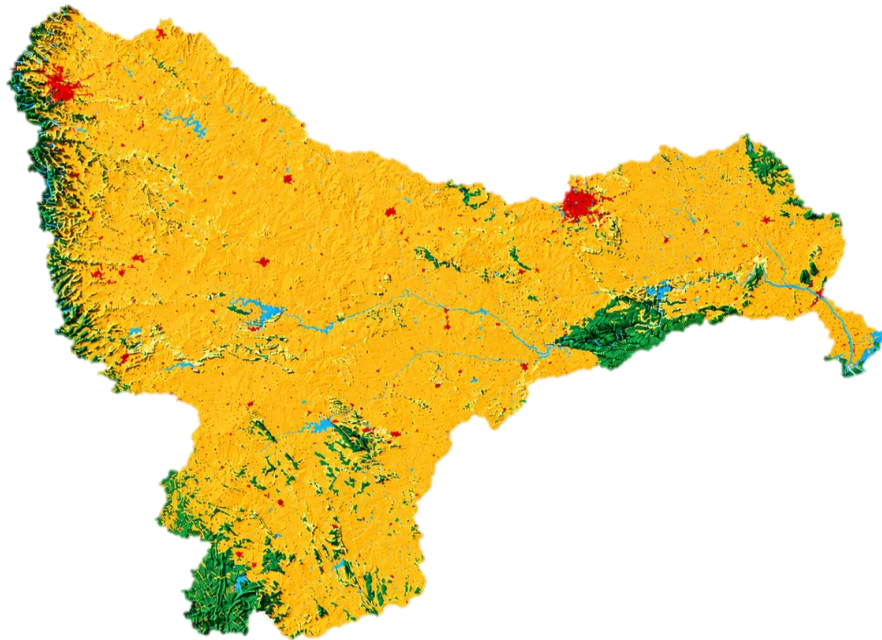




National River Conservation Directorate
Ministry of Jal Shakti,
Department of Water Resources,
River Development & Ganga Rejuvenation
Government of India

Land Use Land Cover (LULC) in the Krishna River Basin



April 2026



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Land Use Land Cover (LULC) in the Krishna River Basin



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National River Conservation Directorate (NRCDD)

The National River Conservation Directorate, functioning under the Department of Water Resources, River Development & Ganga Rejuvenation, and Ministry of Jal Shakti providing financial assistance to the State Government for conservation of rivers under the Centrally Sponsored Schemes of ‘National River Conservation Plan (NRCP)’. National River Conservation Plan to the State Governments/ local bodies to set up infrastructure for pollution abatement of rivers in identified polluted river stretches based on proposals received from the State Governments/ local bodies.

www.nrcd.nic.in

Centres for Krishna River Basin Management Studies (cKrishna)

The Centres for Krishna River Basin Management Studies (cKrishna) is a Brain Trust dedicated to River Science and River Basin Management. Established in 2024 by NIT Warangal and NIT Surathkal, under the supervision of cGanga at IIT Kanpur, the center serves as a knowledge wing of the National River Conservation Directorate (NRCDD). cKrishna is committed to restoring and conserving the Krishna River and its resources through the collation of information and knowledge, research and development, planning, monitoring, education, advocacy, and stakeholder engagement.

www.ckrishna.org

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cGanga is a think tank formed under the aegis of NMCG, and one of its stated objectives is to make India a world leader in river and water science. The Centre is headquartered at IIT Kanpur and has representation from most leading science and technological institutes of the country. cGanga’s mandate is to serve as think-tank in implementation and dynamic evolution of Ganga River Basin Management Plan (GRBMP) prepared by the Consortium of 7 IITs. In addition to this, it is also responsible for introducing new technologies, innovations, and solutions into India.

www.cganga.org

Acknowledgment

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

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Preface

In an era of unprecedented environmental change, understanding our rivers and their ecosystems has never been more critical. This report aims to provide a comprehensive overview of our rivers, highlighting their importance, current health, and the challenges they face. As we explore the various facets of river systems, we aim to equip readers with the knowledge necessary to appreciate and protect these vital waterways.

Throughout the following pages, you will find an in-depth analysis of the principles and practices that support healthy river ecosystems. Our team of experts has meticulously compiled data, case studies, and testimonials to illustrate the significant impact of rivers on both natural environments and human communities. By sharing these insights, we hope to inspire and empower our readers to engage in river conservation efforts.

This report is not merely a collection of statistics and theories; it is a call to action. We urge all stakeholders to recognize the value of our rivers and to take proactive steps to ensure their preservation. Whether you are an environmental professional, a policy maker, or simply someone who cares about our planet, this guide is designed to support you in your efforts to protect our rivers.

We extend our heartfelt gratitude to the numerous contributors who have generously shared their stories and expertise. Their invaluable input has enriched this report, making it a beacon of knowledge and a practical resource for all who read it. It is our hope that this report will serve as a catalyst for positive environmental action, fostering a culture of stewardship that benefits both current and future generations.

As you delve into this overview of our rivers, we invite you to embrace the opportunities and challenges that lie ahead. Together, we can ensure that our rivers continue to thrive and sustain life for generations to come.

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Abbreviations

Abbreviation	Full Form
LULC	Land Use Land Cover
GIS	Geographic Information System
ArcGIS	Arc Geographic Information System
QGIS	Quantum Geographic Information System
Km	Kilometre
Km ²	Square Kilometre
SWAT	Soil and Water Assessment Tool
DEM	Digital Elevation Model
GPS	Global Positioning System
WMS	Watershed Management System

1. Introduction

Land Use and Land Cover (LULC) change is a direct manifestation of human interaction with the natural environment and plays a vital role in regulating hydrological, ecological, and climatic processes. Changes in land cover influence surface runoff, infiltration, evapotranspiration, soil erosion, sediment transport, groundwater recharge, and basin-scale water availability. These impacts are particularly significant in large river basins experiencing rapid population growth, agricultural intensification, urban expansion, and climate variability.

Runoff, infiltration of groundwater, evaporation and demand for water are all affected by Land Use and Land Cover (LULC). These factors influence surface and groundwater yields, and consequently the amount of available water for the functioning of ecosystem and human use. Land use and climate change, as well as rising water demand, are all having an impact on water and energy budgets and water supplies (Sridhar and Wedin, 2009). As a result, one of the most difficult tasks in hydrological research is determining the effects of changing LULC and climate on hydrological processes (Loukika et al., 2021). Furthermore, in many river basins, LULC and climate change (both anthropogenic and natural) are altering the hydrological cycle and the water supply (Sridhar et al., 2019; Sayasane et al., 2020).

The effects of LULC and climate change on watershed hydrology have been studied extensively (Setti et al., 2020; Dostdogru et al., 2020). However, the majority of the studies focused solely on climate change found that there exists an imbalance between water supply and demand which has been increasing under climate and LULC change in recent years and has attracted attention from both the relevant authorities and the general public to water resource planning and management programs (Mishra et al., 2018; Saharia and Sarma 2018).

The Krishna River is one of the major interstate rivers of India and the second largest east flowing river in peninsular India after the Godavari River. The river drains a vast catchment of approximately 258,948 Km² and is of immense ecological, agricultural, economic, and cultural importance. It supports millions of people across southern India by providing water for irrigation, drinking, hydropower generation, fisheries, and industrial development. The basin extends across the states of Maharashtra, Karnataka, Telangana, and Andhra Pradesh on watershed delineation. Originating near Mahabaleshwar in the Western Ghats, the river flows eastward for about 1,400 Km before draining into the Bay of Bengal.

