.30	1026.63	2.29	1090.12	2.43

Barren land occupies only a very small proportion of the Lower Narmada Basin and exhibits minor fluctuations throughout the study period. The barren land area increased from 62.49 km² (0.14%) in 1995 to 106.09 km² (0.24%) in 2005, then rose slightly to 124.21 km² (0.28%) in 2015, before declining to 102.01 km² (0.23%) in 2024. Overall, barren land accounts for less than 0.3% of the basin area, indicating that most landscapes in the lower basin are actively utilized for agriculture, forestry, settlements, or water storage

Table 7.5 presents the district-wise distribution of LULC classes across the Narmada River Basin for the years 1995, 2005, 2015, and 2024. This highlights the spatial heterogeneity in land-use patterns across districts belonging to Madhya Pradesh, Gujarat, Maharashtra, and Chhattisgarh within the basin. The district-level statistics provide a detailed understanding of localized land-use dynamics that are often masked in basin-scale aggregation.

Agriculture remains the dominant land-use category across most districts throughout the study period, though its spatial distribution varies considerably with physiographic and climatic conditions. Districts such as Khargone, Khandwa, Dhar, Hoshangabad (Narmadapuram), and Mandla exhibit particularly large agricultural extents. For instance, Khargone district shows a substantial increase in agricultural area from 4493.79 km² in 1995 to 6237.58 km² in 2024, indicating significant agricultural expansion driven by irrigation development and intensification of cropping systems. Similarly, Khandwa district experienced a steady rise in agricultural land

from 3180.59 km² in 1995 to 4380.73 km² in 2024, reflecting the increasing utilization of cultivable land in the central basin region.

Forest cover shows strong spatial concentration in districts located within the upper and eastern parts of the basin, particularly in Mandla, Dindori, Chhindwara, and Betul. These districts are characterized by dense forest ecosystems associated with the Satpura and Maikal hill ranges, which serve as important ecological zones within the basin. For example, the Mandla district maintained substantial forest cover, with values exceeding 3000 km² in several years of the study period. Similarly, Chhindwara and Betul districts also exhibit extensive forested landscapes, indicating the ecological importance of these regions in maintaining watershed stability and biodiversity.

Urban expansion is clearly visible in several districts over the study period. Built-up areas increased substantially in districts containing major urban centers such as Jabalpur, Indore, Dhar, Bharuch, and Vadodara. For instance, the built-up area in Jabalpur district increased from 199.14 km² in 1995 to 291.95 km² in 2024, while Dhar district experienced a rapid increase from 15.77 km² to 280.90 km² during the same period. Similarly, Bharuch district in Gujarat shows a notable rise in built-up land from 63.96 km² in 1995 to 267.71 km² in 2024, reflecting rapid industrial and urban development in the downstream portion of the basin.

Fallow land exhibits a pronounced decline across nearly all districts over the study period. For example, Alirajpur district recorded a significant reduction in fallow land from 1795.22 km² in 1995 to only 2.61 km² in 2024, indicating that large portions of previously uncultivated land have been brought under agricultural production. Similar declines are observed in districts such as Barwani, Dhar, and Khandwa, highlighting widespread agricultural intensification across the basin. Waterbodies show moderate spatial variation across districts and are strongly influenced by the presence of large reservoirs and river networks.

Districts such as Khandwa, Narmadapuram, Mandla, and Narmada show relatively larger water surface areas due to the presence of major reservoirs, including Indira Sagar, Omkareshwar, and Sardar Sarovar. In Khandwa district, for example, waterbodies increased substantially from 167.24 km² in 1995 to 932.79 km² in 2024, reflecting the influence of reservoir expansion and

hydrological infrastructure development. Barren land constitutes a relatively small proportion of the total area across most districts and shows only minor fluctuations during the study period.

The presence of barren land is generally associated with rocky terrain, degraded land surfaces, or sparsely vegetated areas within the basin. Overall, the district-level statistics presented in Table 7.5 reveal considerable spatial variability in land-use patterns across the Narmada River Basin. While agricultural land dominates the central and western districts, forest cover remains concentrated in the upper-basin districts, which are characterized by mountainous terrain.

Rapid urban expansion is observed in districts with major cities and industrial development, whereas fallow land has declined dramatically across the basin due to increasing agricultural utilization. These district-scale variations highlight the complex interplay between natural landscape characteristics and human activities in shaping land-use dynamics within the Narmada Basin.

