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

Land Use / Land Cover

Mahanadi River Basin

December 2025

cMahanadi

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Mahanadi River Basin

National River Conservation Directorate (NRCD)

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 Mahanadi River Basin Management Studies (cMahanadi)

The Centre for Mahanadi River Basin Management Studies (cMahanadi) is a Brain Trust dedicated to River Science and River Basin Management. Established in 2024 by NIT Raipur and NIT Rourkela, under the supervision of cGanga at IIT Kanpur, the centre serves as a knowledge wing of the National River Conservation Directorate (NRCD). cMahanadi is committed to restoring and conserving the Mahanadi River and its resources through the collation of information and knowledge, research and development, planning, monitoring, education, advocacy, and stakeholder engagement.

www.cmahanadi.org

Centre for Ganga River Basin Management and Studies (cGanga)

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 Raipur (Lead Institute) and NIT Rourkela (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.

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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.

Centre for Mahanadi River Basin
Management Studies (cMahanadi)
NIT Raipur & NIT Rourkela

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Abbreviations and Acronyms

cMahanadi	Centre for Mahanadi River Basin Management and Studies
MRB	Mahanadi River Basin
NIT	National Institute of Technology
IIT	Indian Institute of Technology
ESRI	Environmental Systems Research Institute
LULC	Land Use and Land Cover

1. Introduction

1.1 Background and Rationale

Land Use and Land Cover (LULC) is a primary determinant of hydrological processes in river basins. Changes in land surface characteristics directly influence how rainfall is partitioned into infiltration, runoff, evapotranspiration, and storage. In rapidly transforming basins such as the Mahanadi River Basin (MRB), understanding LULC dynamics is essential for assessing water availability, hydrological stability, and emerging water stress.

Importance of LULC in controlling:

- **Surface Runoff**
  Land cover determines infiltration capacity and surface roughness. Forested and vegetated landscapes promote infiltration and slow overland flow, whereas built-up and compacted agricultural surfaces increase runoff generation. Shifts in land cover can therefore intensify flood peaks and reduce groundwater recharge.
- **Sediment Yield**
  Vegetation cover protects soil from erosion by stabilizing slopes and reducing raindrop impact. Conversion of forests or rangelands to cropland or settlements increases soil exposure and erosion potential, leading to higher sediment delivery to rivers and reservoirs.
- **Nutrient Load**
  Agricultural lands contribute nutrients through fertilizer application and soil disturbance. Urban areas contribute pollutants through storm-water runoff and wastewater discharge. Changes in LULC can therefore influence nutrient transport, eutrophication risk, and overall river water quality.
- **Water Retention and Availability**
  Forests, wetlands, and floodplains act as natural storage systems, regulating streamflow and sustaining dry-season discharge. Alterations in these land covers can reduce natural buffering capacity, increasing dependence on artificial storage and regulated flows.

Relevance to MRB Hydrology and Water Stress

The MRB represents a hydrologically diverse and rapidly developing basin in central-eastern India. Upstream forested catchments, mid-basin agricultural zones, and downstream urban-industrial corridors collectively define its hydrological character. Rapid land transformation within the basin has implications for runoff variability, sediment transport, water quality, and long-term water availability.

A systematic assessment of LULC dynamics is therefore critical to understand emerging water stress patterns and to inform basin-scale management strategies.

Objectives of the Study

The primary objective of this study is to systematically assess the spatial and temporal dynamics of Land Use and Land Cover (LULC) across the Mahanadi River Basin (MRB) to understand ongoing landscape transformations and their eco-hydrological implications. The specific objectives include:

- To analyze and quantify current LULC dynamics (2017–2024) at both basin and sub-basin scales using high-resolution Earth Observation datasets.
- To assess long-term historical trajectories of land transformation across the basin utilizing decadal Landsat data (1985–2005).
- To evaluate the changing spatial configuration of riparian corridors by analyzing multi-distance buffer zones along the river network.
- To project future LULC compositions up to the year 2035.
- To synthesize the eco-hydrological and water stress implications of the observed transformations, providing actionable insights for basin-level management, land-use regulation, and riparian restoration.

Data and Methods

LULC Datasets Used

To ensure spatial detail, thematic consistency, and temporal continuity, multiple satellite-derived LULC datasets were integrated for the assessment of the MRB.

Primary LULC Layers

- **ESRI 10 m Annual Land Cover (2017–2024)**
  The ESRI 10 m Annual Land Cover dataset, derived from Sentinel-2 imagery using deep learning classification, was selected for the 2017–2024 period due to its high spatial resolution (10 m), annual temporal frequency, and standardized nine-class scheme, enabling precise detection of year-to-year LULC shifts across the basin. Its annual updates and consistent class definitions strengthen inter-annual change detection and trend analysis.

- **Decadal Landsat LULC (30 m resolution)**
  Landsat-based LULC products were used to cover the pre-2017 historical period, as Landsat remains the only publicly available medium-resolution (30 m) satellite record extending back to 1972, providing the multi-decadal baseline necessary to detect long-term structural changes such as cropland expansion, deforestation, and urban growth that fall outside the Sentinel-2 temporal window. Despite its coarser resolution, it supports cross-validation of observed trends (Roy et al., 2016).

Methodological Approach

All datasets were harmonized to a common projection system and reclassified into a unified thematic scheme to ensure consistency and comparability across time periods.

Basin and sub-basin boundaries of the Mahanadi River Basin (MRB) were used to clip the LULC layers for spatial analysis at different hydrological scales.

Annual LULC maps were analyzed to identify land use transitions, spatial redistribution patterns, and dominant land transformation processes across the basin. The integration of multi-resolution datasets improves classification robustness by combining high spatial detail with long-term temporal reliability, enabling a more comprehensive understanding of long-term land use dynamics.

To further examine land use dynamics in areas directly influencing the river system, a **riparian buffer-based analysis** was conducted. Multiple buffer zones (100 m, 300 m, 500 m, and 1000 m) were generated along the river network to represent varying levels of proximity to the river channel. The LULC layers were intersected with these buffer zones to quantify class-wise area distribution, assess gain/loss patterns, and identify dominant LULC transitions within the riparian corridor. This buffer-based approach enabled a focused assessment of land cover changes occurring in ecologically sensitive zones that directly influence riverine processes, water quality, and floodplain dynamics.

2. LULC Change Analysis [Present]

The Land Use and Land Cover (LULC) dynamics of the Mahanadi River Basin (MRB) were assessed using ESRI 10 m Annual Land Cover (2017 - 2024) data, followed by projections up to 2035. The analysis reveals significant structural shifts in agricultural dominance, urban expansion, vegetation redistribution, and hydrological class variability.

2.1 Basin-Wide LULC Distribution

The analysis of land use and land cover (LULC) changes across the Mahanadi River Basin (MRB) between 2017 and 2024 indicates substantial anthropogenic transformation. The basin exhibits a clear shift toward agricultural intensification and urban expansion, accompanied by systematic decline in forest and rangeland ecosystems.

At the basin scale, cropland constitutes the dominant land-use category and recorded the largest absolute increase during the study period. Built-up area exhibited the highest relative growth rate, reflecting accelerated infrastructural and settlement expansion. In contrast, tree cover experienced the most substantial absolute decline, indicating progressive forest conversion. Rangeland and flooded vegetation also showed consistent reductions, suggesting landscape restructuring toward productive and urban land uses.

Table 1: Observed LULC change over 2017 and 2024.

LULC Class	2017 (Sq. Km)	2024 (Sq. Km)	Net Change (Sq. Km)	% Change	Trend
Water	4423.23	4496.72	73.49	+1.69%	Stable
Trees	50007.18	43541.06	-6466.12	-12.93%	Declining
Flooded Vegetation	283.12	226.25	-56.87	-20.08%	Slight Decline
Crops	57023.22	65788.82	8765.6	+15.37%	Increasing
Built Area	6113.63	8358.32	2244.69	+36.71%	Rapid Increase
Bare Ground	562.92	358.44	-204.48	-36.32%	Declining
Rangeland	37798.69	33442.38	-4356.31	-11.53%	Declining

Figure 1: LULC Change from ESRI 10m Annual Land Cover (2017-2024)

(Sentinel-2): Mahanadi Basin

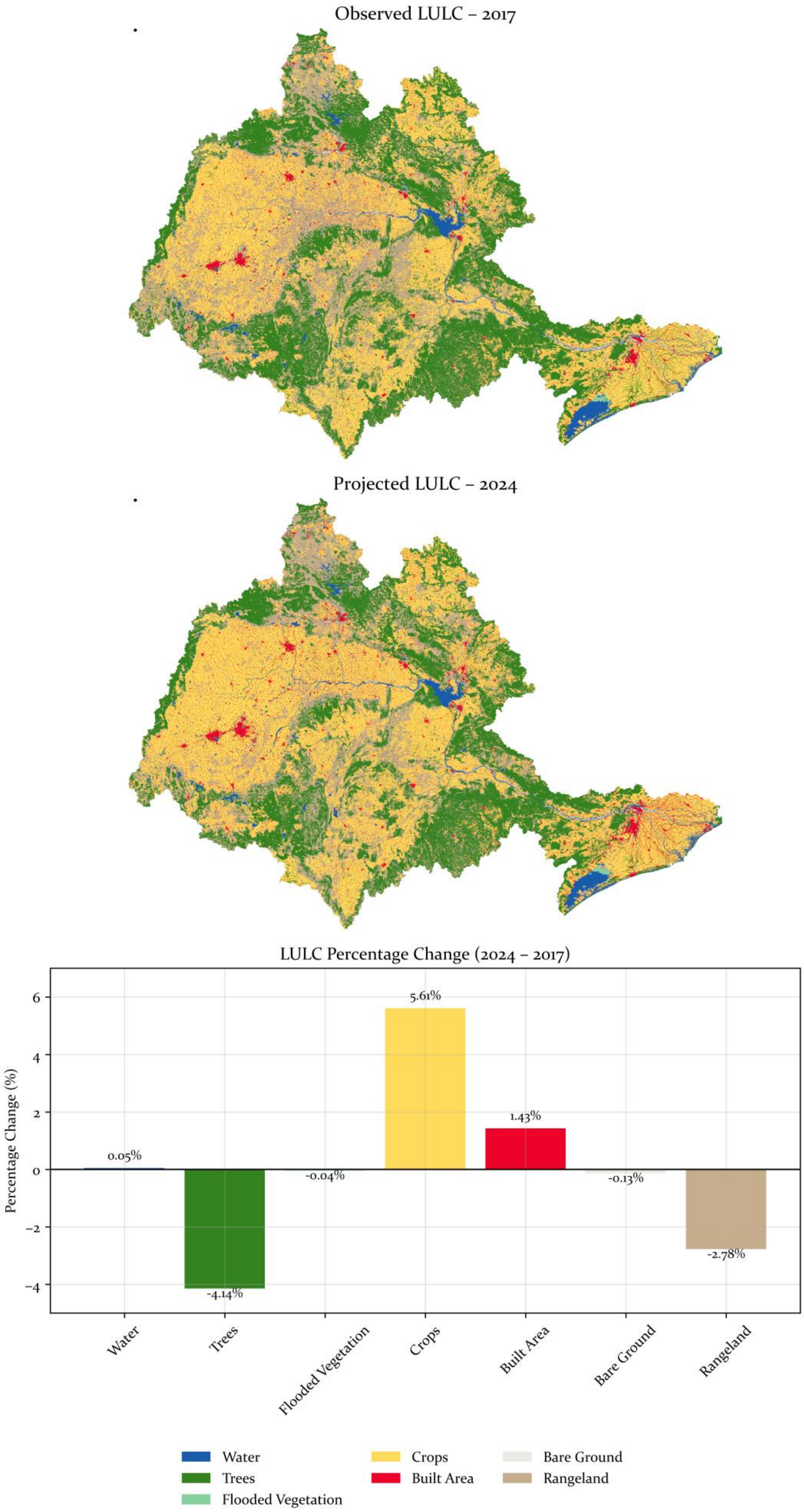

Figure 2: Class-wise percentage change in Land Use Land Cover between observed 2017 and 2025 for the Mahanadi River Basin

2.1.1.1 Class-wise Change in the Mahanadi River Basin (MRB) Agricultural Expansion

The class-wise land use and land cover (LULC) assessment of the Mahanadi River Basin during 2017–2024 indicates substantial landscape transformation driven primarily by agricultural expansion and urban growth. While basin-scale trends provide an overall picture, sub-basin-level variations reveal spatial heterogeneity in land transformation processes.

❖ Cropland (Crops)

At the basin scale, cropland expanded from 57,011.38 Km^2 (2017) to 65,776.26 Km^2 (2024), reflecting a net gain of 8,764.88 Km^2 (+15.37%), making it the largest absolute increasing class.

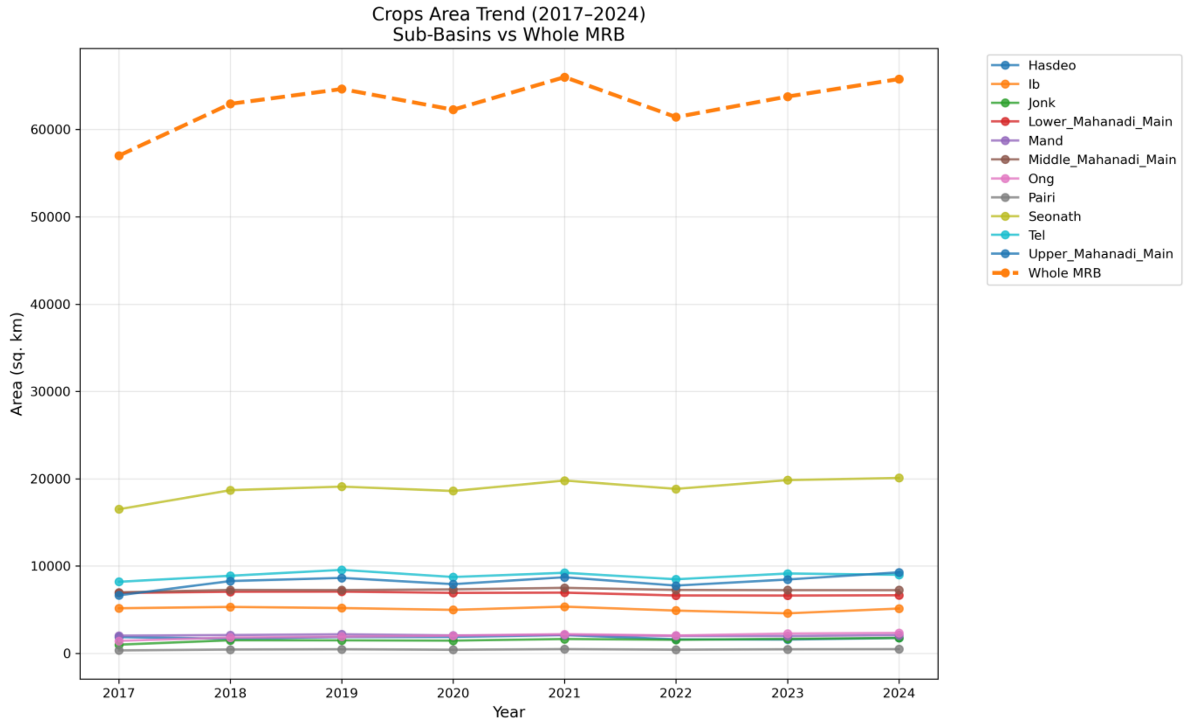

Figure 3: Temporal trend (2017–2024) of cropland area across eleven sub-basins of the Mahanadi River Basin

Sub-basin Insights

- Hasdeo, Mand, and Ib show strong cropland expansion replacing forest and rangeland patches, reflecting agricultural intensification in upper and coal-belt influenced catchments.
- Seonath and Pairi, characterized by fertile plains, display sustained and stable cropland dominance with incremental expansion.
- Tel, Ong, and Jonk exhibit moderate agricultural growth associated with irrigation-dependent farming.

- Middle and Lower Mahanadi show expansion along canal networks and deltaic agricultural zones.
- Upper Mahanadi reflects comparatively slower expansion due to topographic constraints.

Cropland growth is basin-wide and structurally consistent across all eleven sub-basins, though intensity is highest in agriculturally favorable plains (Seonath, Pairi, Lower Mahanadi) and transition zones (Hasdeo, Mand, Ib).

❖ Built-up Area

Built-up land increased from 6,110.90 Km^2 to 8,354.58 Km^2, registering a net gain of 2,243.68 Km^2 (+36.72%), the highest relative growth among all classes.

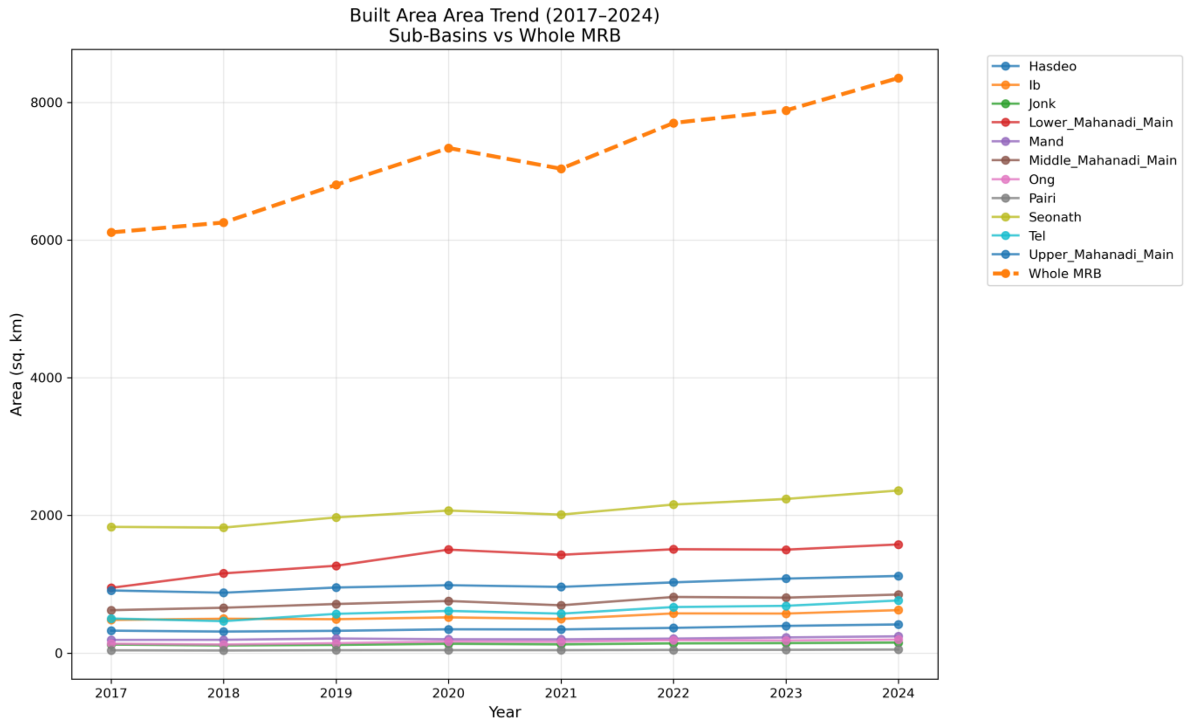

Figure 4: Temporal trend (2017–2024) of built-up area across eleven sub-basins of the Mahanadi River Basin

Sub-basin Insights

- Hasdeo and Mand exhibit rapid built-up growth linked with mining and industrial activities
- Ib shows urban expansion near industrial corridors.
- Seonath and Lower Mahanadi demonstrate steady peri-urban expansion driven by population growth and infrastructure.
- Middle Mahanadi shows moderate urban spread.

- Upper Mahanadi, Ong, Tel, Jonk, and Pairi display relatively slower but consistent built-up growth, largely concentrated around local towns.

While basin-scale growth appears uniform, built-up expansion intensity is disproportionately higher in economically active sub-basins (Hasdeo, Mand, Ib, Seonath), highlighting spatial inequality in urban development.

❖ Tree Cover

Tree cover declined from 49,959.31 Km^2 to 43,495.42 Km^2, representing a reduction of 6,463.89 Km^2 (-12.94%), the largest absolute loss among all classes.

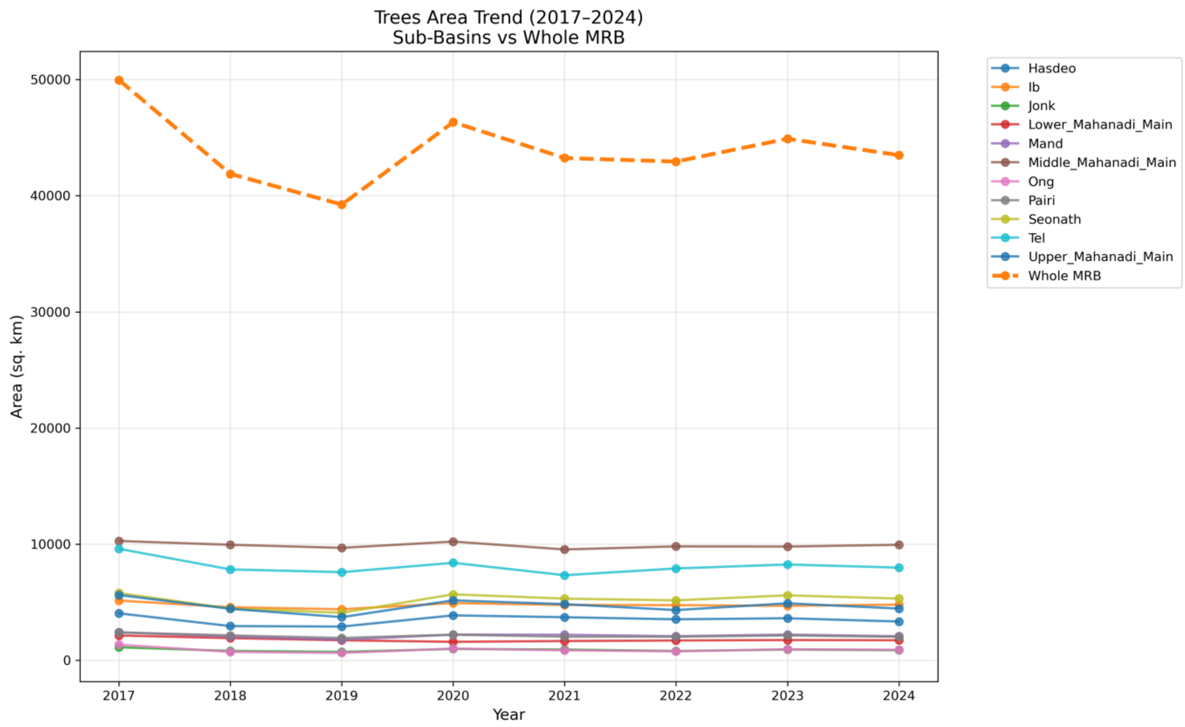

Figure 5: Temporal trend (2017–2024) of tree cover across eleven sub-basins of the Mahanadi River Basin

Sub-basin Insights

- Significant forest reduction is observed in Hasdeo, Mand, and Ib, likely linked with mining expansion and cropland encroachment.
- Upper Mahanadi and Pairi also exhibit measurable decline due to agricultural transition.
- Tel and Ong show moderate forest reduction.
- Seonath, Middle Mahanadi, and Lower Mahanadi demonstrate comparatively smaller forest shares and hence smaller absolute loss.
- Jonk exhibits localized decline along agricultural transition zones.