The Krishna Basin contains diverse physiographic regions including the Western Ghats, Deccan Plateau, semi-arid plains, irrigated command areas, and deltaic lowlands. These

landscapes support varied land use systems such as forests, rainfed agriculture, irrigated agriculture, plantations, urban settlements, wetlands, and reservoir ecosystems. Spatial variations in rainfall, soils, topography and socio-economic development have created distinct sub-regional patterns of resource use and environmental stress.

The basin has undergone substantial transformation due to agricultural expansion, rapid urbanization, industrialization, groundwater development, and the construction of major multipurpose water infrastructure such as Nagarjuna Sagar Dam, Srisaïlam Dam, Almatti Dam, Tungabhadra Dam, and several other reservoirs, barrages, and canal systems. These interventions have significantly altered natural flow regimes, sediment dynamics, groundwater dependence, and land use patterns across the basin.

In this context, the present study investigates the spatial and temporal dynamics of LULC in the Krishna River Basin at a decadal scale for the years 2005, 2010, 2015, 2020 and 2024. The classified thematic maps were further processed, analyzed, and visualized using ArcGIS. The assessment has been carried out at multiple spatial scales, including basin-scale, sub-basin-level to understand long-term landscape transformations and their implications for sustainable basin management.

2. Data Used

The present study analyzes the spatial and temporal dynamics of Land Use and Land Cover (LULC) in the Krishna River Basin at a decadal scale for the years 2005, 2010, 2015, 2020, and 2024 using multi-temporal LULC datasets developed by National Remote Sensing Centre (NRSC). The datasets were obtained at a map scale of 1:250,000 with a spatial resolution of 60 m, making them suitable for basin scale and regional level land use assessment. The NRSC LULC database provides standardized thematic classifications derived from satellite remote sensing data and is widely used for natural resource planning, watershed studies, and environmental monitoring in India. The datasets were used to quantify temporal changes in major land cover classes such as agriculture, forest, built-up land, water bodies, wasteland, and other categories across the Krishna Basin. The basin boundary, sub-basin boundaries, and administrative district boundaries were integrated with the LULC layers in a GIS environment for spatial analysis. The thematic layers were processed using ArcGIS and QGIS for clipping, reclassification, area estimation, and change detection analysis.

3. Methodology

3.1 Classification Scheme

The LULC datasets obtained from NRSC were originally available under the 17-class classification system. To simplify the analysis and ensure consistency for basin-scale change assessment, the detailed classes were reclassified into broader Level-I categories based on the NRSC classification framework. The reclassification was carried out by grouping spectrally and functionally similar land use categories into five major classes. This approach reduces classification complexity and enables effective comparison of temporal LULC changes across the years 2005, 2010, 2015, 2020 and 2024 in the Krishna River Basin. The original 17-class National Remote Sensing Centre (NRSC) LULC raster layers were first imported into the GIS environment for pre-processing and analysis. Each individual land use class was carefully examined and reassigned to the corresponding Level-I category based on thematic similarity and functional characteristics. Raster reclassification tools available in ArcGIS and QGIS were then applied to generate harmonized LULC maps with five generalized classes. The resulting reclassified maps were subsequently used for area estimation, spatial comparison, and temporal change detection analysis to assess long-term land use dynamics in the Krishna River Basin. This generalized classification scheme provides a robust framework for evaluating long-term land use transitions and their implications for hydrology, ecology, and resource management in the Krishna River Basin. Table 3.1 represents the reclassified LULC classes.

Table 3. 1 Reclassified LULC Categories (NRSC Level-I)

Sl. No.	Reclassified Class	Description
1	Agriculture	Cropland, plantations, fallow land, and other cultivated areas
2	Barren Land	Wasteland, scrubland, rocky areas, and uncultivable open land
3	Built-Up	Urban settlements, rural habitations, industrial and infrastructure areas
4	Forest	Dense forest, open forest, plantations, and other tree-covered areas
5	Water Bodies	Rivers, reservoirs, lakes, tanks, canals, and wetlands

4. Basin Characteristics

4.1 Present LULC Map & Statistics (2024)

The present Land Use and Land Cover (LULC) status of the Krishna River Basin for the year 2024 indicates that Agriculture is the dominant land use class, covering 204,875.25 Km² (approximately 78.06% of the total basin area). This reflects the strong dependence of the basin on irrigated and rainfed farming systems. Forest occupies 23,641.68 Km² (9.01%), mainly distributed in upper catchments, hill ranges, and protected regions. Barren Land accounts for 15,342.56 Km² (5.85%), showing a notable reduction compared to earlier years, likely due to agricultural expansion and land development activities. Built-Up land has increased substantially to 9,805.36 Km² (3.74%), indicating rapid urbanization, industrialization, and infrastructure growth across the basin. Water Bodies cover 6,771.66 Km² (2.58%), including rivers, reservoirs, lakes, and tanks. Table 4.1 represents the LULC statistics of the present condition (2024) in the Krishna River Basin.

Table 4. 1 LULC statistics of the present condition (2024) in the Krishna River Basin

Class	Area (Km²)	Percentage (%)
Built-Up	9,805.36	3.74
Agriculture	204,875.25	78.06
Forest	23,641.68	9.01
Barren Land	15,342.56	5.85
Water Bodies	6,771.66	2.58

4.2 Reference LULC Map & Statistics (2005)

The reference LULC condition for the year 2005 represents the baseline land use scenario of the Krishna River Basin. During this period, Agriculture was already the predominant class with an extent of 187,969.07 Km² (71.95%). Barren Land covered 29,129.19 Km² (11.15%), which was significantly higher than the present condition. Forest area was 24,420.40 Km² (9.35%), showing relatively stable coverage compared to later years with minor fluctuations. Water Bodies occupied 10,878.38 Km² (4.16%), while Built-Up land was limited to 6,841.19 Km² (2.62%), reflecting lower urban expansion at that time. Table 4.2 represents the LULC statistics of the reference condition (2005) in the Krishna River Basin.

Table 4. 2 LULC statistics of the reference condition (2005) in the Krishna River Basin

Class	Area (Km²)	Percentage (%)
Built-Up	6,841.19	2.62
Agriculture	187,969.07	71.95
Forest	24,420.40	9.35
Barren Land	29,129.19	11.15
Water Bodies	10,878.38	4.16

A comparison between 2005 and 2024 shows major landscape transformation in the Krishna Basin. Agricultural land increased markedly, built-up area expanded rapidly, and barren land declined significantly. Forest cover remained relatively stable with a slight decrease, while water bodies showed temporal variation, likely influenced by reservoir storage, seasonal hydrology, and climatic variability. These trends indicate growing anthropogenic pressure on basin resources and highlight the need for sustainable land and water management planning.

5. Temporal Analysis

The multi-temporal LULC maps of the Krishna River Basin for the years 2005, 2010, 2015, 2020 and 2024 reveal significant spatial transformations driven by agricultural intensification, urban expansion, infrastructure development, and changing hydrological conditions. The five reclassified categories: Built-Up, Agriculture, Forest, Barren Land and Water Bodies show distinct temporal trends across the basin.

5.1. Overall Spatial Pattern

Throughout the study period, Agriculture remained the dominant land use class in the basin, occupying the largest proportion of total area in every assessment year. Agricultural lands are widely distributed across the central plateau regions, canal command areas, alluvial tracts, and deltaic plains. The persistence and expansion of agriculture indicate increasing pressure on land and water resources to meet food demand and support rural livelihoods.

Built-Up land exhibited the most visible anthropogenic growth during the study period. Major urban centers and peri-urban corridors expanded considerably, particularly around metropolitan and industrial regions such as Pune, Hyderabad fringe zones, Vijayawada-Guntur region, Hubballi-Dharwad belt, and other emerging municipalities within the basin. The spread

of built-up land reflects population growth, transportation networks, industrial clusters, and service-sector development.