Table 6.5: District-wise LULC class area distribution in the Narmada Basin (1995–2024)

S. No.	District	State name	Year	Agriculture (km ²)	Barren (km ²)	Built-up (km ²)	Forest (km ²)	Fallow (km ²)	Waterbodies (km ²)	Total area (km ²)
1	Alirajpur	MP	1995	190.04	5.11	3.09	1795.22	1069.04	46.00	3108.50
2	Anuppur	MP	1995	387.94	3.96	0.00	0.01	136.95	6.00	534.85
3	Balaghat	MP	1995	837.57	3.29	3.90	160.36	1279.31	19.06	2303.48
4	Barwani	MP	1995	2010.01	29.44	10.08	173.71	1629.95	138.31	3991.50
5	Betul	MP	1995	1057.13	0.51	27.65	413.90	2287.77	82.98	3869.94
6	Bharuch	GJ	1995	1990.62	57.99	63.96	183.53	167.48	150.68	2614.87
7	Bhopal	MP	1995	2.59	0.00	0.00	0.00	8.22	0.00	10.82
8	Burhanpur	MP	1995	112.67	5.58	0.00	8.69	247.50	9.41	383.85
9	Chhindwara	MP	1995	737.85	0.00	1.17	281.88	2469.47	65.35	3555.72
10	Chhota Udepur	GJ	1995	2006.57	5.98	5.82	413.80	678.06	214.40	3324.63
11	Dahod	GJ	1995	25.53	0.66	0.00	1.19	37.82	0.43	65.63
12	Damoh	MP	1995	101.14	0.00	0.00	18.59	296.53	5.00	421.26
13	Dewas	MP	1995	1643.42	0.00	6.30	302.59	1913.18	69.74	3935.24
14	Dhar	MP	1995	2523.81	45.34	15.77	969.08	1230.46	143.14	4939.28
15	Dhule	MH	1995	0.00	0.00	0.00	0.00	9.45	0.00	9.45
16	Dindori	MP	1995	2817.64	5.37	2.05	249.04	1657.88	45.37	4777.35
17	Gaurela-pendra-marwahi	CG	1995	0.00	0.00	0.00	0.00	0.18	0.00	0.18
18	Harda	MP	1995	2109.13	0.41	18.75	71.48	1016.92	73.14	3289.82
19	Narmadapuram	MP	1995	2481.06	2.68	35.00	1170.77	2661.88	355.85	6707.25
20	Indore	MP	1995	353.32	0.00	0.00	30.64	659.25	8.72	1051.93
21	Jabalpur	MP	1995	3451.20	13.10	199.14	53.09	1019.44	132.14	4868.10

22	Jhabua	MP	1995	0.00	0.00	0.00	8.51	0.79	0.00	9.30
23	Kabirdham	CG	1995	121.15	0.64	0.00	8.82	489.59	2.06	622.26
24	Katni	MP	1995	643.98	0.00	0.00	10.62	471.80	13.38	1139.77
25	Khandwa	MP	1995	3180.59	7.53	29.93	1273.84	2100.53	167.24	6759.66
26	Khargone	MP	1995	4493.79	147.69	27.15	464.38	2302.27	182.23	7617.50
27	Mandla	MP	1995	2527.26	12.90	10.93	570.30	3295.02	244.52	6660.94
28	Mungeli	CG	1995	0.23	0.00	0.00	0.00	0.16	0.00	0.39
29	Nandurbar	MH	1995	100.94	0.01	0.00	0.00	1490.16	71.45	1662.57
30	Narmada	GJ	1995	525.47	97.26	20.37	359.03	1246.39	144.98	2393.50
31	Narshimapura	MP	1995	3468.10	3.78	20.94	136.40	1272.82	109.55	5011.58
32	Panch Mahals	GJ	1995	82.44	0.00	0.00	0.08	50.27	1.31	134.09
33	Raisen	MP	1995	2484.11	0.00	6.52	77.50	1944.82	102.64	4637.97
34	Raj Nandgaon	CG	1995	46.59	3.46	0.00	0.84	33.86	0.00	84.74
35	Sagar	MP	1995	144.10	0.00	0.00	13.21	217.98	1.94	377.23
36	Sehore	MP	1995	1788.43	1.30	4.17	46.24	1370.73	98.35	3318.05
37	Seoni	MP	1995	1138.97	15.88	0.00	95.17	889.36	110.95	2250.33
38	Surat	GJ	1995	36.99	1.39	0.17	106.87	57.88	3.67	206.97
39	Vadodara	GJ	1995	512.40	31.67	0.00	0.00	14.52	28.57	587.15
40	Alirajpur	MP	2005	1905.52	4.46	5.88	175.87	957.82	46.83	3096.37
41	Anuppur	MP	2005	391.02	5.13	0.00	0.00	134.04	4.97	535.16
42	Balaghat	MP	2005	1005.91	4.17	7.62	3.59	1267.38	16.69	2305.35
43	Barwani	MP	2005	2739.82	37.78	19.58	179.00	877.97	125.01	3979.16
44	Betul	MP	2005	1670.60	0.59	53.99	205.18	1868.52	74.09	3872.96
45	Bharuch	GJ	2005	1779.31	56.17	131.44	445.35	111.68	128.36	2652.91
46	Bhopal	MP	2005	1.99	0.00	0.00	0.71	8.08	0.00	10.77
47	Burhanpur	MP	2005	169.52	7.19	0.00	7.90	190.51	8.45	383.58