Forest decline is spatially concentrated in upper and resource-rich sub-basins (Hasdeo, Mand, Ib), whereas downstream agricultural plains exhibit comparatively lower absolute forest loss due to historically lower baseline forest cover.

❖ Rangeland

Rangeland decreased from 37,781.54 Km^2 to 33,424.12 Km^2, marking a net reduction of 4,357.42 Km^2 (-11.53%).

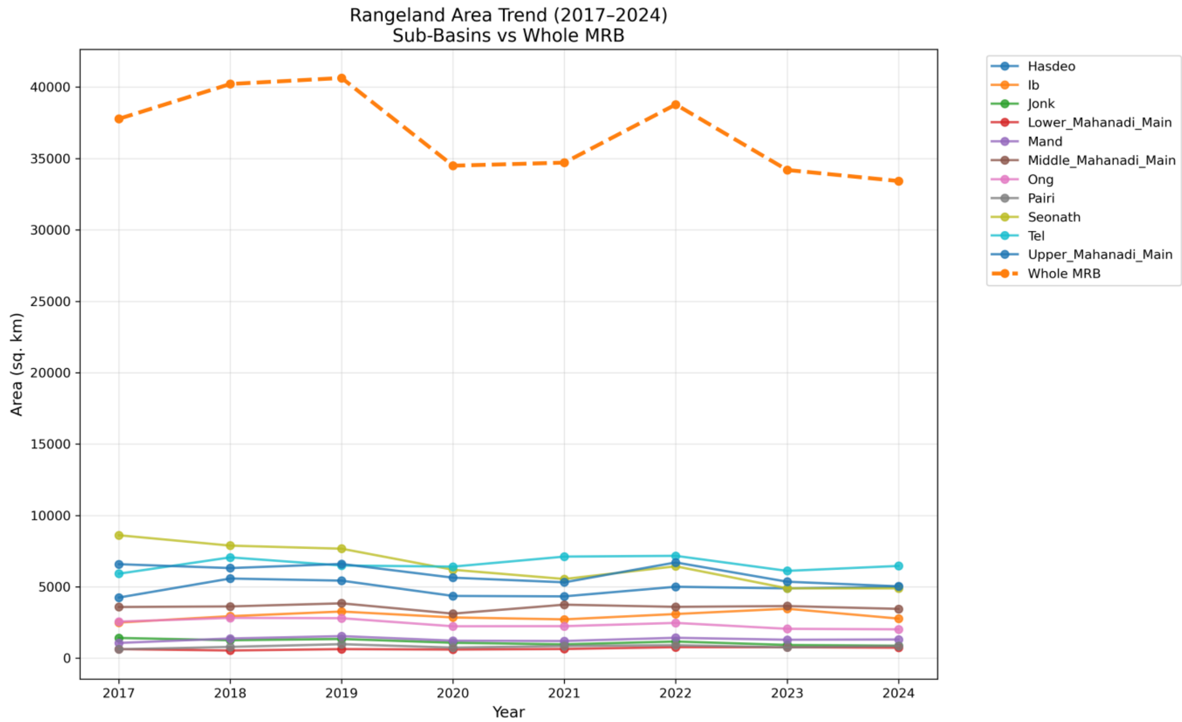

Figure 6: Temporal trend (2017–2024) of rangeland area across eleven sub-basins of the Mahanadi River Basin

Sub-basin Insights

- Upper Mahanadi, Ong, and Tel retain relatively higher rangeland proportions but show gradual decline.
- Hasdeo, Mand, and Ib reflect conversion of grazing land to agriculture or mining.
- Middle and Lower Mahanadi show steady reduction associated with agricultural intensification.
- Seonath and Pairi show moderate contraction due to cropland expansion.
- Jonk indicates localized variability.

Rangeland decline mirrors cropland expansion spatially, especially in transitional agro-forest sub-basins.

❖ Flooded Vegetation

Flooded vegetation reduced from 283.10 Km^2 to 226.24 Km^2, showing a decrease of 56.86 Km^2 (-20.08%).

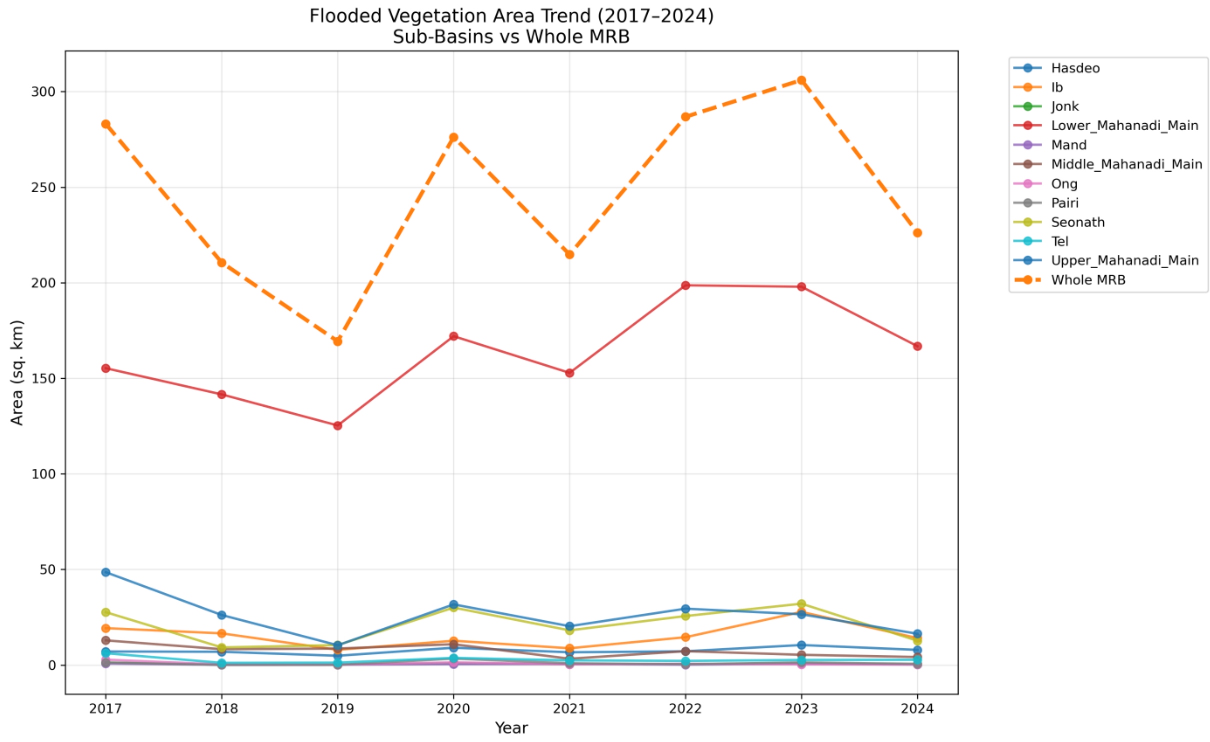

Figure 7: Temporal trend (2017–2024) of flooded vegetation across eleven sub-basins of the Mahanadi River Basin

Sub-basin Insights

- Changes are prominent in Lower Mahanadi and Middle Mahanadi, where floodplains and reservoirs influence seasonal inundation.
- Tel and Ong show variability associated with reservoir backwaters.
- Hasdeo and Mand exhibit localized changes around mining-induced hydrological alteration.
- Other sub-basins show relatively minor fluctuations due to limited wetland extent.

Wetland-associated changes are spatially concentrated in hydrologically active sub-basins (Lower and Middle Mahanadi), whereas upland basins show minimal contribution.

❖ Bare Ground

Bare ground reduced from 561.18 Km2 to 357.47 Km^2, corresponding to a decline of 203.72 Km2 (-36.30%).

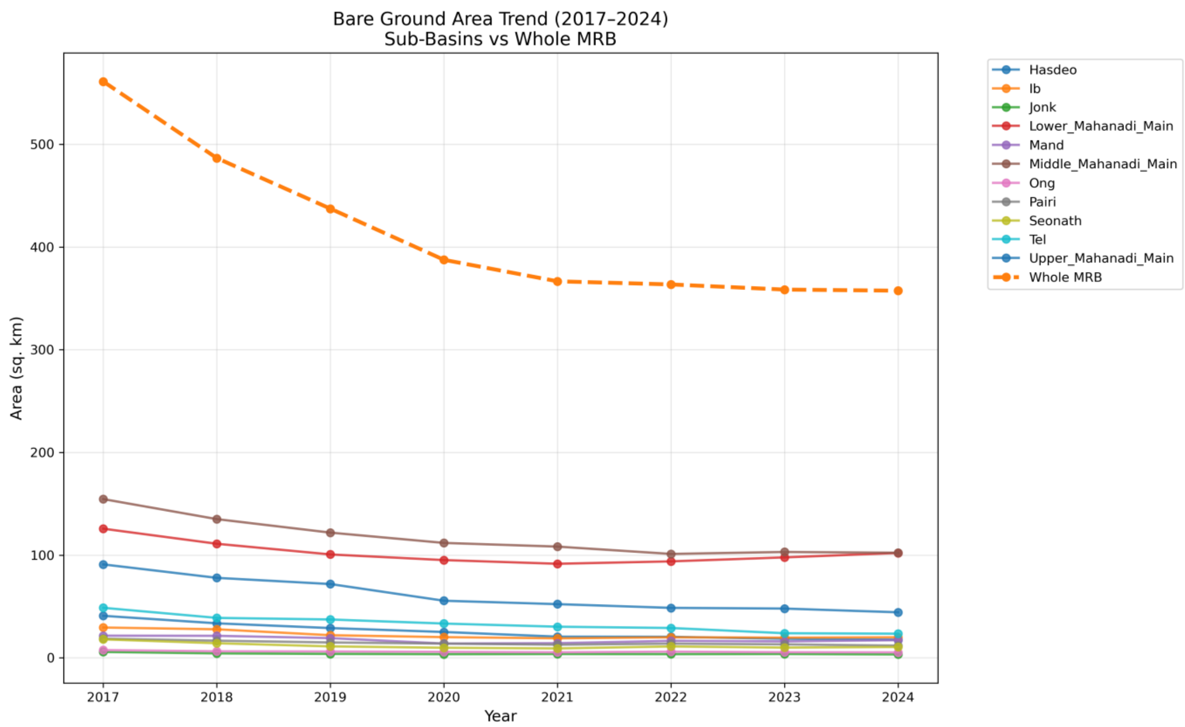

Figure 8: Temporal trend (2017–2024) of bare ground area across eleven sub-basins of the Mahanadi River Basin

Sub-basin Insights

- Hasdeo and Mand show reduction due to vegetation regrowth and land reclamation.
- Ib reflects partial conversion of exposed land into built-up surfaces.
- Upper Mahanadi and Ong retain limited bare patches in erosion-prone areas.
- Seonath, Pairi, and Lower Mahanadi show minimal bare ground due to intensive land utilization.

Reduction in bare ground across sub-basins indicates increasing land utilization intensity and surface stabilization.

❖ Water Bodies

Water bodies increased marginally from 4,349.70 Km² to 4,423.03 Km², registering a gain of 73.32 Km² (+1.69%).

Sub-basin Insights

- Lower and Middle Mahanadi show relative stability due to regulated flows and reservoir systems.
- Tel and Ong display variability associated with seasonal storage structures.
- Hasdeo and Mand show localized increases linked with mining ponds and reservoirs.
- Remaining sub-basins show limited fluctuation.

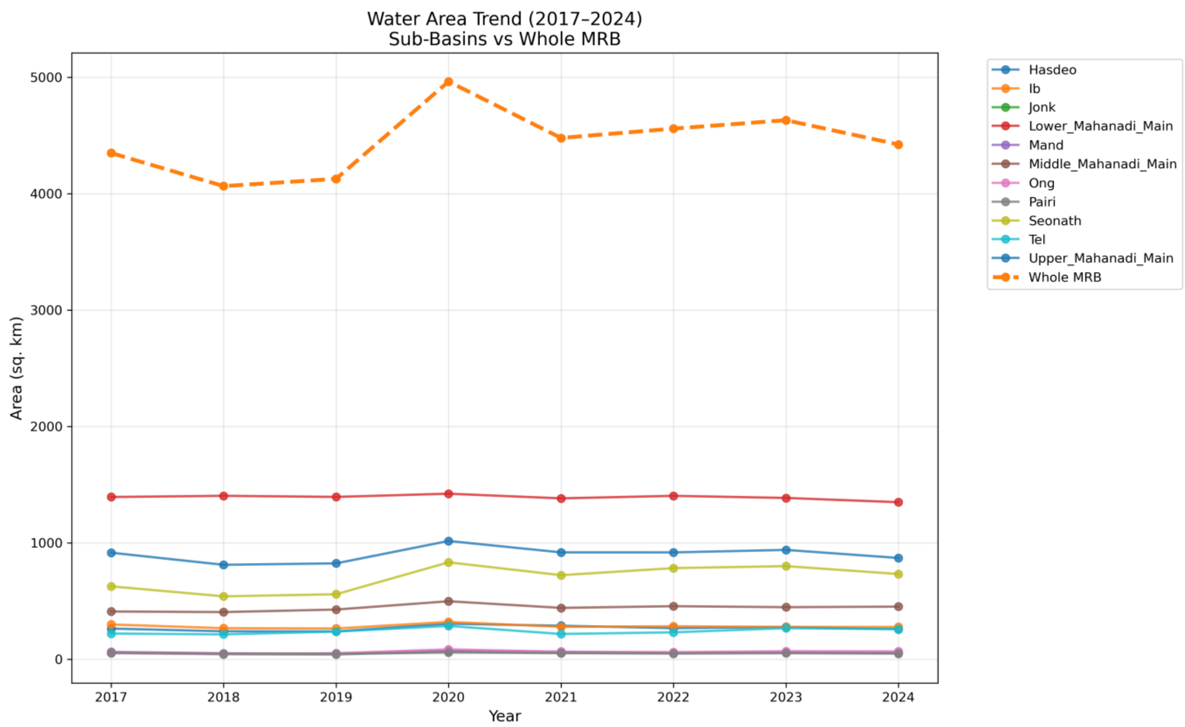

Figure 9: Temporal trend (2017–2024) of water area across eleven sub-basins of the Mahanadi River Basin

Water extent remains structurally stable across most sub-basins, with changes largely controlled by anthropogenic water management rather than natural expansion.

2.2 Sub-Basin Wise LULC Distribution

The sub-basin level analysis provides a detailed understanding of the spatial heterogeneity in Land Use and Land Cover (LULC) patterns across the Mahanadi River Basin. While basin-scale assessments reveal overall trends, sub-basin evaluation highlights localized dynamics driven by topography, hydrology, and anthropogenic pressures.

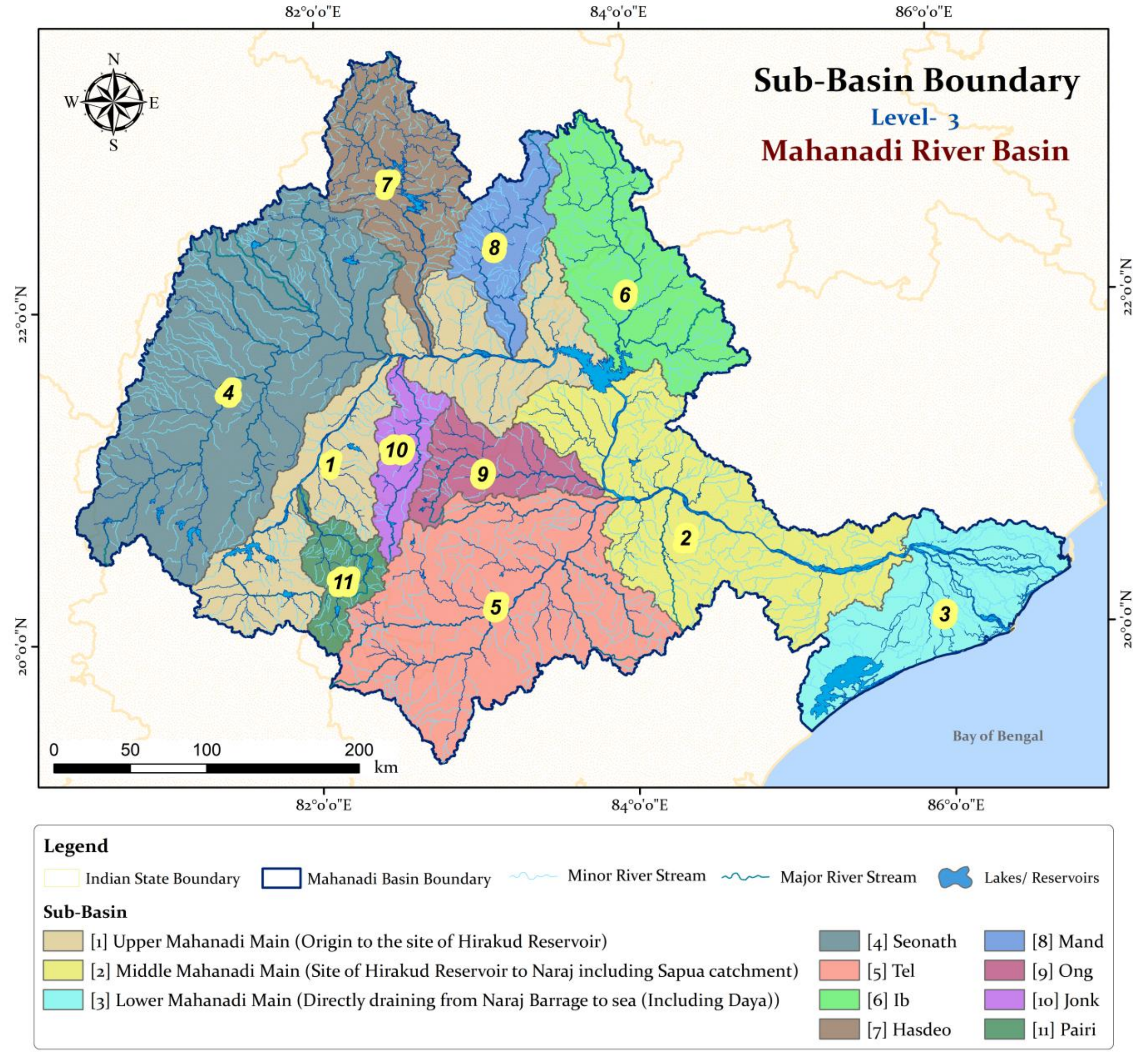

Figure 10: Sub-Basin Boundary of Mahanadi River Basin

The eleven sub-basins (as mentioned in Figure 10) exhibit distinct variations in the proportion and temporal evolution of major LULC classes during 2017–2024. Examining these differences is essential for identifying priority zones of land transformation, ecological sensitivity, and development pressure. The graphical representation presented below (Figure 11 to 21) illustrates the comparative distribution and temporal changes of LULC classes (Land Use/Land Cover data derived from the ESRI Sentinel-2 Global Land Cover dataset (10 m resolution)) across all eleven sub-basins.