Forest cover remained comparatively stable in spatial extent, though localized fragmentation and minor decline are visible in some sub-basins. Forests are mainly concentrated in the Western Ghats, upper catchments, escarpments, reserve forests, and hilly terrain of the southern and western basin. These regions continue to provide ecological services such as biodiversity conservation, slope stabilization, and watershed protection.

Barren Land showed a consistent declining trend from 2005 to 2024. Many previously open, degraded, or sparsely vegetated lands appear to have been converted into agriculture and settlements, plantations, or other managed land uses. This decline is an indicator of landscape transformation and intensification of land utilization.

Water Bodies exhibited strong temporal fluctuations rather than a monotonic trend. Reservoir extents, river reaches, tanks, lakes, and wetlands vary with monsoon conditions, storage operations, irrigation demand, sedimentation, and climatic variability. While some years show expanded water spread, the 2024 map indicates an overall reduction in surface water area compared with earlier years.

5.2 Quantitative Change Detection

Built-up area increased from 6,841.19 Km² in 2005 to 9,805.36 Km² in 2024, representing an increase of approximately 43.3%. This is one of the most significant land transitions observed in the basin. The increase indicates rapid urbanization and associated conversion of agricultural or barren lands into residential, commercial, industrial, and transportation infrastructure.

Agricultural land increased from 187,969.07 Km² in 2005 to 204,875.25 Km² in 2024, with a net gain of about 16,906 Km². This expansion suggests continued cultivation growth, improved irrigation access, reclamation of wastelands, and changing cropping patterns. The increase also highlights rising demand for food production and economic dependence on agriculture.

Forest area changed from 24,420.40 Km² in 2005 to 23,641.68 Km² in 2024, indicating a marginal net decline. Although basin-scale forest loss is relatively limited compared to other classes, local degradation and fragmentation may still have significant ecological consequences, especially in erosion-prone and biodiversity-rich regions.

Barren land declined sharply from 29,129.19 Km² in 2005 to 15,342.56 Km² in 2024, a reduction of nearly 47.3%. This class experienced the largest proportional decrease. Much of

this land appears to have transitioned into agriculture, built-up land, plantations, or mixed-use landscapes.

Water bodies reduced from 10,878.38 Km² in 2005 to 6,771.66 Km² in 2024, though intermediate years showed fluctuations. The reduction may be linked to seasonal storage variation, drought conditions, reservoir operation patterns, siltation, and increasing abstraction for irrigation and domestic uses.

5.3 Period-wise Interpretation

The temporal LULC statistics of the Krishna River Basin for the years 2005, 2010, 2015, 2020, and 2024 expressed in Km² were represented in Table 5.1. The table provides a comparative assessment of major land cover categories over the selected time periods, highlighting the spatial extent and variations in each class. These temporal statistics are useful for understanding the dynamics of landscape transformation driven by urbanization, agricultural expansion, deforestation, water resource development and climatic influences within the basin. The analysis of LULC changes over time offers valuable insights into long-term environmental trends and supports sustainable planning, watershed management, and policy formulation for the Krishna River Basin. The period wise analysis as follows.

Table 4. 3 Temporal LULC statistics for the years 2005, 2010, 2015, 2020 and 2024 in the Krishna River Basin (Area in Km²)

LULC Class/ Year	2005	2010	2015	2020	2024
Built Up	6910.95	7511.16	7595.52	7772.85	9841.92
Agriculture	189885.88	189677.76	192680.88	194408.40	205935.27
Forest	24669.43	24669.43	24740.54	24733.47	23880.16
Barren Land	29426.23	29024.44	26506.10	23287.69	15420.13
Water Bodies	10989.31	10999.02	10358.77	11679.40	6804.33

5.3.1 LULC Change During 2005-2010

This period shows relatively modest land use change. Agricultural area remained nearly stable, while built-up land increased gradually. Barren land showed an early decline, indicating the beginning of land conversion processes. Water bodies remained largely similar to the baseline condition.

5.3.2 LULC Change During 2010-2015

During this interval, agriculture expanded more visibly, and urban areas continued to grow. Forest cover remained stable, while barren land reduced further. Water bodies decreased moderately, reflecting hydrological variability and land management changes.

5.3.3 LULC Change During 2015-2020

This phase shows continued agricultural growth and further built-up expansion. Water bodies increased temporarily in 2020, likely associated with favourable rainfall years or higher reservoir storage conditions. Barren land continued to decline steadily.

5.3.4 LULC Change During 2020-2024

The most pronounced changes occurred during the latest period. Built-up land expanded sharply, agriculture recorded its highest extent, barren land reduced substantially, and water bodies declined considerably. This suggests accelerated anthropogenic transformation combined with hydrological stress.

The Land Use and Land Cover (LULC) maps prepared for the years 2005, 2010, 2015, 2020, and 2024 provide a comprehensive representation of the spatial and temporal transformation of the Krishna River Basin over the study period. Figures 5.1 to 5.5 represent the spatial variations of Land Use and Land Cover (LULC) in the Krishna River Basin for the years 2005, 2010, 2015, 2020, and 2024, respectively.