48	Chhindwara	MP	2005	966.01	0.00	2.33	137.02	2380.08	55.50	3540.94
49	Chhota Udepur	GJ	2005	2353.30	7.71	11.43	128.38	609.45	188.76	3299.04
50	Dahod	GJ	2005	26.18	0.88	0.00	1.09	37.19	0.35	65.69
51	Damoh	MP	2005	167.61	0.00	0.00	18.27	228.27	5.08	419.23
52	Dewas	MP	2005	2276.07	1.02	12.25	100.59	1456.34	76.70	3922.97
53	Dhar	MP	2005	3604.77	41.81	33.82	386.03	724.72	124.98	4927.80
54	Dhule	MH	2005	0.00	0.00	0.00	0.00	9.45	0.00	9.45
55	Dindori	MP	2005	2795.43	6.83	3.84	110.32	1798.85	51.55	4766.82
56	Gaurela-pendra-marwahi	CG	2005	0.00	0.00	0.00	0.00	0.18	0.00	0.18
57	Harda	MP	2005	2220.46	1.54	37.08	51.79	913.19	70.66	3294.72
58	Narmadapuram	MP	2005	3858.28	49.13	121.35	15.25	2461.86	239.01	6744.87
59	Indore	MP	2005	418.47	0.00	0.00	89.13	526.42	10.64	1044.65
60	Jabalpur	MP	2005	3592.30	16.09	393.42	23.44	903.90	117.51	5046.67
61	Jhabua	MP	2005	8.62	0.00	0.00	0.02	0.66	0.00	9.30
62	Kabirdham	CG	2005	149.21	0.85	0.00	8.22	461.44	1.81	621.54
63	Katni	MP	2005	772.70	0.00	1.91	7.86	342.84	12.91	1138.22
64	Khandwa	MP	2005	3705.09	11.22	58.60	762.97	1558.92	566.55	6663.35
65	Khargone	MP	2005	5196.57	182.02	53.61	638.65	1386.74	163.80	7621.40
66	Mandla	MP	2005	3070.96	16.51	21.17	109.03	3203.37	217.80	6638.85
67	Mungeli	CG	2005	0.00	0.00	0.00	0.00	0.39	0.00	0.39
68	Nandurbar	MH	2005	667.81	0.03	0.00	0.00	917.86	66.14	1651.84
69	Narmada	GJ	2005	827.11	126.75	39.25	295.62	978.54	136.09	2403.36
70	Narshimapura	MP	2005	3653.96	4.75	39.32	12.41	1208.00	98.18	5016.63
71	Panch Mahals	GJ	2005	82.28	0.00	0.00	0.07	50.52	1.05	133.92
72	Raisen	MP	2005	2616.50	3.25	12.57	16.71	1869.69	89.19	4630.30
73	Raj Nandgaon	CG	2005	53.30	4.37	0.00	0.76	27.19	0.00	85.62