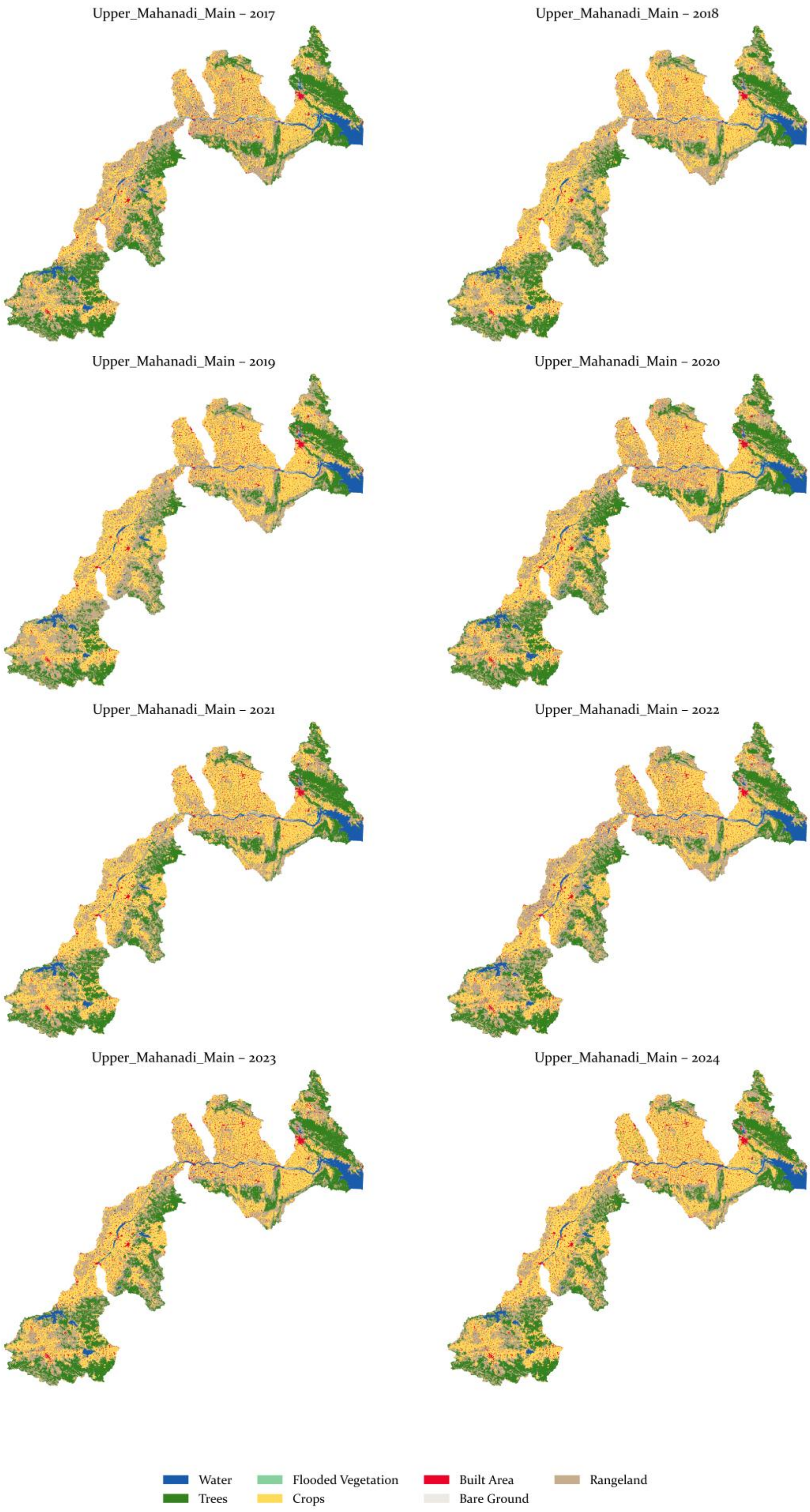

Figure 11: Annual LULC maps (2017–2024) for the Upper Mahanadi Main sub-basin.

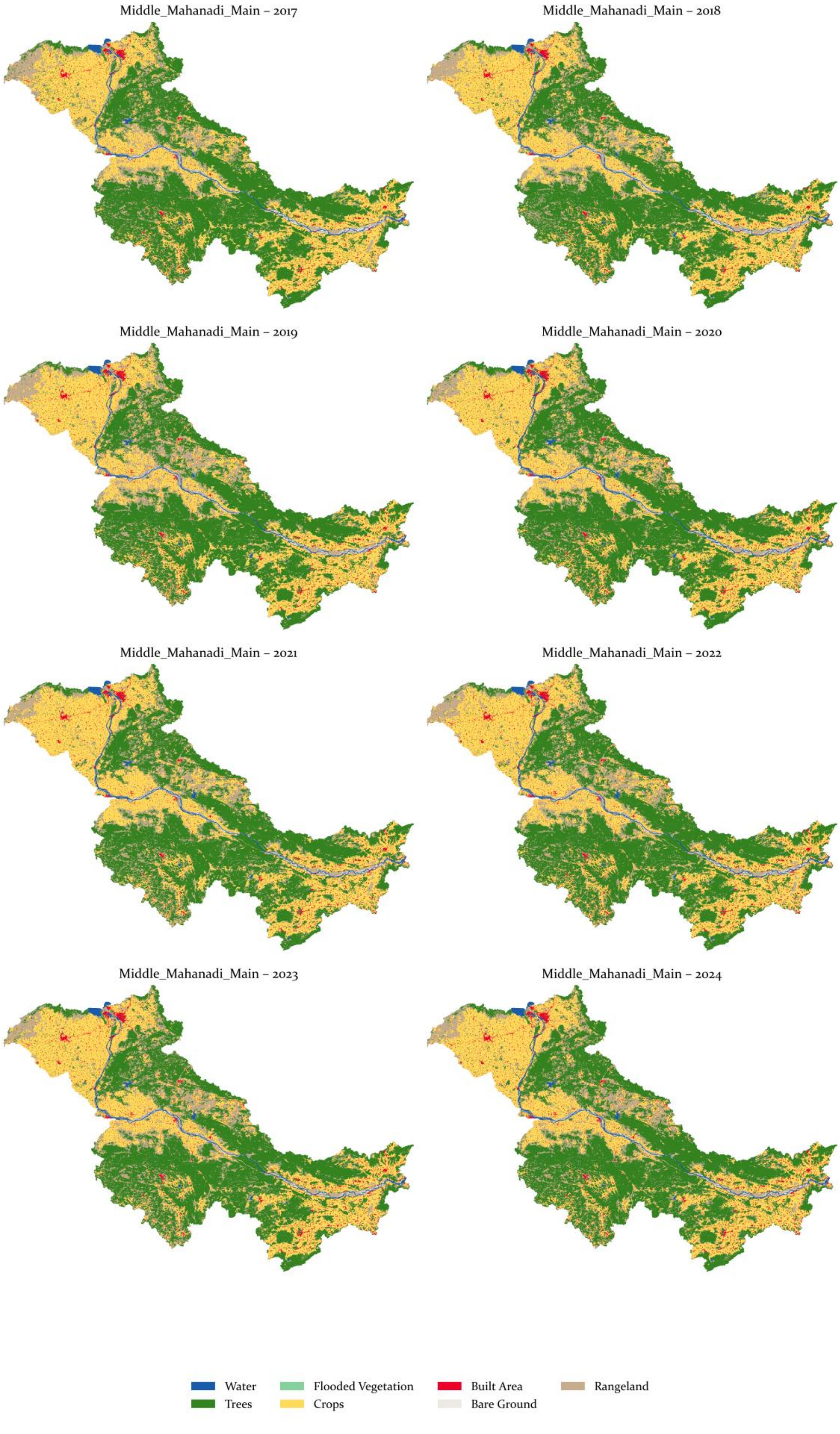

Figure 12: Annual LULC maps (2017–2024) for the Middle Mahanadi Main sub-basin.

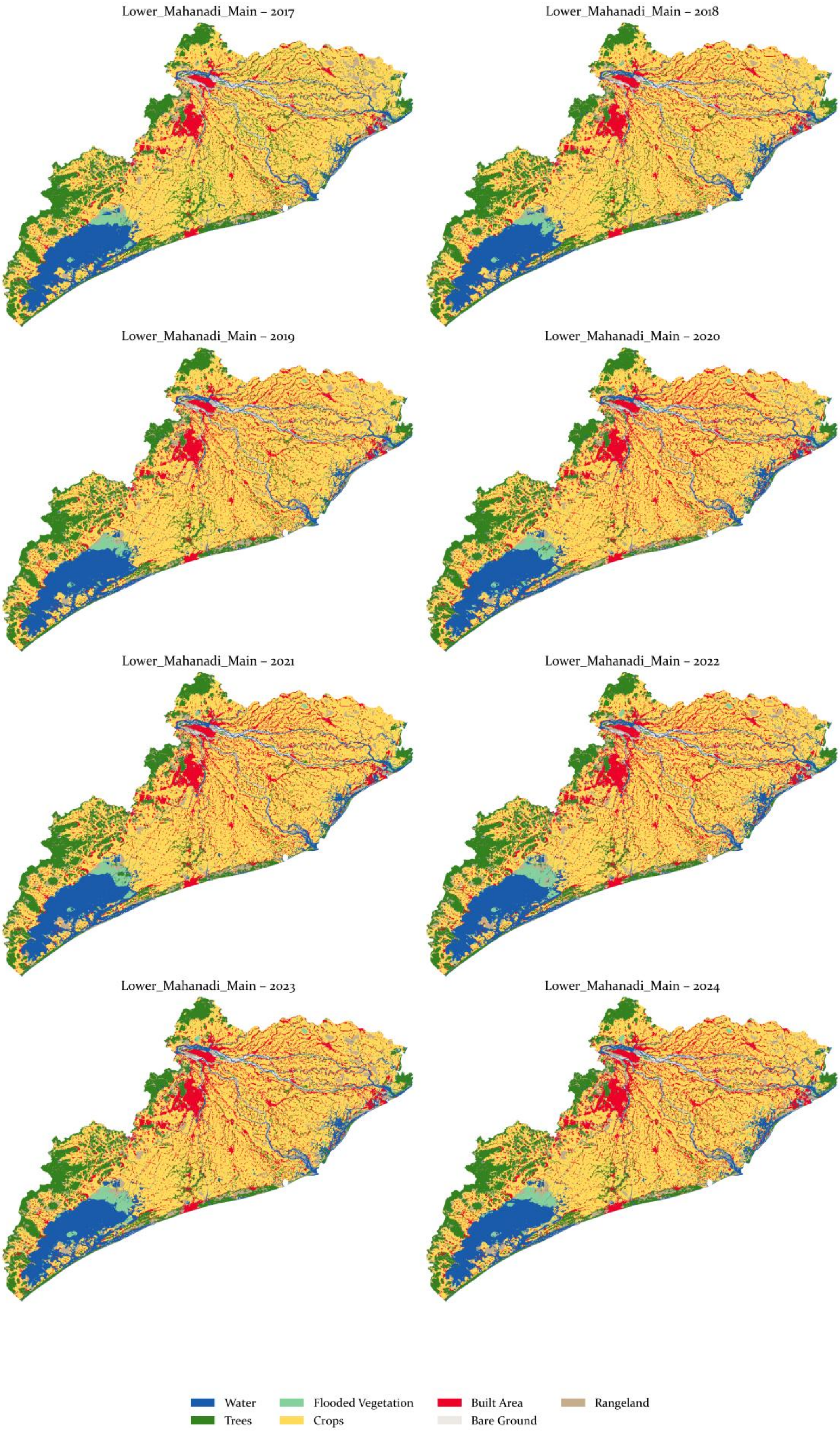

Figure 13: Annual LULC maps (2017–2024) for the Lower Mahanadi Main sub-basin.

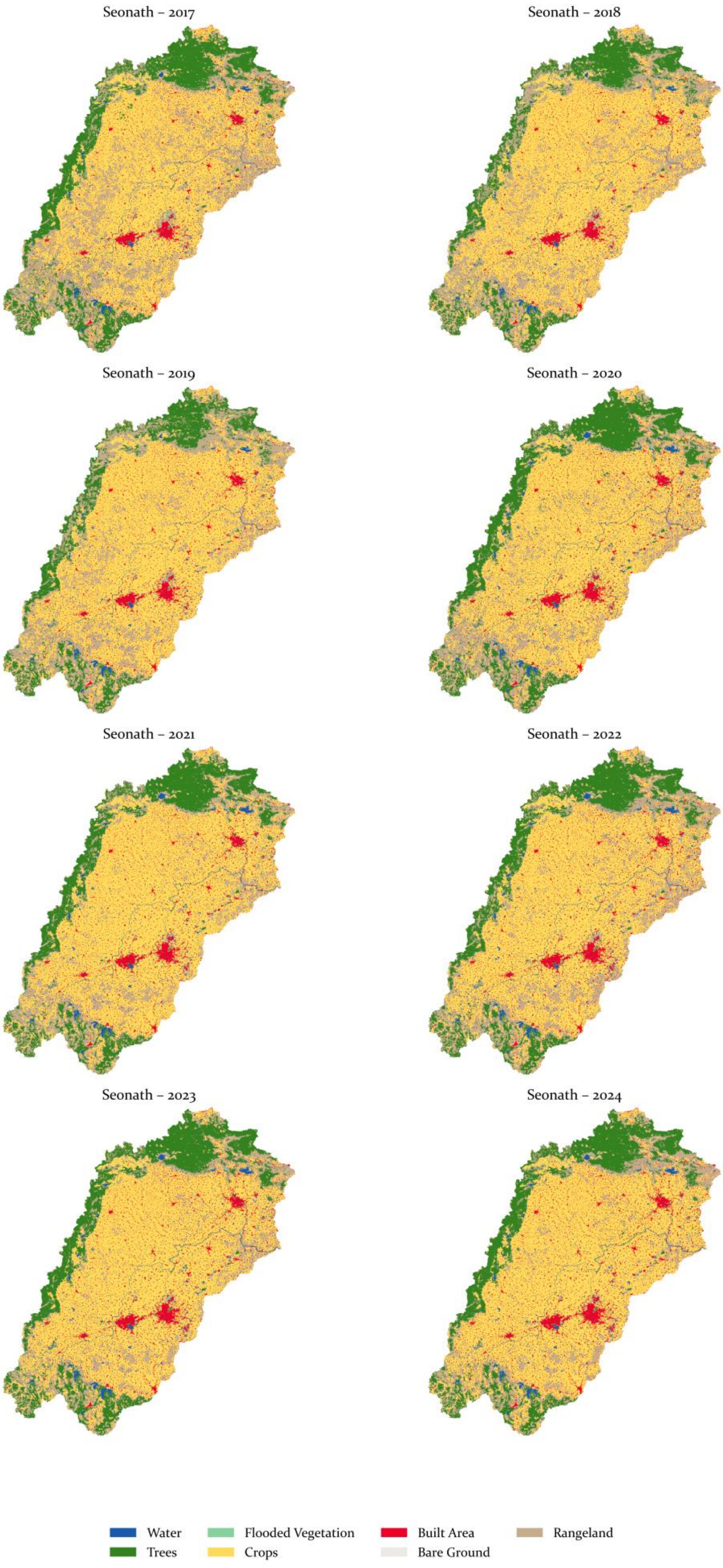

Figure 14: Annual LULC maps (2017–2024) for the Seonath sub-basin.

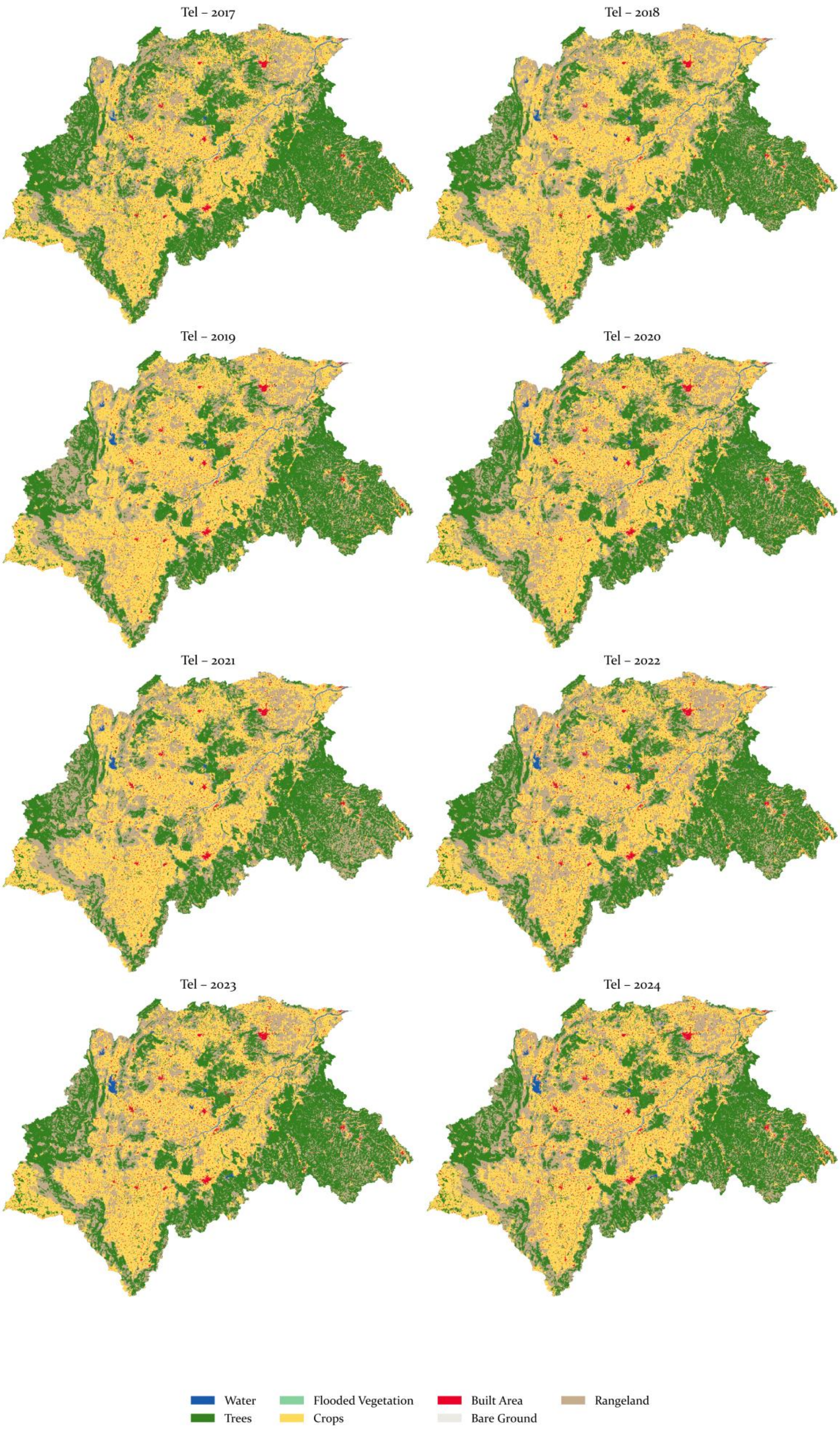

Figure 15: Annual LULC maps (2017–2024) for the Tel sub-basin.

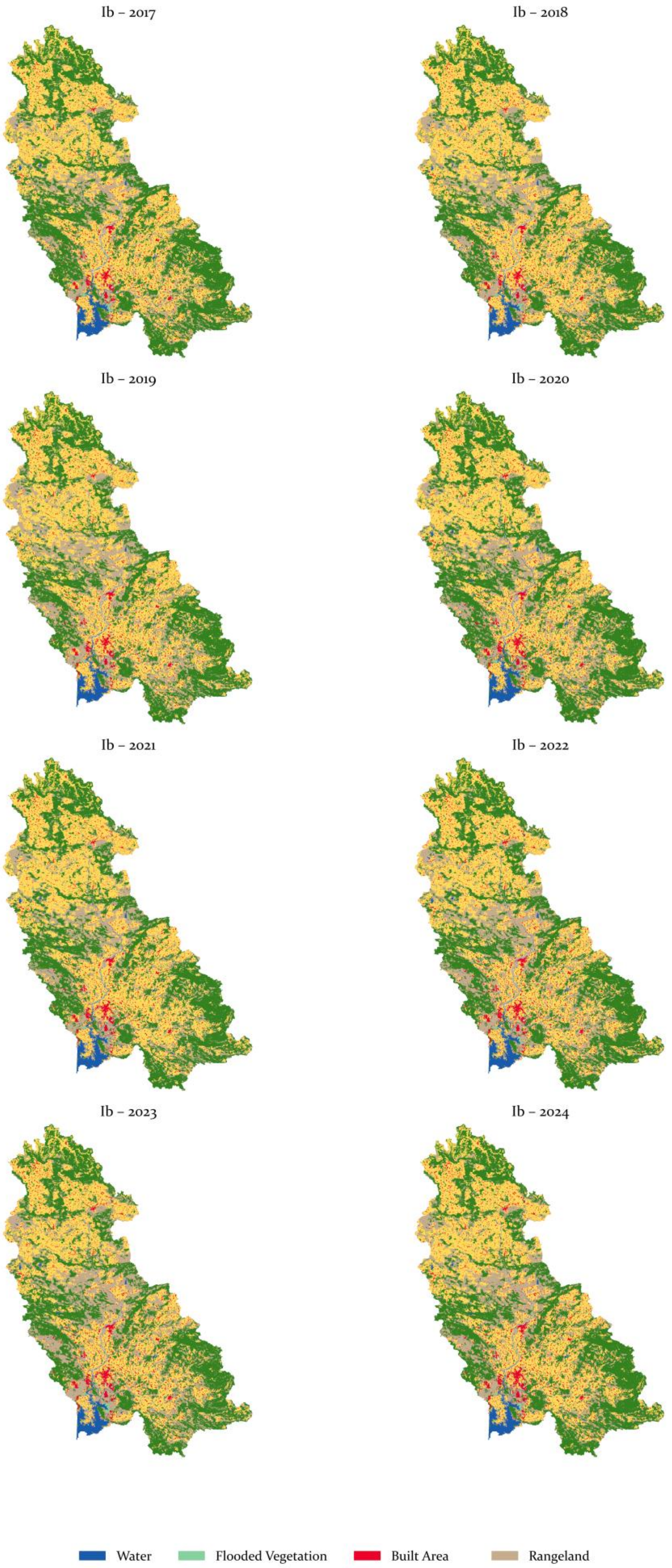

Figure 16: Annual LULC maps (2017–2024) for the Ib sub-basin

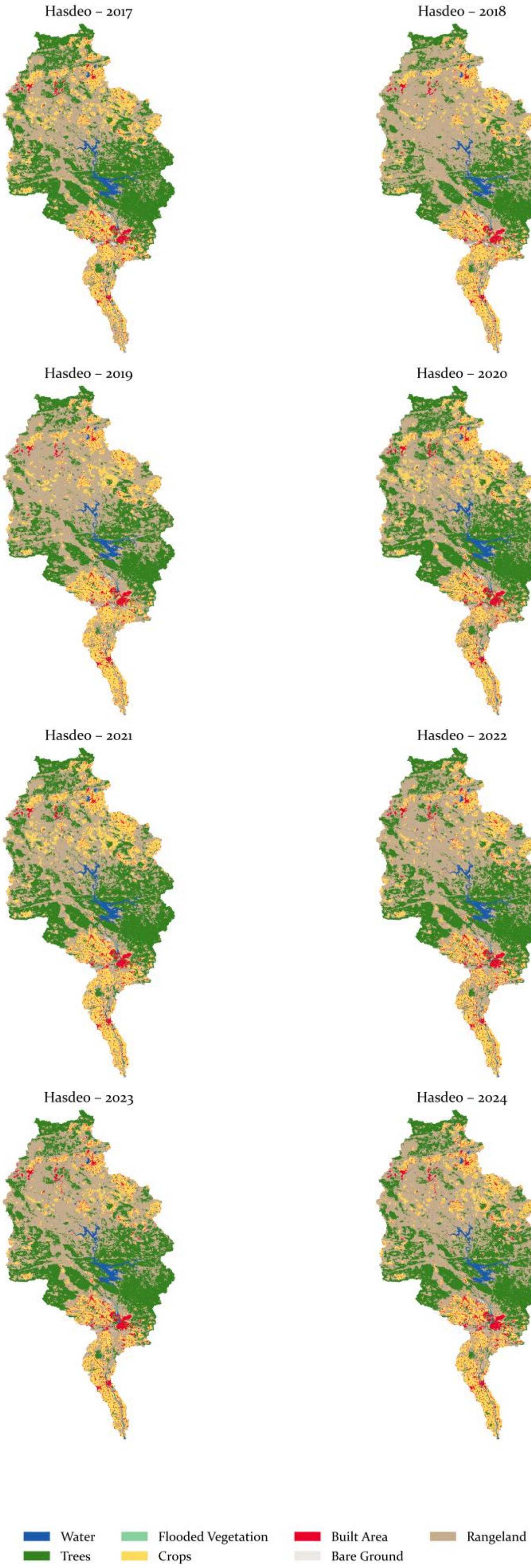

Figure 17: Annual LULC maps (2017–2024) for the Hasdeo sub-basin.