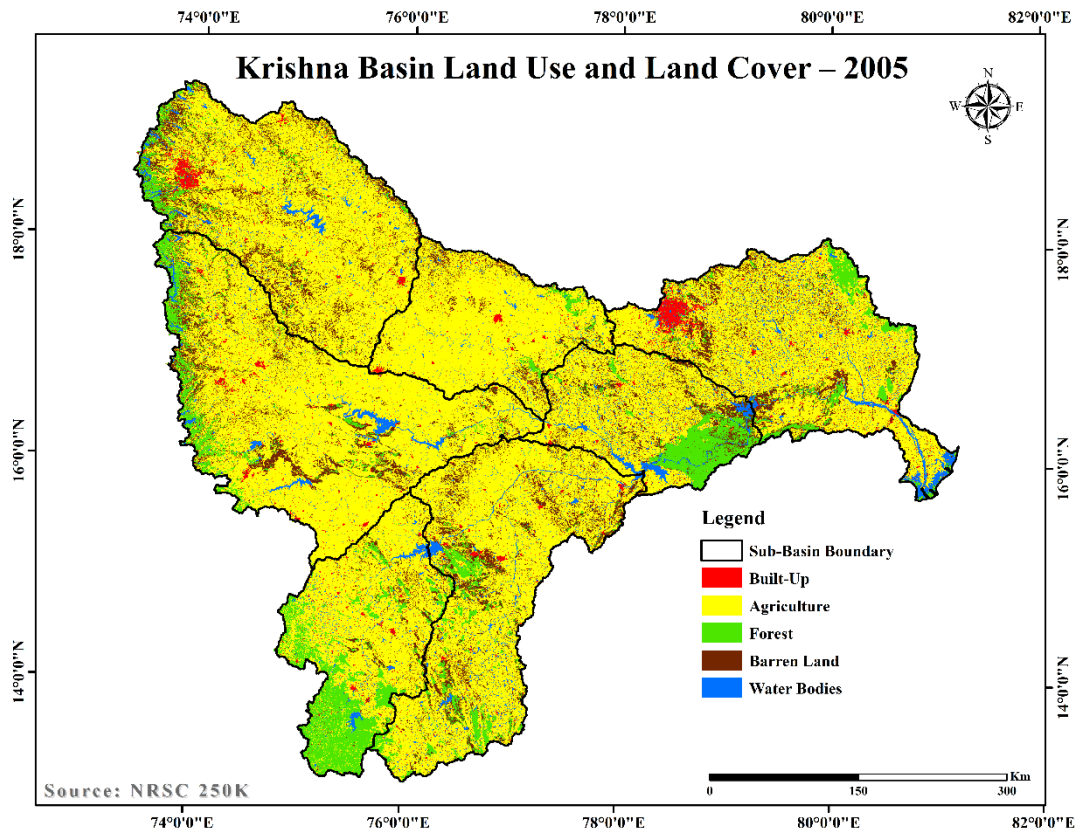


Figure 5. 1 LULC map of the Krishna River Basin for the year 2005

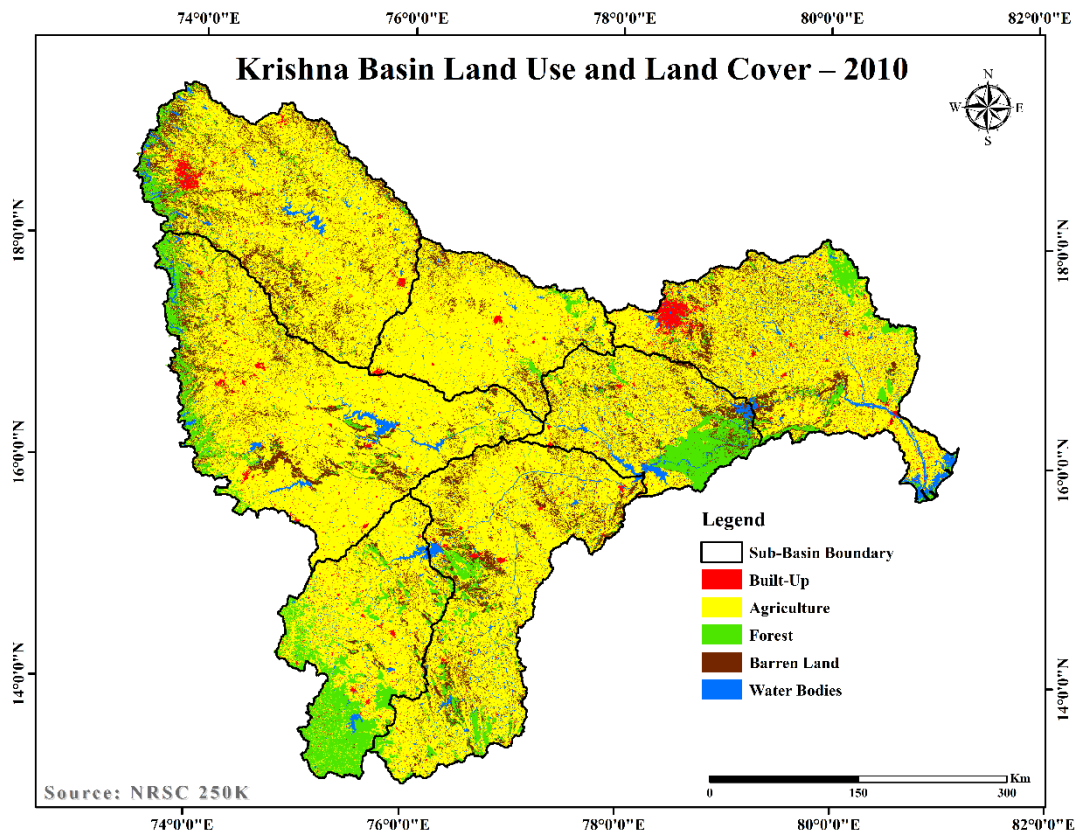


Figure 5. 2 LULC map of the Krishna River Basin for the year 2010

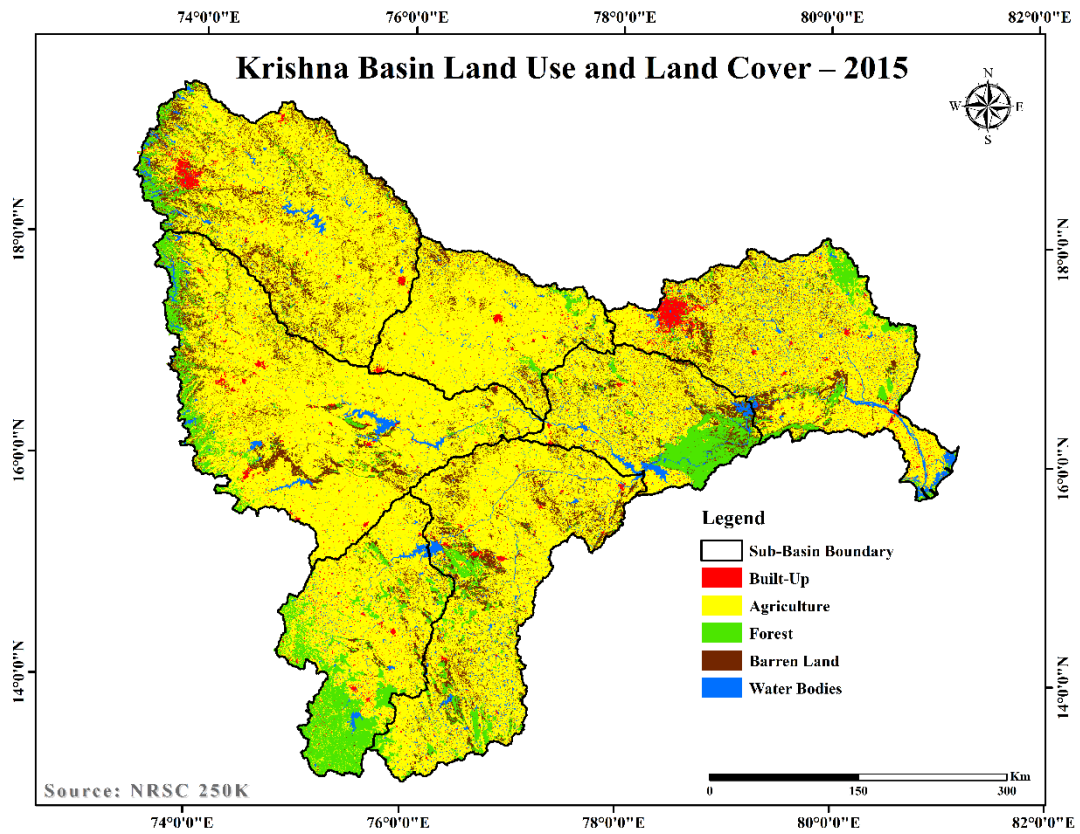


Figure 5. 3 LULC map of the Krishna River Basin for the year 2015

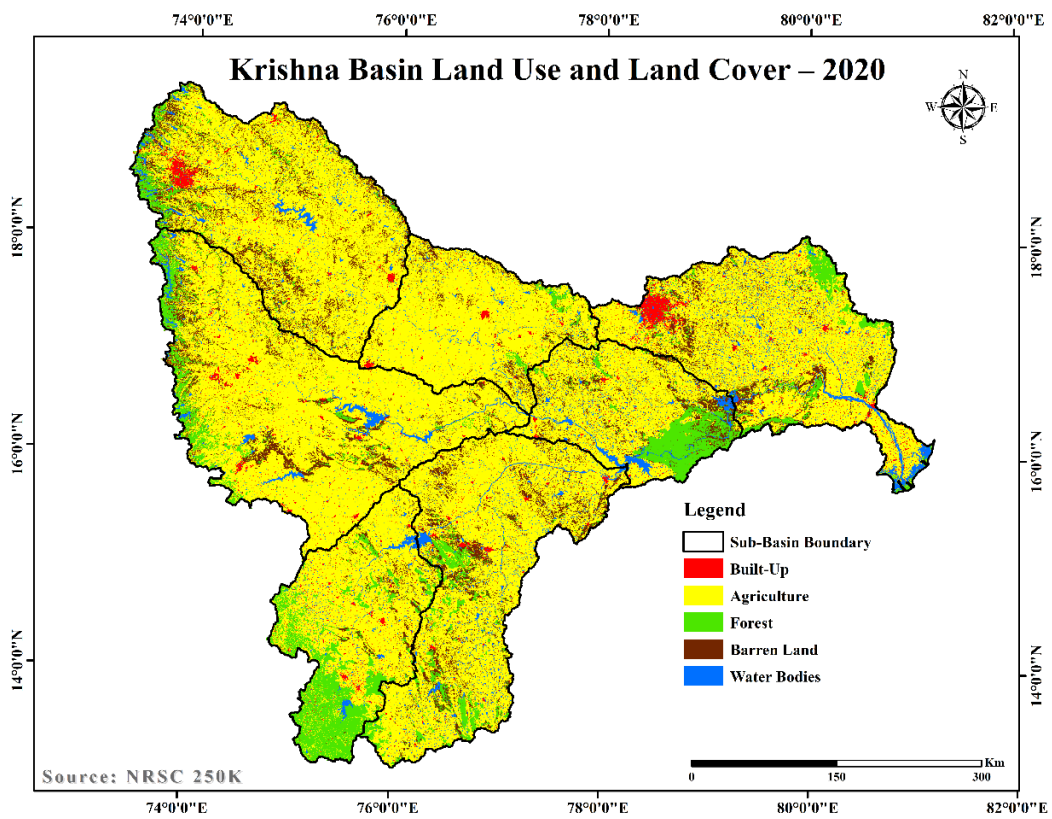


Figure 5. 4 LULC map of the Krishna River Basin for the year 2020

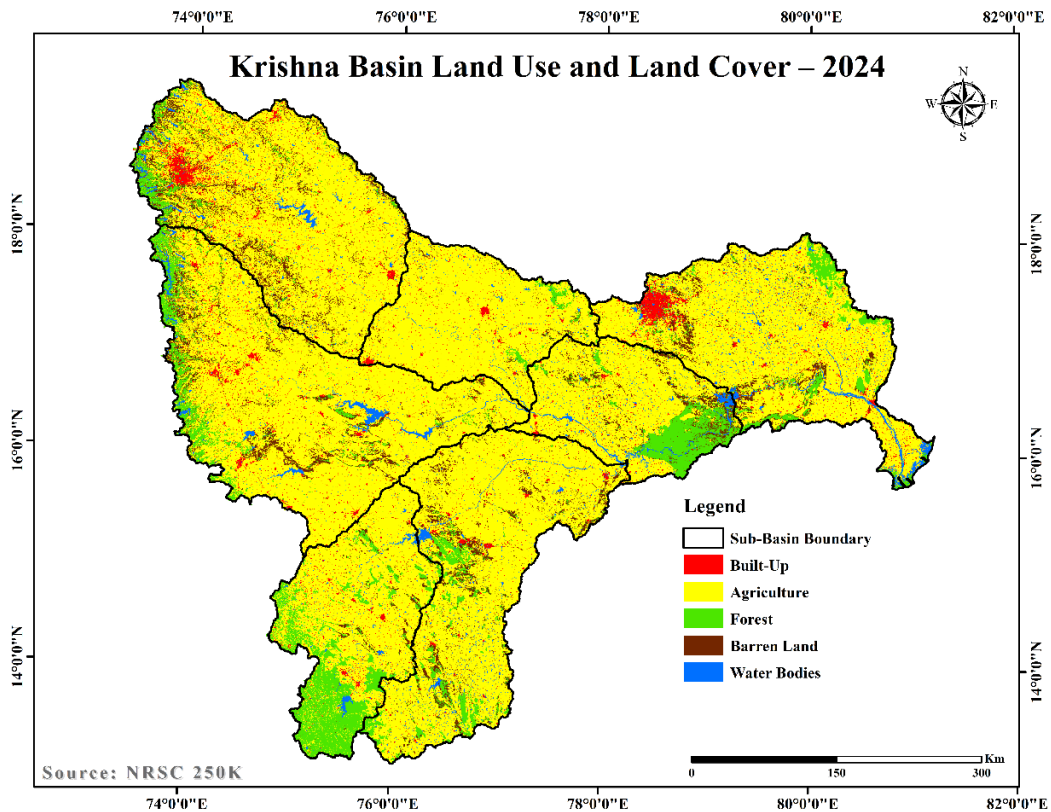


Figure 5. 5 LULC map of the Krishna River Basin for the year 2024

Figure 5.6 illustrates the temporal LULC trends across the seven major sub-basins of the Krishna River Basin, namely Lower Bhima, Lower Krishna, Lower Tungabhadra, Middle Bhima, Upper Bhima, Upper Krishna, and Upper Tungabhadra for the period 2005-2024. The multi-panel representation highlights the changes in major land cover classes including Agriculture, Barren Land, Built-up Area, Forest, and Water Bodies, providing a comparative understanding of landscape dynamics at the sub-basin scale. The agriculture category remains the dominant land use in all sub-basins throughout the study period. Upper Krishna records the highest agricultural area, followed by Upper Bhima and Lower Krishna, with a gradual increasing trend observed by 2024. Lower Bhima, Middle Bhima and Upper Tungabhadra also show moderate increases, indicating continued agricultural expansion and intensification across the basin. Barren land exhibits a declining trend in most sub-basins, suggesting conversion of unused or degraded lands into productive land uses such as agriculture or settlements. Upper Bhima initially shows the highest barren land extent but decreases sharply after 2020. Similar reductions are observed in Lower Krishna, Lower Tungabhadra and Upper Krishna, reflecting significant land transformation processes.

Built-up area shows a consistent increase across all sub-basins, indicating rapid urbanization and infrastructure growth over the two decades. Upper Bhima and Upper Krishna demonstrate the most significant rise in built-up land by 2024, while Lower Krishna and Upper Tungabhadra also register steady growth. This trend reflects increasing population pressure and regional economic development within the basin. Forest area remains relatively stable compared to other land use classes, with only minor fluctuations across the study period. Upper Tungabhadra maintains the highest forest cover, followed by Upper Krishna and Middle Bhima. Slight declines in some sub-basins by 2024 may indicate localized deforestation or land conversion, but overall forest resources remain comparatively preserved.

Water bodies show noticeable temporal fluctuations, particularly a decline in 2024 across all sub-basins. Lower Krishna consistently contains the largest water spread area due to the presence of major reservoirs and river networks. The reduction in water bodies during later years may be associated with climatic variability, reduced storage levels or changes in hydrological conditions. Overall, the figure demonstrates that agricultural dominance, declining barren lands, increasing built-up areas, relatively stable forest cover and fluctuating water bodies are the key LULC characteristics across the Krishna River Basin sub-basins. These trends are important for regional planning, water resources management and sustainable land use policy development.