74	Sagar	MP	2005	157.39	0.00	0.00	76.89	135.81	2.01	372.11
75	Sehore	MP	2005	1844.97	7.52	10.82	114.10	1248.62	72.32	3307.19
76	Seoni	MP	2005	1102.30	0.00	0.00	186.38	848.06	94.31	2231.04
77	Surat	GJ	2005	36.16	1.83	0.26	103.03	53.91	5.50	200.68
78	Vadodara	GJ	2005	528.26	40.29	0.00	0.06	0.00	24.00	592.62
79	Alirajpur	MP	2015	2089.95	22.90	84.97	24.08	819.88	67.33	3109.10
80	Anuppur	MP	2015	278.78	0.77	4.80	5.63	239.22	6.23	535.44
81	Balaghat	MP	2015	673.65	2.17	19.15	49.63	1529.24	23.29	2297.13
82	Barwani	MP	2015	3293.12	39.31	92.06	2.88	487.45	81.74	3996.55
83	Betul	MP	2015	1738.13	14.00	89.37	4.27	1953.72	53.20	3852.69
84	Bharuch	GJ	2015	1739.37	58.85	207.86	22.24	485.53	99.34	2613.24
85	Bhopal	MP	2015	3.77	0.00	0.01	0.00	6.98	0.02	10.78
86	Burhanpur	MP	2015	279.73	0.94	2.49	0.82	90.16	11.01	385.15
87	Chhindwara	MP	2015	1525.71	10.96	11.12	2.71	1980.54	14.15	3545.19
88	Chhota Udepur	GJ	2015	1594.60	18.32	234.90	15.26	1385.04	77.54	3325.66
89	Dahod	GJ	2015	8.98	0.00	0.68	0.02	55.88	0.01	65.57
90	Damoh	MP	2015	206.08	0.45	3.24	2.51	201.51	6.52	420.31
91	Dewas	MP	2015	2196.54	1.31	70.13	4.88	1558.72	98.02	3929.61
92	Dhar	MP	2015	3917.71	41.91	160.44	13.52	683.32	133.71	4950.61
93	Dhule	MH	2015	6.08	0.00	0.09	0.01	3.24	0.00	9.41
94	Dindori	MP	2015	2265.00	5.80	34.39	46.97	2360.58	58.94	4771.70
95	Gaurela-pendra-marwahi	CG	2015	0.00	0.00	0.00	0.00	0.18	0.00	0.18
96	Harda	MP	2015	2260.80	5.66	71.04	0.54	872.85	72.06	3282.96
97	Narmadapuram	MP	2015	3850.45	44.72	152.90	3.57	2408.25	238.93	6698.83
98	Indore	MP	2015	592.16	1.02	29.99	0.54	415.25	10.73	1049.70
99	Jabalpur	MP	2015	3171.52	3.83	226.24	28.12	1242.19	130.58	4802.48

100	Jhabua	MP	2015	8.63	0.13	0.15	0.02	0.24	0.13	9.31
101	Kabirdham	CG	2015	153.50	0.47	1.15	2.63	457.24	5.17	620.17
102	Katni	MP	2015	612.49	4.42	21.59	9.63	468.27	22.19	1138.59
103	Khandwa	MP	2015	4137.31	30.66	152.03	23.70	1552.28	889.11	6785.09
104	Khargone	MP	2015	6083.12	21.28	209.59	14.64	1158.45	164.09	7651.17
105	Mandla	MP	2015	2305.47	6.72	60.97	56.15	4009.94	215.82	6655.08
106	Mungeli	CG	2015	0.04	0.00	0.00	0.00	0.35	0.00	0.39
107	Nandurbar	MH	2015	865.89	2.18	6.58	2.90	721.53	61.15	1660.24
108	Narmada	GJ	2015	884.76	7.71	71.65	5.68	1348.90	94.18	2412.89
109	Narshimapura	MP	2015	3524.02	18.53	115.75	3.05	1292.16	49.49	5003.00
110	Panch Mahals	GJ	2015	31.93	0.00	10.06	0.12	90.53	1.15	133.78
111	Raisen	MP	2015	2851.33	11.33	66.16	2.23	1589.79	112.43	4633.28
112	Raj Nandgaon	CG	2015	49.03	0.03	0.77	2.01	32.84	0.92	85.59
113	Sagar	MP	2015	218.19	2.01	1.27	1.29	152.82	0.76	376.34
114	Sehore	MP	2015	2104.12	11.43	63.33	6.11	1044.87	86.21	3316.09
115	Seoni	MP	2015	1257.12	2.97	19.07	40.71	829.47	107.58	2256.91
116	Surat	GJ	2015	118.96	0.02	10.20	1.41	76.00	0.53	207.12
117	Vadodara	GJ	2015	414.49	15.07	22.28	0.44	127.64	16.98	596.90
118	Alirajpur	MP	2024	1985.85	7.49	218.41	2.61	802.68	81.11	3098.14
119	Anuppur	MP	2024	260.47	0.49	15.10	2.29	250.38	6.79	535.52
120	Balaghat	MP	2024	758.78	1.71	52.79	39.93	1419.42	27.86	2300.49
121	Barwani	MP	2024	3285.92	46.59	180.45	0.17	363.12	113.56	3989.81
122	Betul	MP	2024	1620.77	3.40	145.46	1.95	2017.71	62.65	3851.94
123	Bharuch	GJ	2024	1707.56	61.21	267.71	2.37	432.27	128.37	2599.53
124	Bhopal	MP	2024	3.74	0.00	0.07	0.00	6.99	0.01	10.80
125	Burhanpur	MP	2024	309.60	2.67	4.43	0.04	59.48	9.26	385.48