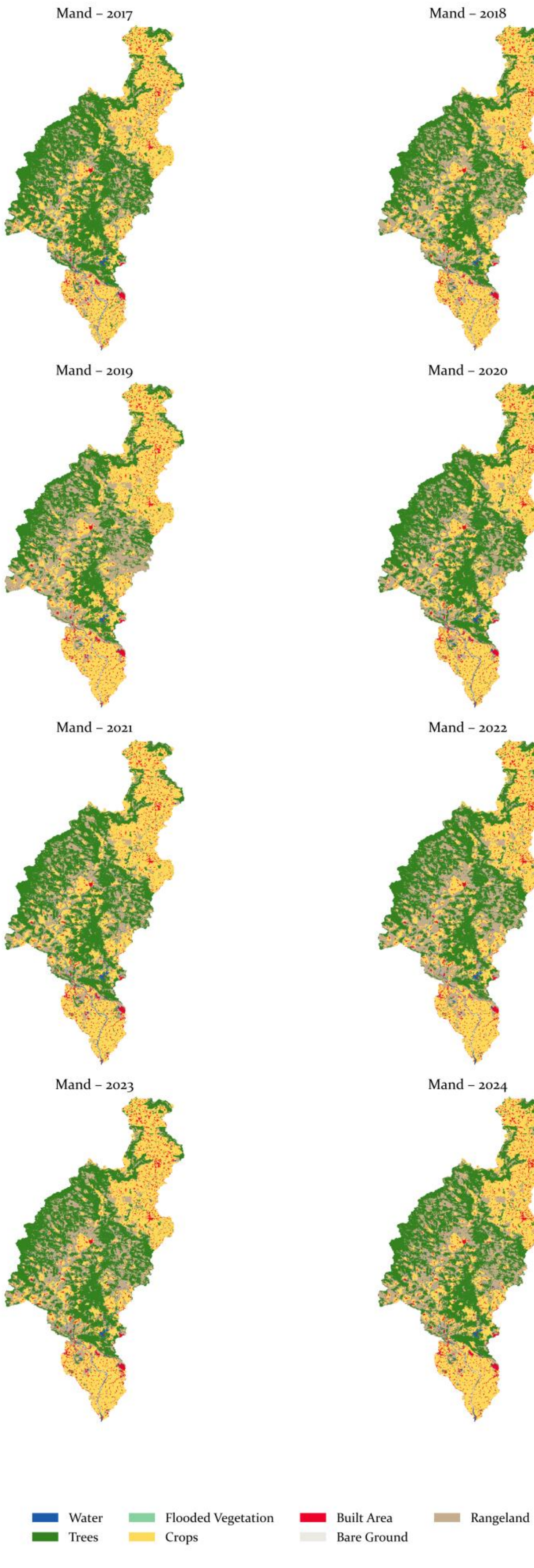

Figure 18: Annual LULC maps (2017–2024) for the Mand sub-basin.

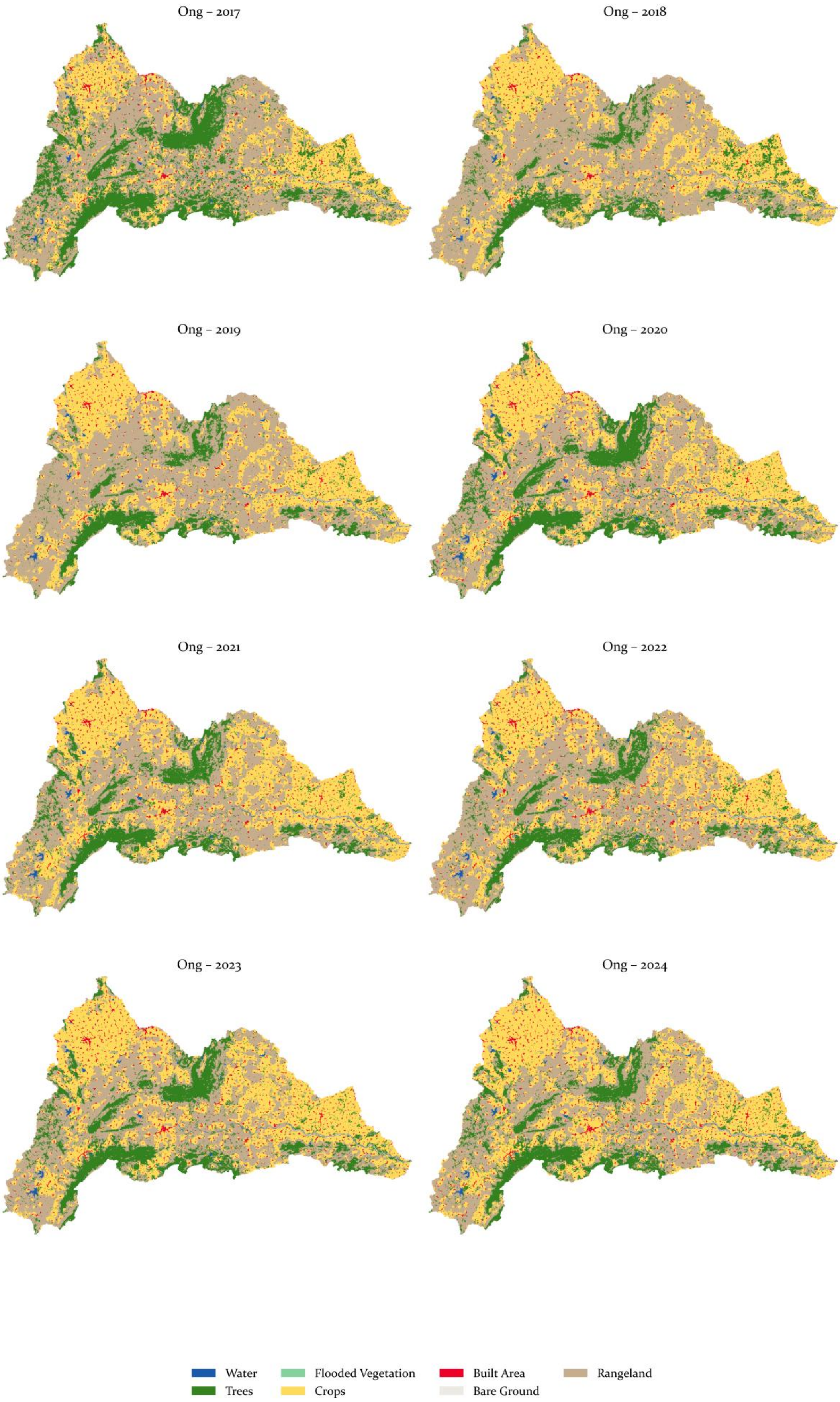

Figure 19: Annual LULC maps (2017–2024) for the Ong sub-basin.

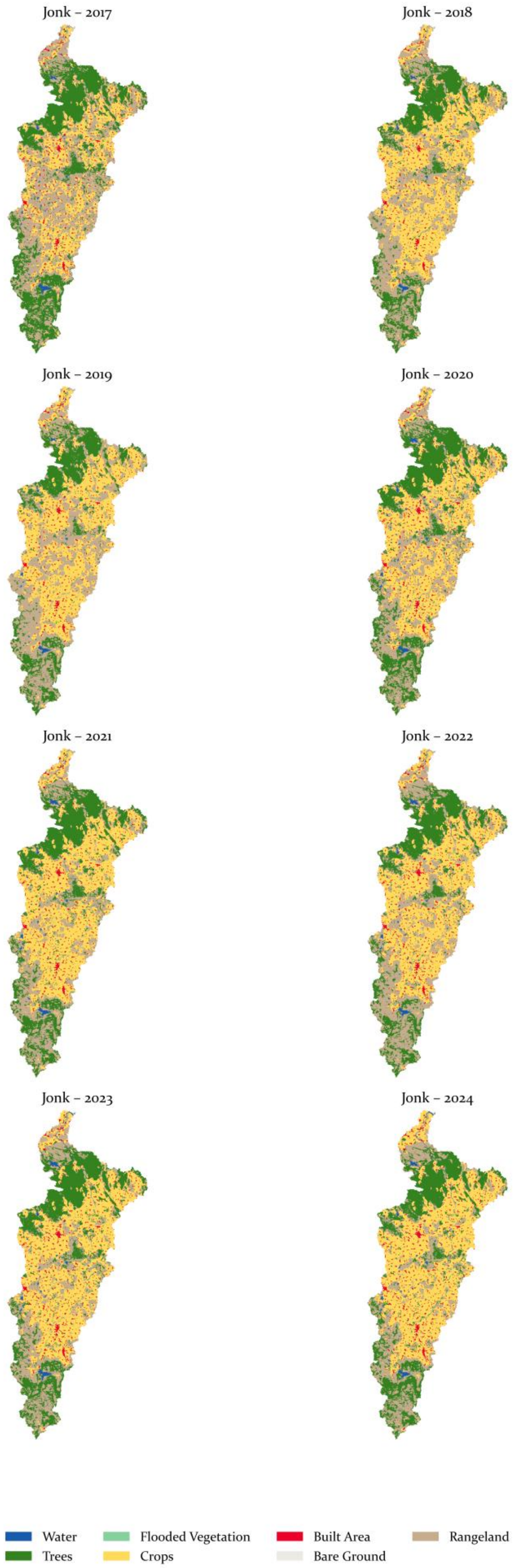

Figure 20: Annual LULC maps (2017–2024) for the Jonk sub-basin.

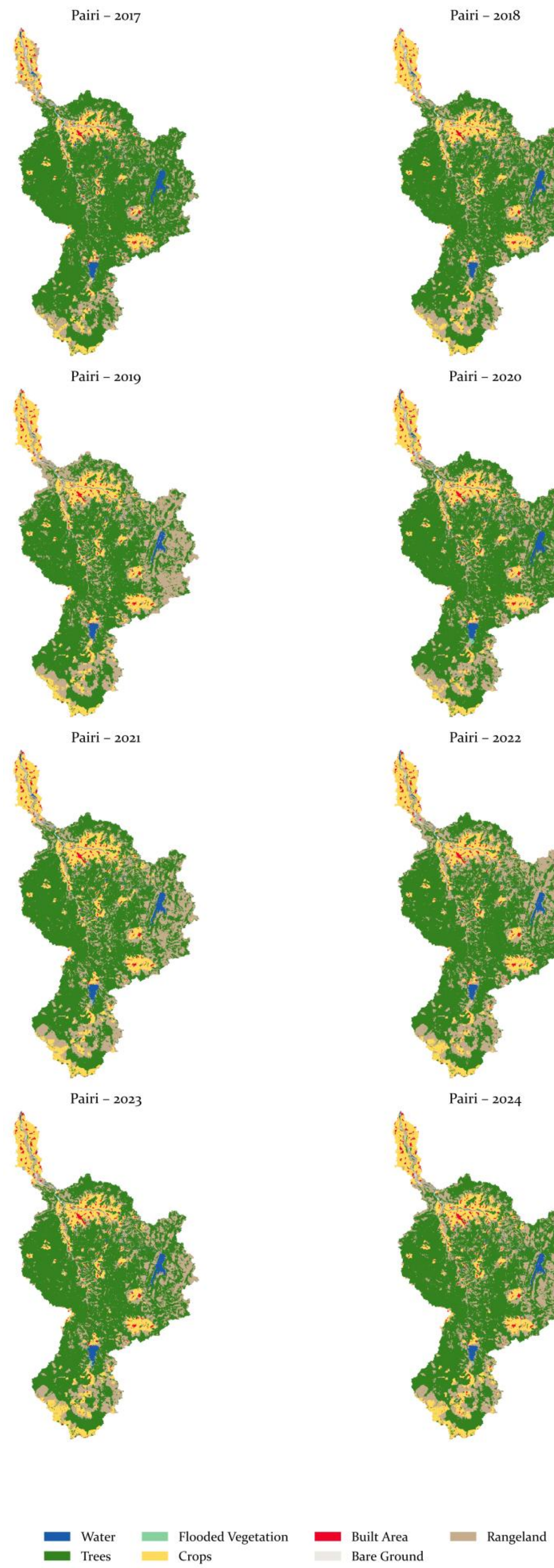

Figure 21: Annual LULC maps (2017–2024) for the Pairi sub-basin.

2.2.1 Upper Mahanadi Main Sub-basin

Upper Mahanadi exhibited significant cropland expansion (+39.58%) and built-up growth (+23.13%), coupled with major forest decline (-20.71%) and rangeland reduction (-23.54%). Flooded vegetation decreased by 66.32%, indicating loss of seasonal wetlands. These changes highlight substantial land conversion in upstream catchments, potentially influencing downstream hydrological response.

2.2.2 Middle Mahanadi Main Sub-basin

This central basin displayed relatively stable tree cover (-3.17%) compared to other sub-basins, while cropland increased moderately (+3.61%). Built-up area rose significantly (+36.40%), indicating urbanization along the river corridor. Flooded vegetation decreased sharply (-67.52%), pointing to floodplain modification or drainage changes. The mixed pattern indicates urban expansion within a largely agricultural landscape.

2.2.3 Lower Mahanadi Main Sub-basin

This downstream sub-basin exhibited substantial built-up growth (+66.59%), the highest relative increase among sub-basins, reflecting urban expansion in the deltaic and coastal plains. Tree cover declined (-19.17%), while flooded vegetation increased (+7.41%), possibly due to dynamic floodplain processes. Cropland marginally decreased (-3.76%), suggesting urban encroachment into agricultural zones. The area reflects strong anthropogenic restructuring associated with urban-industrial development corridors.

2.2.4 Seonath Sub-basin

Seonath, one of the largest agricultural contributors, showed major cropland expansion (+21.72%; ≈3584 Km^2) and built-up growth (+28.84%). Tree cover declined moderately (-8.22%), while rangeland decreased sharply (-43.19%). Water area increased (+16.97%), potentially linked to irrigation reservoirs and water infrastructure. This pattern confirms Seonath as a core agricultural transformation zone within MRB.

2.2.5 Tel Sub-basin

Tel recorded cropland increase (+9.87%) and strong built-up expansion (+52.25%). Forest cover declined notably (-16.89%), while rangeland increased slightly (+9.17%). Flooded vegetation reduced by over 55%, indicating contraction of wetland systems. The basin reflects steady agricultural intensification and settlement growth.

2.2.6 Ib Sub-basin

The Ib sub-basin recorded moderate forest decline (-6.77%) and substantial built-up growth (+29.75%). Cropland remained relatively stable (-0.66%), indicating agricultural consolidation rather than expansion. Rangeland increased (+11.04%), possibly reflecting transitional land conversion from degraded forest patches. The decline in flooded vegetation (-26.95%) suggests shrinkage of wetland patches, potentially due to land reclamation or hydrological variability. Overall, Ib shows a mixed pattern of moderate urban growth and landscape restructuring.

2.2.7 Hasdeo Sub-basin

Between 2017 and 2024, Hasdeo experienced a decline in tree cover (-702.82 Km^2; -17.35%) alongside a notable increase in rangeland (+742.73 Km^2; +17.47%). Built-up area expanded by 27.94%, reflecting industrial and mining-linked growth in the Hasdeo coalfield region. Cropland slightly declined (-5.54%), suggesting partial land reallocation toward grazing and settlement expansion. The reduction in bare ground (-57.03%) indicates conversion into productive or managed land uses. These patterns align with known mining and peri-urban development pressures in northern Chhattisgarh, contributing to altered land surface characteristics and increased anthropogenic influence.

2.2.8 Mand Sub-basin

Mand recorded forest decline (-14.45%) alongside increases in cropland (+3.38%), built-up area (+27.52%), and rangeland (+22.74%). Water bodies declined (-14.50%), potentially reflecting seasonal variability or reduced surface storage. The transformation suggests gradual agricultural expansion and settlement growth in an upland-dominated terrain.

2.2.9 Ong Sub-basin

Ong showed one of the highest cropland expansions (+64.02%) accompanied by substantial forest loss (-32.84%) and rangeland decline (-20.96%). Built-up area increased by 44.20%. Flooded vegetation decreased drastically (-90.66%), suggesting near disappearance of minor wetland patches. These changes indicate strong agricultural encroachment and land conversion in a previously forest–rangeland dominated catchment.

2.2.10 Jonk Sub-basin

Jonk underwent significant agricultural intensification, with cropland expanding by 77.41% (≈768 Km^2). This expansion corresponded with sharp declines in tree cover (-22.12%) and rangeland (-38.53%). Flooded vegetation reduced drastically (-77.10%), indicating contraction of small wetlands. Built-up area grew by 22.59%, though at smaller absolute magnitude. These shifts suggest rapid agrarian transformation, possibly driven by irrigation development and land conversion from scrub–forest mosaics to cultivated land.

2.2.11 Pairi Sub-basin

Pairi experienced cropland growth of 42.23% and built-up increase of 26.49%, alongside tree cover decline (-15.28%). Rangeland increased (+36.74%), possibly due to classification shifts or transition zones between agriculture and scrubland. The reduction in bare ground (-36.13%) suggests increasing land utilization intensity. The basin reflects progressive agricultural development.

3. Decadal LULC Dynamics from Landsat (30 m Resolution): 1985 - 2005

The Land Use and Land Cover (LULC) dynamics of the Mahanadi River Basin (MRB) have evolved significantly over the past four decades under the combined influence of agricultural expansion, forest transformation, hydrological variability, and rapid urbanization. Understanding the present landscape configuration of the basin requires a clear reference to its historical baseline conditions. In this context, decadal LULC data derived from Landsat (30 m spatial resolution) for the period 1984-2005 provide an essential benchmark against which recent trends from Sentinel-2 (10-20 m resolution) for 2017-2024 can be interpreted.

3.1 Forest Cover (Trees)

Forest classes show a mixed trend.

- **Deciduous Broadleaf Forest** declined from 3672.21 sq. km (1985) to 3413.99 sq. km (2005), reflecting gradual forest depletion.
- **Mixed Forests** increased slightly from 485.66 sq. km to 505.64 sq. km, suggesting localized regeneration or reclassification.
- **Deciduous Needleleaf Forest**expanded from 60.67 sq. km to 88.01 sq. km, while
- **Mangrove Forest** declined from 4.60 sq. km to 2.65 sq. km, indicating pressure in coastal/estuarine zones.
- **Plantations** remained relatively stable (~34–37 sq. km).

Overall, natural forest cover experienced fragmentation and minor redistribution across forest sub-types.

3.2 Agriculture and Cropland

Agriculture remained the dominant land use category:

- **Cropland** increased from 7223.45 sq. km (1985) to 7341.38 sq. km (2005), peaking in 1995.
- **Fallow land** decreased steadily from 300.74 sq. km to 265.92 sq. km, suggesting intensification of cultivation.

This trend indicates expansion and consolidation of agricultural activities during the two decades.