LULC Trends Across Sub-Basins (2005–2024)

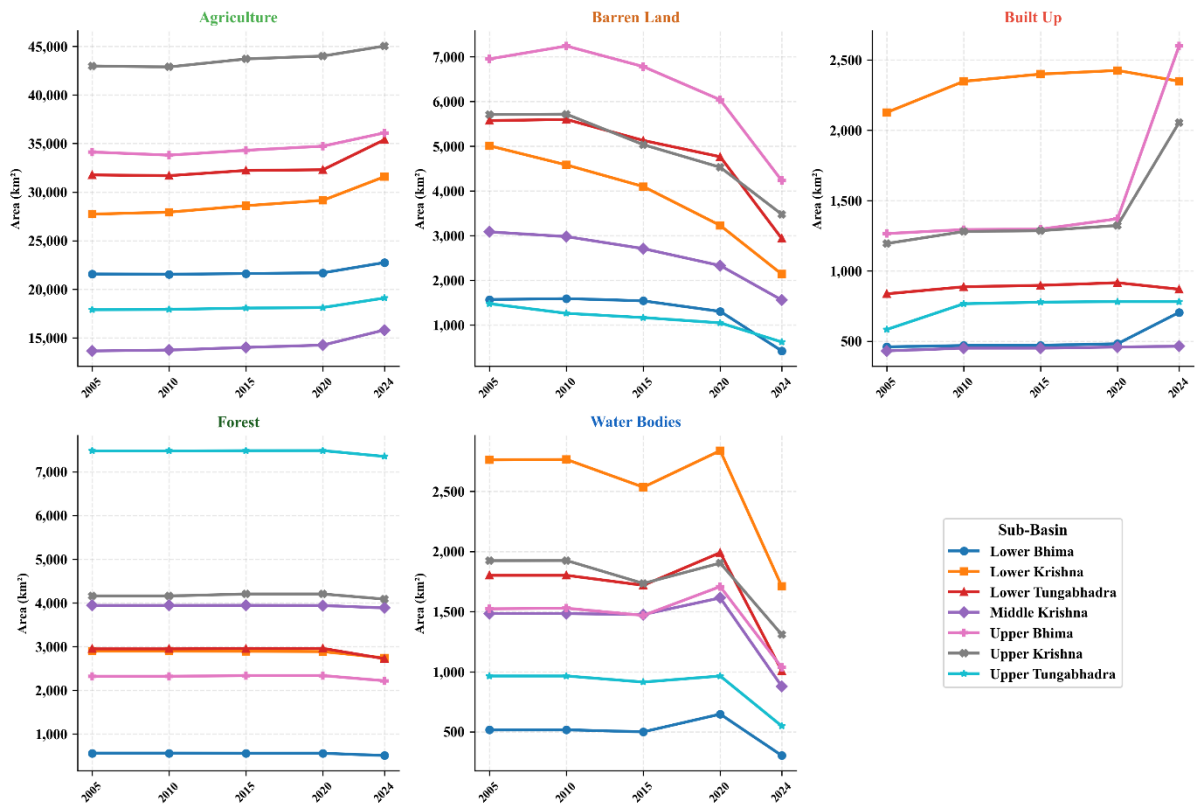


Figure 5. 6 LULC trends across major sub-basins of the Krishna River Basin during 2005-2024 showing temporal variations in Agriculture, Barren Land, Built-up Area, Forest and Water Bodies

Figure 5.7 presents the sub-basin-wise percentage change in major LULC classes between 2005 and 2024 for the Krishna River Basin. The heatmap clearly highlights the magnitude and direction of changes in Agriculture, Barren Land, Built-up Area, Forest, and Water Bodies across Lower Bhima, Lower Krishna, Lower Tungabhadra, Middle Krishna, Upper Bhima, Upper Krishna, and Upper Tungabhadra sub-basins. Positive values indicate an increase in area, while negative values represent a decline over the study period.

Agricultural land shows a positive increase in all sub-basins, indicating continued expansion of cultivated area. The highest growth is observed in Middle Krishna (+15.8%), followed by Lower Krishna (+13.9%) and Lower Tungabhadra (+11.4%). Moderate increases are seen in Upper Bhima (+5.8%), Lower Bhima (+5.4%), Upper Tungabhadra (+6.7%), and Upper Krishna (+4.8%). This reflects sustained agricultural development and conversion of other land classes into cropland. Barren land records a substantial decline across all sub-basins, signifying reclamation or transformation of degraded and unused lands. The most significant reduction

occurs in Lower Bhima (-73.2%), followed by Upper Tungabhadra (-58.0%), Lower Krishna (-57.3%), Middle Krishna (-49.4%), Lower Tungabhadra (-47.3%), Upper Bhima (-39.1%), and Upper Krishna (-39.1%). This consistent decline indicates improved land utilization throughout the basin.

Built-up area exhibits the most prominent positive growth among all classes, emphasizing rapid urbanization and infrastructure expansion. Upper Bhima shows the highest increase (+105.4%), followed by Upper Krishna (+72.0%) and Lower Bhima (+53.3%). Other sub-basins also register growth, including Upper Tungabhadra (+34.0%), Lower Krishna (+10.4%), Middle Krishna (+7.8%), and Lower Tungabhadra (+3.9%). These trends indicate increasing population concentration and regional development. Forest area remains relatively stable, with only marginal declines in most sub-basins. The largest reduction is observed in Lower Bhima (-9.5%), followed by Lower Tungabhadra (-7.7%), Lower Krishna (-5.3%), Upper Bhima (-4.4%), Upper Krishna (-1.7%), Upper Tungabhadra (-1.7%), and Middle Krishna (-1.5%). Although the changes are comparatively small, they indicate gradual pressure on forest resources.

Water bodies show a noticeable decline in all sub-basins between 2005 and 2024. The largest reduction is found in Lower Tungabhadra (-44.1%), followed by Upper Tungabhadra (-43.1%), Lower Bhima (-41.2%), Middle Krishna (-40.8%), Lower Krishna (-38.0%), Upper Bhima (-32.0%), and Upper Krishna (-31.9%). This decline may be associated with hydrological variability, reduced reservoir storage, sedimentation, or changing climatic conditions. Overall, the figure reveals a clear pattern of agricultural expansion, sharp reduction in barren lands, strong urban growth, slight forest decline, and shrinking water bodies across the Krishna River Basin. These findings are significant for sustainable watershed planning, ecological conservation, and future resource management strategies.

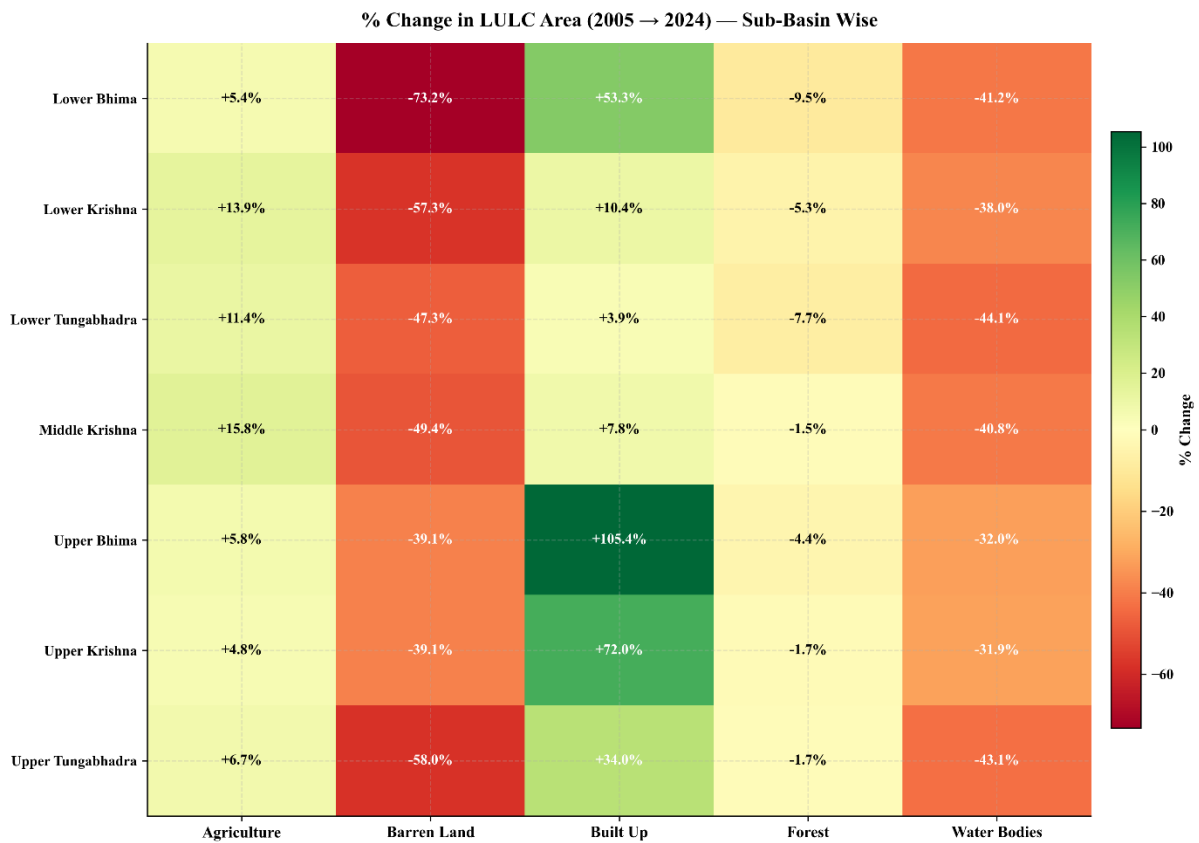


Figure 5. 7 Percentage change in LULC area from 2005 to 2024 across the major sub-basins of the Krishna River Basin