126	Chhindwara	MP	2024	1337.53	1.04	23.68	1.61	2170.87	18.22	3552.95
127	Chhota Udepur	GJ	2024	1884.50	21.60	324.24	1.59	981.59	94.75	3308.28
128	Dahod	GJ	2024	10.65	0.00	2.19	0.02	52.67	0.08	65.62
129	Damoh	MP	2024	244.96	0.51	4.86	0.79	164.57	5.21	420.90
130	Dewas	MP	2024	2314.23	1.62	92.12	0.85	1420.03	104.51	3933.36
131	Dhar	MP	2024	3925.58	16.02	280.90	0.79	551.06	164.02	4938.37
132	Dhule	MH	2024	6.00	0.00	0.15	0.00	3.27	0.00	9.41
133	Dindori	MP	2024	2287.85	6.93	83.33	16.87	2319.69	63.03	4777.69
134	Gaurela-pendra-marwahi	CG	2024	0.00	0.00	0.00	0.00	0.18	0.00	0.18
135	Harda	MP	2024	2333.84	1.94	86.63	0.13	789.57	70.38	3282.49
136	Narmadapuram	MP	2024	3768.52	42.34	203.79	5.77	2421.74	262.81	6704.96
137	Indore	MP	2024	566.74	1.38	46.58	0.07	421.21	12.14	1048.12
138	Jabalpur	MP	2024	3259.63	9.03	291.95	7.32	1080.38	141.35	4789.67
139	Jhabua	MP	2024	8.38	0.00	0.60	0.00	0.24	0.03	9.26
140	Kabirdham	CG	2024	177.47	0.21	5.80	2.06	430.97	5.31	621.82
141	Katni	MP	2024	684.62	4.51	33.45	3.93	395.52	16.09	1138.12
142	Khandwa	MP	2024	4380.73	32.15	189.98	1.78	1281.75	932.79	6819.74
143	Khargone	MP	2024	6237.58	33.14	297.81	0.92	891.37	178.75	7639.56
144	Mandla	MP	2024	2463.94	9.70	151.25	24.82	3801.31	217.82	6668.84
145	Mungeli	CG	2024	0.07	0.00	0.00	0.00	0.32	0.00	0.39
146	Nandurbar	MH	2024	963.64	1.64	16.77	0.31	608.47	74.96	1665.79
147	Narmada	GJ	2024	1148.92	4.78	104.61	0.69	1037.17	119.62	2415.80
148	Narshimpura	MP	2024	3270.58	16.39	167.17	0.62	1484.85	58.16	4997.78
149	Panch Mahals	GJ	2024	48.88	0.00	15.30	0.01	67.27	1.44	132.90
150	Raisen	MP	2024	2819.74	7.58	99.20	0.55	1596.93	112.94	4636.95
151	Raj Nandgaon	CG	2024	54.74	0.06	4.01	0.97	24.95	0.66	85.39

152	Sagar	MP	2024	218.06	0.24	3.80	0.15	152.06	2.57	376.88
153	Sehore	MP	2024	2159.63	7.77	85.15	0.44	973.71	90.98	3317.68
154	Seoni	MP	2024	1358.18	1.53	45.00	5.43	741.36	110.13	2261.63
155	Surat	GJ	2024	123.80	0.14	15.43	0.27	65.01	1.57	206.23
156	Vadodara	GJ	2024	430.23	12.29	27.44	0.07	104.61	21.66	596.30

Note: The abbreviations MP, MH, CG, and GJ denote Madhya Pradesh, Maharashtra, Chhattisgarh, and Gujarat, respectively.