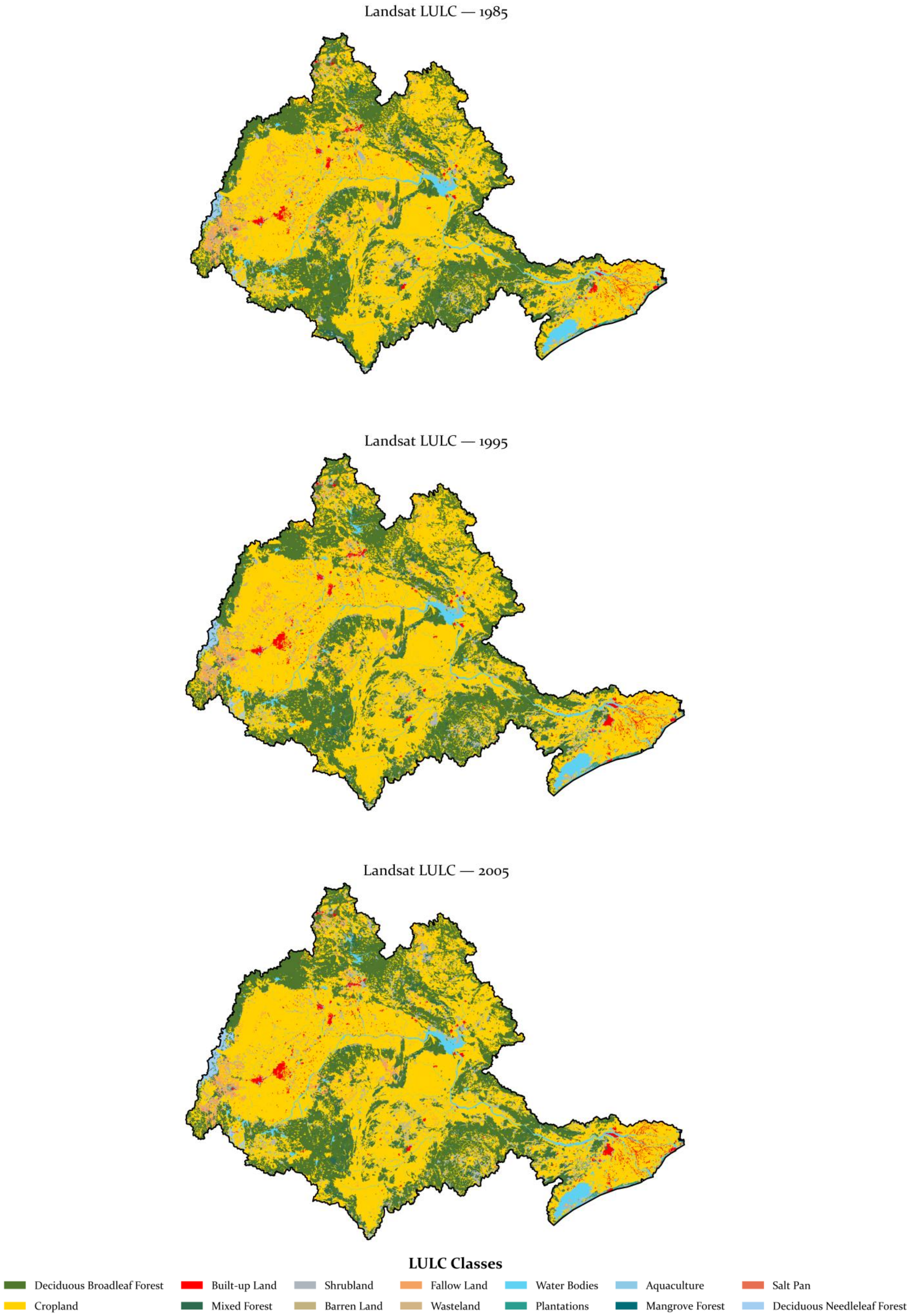

Figure 22: Decadal LULC Change - Landsat (30 m Resolution) from 1985 to 2005

3.3 Built-up, Rangeland, and Other Classes

- **Built-up Land**increased from 175.21 sq. km (1985) to 199.41 sq. km (2005) (~14% rise), reflecting gradual urban expansion.
- **Shrubland (Rangeland)** expanded significantly from 539.29 sq. km to 621.20 sq. km, possibly linked to forest degradation or transitional land states.
- **Barren Land** declined slightly (56.01 to 51.08 sq. km).
- **Water bodies** increased marginally (459.76 to 480.96 sq. km), while**Aquaculture**expanded after 1995.

Overall, the 1985–2005 period reflects agricultural dominance, slow urban growth, partial forest decline, and expansion of shrub-dominated transitional landscapes.

4. Sub Basin-Wise Comparative Assessment of LULC Trends (1985–2005 vs 2017–2024)

A sub-basin level comparison within the Mahanadi River Basin (MRB) reveals spatially differentiated land transformation patterns between 1985–2005 and 2017–2024.

4.1 Forest Cover: From Gradual Decline to High Variability
1985–2005 : Slow, Directional Change

- Forest cover showed a moderate but steady decline, particularly in deciduous forests across Middle and Upper basin sub-regions.
- Losses were incremental and spatially concentrated.
- The overall trajectory was structurally downward but stable, without sharp inter-decadal fluctuations.

2017–2024 : Fluctuating but Pressured System

- Tree cover displays strong year-to-year oscillations across Upper Mahanadi, Hasdeo, Mand, and Ib sub-basins.
- No consistent recovery trend is observed despite short-term rebounds.
- The pattern reflects instability rather than uniform decline, suggesting recurring disturbance and regeneration cycles.

Forest dynamics have transitioned from slow structural reduction (1985–2005) to high temporal variability under sustained pressure (2017–2024).

4.2 Agriculture: From Consolidation to Renewed Expansion
1985–2005 : Stabilized Dominance

- Agriculture remained the largest land-use class throughout the basin.
- Expansion occurred mainly between 1985–1995, followed by stabilization toward 2005.
- Fallow land declined steadily, indicating intensification rather than area expansion.

2017–2024 : Expansion with Variability

- Cropland increased significantly in Seonath and Upper Mahanadi sub-basins.
- Agriculture surpassed previous peaks in several regions by 2024.
- Annual variability is evident, but the overall trajectory is upward.

Agriculture shifted from intensification-driven consolidation (1985–2005) to area-based expansion with dynamic fluctuations (2017–2024).

4.3 Built-up Area: From Incremental Growth to Accelerated Expansion
1985–2005 : Gradual Urban Growth

- Built-up area increased steadily but moderately.
- Growth was concentrated in Lower Mahanadi and Seonath sub-basins.
- Spatial spread remained limited.

2017–2024 : Rapid and Widespread Increase

- Built-up area shows a consistent upward trajectory across all major sub-basins.
- Lower Mahanadi and Seonath record the highest absolute increases.
- Even forest-dominated sub-basins now exhibit continuous growth.

Urban expansion transitioned from slow, localized growth to rapid, basin-wide expansion, making it the most consistently increasing class in the recent period.

4.4 Rangeland / Shrubland: From Gradual Expansion to Dynamic Transition
1985–2005

- Shrubland expanded gradually, particularly in forested sub-basins.
- This indicated transitional landscapes linked to forest degradation or land-use shifts.

2017–2024

- Rangeland fluctuates considerably year to year.
- Some sub-basins show decline where agriculture expands (e.g., Seonath).
- No single directional trend dominates.

Earlier gradual expansion has been replaced by highly dynamic land transitions, reflecting competition between forest, agriculture, and built-up land.

4.5 Water Bodies: From Stability to Inter-Annual Variability
1985–2005

- Water extent remained relatively stable across sub-basins.
- No major structural shifts were observed.

2017–2024

- Water bodies show noticeable year-to-year changes.
- Flooded vegetation emerges as a dynamic class.
- Variability is stronger in Upper and Middle basin regions.

Hydrological stability of the earlier period has shifted toward greater seasonal and inter-annual variability in recent years.

4.6 Key Trend Highlight

The basin has shifted from a phase of slow structural land transformation (1985–2005) to a phase characterized by accelerated urban expansion, agricultural resurgence, and heightened variability in natural landscapes (2017–2024).

The most consistent upward trend in the recent period is built-up expansion, while the most unstable class is forest/tree cover, reflecting growing anthropogenic influence and intensified land-use competition across sub-basins.

5. Future Projection [Till 2035]

5.1 Linear Regression-Based Area Projection

Projections for 2025-2035 indicate continued expansion of cropland and built-up areas across the Mahanadi River Basin, reflecting ongoing anthropogenic pressure. Flooded vegetation shows a notable increase, suggesting either wetland expansion or model-driven redistribution. Rangeland and bare ground decline steadily, while tree cover shows a slight decrease, highlighting persistent vegetation loss which is also reported in Sahu & Vidyarthi (2024) in their study for LULC projected for the duration till 2027. These trends emphasize the need for targeted forest and wetland management, sustainable urban planning, and agricultural regulation to balance land use and ecological integrity.

Key Insights

- Flooded Vegetation: Strong projected increase (266 : 311 sq. km), indicating potential wetland expansion or model redistribution.
- Built-up areas are expanding rapidly, while cropland increases steadily, reflecting sustained anthropogenic pressure on the landscape. Rangeland and Bare Ground: Continuous decline reflects conversion to agriculture and settlements.
- Tree Cover: Slight decline emphasizes the need for forest conservation and afforestation initiatives.
- Management Implication: Sustainable land-use planning, wetland restoration, and urban regulation are crucial to mitigate ecological stress and preserve basin integrity.

Table 2: Summary: Projected LULC change over 2025 and 2035.

LULC Class	2025 (Sq. Km)	2035 (Sq. Km)	Net Change (Sq. Km)	% Change	Trend
Water	4746.85	5242.21	495.36	+10.43%	Increasing
Trees	42859.88	40228.04	-2631.84	-6.14%	Declining
Flooded Vegetation	266.51	310.61	44.1	+16.55%	Increasing
Crops	66185.09	73280.94	7095.85	+10.72%	Increasing
Built Area	8594.87	11720.81	3125.94	+36.38%	Rapid Increase
Bare Ground	291.8	15.79	-276.01	-94.60%	Declining
Rangeland	33266.8	25413.12	-7853.68	-23.60%	Declining

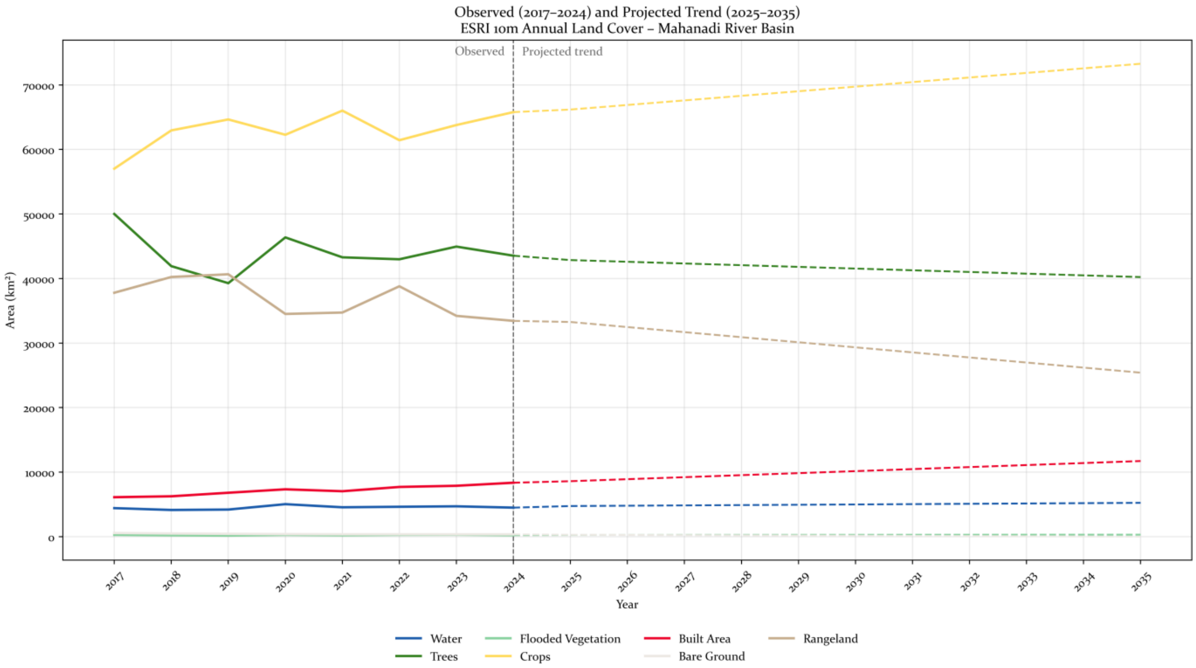

Figure 23: Temporal evolution of major LULC classes in the MRB, with observed data (2017–2024) and projections (2025–2035) plotted as area in km² for each class [Derived from Sentinel-2 Imagery].

Table 3: LULC Structural Trajectory and Predictability Matrix (1985–2035)

LULC Class	1985 Baseline State	2020 Transition State	2035 Projected State	Structural Stability(Reversibility & Replacement)	Probability of Future Change
Built Area	Small localized hubs	Rapid peri-urban spread	Dominant driver of land cover replacement	Highly Stable. Once land is converted to built infrastructure, it functionally never reverts to natural vegetation or agriculture.	**High Probability of Increase(Expansion).** Certain to expand, continuously absorbing surrounding croplands and rangelands near urban centres.
Cropland	Dominant (Intensifying)	Consolidating & encroaching into scrubland	Peak extent, encroaching into forest margins	Moderately Stable. Core agricultural plains (Seonath) are stable, but peripheral croplands near cities are lost to urbanization.	**High Probability of Increase(Expansion).** Continues to expand into Rangeland and Tree Cover in upper sub-basins (Ong, Tel, Jonk).
Tree Cover	Intact upper catchments	Fragmented and degraded by mining/agriculture	High vulnerability; restricted to protected cores	Highly Vulnerable (Unstable). Natural forest boundaries are fluid and constantly under pressure from anthropogenic edge effects.	**High Probability of Decrease (Loss).** Expected to systematically decline, primarily transitioning into Rangeland and Cropland (esp. in Hasdeo, Ib, Tel).
Rangeland	Scrub/transitional buffer	Expanding near mines, shrinking near farms	Transient class; continuously traded	Highly Unstable. Acts as a "bridge" class: forests degrade into rangeland, while rangelands are subsequently upgraded into croplands.	**Dynamic Probability (Both Gain and Loss).** Gains from deforested areas but immediately loses area to agricultural expansion. Net trend is a steady decline.
Water	Stable natural flows	Reservoir-regulated	Artificially maintained	Moderately Stable. Surface area is maintained structurally by dams, but seasonal variability is high.	**Low Probability of Major Area Change.** Surface water area will likely remain stable or slightly increase due to new reservoirs, despite underlying water stress.
Flooded Veg	Natural floodplain wetlands	Contracting due to drainage	Shrinking to isolated patches	Vulnerable (Unstable). Highly sensitive to river flow regulation and floodplain construction.	**Moderate Probability of Decrease**. Wetlands and flooded margins are expected to be reclaimed for downstream agriculture or urban infrastructure.
Bare Ground	Natural erosional features	Reclaimed or colonized by scrub	Declining	Unstable. Exposed land is actively utilized for development or naturally vegetated.	**High Probability of Decrease.** Bare patches will systematically disappear into the Built Area and Cropland matrices.

6. LULC Composition Around Riparian Buffer

6.1 Riparian Buffer Analysis

Figure 24: Major Riparian Buffer Zones [100- 1000 m] over MRB

The riparian zone of the Mahanadi River Basin represents a critical transitional landscape between terrestrial and aquatic ecosystems. To understand the extent and nature of Land Use Land Cover (LULC) change pressure on the river corridor, a multi-scale buffer analysis was conducted at four distances: 100 m, 300 m, 500 m, and 1,000 m from the river network as shown in Figure-26. These buffer zones capture progressively broader zones of human influence and ecological transition, ranging from the immediate riparian fringe to the wider floodplain and peri-riparian landscape.

LULC transitions within each buffer were derived from temporal comparison of classified land cover rasters (Source: ESRI 10m Annual Land Cover (2017-2024) (Sentinel-2)). All detected changes were encoded as composite raster values representing from-class and to-class pairs, enabling precise quantification of the direction, magnitude, and spatial distribution of land cover change. The following sub-sections present the composition, dominant transitions, and ecological significance of LULC change across each buffer distance.

Table 4: Summary of Total LULC Change by Buffer Zone

Buffer Zone	Total Changed Pixels	Total Changed Area (sq. km)
100 m	17,577,325	1594.20
300 m	29,497,035	2675.27
500 m	39,481,623	3580.84
1000 m	61,543,794	5581.80

Note: Total pixels and area subject to LULC change across four riparian buffer distances in the Mahanadi River Basin.

The total area under LULC transition increases proportionally with buffer width, from approximately 1,594 sq. km within the 100 m buffer to over 5,582 sq. km within the 1,000 m buffer. The analysis revealed substantial land cover transformations within the riparian zones, particularly involving rangeland, cropland, and tree cover classes. The magnitude of change increases with buffer distance, indicating that anthropogenic modifications extend beyond the immediate riverbank into the broader floodplain landscape.

6.1.1 Raster Transition Coding and Theoretical LULC Transitions

To quantify LULC changes between different classes, a raster transition coding system was used. Each transition between two land cover classes was assigned a unique raster value representing the change from one class to another. The coding scheme was derived by combining the class codes of the “from” and “to” categories.

The LULC classification [ESRI 10 m Annual Land Cover (2017-2024)] used in this study includes the following classes:

Table 5: LULC Classification

Class Code	LULC Class
1	Water
2	Trees
3	Flooded Vegetation
4	Cropland
5	Built Area
6	Bare Ground
9	Rangeland

Note: *Out of the nine LULC classes available in the ESRI 10 m Annual Land Cover dataset, two were excluded from this analysis, (Class 9) Snow/Ice, which is climatologically absent within the tropical extent of the Mahanadi River Basin, and Clouds (Class 10), which represent a sensor acquisition artefact rather than a true land cover class and were removed during pre-processing.*

The raster transition value represents a specific conversion from one LULC class to another. For example:

Table 6: Raster Transition Values

Raster Value	Transition
14	Water : Cropland
24	Trees : Cropland
45	Cropland : Built Area
69	Bare Ground : Rangeland
94	Rangeland : Cropland

Using these class combinations, all possible theoretical transitions between the seven LULC categories were defined. In total, 42 theoretical transitions are possible when considering directional changes between the classes. These transitions form the basis for the change detection analysis and enable the identification of dominant land transformation processes across the riparian buffers.

However, not all theoretical transitions occur in practice. The observed transitions extracted from the change raster represent actual land cover dynamics within the Mahanadi River riparian zone.

This transition coding approach enables efficient mapping, quantification, and interpretation of complex land cover dynamics and supports detailed spatial assessment of landscape transformations within the river basin.

6.1.2 LULC Transitions in the 100 m Riparian Buffer

Within the 100 m riparian buffer, a total area of 1594.20 sq. km experienced land cover change. The most dominant transition was rangeland to cropland (321.46 sq. km), highlighting the expansion of agricultural activities in areas immediately adjacent to the river channel. Other significant transitions include trees to rangeland (138.21 sq. km) and cropland to rangeland (127.38 sq. km), suggesting vegetation degradation and fluctuating land management practices in the immediate riparian zone. Transitions such as rangeland to water (114.54 sq. km) and water to rangeland (110.76 sq. km) indicate the dynamic nature of the floodplain environment, where seasonal flooding, sediment deposition, and channel migration frequently alter land cover patterns along the river margins.

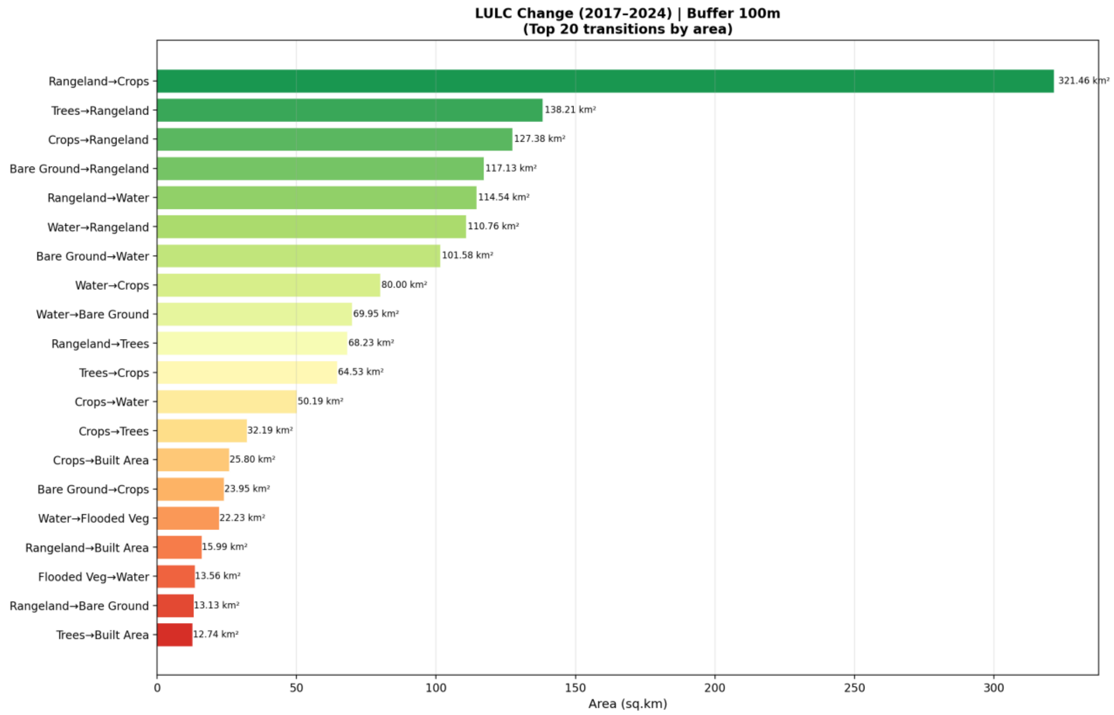

Figure 25: Major LULC Change (2017-2024) over 100 m Riparian Area Buffer

Table 7: Top 10 LULC Transitions in the 100 m Riparian Buffer

Rank	LULC Transition	Raster Value	Pixel Count	Area (sq. km)	% of Total Change

Rank	LULC Transition	Raster Value	Pixel Count	Area (sq. km)	% of Total Change
1	Rangeland:Crops	94	3,544,351	321.46	20.16%
2	Trees:Rangeland	29	1,523,855	138.21	8.67%
3	Crops:Rangeland	49	1,404,518	127.38	7.99%
4	Bare Ground:Rangeland	69	1,291,493	117.13	7.35%
5	Rangeland:Water	91	1,262,879	114.54	7.18%
6	Water:Rangeland	19	1,221,239	110.76	6.95%
7	Bare Ground:Water	61	1,120,042	101.58	6.37%
8	Water:Crops	14	882,043	80.00	5.02%
9	Water:Bare Ground	16	771,226	69.95	4.39%
10	Rangeland:Trees	92	752,330	68.23	4.28%
Total (All Transitions)			17,577,325	1594.20	100.00%