Figure 5.8 illustrates the absolute net change in major LULC classes from 2005 to 2024 for the major sub-basins of the Krishna River Basin. The bar charts quantify gains and losses in Agriculture, Barren Land, Built-up Area, Forest, and Water Bodies, thereby providing a clearer measure of spatial transformation in terms of area (Km²). Positive values indicate an increase in land cover extent, whereas negative values represent a decline during the study period.

Agricultural land records a net increase in all sub-basins, confirming the dominance and expansion of cultivation across the basin. The highest gain is observed in Lower Krishna (+3853 Km²), followed by Lower Tungabhadra (+3623 Km²), Middle Krishna (+2152 Km²), Upper Krishna (+2057 Km²), Upper Bhima (+1976 Km²), Upper Tungabhadra (+1201 Km²), and Lower Bhima (+1170 Km²). These gains suggest continued conversion of barren or other land classes into agricultural use. Barren land shows a considerable net reduction in every sub-basin, indicating improved land utilization and reclamation of degraded lands. Lower Krishna experiences the largest decline (-2869 Km²), followed by Upper Bhima (-2721 Km²), Lower Tungabhadra (-2635 Km²), Upper Krishna (-2229 Km²), Middle Krishna (-1523 Km²), Lower

Bhima (-1148 Km²), and Upper Tungabhadra (-856 Km²). This widespread decrease corresponds with increasing agricultural and urban land demand.

Built-up area demonstrates substantial positive growth across all sub-basins, highlighting urban expansion and infrastructure development. Upper Bhima records the highest increase (+1334 Km²), followed by Upper Krishna (+860 Km²), Lower Bhima (+245 Km²), Lower Krishna (+222 Km²), Upper Tungabhadra (+198 Km²), Middle Krishna (+33 Km²), and Lower Tungabhadra (+33 Km²). The pronounced rise in Upper Bhima and Upper Krishna indicates concentrated urban growth in these regions. Forest area undergoes only moderate losses compared with other classes. The greatest decline occurs in Lower Tungabhadra (-226 Km²), followed by Lower Krishna (-155 Km²), Upper Tungabhadra (-127 Km²), Upper Bhima (-101 Km²), Upper Krishna (-72 Km²), Middle Krishna (-57 Km²), and Lower Bhima (-53 Km²). Although relatively smaller in magnitude, these reductions reflect gradual pressure on forest ecosystems.

Water bodies register net losses across all sub-basins, indicating a contraction in surface water extent over the study period. Lower Krishna shows the highest decline (-1051 Km²), followed by Lower Tungabhadra (-794 Km²), Upper Krishna (-615 Km²), Middle Krishna (-605 Km²), Upper Bhima (-488 Km²), Upper Tungabhadra (-416 Km²), and Lower Bhima (-213 Km²). These decreases may be linked to reservoir storage fluctuations, sedimentation, land encroachment, or climatic variability. Overall, the figure confirms a basin-wide transition characterized by expansion of agriculture and built-up land, sharp reduction in barren areas, minor forest loss, and shrinking water bodies. The net LULC changes emphasize the need for integrated land and water management strategies to ensure sustainable development in the Krishna River Basin.

Net LULC Change (km²): 2005 to 2024 - Sub-Basin Wise

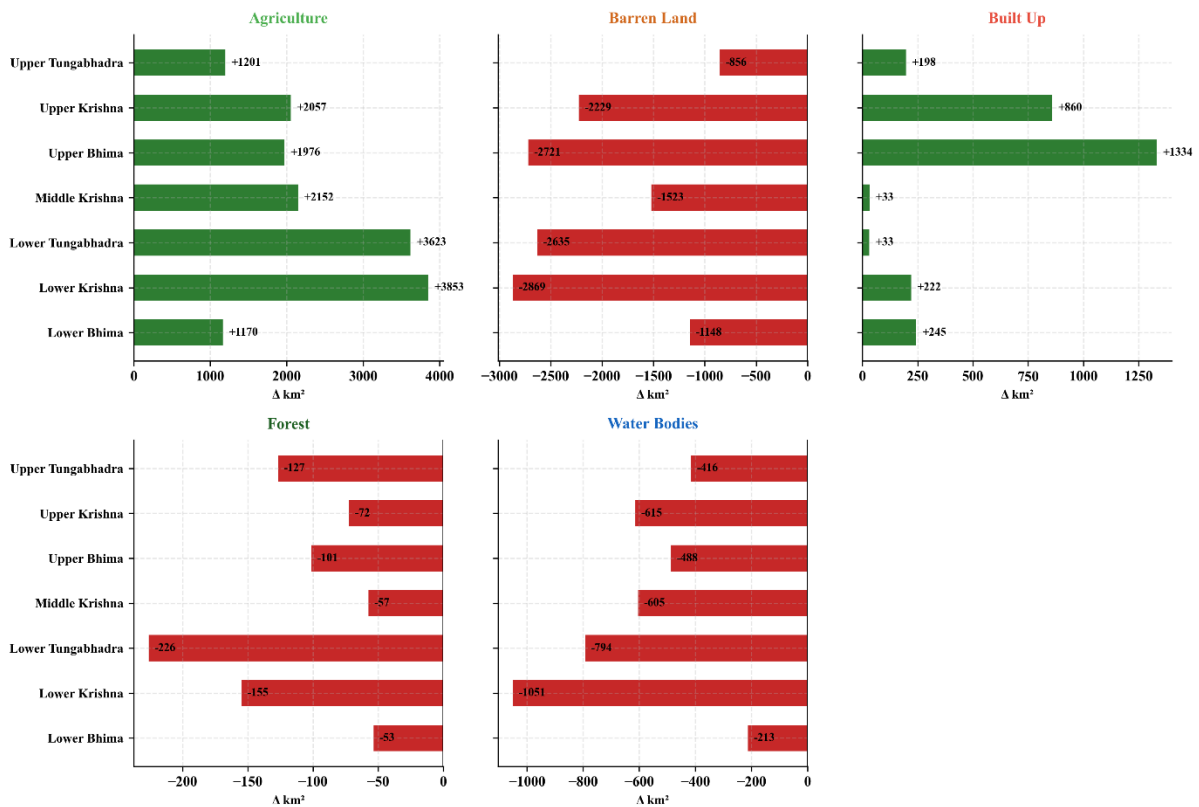


Figure 5. 8 Net Land Use/Land Cover (LULC) change (Km²) between 2005 and 2024 across the major sub-basins of the Krishna River Basin

6. Impact Assessment

The temporal LULC changes observed in the Krishna River Basin from 2005 to 2024 indicate significant environmental, hydrological, socio-economic and ecological impacts across the sub-basins. The expansion of agricultural land has contributed positively to food production, rural livelihoods, and regional economic growth. However, continuous agricultural intensification may increase dependency on irrigation water, fertilizers and groundwater extraction, thereby exerting pressure on already stressed water resources. The substantial rise in built-up areas reflects rapid urbanization, industrialization and infrastructure development. While this transformation supports economic progress, employment generation and improved connectivity, it also results in loss of permeable surfaces, increased runoff, urban flooding risks, and greater demand for domestic and industrial water supply. Expansion of settlements into productive lands may further intensify land-use conflicts.