7. SUMMARY

This study analyzed the spatio-temporal dynamics of Land Use Land Cover (LULC) in the Narmada River Basin for the period 1995–2024 using geospatial techniques and statistical analysis. The basin, sub-basin, and district-level assessments provide a comprehensive understanding of landscape transformations over the past three decades. The results reveal significant land use transitions driven by agricultural expansion, urbanization, reservoir development, and changes in land management practices.

At the basin scale, agriculture remained the dominant land use category throughout the study period. Agricultural land increased substantially from 46,144.81 km² (47.50%) in 1995 to 58,358.59 km² (60.07%) in 2024, indicating a strong trend toward agricultural intensification across the basin. This expansion reflects increasing food demand, improved irrigation infrastructure, and the conversion of fallow and forest lands into cultivated areas. The dramatic reduction in fallow land from 9,467.38 km² in 1995 to only 127.51 km² in 2024 further supports the observation that previously unused lands have been increasingly brought under agricultural production.

Forest cover showed a declining trend over the study period, decreasing from 37,609.40 km² in 1995 to 31,311.63 km² in 2024. Although forests still constitute a significant portion of the basin landscape, the overall reduction underscores increasing pressure on natural ecosystems from agricultural expansion, infrastructure development, and urban growth. The decline of forest areas is particularly evident in the middle basin region, where agricultural expansion has been most prominent.

Urbanization emerged as another important driver of land use change within the basin. Built-up areas increased significantly from 513.60 km² in 1995 to 3,589.13 km² in 2024, representing more than a sevenfold increase. This rapid urban expansion reflects growing population pressure, economic development, and infrastructural growth in major urban centers such as Jabalpur, Narmadapuram, Dindori, Mandla, and Bharuch. The expansion of built-up areas is mainly

associated with the conversion of agricultural land and peri-urban landscapes into residential, industrial, and commercial zones.

The study also highlights a gradual increase in the number of water bodies within the basin. Water surface area increased from 2,905.99 km² in 1995 to 3,358.42 km² in 2024, primarily due to the construction of large reservoirs, including Indira Sagar, Omkareshwar, and Sardar Sarovar. These reservoirs have significantly altered the basin's hydrological landscape by increasing water storage capacity and enhancing irrigation potential. However, reservoir construction has also submerged forest and agricultural lands, contributing to landscape transformation.

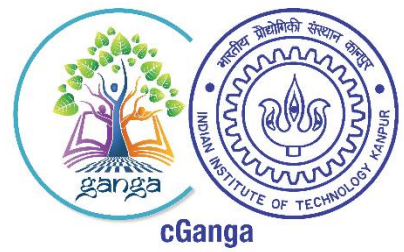
The sub-basin-level analysis reveals considerable spatial variability in land-use patterns across the Narmada Basin. The Lower Narmada Basin is largely agricultural and is experiencing rapid urban expansion driven by industrial development in Gujarat. The Middle Narmada Basin experienced the most dramatic land use changes, characterized by rapid agricultural expansion, forest decline, and reservoir development. In contrast, the Upper Narmada Basin continues to maintain relatively higher forest cover due to its rugged terrain and lower population density, although gradual agricultural expansion and urban growth are becoming increasingly evident.

District-level analysis further highlights the heterogeneous nature of land use change across the basin. Districts such as Kargone, Khandwa, and Dhar show significant agricultural expansion, while forest-rich districts, including Mandla, Dindori, and Chhindwara, continue to maintain substantial forest cover despite localized deforestation. Rapid urban expansion is observed in districts with major urban centers, such as Jabalpur and Dhar, reflecting increasing economic activity and infrastructure development.

Overall, the LULC transition analysis indicates that the dominant land conversions within the basin include fallow land to agriculture, forest to agriculture, and agriculture to built-up areas. These transitions reflect increasing anthropogenic pressure on the basin's natural landscapes and highlight the need for sustainable land management strategies. The observed land use transformations have important implications for watershed hydrology, soil erosion, biodiversity conservation, and regional climate dynamics. Agricultural expansion and deforestation may

increase soil erosion risk and alter runoff patterns, while urbanization may reduce infiltration and increase surface runoff. Similarly, the expansion of reservoirs may influence sediment transport and river flow regimes.

Therefore, understanding the long-term dynamics of land use change is essential for developing sustainable watershed management policies in the Narmada Basin. The findings of this study provide valuable insights for planners and policymakers to balance agricultural development, forest conservation, and urban growth while ensuring the ecological sustainability of the basin.



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