6.1.3 LULC Transitions in the 300 m Riparian Buffer

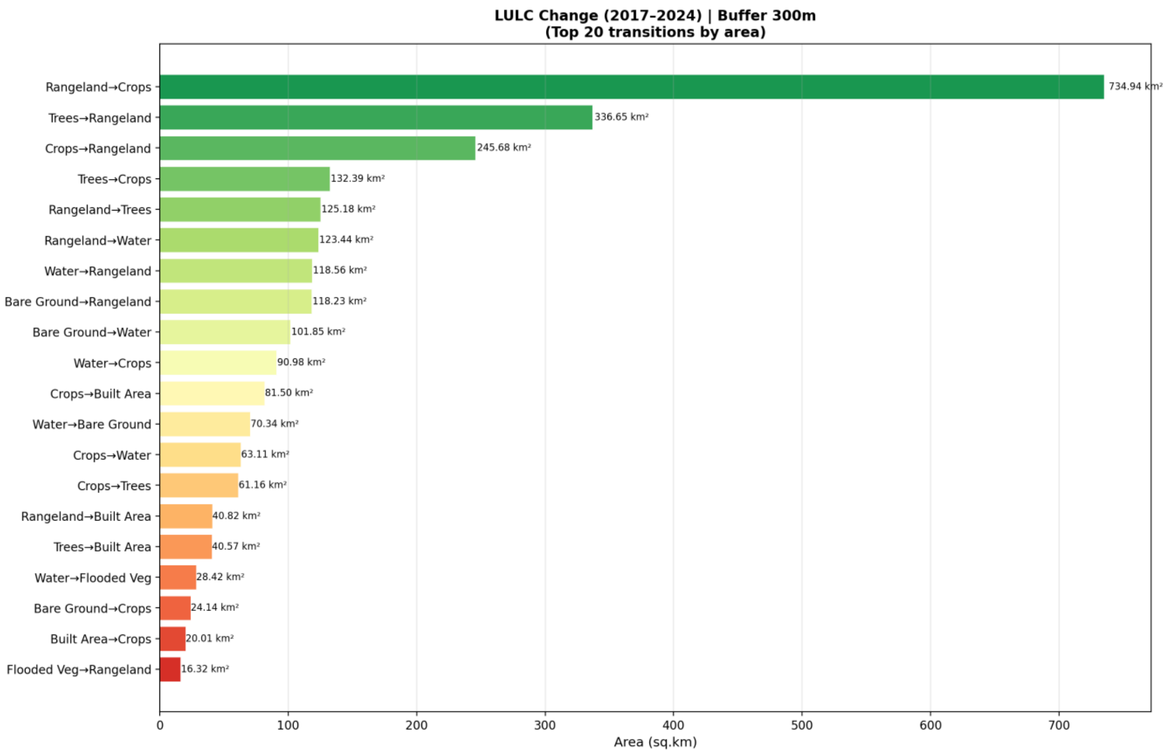

Figure 26: Major LULC Change (2017-2024) over 300 m Riparian Area Buffer

In the 300 m buffer zone, the total area undergoing LULC change increased to 2675.27 sq. km, reflecting a broader spatial influence of land use dynamics. The dominant transition remained rangeland to cropland (734.94 sq. km), indicating continued agricultural expansion beyond the immediate riverbanks. Additional major transitions included trees to rangeland (336.65 sq. km) and cropland to rangeland (245.68 sq. km). These patterns suggest a combination of vegetation clearing and changes in agricultural practices across the riparian landscape. The transition from trees to cropland (132.39 sq. km) indicates conversion of vegetated areas into agricultural land, while rangeland to trees (125.18 sq. km) suggests localized vegetation regeneration or plantation activities in some sections of the buffer zone.

Table 8: Top 10 LULC Transitions in the 300 m Riparian Buffer

Rank	LULC Transition	Raster Value	Pixel Count	Area (sq. km)	% of Total Change
1	Rangeland:Crops	94	8,103,306	734.94	27.47%
2	Trees:Rangeland	29	3,711,784	336.65	12.58%
3	Crops:Rangeland	49	2,708,781	245.68	9.18%
4	Trees:Crops	24	1,459,753	132.39	4.95%
5	Rangeland:Trees	92	1,380,202	125.18	4.68%
6	Rangeland:Water	91	1,361,002	123.44	4.61%
7	Water:Rangeland	19	1,307,221	118.56	4.43%
8	Bare Ground:Rangeland	69	1,303,526	118.23	4.42%
9	Bare Ground:Water	61	1,123,009	101.85	3.81%
10	Water:Crops	14	1,003,078	90.98	3.40%
Total (All Transitions)			29,497,035	2675.27	100.00%

6.1.4 LULC Transitions in the 500 m Riparian Buffer

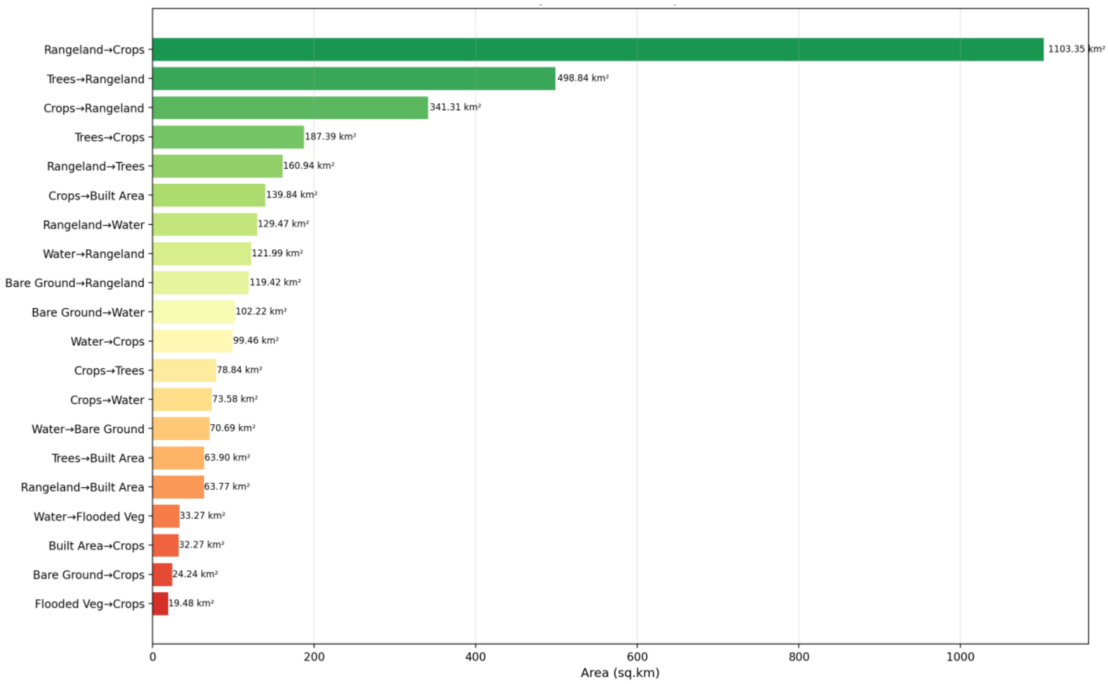

Figure 27: Major LULC Change (2017-2024) over 500 m Riparian Area Buffer

The 500 m buffer exhibited further increases in land cover transitions, with a total change area of 3580.84 sq. km. The dominant transformation continued to be rangeland to cropland (1103.35 sq. km), followed by trees to rangeland (498.84 sq. km) and cropland to rangeland (341.31 sq. km). These trends highlight ongoing modifications of natural and semi-natural landscapes for agricultural purposes. Additionally, transitions such as trees to cropland (187.39 sq. km) and cropland to built area (139.84 sq. km) indicate increasing human intervention within the broader riparian environment. The emergence of built-up expansion suggests the gradual growth of settlements, infrastructure, and peri-urban development within the floodplain areas of the basin.

Table 9: Top 10 LULC Transitions in the 500 m Riparian Buffer

Rank	LULC Transition	Raster Value	Pixel Count	Area (sq. km)	% of Total Change
1	Rangeland:Crops	94	1,21,65,310	1103.35	30.81%
2	Trees:Rangeland	29	55,00,139	498.84	13.93%
3	Crops:Rangeland	49	37,63,250	341.31	9.53%
4	Trees:Crops	24	20,66,150	187.39	5.23%
5	Rangeland:Trees	92	17,74,503	160.94	4.49%
6	Rangeland:Water	91	14,27,561	129.47	3.62%

7	Crops:Built Area	45	15,41,887	139.84	3.91%
8	Water:Rangeland	19	13,44,983	121.99	3.41%
9	Bare Ground:Rangeland	69	13,16,737	119.42	3.33%
10	Bare Ground:Water	61	11,27,072	102.22	2.85%
Total (All Transitions)			3,94,81,623	3580.84	100.00%

6.1.5 LULC Transitions in the 1000 m Riparian Buffer

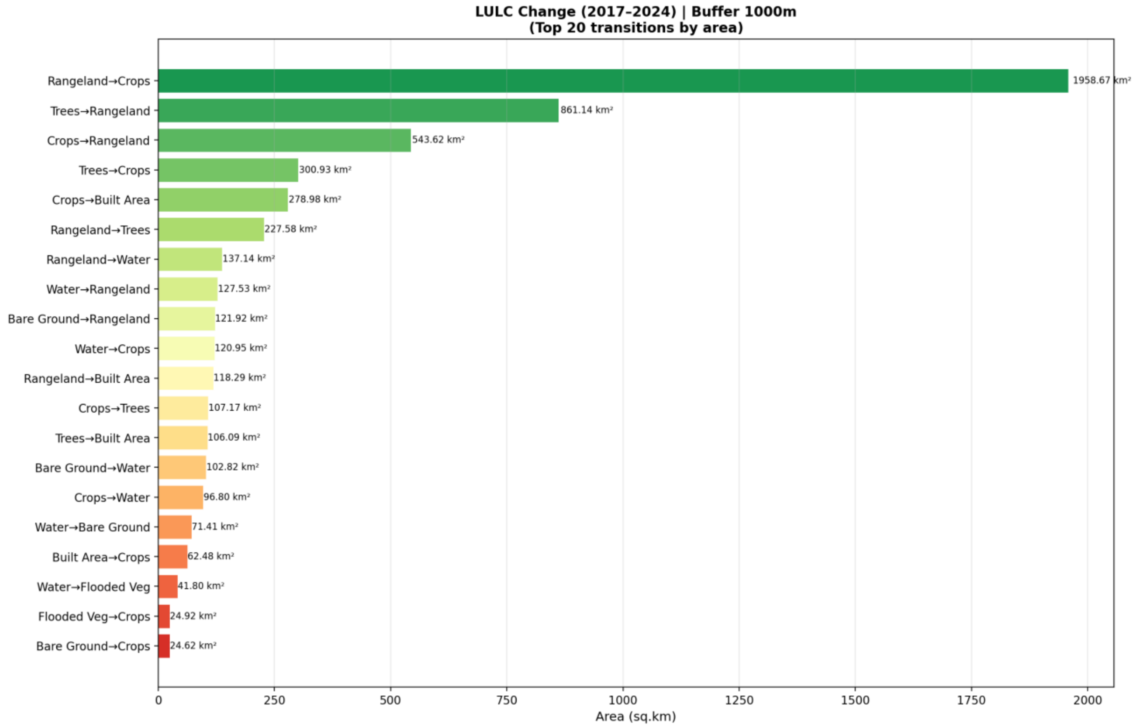

Figure 28: Major LULC Change (2017-2024) over 1000 m Riparian Area Buffer

Figure 29: LULC Class to Class Transition Matrix for 1000 m Riparian Area Buffer

In the 1000 m buffer, the largest extent of land transformation was observed, with a total area of 5581.80 sq. km undergoing LULC change. The most dominant transition was again rangeland to cropland (1958.67 sq. km), confirming that agricultural expansion is the primary driver of landscape change within the riparian corridor of the Mahanadi Basin. Other notable transitions include trees to rangeland (861.14 sq. km) and cropland to rangeland (543.62 sq. km), indicating ongoing vegetation conversion and land management dynamics. Significant changes such as cropland to built area (278.98 sq. km) and trees to built area (106.09 sq. km) highlight increasing urbanization and infrastructure development within the wider floodplain environment.

Table 10: LULC Transitions in the 1,000 m Riparian Buffer

Rank	LULC Transition	Raster Value	Pixel Count	Area (sq. km)	% of Total Change
1	Rangeland:Crops	94	21,595,877	1958.67	35.09%
2	Trees:Rangeland	29	9,494,760	861.14	15.43%
3	Crops:Rangeland	49	5,993,810	543.62	9.74%
4	Trees:Crops	24	3,317,984	300.93	5.39%

Rank	LULC Transition	Raster Value	Pixel Count	Area (sq. km)	% of Total Change
5	Crops:Built Area	45	3,075,955	278.98	5.00%
6	Rangeland:Trees	92	2,509,289	227.58	4.08%
7	Rangeland:Water	91	1,512,087	137.14	2.46%
8	Water:Rangeland	19	1,406,106	127.53	2.28%
9	Rangeland:Built Area	95	1,304,221	118.29	2.12%
10	Bare Ground:Rangeland	69	1,344,277	121.92	2.18%
Total (All Transitions)			61,543,794	5581.80	100.00%

6.2 Net LULC Class Balance (Gain - Loss)

The net land use and land cover (LULC) class balance analysis provides an integrated view of overall gains and losses of each land cover class within different riparian buffer zones of the Mahanadi River Basin. The analysis compares total transitions into a class (gain) against transitions out of that class (loss), thereby indicating whether a particular land cover category is expanding (positive balance) or shrinking (negative balance) within the riparian corridor.

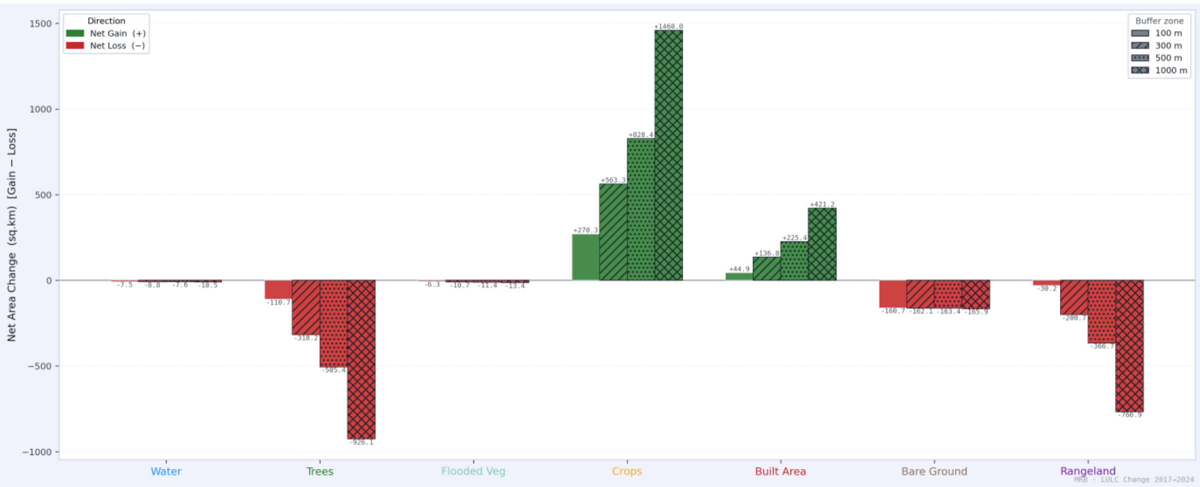

Figure 30: Net LULC class balance (gain–loss) across 100 m, 300 m, 500 m, and 1000 m riparian buffers of the Mahanadi River Basin

The results show a clear dominance of agricultural expansion, with the cropland class exhibiting the highest net gain across all buffer zones. The magnitude of cropland expansion increases progressively with buffer width, reflecting a broader spread of agricultural activities within the floodplain landscape. While the gain in cropland is relatively moderate within the 100 m buffer, it increases substantially in the 300 m and 500 m buffers, and becomes most pronounced within the 1000 m buffer, indicating large-scale agricultural conversion in the wider riparian zone. This pattern aligns with the dominant transitions observed earlier, particularly the conversion of rangeland and tree-dominated areas into cropland, suggesting that agricultural intensification is one of the primary drivers of landscape transformation along the Mahanadi River corridor.

In contrast, tree cover shows a consistent net loss across all buffer zones, indicating a decline in vegetated areas within the riparian landscape. The magnitude of tree loss increases with buffer distance, with the largest decline observed in the 1000 m buffer zone. This reduction is primarily associated with transitions from trees to rangeland and trees to cropland, reflecting both vegetation degradation and land clearing for agriculture. The decline of riparian vegetation is particularly concerning from an ecological perspective, as tree cover plays a crucial role in bank stabilization, habitat support, and regulation of sediment and nutrient flow into the river system.

The rangeland class also exhibits a substantial net loss, which becomes increasingly pronounced in wider buffer zones. This trend indicates that rangelands are the major source class for land conversions, especially toward cropland. The progressive reduction of rangelands across the riparian landscape suggests changes in traditional land use patterns, including the intensification of agriculture and shifts in grazing or open vegetation systems.

The built-up area shows a moderate but consistent net gain, particularly noticeable in the 500 m and 1000 m buffers. This indicates gradual expansion of settlements, infrastructure, and peri-urban development within the river basin. Although the absolute magnitude of built-up expansion is smaller compared to cropland expansion, its presence within riparian zones has important implications for river basin management, as increased impervious surfaces can enhance surface runoff and introduce pollutants into the river system.

Other classes such as water bodies, flooded vegetation, and bare ground exhibit relatively minor net changes, indicating that while localized transitions occur among these categories, they do not dominate the overall landscape transformation. Small fluctuations in water and flooded vegetation classes reflect the natural variability of the floodplain environment influenced by seasonal flooding, sediment deposition, and channel dynamics.

Overall, the net class balance highlights a clear structural shift in the riparian landscape of the Mahanadi River Basin, characterized by expansion of cropland and built-up areas at the expense of rangelands and tree cover. The increasing magnitude of gains and losses with wider buffer distances suggests that the broader floodplain zone is experiencing more extensive land transformation than the immediate riverbank areas. These trends underscore the need for strengthened riparian land management strategies, including conservation of vegetation buffers, sustainable agricultural practices, and regulated land development within floodplain areas to ensure long-term ecological stability and river health.

6.3 Sub-Basin Wise Net LULC Class Balance (Gain–Loss) in River Buffer Zones of the MRB (2017–2024)

The sub-basin wise assessment of Net Land Use/Land Cover (LULC) balance within river buffer zones (100 m, 300 m, 500 m, and 1000 m) provides insights into the spatial dynamics of land transformation along the riparian corridors of the Mahanadi River Basin (MRB) between 2017 and 2024. The net balance represents the difference between the area gained and lost for each LULC class, thereby indicating the dominant land conversion trends occurring along the riverine landscape.

Overall, the analysis highlights three prominent basin-wide processes:

1. Expansion of built-up land and cropland,
2. Substantial decline in tree cover, and
3. Large-scale transformation between rangeland and agricultural landscapes, particularly in the middle and lower basin segments.

Across most sub-basins and buffer widths, the patterns remain consistent, indicating that the observed land transformations are not confined only to the immediate riverbanks but extend across wider riparian landscapes.

6.3.1 Upper Sub-Basins

❖ Upper Mahanadi Main

The Upper Mahanadi Main sub-basin exhibits one of the most pronounced land transformation patterns within the MRB riparian zone. Cropland shows a very large net gain, increasing from approximately +2,399 sq. km (100 m buffer) to +2,519 sq. km (1000 m buffer). This substantial expansion is largely associated with the conversion of rangeland (-1,414 to -1,477 sq. km) and tree cover (-1,069 to -1,142 sq. km).

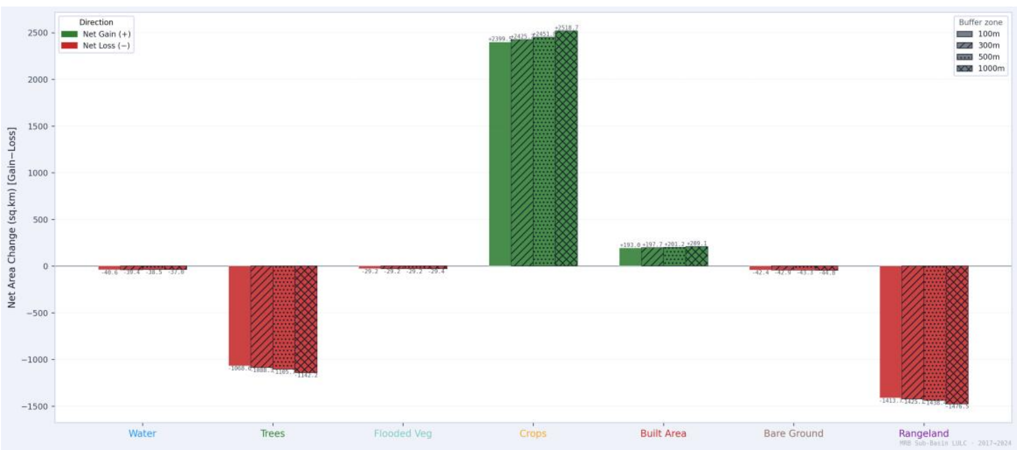

Figure 31: Net LULC Class Balance (Gain–Loss) in River Buffer Zones of Upper Mahanadi Main Sub Basin

Built-up area also shows a steady increase, with net gains rising from +193 sq. km to +209 sq. km across increasing buffer distances, suggesting gradual urban and settlement expansion along the upper river corridor. Meanwhile, water bodies and bare ground exhibit moderate declines, indicating either seasonal fluctuations or conversion into other land uses.

Overall, the upper basin riparian landscape reflects a strong agricultural intensification process coupled with forest and rangeland decline.

❖ **Seonath**

The Seonath sub-basin, one of the largest tributary systems of the MRB, demonstrates the most dramatic cropland expansion among all sub-basins. Net cropland gain increases from +3,254 sq. km in the 100 m buffer to over +3,301 sq. km in the 1000 m buffer.