The decline in barren land suggests improved land utilization and reclamation of previously underused areas. This can be considered a positive development if supported by sustainable

planning. However, conversion of barren or open lands may also reduce natural recharge zones and alter local biodiversity habitats. Relatively minor but continuous reduction in forest cover may have long-term ecological consequences, including habitat fragmentation, biodiversity loss, soil erosion, reduced carbon sequestration, and altered micro-climatic conditions. Forest degradation in upstream areas can directly influence sediment yield and downstream reservoir sustainability. The consistent reduction in water bodies across several sub-basins is a critical concern. Shrinking surface water extent may affect irrigation reliability, hydropower generation, drinking water availability, wetland ecosystems, and drought resilience. These changes may be associated with climate variability, sedimentation, encroachment, and increasing consumptive water use. Overall, the basin is undergoing a transition toward more intensive human use of land resources. Without integrated planning, these changes may lead to increasing water scarcity, environmental degradation, and vulnerability to climate extremes.

7. Conclusion

The present study analysed the spatial and temporal dynamics of LULC in the Krishna River Basin for the years 2005, 2010, 2015, 2020, and 2024 at both basin and sub-basin scales. The results reveal clear patterns of increasing agricultural and built-up areas, significant reduction in barren lands, relatively stable but gradually declining forest cover, and noticeable shrinkage of water bodies. Agriculture remains the dominant land use across all sub-basins, indicating the continued importance of the basin for food production and rural livelihoods. Rapid growth in built-up land reflects urban expansion and socio-economic development, particularly in Upper Bhima and Upper Krishna regions. Declining barren land demonstrates active land transformation, while forest losses, though comparatively smaller, indicate ecological pressure. The reduction in water spread area across several sub-basins highlights emerging hydrological stress and the need for improved water governance. The study confirms that LULC dynamics are strongly linked with population growth, irrigation development, reservoir operations, climatic variability, and economic activities. These changes have direct implications for watershed management, agricultural sustainability, flood control, groundwater recharge, biodiversity conservation, and climate resilience. Hence, continuous geospatial monitoring and integrated basin-scale planning are essential for balancing development needs with environmental sustainability in the Krishna River Basin.

8. Recommendations and Role of Stakeholders

The analysis of LULC changes in the Krishna River Basin highlights the increasing pressure on land, water, and ecological resources due to agricultural expansion, urbanization, declining water bodies, and gradual forest degradation. These changes emphasize the need for sustainable and integrated basin management approaches that balance developmental activities with environmental conservation. Effective implementation of scientific planning, policy interventions, technological advancements, and community participation is essential to ensure long-term water security, ecological stability, and climate resilience within the basin. In this context, the following recommendations and stakeholder responsibilities are proposed for sustainable management of the Krishna River Basin.

8.1 Recommendations

Sustainable agricultural practices should be promoted throughout the basin to reduce excessive water consumption and improve resource-use efficiency. Adoption of micro-irrigation systems such as drip and sprinkler irrigation, crop diversification, precision farming techniques and climate-resilient cropping patterns can significantly enhance agricultural productivity while minimizing pressure on water resources. Efficient irrigation scheduling and soil moisture conservation measures are also essential for sustainable agricultural development. Unplanned urban expansion must be controlled through effective land-use zoning regulations and planned infrastructure development. Rapid growth of built-up areas has increased environmental stress, reduced permeable surfaces and intensified flood risks in urban regions. Therefore, implementation of green infrastructure, urban storm-water management systems, and environmentally sustainable urban planning practices is necessary to reduce ecological impacts and improve urban resilience. Forest conservation and ecological restoration should be strengthened, particularly in environmentally sensitive and upstream catchment regions. Afforestation programs, watershed treatment measures, riparian buffer zone development and protection of degraded forest lands are essential to reduce soil erosion, improve groundwater recharge, enhance biodiversity conservation and maintain ecological balance within the basin.

Restoration and conservation of water bodies should receive high priority due to the observed decline in surface water extent across several sub-basins. Tanks, lakes, wetlands, and reservoir catchments should be rejuvenated through desiltation, encroachment removal, catchment treatment, and integrated watershed management practices. Protection of natural drainage systems and wetland ecosystems is also necessary to improve hydrological sustainability. Water governance mechanisms should be strengthened through integrated river basin

management approaches involving surface water, groundwater, irrigation systems, environmental flows and interstate coordination. Scientific water allocation policies, real-time monitoring systems, and participatory water management practices are necessary for efficient and equitable utilization of basin resources.

Climate adaptation and disaster preparedness measures should be enhanced to address increasing climate variability and hydrological uncertainties. Use of climate projections, drought preparedness strategies, flood forecasting systems, and early warning mechanisms can improve basin resilience against extreme climatic events. Integration of climate change considerations into water resources planning and land management policies is essential for sustainable development. Continuous monitoring using GIS and Remote Sensing technologies should be adopted for periodic assessment of LULC dynamics and environmental changes within the basin. Regular updating of spatial databases, land-use maps, hydrological indicators, and ecological assessments will support evidence-based decision making and long-term basin management planning.

8.2 Role of Stakeholders

Sustainable management of the Krishna River Basin requires coordinated participation from multiple stakeholders at local, regional and national levels. Government agencies play a crucial role in developing policies, enforcing land-use regulations, improving irrigation efficiency, and coordinating interstate river basin management activities. Effective policy implementation and institutional coordination are essential for balancing developmental and environmental objectives. Water Resource Departments are responsible for reservoir operations, canal management, flood control infrastructure, water allocation planning, and hydrological monitoring. Adoption of real-time data systems and integrated water management strategies can improve operational efficiency and water security across the basin. Agriculture Departments should support farmers through extension services, improved seed distribution, efficient irrigation technologies, climate-smart agricultural practices and awareness programs related to sustainable farming methods. Capacity building and technical support can significantly enhance agricultural resilience and productivity. Forest Departments play an important role in protecting forest ecosystems, regulating land conversion, implementing afforestation programs and conserving ecologically sensitive areas. Strengthening forest governance and promoting ecosystem restoration activities are necessary for maintaining biodiversity and environmental sustainability.

Urban Local Bodies are responsible for sustainable urban planning, drainage management, wastewater treatment and reuse, solid waste management and implementation of environmentally sustainable infrastructure systems. Planned urban development can reduce environmental degradation and improve urban resilience. Research Institutions and Universities contribute through scientific investigations, geospatial analysis, climate studies, hydrological assessments and development of decision-support systems. Their role in providing technical expertise, policy inputs, and innovative solutions is critical for evidence-based basin management. Local communities and farmers are key stakeholders in watershed conservation and sustainable resource management. Community participation in watershed development programs, efficient water use practices, ecosystem protection and local conservation initiatives can significantly improve the success of basin management strategies. Non-Governmental Organizations (NGOs) contribute by facilitating awareness programs, environmental education, participatory planning, capacity building, and ecological restoration activities. NGOs also act as an important link between local communities, researchers, and government institutions. In conclusion, a coordinated multi-stakeholder approach integrating scientific management, policy support, technological interventions and community participation is essential for ensuring long-term water security, ecological balance, and sustainable development in the Krishna River Basin.

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