This gain is primarily offset by a massive reduction in rangeland (-3,377 to -3,414 sq. km) and a significant loss of tree cover (-435 to -448 sq. km). Built-up areas also expanded considerably, reaching +481 sq. km at the 1000 m buffer, indicating strong pressure from settlement growth and infrastructure development in the riparian zone.

Interestingly, water bodies show notable net gains (about +96 to +98 sq. km), possibly reflecting reservoir expansion, river widening, or seasonal wetland formation.

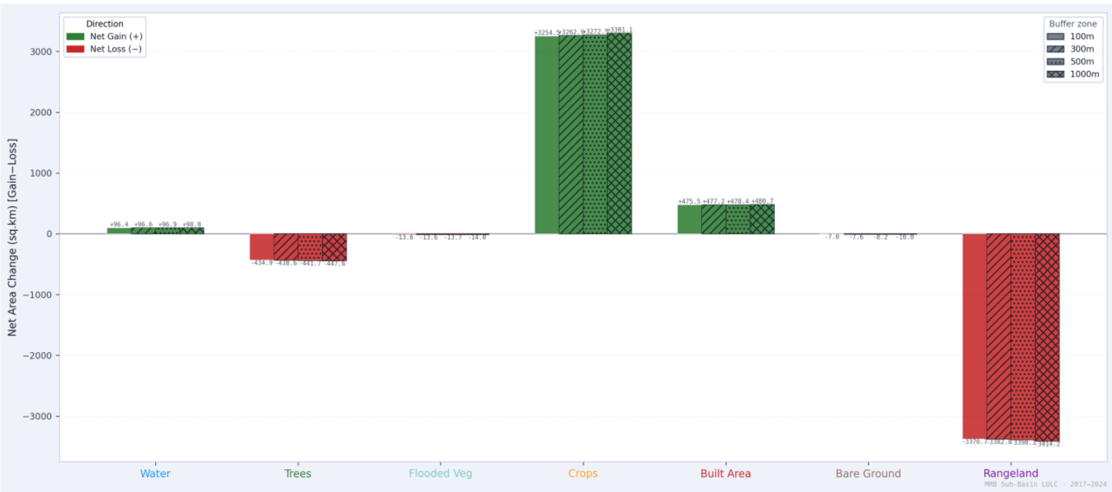

Figure 32: Net LULC Class Balance (Gain–Loss) in River Buffer Zones of Seonath Sub Basin

Overall, the Seonath riparian corridor is undergoing rapid agricultural transformation and urban expansion at the expense of rangeland and tree cover.

❖ **Hasdeo**

The Hasdeo sub-basin, a major coal-bearing tributary of the Mahanadi, exhibits a pronounced ecological transition driven by mining activity, infrastructure expansion, and forest fragmentation between 2017 and 2024.

Key Observations

- Rangeland: Largest net gainer across all buffers (~+652 to +672 Km²), indicating rapid conversion of forest lands to degraded scrub likely in mining-affected zones.
- Trees: Catastrophic net loss of -639 to -647 Km². This is the most severe deforestation signal in the Hasdeo basin, consistent with large-scale coal mine clearances.
- Built Area: Consistent net gain of ~+83 to +86 Km². Growth of townships, mining infrastructure, and road networks is driving built-up expansion.
- Crops: Net decline of -67 to -90 Km². Agricultural contraction suggests displacement of farming communities and land-use pressures from encroaching development.
- Water: Marginally negative net balance (-3.7 to -4.8 Km²) indicating water body shrinkage likely reservoir sedimentation or drainage diversion.
- Bare Ground: Steady loss (~-21 to -23 Km²) absorbed into Rangeland and Built-up categories.

Figure 33: Net LULC Class Balance (Gain–Loss) in River Buffer Zones of Hasdeo Sub Basin

The Hasdeo basin stands out as the most ecologically stressed, with the Trees-to-Rangeland conversion dominating the landscape signal a hallmark of mine-related deforestation.

❖ Mand

The Mand sub-basin, a right-bank tributary flowing through largely forested terrain, shows a Rangeland-dominated transition with moderate agricultural and urban growth.

Key Observations

- Trees: Net loss of -320 to -339 Km² substantial deforestation, second only to larger basins in absolute terms.

- Rangeland: Net gain of +222 to +238 Km², indicating degraded forest edge conversion to scrublands.
- Crops: Positive net balance of ~+60 Km² moderate agricultural expansion, relatively stable across buffers.
- Built Area: Gain of ~+49 to +53 Km² incremental urban growth, likely around district towns.
- Water: Net loss of -8.1 to -8.3 Km². Water body contraction consistent with rain-fed tank drying.
- Bare Ground: Small consistent loss (-3.95 to -4.20 Km²) with little variation across buffer distances.

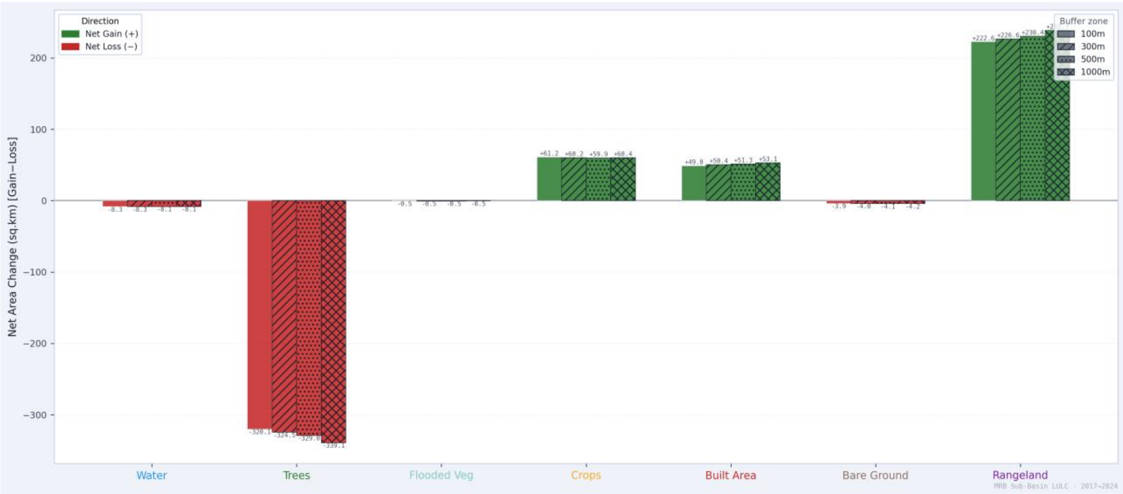

Figure 34: Net LULC Class Balance (Gain–Loss) in River Buffer Zones of Mand Sub Basin

Mand sub-basin reflects moderate forest pressure with trees consistently converting to rangeland a pattern typical of unregulated grazing and selective felling in Central India tribal forest regions. The Mand riparian region therefore reflects a transition from forested landscapes toward agro-pastoral land systems.

6.3.2 Middle Sub-Basins

❖ Middle Mahanadi Main

The Middle Mahanadi main covering the transition from plateau to plains records significant cropland gains alongside forest loss and rangeland contraction, with a notable water body surplus.

Key Observations

- Crops: Net gain of +231 to +250 Km², signifying active agricultural expansion in the floodplain areas.

- Built Area: Positive net balance of +207 to +214 Km², reflecting mid-basin urban and infrastructure growth.

- Trees: Net loss of -295 to -305 Km² significant, though less acute than upper tributaries.
- Rangeland: Net loss of -125 to -141 Km² rangeland is contracting as both crops and built-up areas expand.
- Water: Positive net balance of +37 to +38 Km² among the largest water gains in the MRB, possibly reflecting reservoir expansion or seasonal ponding.
- Bare Ground: Net loss of -47.5 Km² consistent across all buffers.

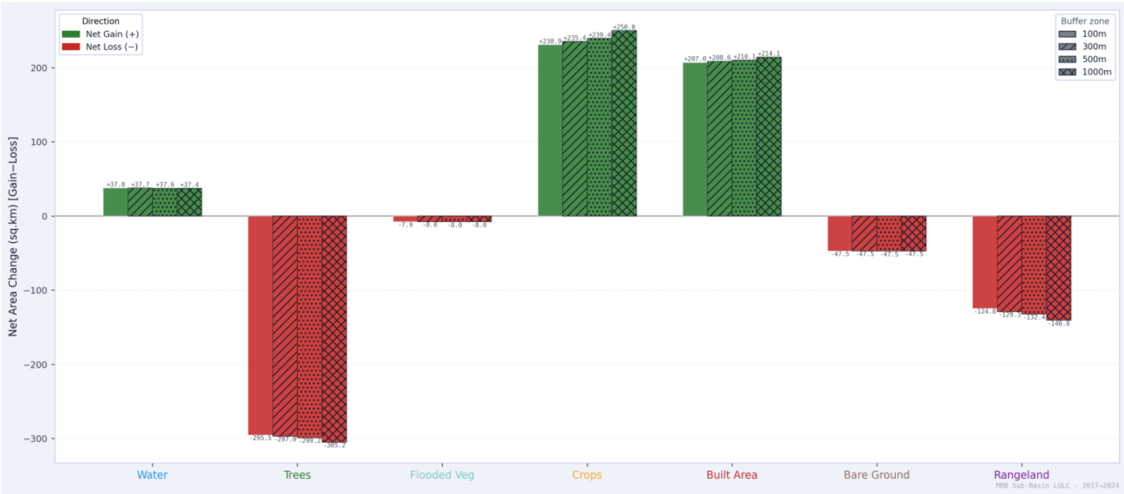

Figure 35: Net LULC Class Balance (Gain–Loss) in River Buffer Zones of Middle Mahanadi Main Sub Basin

The Middle Mahanadi main exhibits a multi-directional transformation: both agricultural and urban expansion are occurring simultaneously while forest cover retreats a complex mosaic of land transitions.

❖ Pairi

The Pairi sub-basin a forested upper tributary is experiencing deep forest depletion driven by rangeland encroachment and modest agricultural expansion.

Key Observations

- Trees: Severe net loss of -339 to -372 Km² the proportionally deepest tree cover decline relative to basin size, indicating intense deforestation.
- Rangeland: Net gain of +211 to +214 Km², absorbing converted forest lands.
- Crops: Positive net balance of +130 to +158 Km² moderate but growing agricultural area.
- Built Area: Modest gain of ~+10 to +12 Km² reflecting very limited urbanisation in this upland basin.
- Water: Net loss of -5.7 to -5.8 Km² indicating drying of seasonal water bodies.
- Bare Ground: Net loss of -6.1 Km², absorbed into vegetation or cropland.

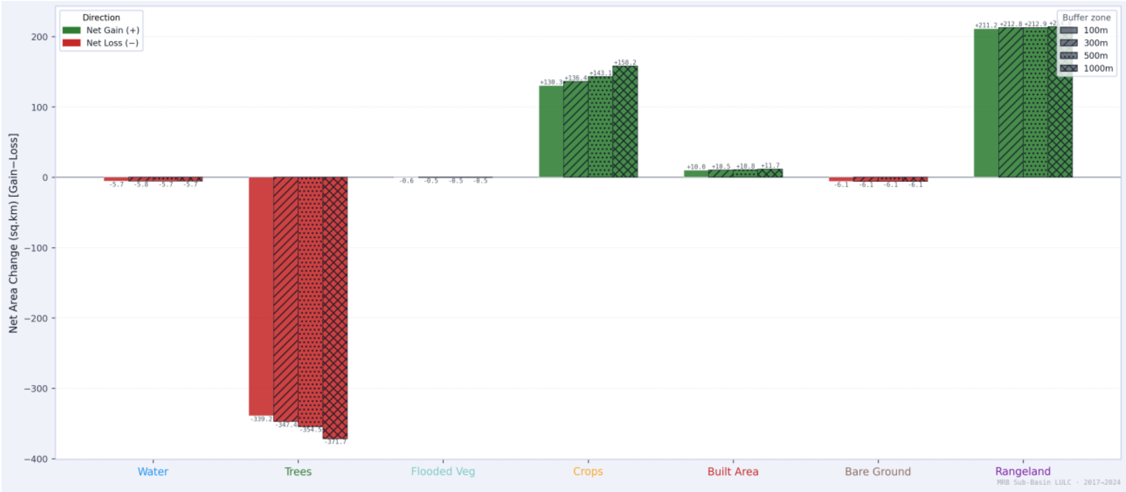

Figure 36: Net LULC Class Balance (Gain–Loss) in River Buffer Zones of Pairi Sub Basin

Pairi is an ecologically vulnerable upper tributary forest loss here feeds downstream sedimentation and hydrological variability. The Trees-to-Rangeland conversion ratio is alarming relative to basin size.

6.3.3 Lower Sub-Basins

❖ Lower Mahanadi Main

The Lower Mahanadi encompassing the deltaic and coastal stretch is undergoing rapid urbanisation and infrastructure-led growth, with Built Area recording the single largest absolute gain among all sub-basins.

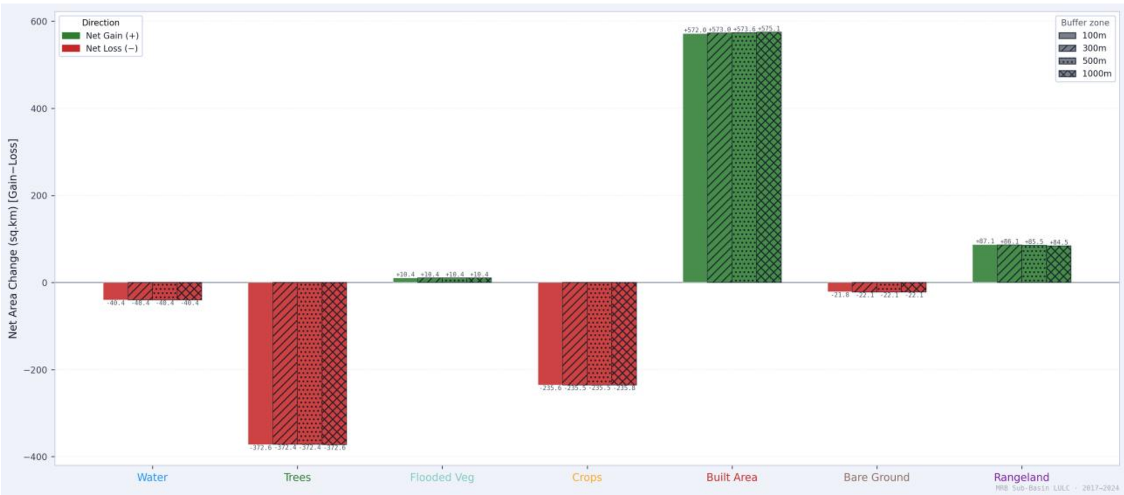

Figure 37: Net LULC Class Balance (Gain–Loss) in River Buffer Zones of Lower Mahanadi Main Sub Basin

Key Observations

- Built Area: Extraordinary net gain of +572 to +575 Km^2 the highest of all sub-basins, reflecting Bhubaneswar-Cuttack urban agglomeration expansion and coastal development.
- Crops: Net loss of -235 to -236 Km^2 indicating significant periurban farmland conversion.
- Trees: Net loss of -372 Km^2 across all buffers consistent forest degradation in hilly fringes.
- Rangeland: Modest net gain of +84 to +87 Km^2 degraded land replacing forest margins.
- Flooded Vegetation: Positive net balance of +10.4 Km^2 across all buffers, indicating floodplain vegetation persistence in delta zones.
- Water: Net loss of -40 Km^2 potentially reflecting urban encroachment on water bodies and wetlands.

❖ **Ib**

The Ib sub-basin, another coal-intensive watershed in Odisha's Jharsuguda district, mirrors Hasdeo with forest degradation but shows relatively more balanced agricultural dynamics.

Key Observations

- Built Area: Strong positive net balance (~+130 to +132 Km^2), reflecting rapid urbanisation and industrial expansion around Jharsuguda and Rourkela corridor.
- Trees: Net loss of -317 to -325 Km2 severe deforestation driven by coal mining and industrial development.
- Rangeland: Net gain of ~+250 to +252 Km^2, indicating degraded forest land transitioning to scrubland.
- Crops: Marginal net decline (-27 to -31 Km^2), suggesting relatively stable agricultural land compared to Hasdeo.
- Water: Net loss of -19.6 to -20 Km^2, a significant shrinkage of water bodies possibly from mining drainage.
- Flooded Vegetation: Consistent net loss (-4.75 to -4.84 Km^2) across all buffers indicating wetland regression.

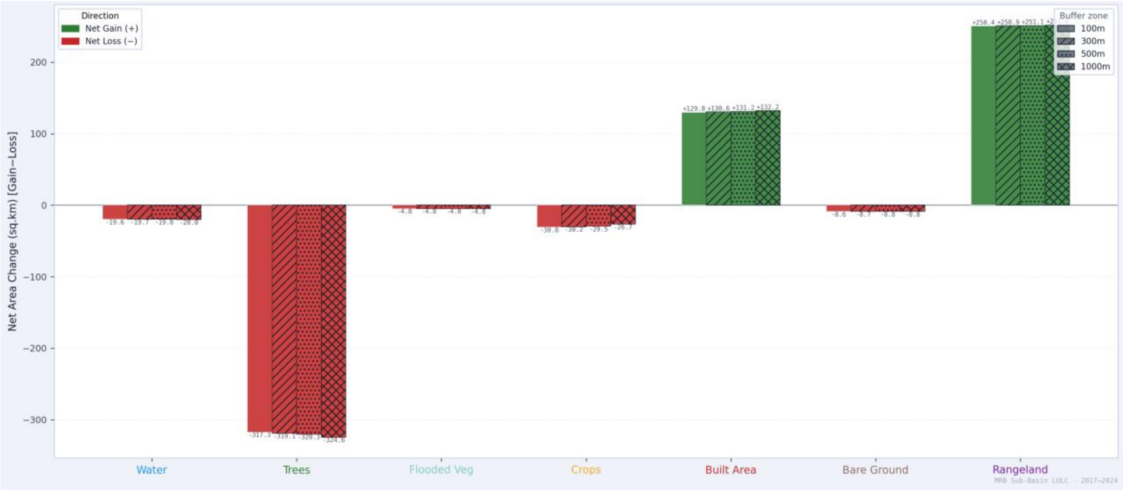

Figure 38: Net LULC Class Balance (Gain–Loss) in River Buffer Zones of Ib Sub Basin

Cropland shows only minor net losses, suggesting relative stability in agricultural land use compared with other sub-basins. Also, reflects an industrial landscape in transition with forest cover giving way to Rangeland and Built Area at rates second only to Hasdeo in terms of industrial pressure.

❖ Jonk

The Jonk sub-basin presents a contrasting land-use shift where agriculture is dramatically expanding at the expense of Rangeland, suggesting intensification of cultivation in previously fallow or degraded lands.

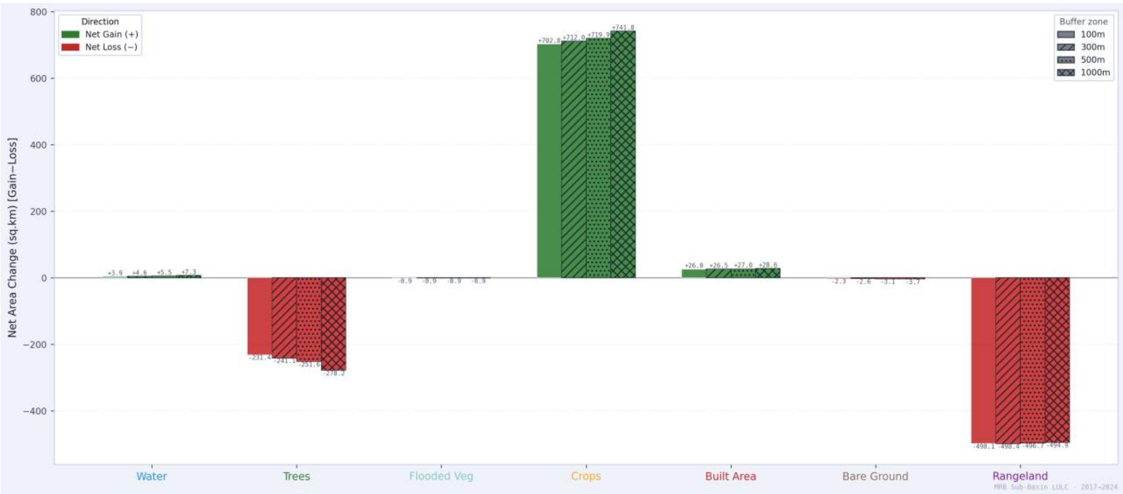

Figure 39: Net LULC Class Balance (Gain–Loss) in River Buffer Zones of Jonk Sub Basin

Key Observations

- Crops: Massive net gain of +703 to +742 Km² the dominant change signal, suggesting large-scale conversion of rangeland to farmland.
- Rangeland: Large net loss of -495 to -498 Km², indicating that prior grazing or fallow lands are being brought under cultivation.

- Trees: Net loss of -231 to -278 Km². Forest clearing, though less severe than in Hasdeo, is ongoing.
- Built Area: Modest gain of ~+26 to +29 Km² indicating incremental urbanisation.
- Water: Positive net balance (+3.85 to +7.28 Km²), unique among sub-basins possibly reflecting new irrigation reservoirs or pond construction.
- Bare Ground: Small net loss (-2.3 to -3.7 Km²) absorbed into crops or rangeland.

❖ Ong

The Ong sub-basin, an important agricultural tributary, shows the most dramatic crop expansion in the MRB alongside severe rangeland and tree cover losses.

Key Observations

- Crops: Massive net gain of +835 to +904 Km² the highest among all sub-basins in proportional terms, indicating agricultural intensification or new irrigation-enabled cultivation.
- Rangeland: Net loss of -492 to -536 Km² the primary source land for crop conversion.
- Trees: Net loss of -408 to -439 Km², second only to Tel basin in magnitude among smaller basins.
- Built Area: Consistent gain of +55 to +60 Km² reflecting moderate urban growth.
- Water: Positive net balance (+14.3 to +15.2 Km²) likely reflecting dam/reservoir construction supporting the irrigation expansion.
- Flooded Vegetation: Small but consistent net loss (-2.3 to -2.5 Km²).

Figure 40: Net LULC Class Balance (Gain–Loss) in River Buffer Zones of Ong Sub Basin

Ong is the agricultural expansion frontier of the MRB. Rangeland and forest are both being converted to cropland at a pace that suggests active irrigation infrastructure development and command area expansion.

❖ Tel

The Tel sub-basin the largest tributary by area records the most severe absolute deforestation in the MRB alongside significant agricultural expansion and rangeland growth.

Key Observations

- Trees: Largest absolute net loss in the MRB: -1,476 to -1,516 Km² reflecting deep structural deforestation across the Odisha-Chhattisgarh uplands.
- Rangeland: Net gain of +494 to +506 Km² forest edge degradation feeding scrubland expansion.
- Crops: Net gain of +735 to +761 Km² active agricultural expansion, likely irrigation-driven.
- Built Area: Net gain of +238 to +241 Km² significant urban growth in Bolangir and Kalahandi districts.
- Water: Positive net balance of +34.5 to +35.2 Km², possibly from new reservoir inundation.
- Bare Ground: Consistent net loss of -22.9 to -23.4 Km² across all buffers.

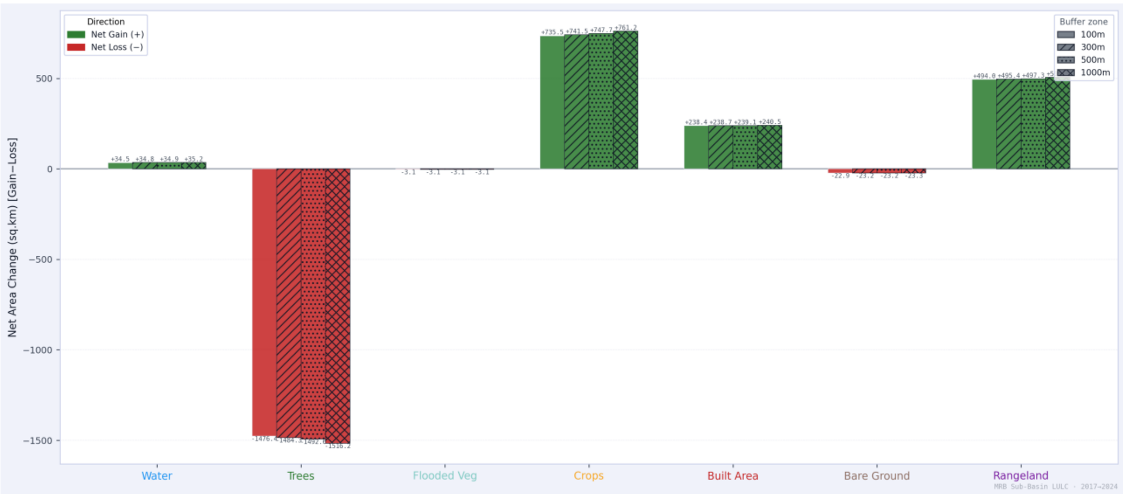

Figure 41: Net LULC Class Balance (Gain–Loss) in River Buffer Zones of Tel Sub Basin

Tel basin's trajectory is alarming it combines the most severe tree cover loss with cropland and rangeland expansion. This basin likely represents the epicentre of land degradation pressure in the MRB.

6.3.4 Buffer Distance Sensitivity Analysis

The analysis at four buffer distances (100m, 300m, 500m, and 1000m) allows an assessment of how LULC changes proximate to the river network vary with spatial extent.

Key observations across sub-basins include:

- Consistency of Direction: Across all sub-basins and all LULC classes, the sign of the net balance (positive or negative) remains consistent across all four buffer distances. This confirms the robustness of identified change signals no class reversal from gain to loss (or vice versa) with increasing buffer width.
- Magnitude Amplification: Net balance magnitudes generally increase (in absolute value) with buffer distance, as larger buffer zones encompass more changed pixels. The incremental increase from 100m to 1000m is moderate (5–15% in most cases), indicating that core LULC changes are concentrated near the river channel.
- Built Area: Shows a consistent incremental gain as buffer widens, confirming that urban expansion is occurring across all zones proximate to the river network not just in immediate riparian strips.
- Trees: Net loss increases systematically with buffer distance, with the largest jumps observed in Tel and Seonath sub-basins. This confirms that deforestation is extending from river margins into broader watersheds.
- Rangeland: The amplification of Rangeland gain with buffer (particularly in Hasdeo and Tel) indicates that mine-degradation or scrubland encroachment extends well beyond immediate river banks.
- Crops (Seonath, Upper Mahanadi): Crop gains increase significantly from 100m to 1000m buffers, confirming that agricultural expansion is distributed broadly across the landscape rather than concentrated near river channels.
- Water: Changes are modest and relatively stable across buffer distances, suggesting that water body changes are localised phenomena rather than broad landscape-scale events.

6.3.5 Basin-Wide Riparian Trends and Synthesis

When aggregated across all sub-basins and buffer widths, several consistent basin-level trends emerge:

- **Major decline in tree cover**
  Almost every sub-basin shows substantial negative net balance for trees, often exceeding -300 sq. km and reaching over -1,500 sq. km in the Tel sub-basin, indicating widespread deforestation or degradation of riparian vegetation.
- **Strong agricultural expansion**
  Cropland gains dominate in many sub-basins particularly Seonath, Upper Mahanadi Main, Ong, Tel, and Jonk reflecting agricultural intensification and expansion along river corridors.
- **Rapid urban growth in riparian zones**
  Built-up area consistently shows positive net gains across all sub-basins, with

particularly large increases in Lower Mahanadi Main, Seonath, Middle Mahanadi Main, and Tel, highlighting increasing settlement pressure near rivers.

- **Dynamic rangeland transformations**
  Rangeland exhibits both gains and losses depending on the sub-basin. In some regions (Hasdeo, Mand, Tel), rangeland expands, while in others (Seonath, Ong, Jonk, Upper Mahanadi), it declines due to cropland conversion.
- **Limited changes in flooded vegetation and bare ground**
  These classes show relatively small net changes compared with other land categories, indicating that the major transformations involve forest, agriculture, and settlement systems.

6.4 Implications of Riparian LULC Changes over MRB

River Basin Ecology and Management

The net land use and land cover (LULC) balance across riparian buffers of the Mahanadi River Basin (MRB) between 2017 and 2024 reveals substantial transformation of the basin's riparian landscape. Sub-basin level analysis shows widespread expansion of cropland and built-up areas, accompanied by significant reductions in tree cover and localized changes in rangeland extent. These patterns are consistent across the 100 m to 1000 m buffer zones, indicating that not only the immediate riverbanks but also the broader floodplain environment is undergoing considerable anthropogenic modification.

Several tributary basins exhibit particularly strong land transformations. The Seonath and Upper Mahanadi sub-basins show the largest cropland gains, reflecting rapid agricultural intensification within floodplain landscapes. Similarly, significant agricultural expansion is observed in the Ong, Tel, and Jonk sub-basins, where cropland growth has been accompanied by notable declines in rangeland and tree cover. In contrast, certain sub-basins such as Hasdeo and Mand show expansion of rangeland, suggesting a shift toward open vegetation or grazing landscapes following forest loss.

Across most sub-basins, tree cover shows a consistently negative net balance, with particularly large losses in the Tel, Upper Mahanadi, Seonath, and Lower Mahanadi riparian corridors. Riparian forests play a vital ecological role in stabilizing riverbanks, regulating stream temperatures through shading, and providing habitat corridors for aquatic and terrestrial species (Naiman &Décamps, 1997; Gregory et al., 1991). The observed decline in riparian tree cover therefore reduces ecological resilience and weakens the ability of riparian zones to function as natural filters for sediments and pollutants.

Urban expansion within riparian buffers is another prominent trend identified in the basin. The Lower Mahanadi Main and Seonath sub-basins exhibit particularly large increases in built-up areas, reflecting growing settlement and infrastructure development along major river corridors. While such growth supports economic development, expansion of settlements near rivers increases pressure on floodplain ecosystems and can disrupt natural riparian processes.

Agricultural expansion in riparian zones also has important ecological implications. Cultivation close to riverbanks increases soil disturbance and often involves intensive fertilizer and pesticide application. Surface runoff during rainfall events can transport sediments and nutrients into nearby rivers, contributing to increased turbidity and nutrient enrichment in aquatic systems (Allan, 2004; Foley et al., 2005). Maintaining vegetated buffer strips between croplands and riverbanks can help filter sediments, reduce nutrient runoff, and stabilize soils along river corridors.

Overall, the sub-basin LULC balance indicates a basin-wide transition toward agriculture and settlement dominated riparian landscapes, accompanied by declining natural vegetation. Integrated basin management strategies should therefore prioritize riparian vegetation restoration, sustainable agricultural practices, and regulated floodplain development to maintain ecological stability and biodiversity within the Mahanadi River Basin.

Hydrological Significance

Changes in riparian LULC also have significant implications for hydrological processes across the basin. The observed expansion of cropland and built-up areas, coupled with reductions in tree cover and rangelands in several sub-basins, can directly influence infiltration, runoff generation, groundwater recharge, and sediment transport.

The substantial increase in cropland within riparian buffers particularly in the Seonath, Upper Mahanadi, Ong, Tel, and Jonk sub-basins indicates intensified agricultural activity in floodplain areas. Agricultural expansion often involves soil disturbance and intensive land management practices that can increase runoff and soil erosion. These processes may elevate sediment loads entering river channels and alter channel morphology, while also affecting sediment deposition patterns in downstream reservoirs (Foley et al., 2005).

The decline in riparian tree cover observed across most sub-basins further affects hydrological regulation. Riparian vegetation enhances infiltration, stabilizes riverbanks, and reduces surface runoff through extensive root systems and improved soil structure (Naiman &Décamps, 1997). Loss of such vegetation may weaken natural hydrological buffering, potentially leading to higher peak flows during rainfall events and reduced base flows during dry periods. Sub-basins experiencing significant forest loss such as Tel, Upper Mahanadi, and Seonath may therefore experience greater hydrological variability.

Rangeland dynamics also play a role in hydrological responses. While rangeland declined sharply in several sub-basins such as Seonath, Ong, and Jonk, it expanded in others including Hasdeo and Mand. Natural grasslands typically allow greater infiltration and slower runoff generation due to their vegetation structure and soil characteristics. Conversion of such areas to cropland or built-up land can increase soil compaction and reduce permeability, leading to faster runoff and lower groundwater recharge.

Urban growth within riparian buffers introduces additional hydrological challenges. The notable expansion of built-up areas in Lower Mahanadi, Seonath, and Middle Mahanadi sub-basins increases impervious surfaces that limit infiltration and accelerate stormwater runoff into river channels. This may intensify flood peaks and increase pollutant transport during storm events (Paul & Meyer, 2001). Adoption of green infrastructure approaches such as permeable pavements, rainwater harvesting, and improved urban drainage systems can help mitigate these impacts.

Overall, the net LULC balance indicates a gradual shift toward land uses that increase runoff generation and reduce natural infiltration within riparian landscapes. Effective river basin management should therefore emphasize riparian vegetation conservation, soil and water conservation practices in agriculture, and restoration of natural infiltration zones.

Water Availability Response to LULC Change

Riparian LULC transformations also influence the availability and seasonal regulation of water resources within the basin. The expansion of cropland across riparian buffers particularly in Seonath, Upper Mahanadi, Ong, and Telindicates intensified agricultural activity within floodplain areas. Such expansion often increases irrigation demand, placing additional pressure on both surface water and groundwater resources, especially during dry seasons.

Agricultural land uses may also reduce infiltration capacity due to soil compaction and repeated cultivation, leading to greater surface runoff and reduced groundwater recharge. Over time, these processes can diminish the natural ability of floodplain landscapes to store water and sustain river flows during dry periods (Foley et al., 2005).

The decline in riparian tree cover further affects water regulation. Riparian vegetation enhances soil water retention, promotes infiltration, and supports groundwater recharge through improved soil structure and organic matter accumulation (Gregory et al., 1991). Large-scale forest losses observed in sub-basins such as Tel, Upper Mahanadi, and Seonath may therefore reduce the natural water storage capacity of riparian ecosystems.

Changes in rangeland extent also influence basin water balance. Grasslands and shrublands generally promote infiltration and moderate runoff, contributing to groundwater recharge and soil moisture conservation. Their conversion into cropland or built-up land can reduce subsurface water storage and accelerate runoff.

Urban expansion further affects water availability by increasing impervious surfaces that limit infiltration and accelerate stormwater runoff. Although this may temporarily increase river discharge during rainfall events, it often reduces groundwater recharge and long-term water retention within the landscape.

Consequently, the net LULC balance across sub-basins indicates a transition toward land uses that may reduce natural water storage and groundwater recharge within riparian corridors. Sustainable basin management should therefore emphasize riparian afforestation, improved agricultural water-use efficiency, protection of natural vegetation patches, and controlled development within floodplain areas.

Water Quality

Changes in land use and land cover within riparian buffers can significantly influence the physical, chemical, and biological quality of river water. The net LULC class balance across the MRB riparian buffers indicates substantial expansion of cropland and built-up areas, accompanied by declines in tree cover and rangelands. These shifts in landscape composition have direct implications for sediment transport, nutrient loading, and pollutant influx into river systems.

Agricultural expansion in riparian zones particularly evident in Seonath, Upper Mahanadi, Ong, Tel, and Jonk sub-basins increases the likelihood of fertilizer, pesticide, and agrochemical runoff entering river systems during rainfall events. Such inputs often elevate concentrations of nutrients such as nitrogen and phosphorus, contributing to eutrophication and algal blooms in aquatic ecosystems (Allan, 2004; Carpenter et al., 1998). Soil disturbance associated with cultivation can also increase sediment erosion, leading to higher turbidity and degradation of aquatic habitats.

The decline in riparian tree cover further reduces the natural filtration capacity of river corridors. Riparian vegetation traps sediments, absorbs nutrients, and reduces pollutant loads entering streams (Naiman &Décamps, 1997; Gregory et al., 1991). Loss of such vegetation weakens these protective functions and increases the vulnerability of rivers to water quality degradation.

Rangelands and natural grasslands also play an important role in slowing runoff and promoting infiltration. Their reduction in several sub-basins may therefore increase surface runoff and facilitate the transport of sediments and contaminants into river channels.

Urban expansion within riparian buffers introduces additional water quality concerns. Rapid growth of built-up areas in Lower Mahanadi and Seonath sub-basins increases the generation of pollutants such as heavy metals, hydrocarbons, nutrients, and solid waste, which may be transported into rivers through storm water runoff (Paul & Meyer, 2001). Without adequate wastewater treatment and storm water management systems, such development can significantly degrade river water quality.

Overall, the observed LULC changes suggest increasing pressure on the water quality of the Mahanadi River system. Protecting riparian vegetation, promoting sustainable agricultural practices, implementing urban storm water management, and regulating development within riparian zones are therefore essential for maintaining water quality and ecological health within the basin.

7. Conclusion and Discussion

Between 2017 and 2024, the Mahanadi River Basin experienced strong agricultural intensification and rapid urban expansion alongside significant forest decline. While total mapped water area shows a marginal increase, spatial heterogeneity indicates localized stress particularly in upper catchments.

- Mining-Driven Forest Degradation (Hasdeo, Ib): These coal-bearing sub-basins are characterised by the Trees:Rangeland:Built Area transition cascade. Forest loss driven by mining clearances is converting ecologically rich sal forests to degraded scrublands and eventually mine infrastructure. Immediate priority for reforestation and compensatory afforestation compliance monitoring.
- Agricultural Intensification Frontier (Seonath, Upper Mahanadi Main, Ong, Jonk): Large-scale Rangeland:Crops conversion is transforming the agrarian landscape of the Chhattisgarh plains and Odisha plateau. The scale of change in Seonath (>3,000 Km^2 net crop gain) is exceptional and demands watershed-level soil health and water resource monitoring.
- Coastal-Urban Transformation (Lower Mahanadi Main): Rapid Built Area expansion (+572 Km^2) in the deltaic and coastal stretch is the defining feature, with significant cropland and forest loss as secondary consequences. Urban growth here poses the greatest flood risk amplification challenge given delta hydrology.
- Forest-Scrub Transition (Mand, Pairi, Tel): Upper and mid-basin forested sub-basins are uniformly experiencing Trees:Rangeland transition driven by combinations of grazing pressure, encroachment, and timber extraction. Pairi and Mand warrant special attention given their headwater ecological roles.
- Mixed Transformation (Middle Mahanadi Main): The transitional mid-basin shows concurrent multi-directional changes cropland expansion, urban growth, forest loss, and positive water balance reflecting the complex land-use pressures of a developing agrarian and urban landscape.

The basin is transitioning toward a more anthropogenically controlled hydrological regime characterized by:

- Reduced natural buffering
- Increased runoff variability
- Greater irrigation dependence

Sustainable basin management will require restoring riparian vegetation, regulating urban expansion near reservoirs, and integrating LULC-based indicators into long-term water resource planning.

8.1. Management and Planning Implications

Priority Zones

Riparian Restoration:

- Upper Mahanadi
- Tel headwaters
- Seonath tributaries

Land-use Regulation:

- Lower Mahanadi urban corridors
- Rapidly expanding Ong and Jonk agricultural belts

LULC-Based Indicators for Basin Monitoring

- Forest-to-crop conversion rate
- Built-up growth within 1–2 km of major water bodies
- Flooded vegetation decline as wetland health indicator
- Crop expansion to water ratio (irrigation pressure index)

Early Warning of Water Stress

Declining flooded vegetation combined with rapid cropland growth may serve as an early indicator of increasing seasonal water stress.

The basin-wide transformation detailed in this study necessitates targeted, area-specific policy interventions:

Mining and Forest Rehabilitation (Hasdeo, Ib, Mand): The systematic degradation of tree cover into rangeland and built infrastructure requires stringent compliance monitoring of Compensatory Afforestation Fund Management and Planning Authority (CAMPA) guidelines. Buffer zones of intact forest must be strictly enforced around active coal blocks to arrest further structural degradation of these essential headwaters.

Agricultural Runoff & Water Efficiency (Seonath, Ong, Jonk): The massive expansion of cropland—frequently at the expense of rangeland—signals increasing irrigation dependency and agro-chemical usage. Watershed management programs (such as PMKSY) in these sub-basins should prioritize micro-irrigation schemes, the construction of farm ponds (to reduce reservoir reliance), and the establishment of vegetated riparian filter strips to mitigate non-point source nutrient pollution entering the river system.

Riparian Corridor Protection Policy: Across almost all sub-basins, natural vegetation within 100m to 1000m of the river channel is facing intense encroachmentfrom agriculture and settlement. We recommend the notification of "No-Development Ecological Buffer Zones" for at least 100 meters along main river channels, restricting new construction and intensive cultivation.

Urban Flood Resilience (Lower Conservancy): The staggering built-up expansion in the Lower Mahanadi delta directly amplifies urban flood risks due to increased impervious surfaces and floodplain encroachment. State urban planning guidelines must urgently incorporate "Sponge City" concepts—mandating permeable pavements, protecting remnant urban wetlands, and ensuring zero encroachment on natural storm-water drainage networks.

8.2. Comparison with Previous Studies in MRB and Similar Basins

Alignment

- Agricultural expansion and forest decline align with trends reported in central Indian basins under intensifying irrigation and settlement growth.
- Urban expansion concentrated along main channels and reservoir zones matches observed demographic patterns.

Divergence

- Slight overall increase in mapped water area despite forest loss suggests reservoir regulation and irrigation return flows are compensating natural hydrological decline in some sub-basins (e.g., Seonath, Tel).
- Upper Mahanadi shows declining water despite cropland expansion, indicating possible upstream stress not fully offset by storage systems.

8. Limitations and Future Scope

Classification Uncertainties

Remote sensing classification errors may influence flooded vegetation and small water body mapping.

Proxy-Based Water Quality Assessment

Water quality impacts are inferred conceptually from LULC transitions, not directly measured. Need for Integration With:

- In-situ water quality monitoring
- Sediment load measurements
- Groundwater level data
- Reservoir operation records

Coupling LULC analysis with hydrological modeling would improve predictive insights.

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References

ESRI. (2023). ESRI 10 m annual land cover (2017–2024) [Data set]. Living Atlas of the World. https://livingatlas.arcgis.com/landcover/

National Remote Sensing Centre. Land use land cover (LULC) database [1:250K Scale]. Indian Space Research Organisation. https://www.nrsc.gov.in/

Roy, P. S., Meiyappan, P., Joshi, P. K., Kale, M. P., Srivastav, V. K., Srivasatava, S. K., Behera, M. D., Roy, A., Sharma, Y., Ramachandran, R. M., Bhavani, P., Jain, A. K., & Krishnamurthy, Y. V. N. (2016). Decadal Land Use and Land Cover Classifications across India, 1985, 1995, 2005 (Version 1). ORNL Distributed Active Archive Center. https://doi.org/10.3334/ORNLDAAC/1336

Allan, J. D. (2004). Landscapes and riverscapes: The influence of land use on stream ecosystems. Annual Review of Ecology, Evolution, and Systematics, 35, 257–284.

Foley, J. A., et al. (2005). Global consequences of land use. Science, 309, 570–574.

Gregory, S. V., Swanson, F. J., McKee, W. A., & Cummins, K. W. (1991). An ecosystem perspective of riparian zones. BioScience, 41(8), 540–551.

Naiman, R. J., &Décamps, H. (1997). The ecology of interfaces: Riparian zones. Annual Review of Ecology and Systematics, 28, 621–658.

Paul, M. J., & Meyer, J. L. (2001). Streams in the urban landscape. Annual Review of Ecology and Systematics, 32, 333–365.

Sahu, G., & Vidyarthi, V. K. (2024). Modeling land use/land cover transformations in Mahanadi River basin in Chhattisgarh, India: Trends and future projections. GeoJournal, 89, Article 132. https://doi.org/10.1007/s10708-024-11152-0

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