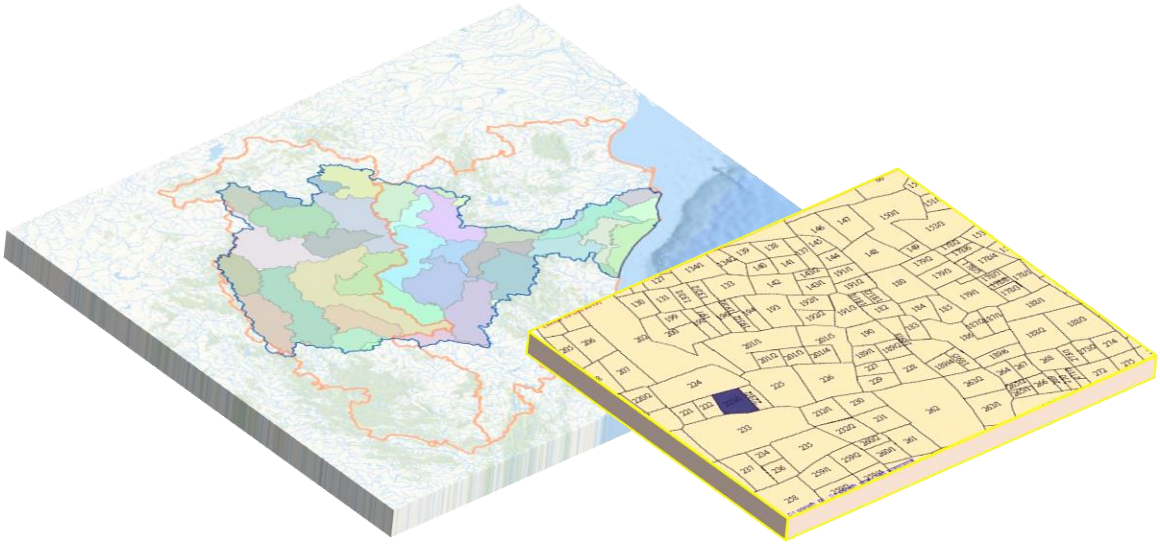
National River Conservation Directorate
Ministry of Jal Shakti,
Department of Water Resources,
River Development & Ganga Rejuvenation
Government of India

Revenue Map of Mahanadi River Basin



August 2025

Revenue Map of 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 Centres 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 center 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

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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 and 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
DES	Directorate of Economics and Statistics
MNCFC	Mahalanobis National Crop Forecast Centre
NIT	National Institute of Technology
IIT	Indian Institute of Technology
HAPIS	Horticultural Area Production Information System
GCA	Gross Cultivated Area
NSA	Net Sown Area
LULC	Land Use Land Cover

1. Introduction

The Mahanadi River Basin, spanning over 141,600 square kilometers across five states Chhattisgarh, Odisha, Jharkhand, Maharashtra, and Madhya Pradesh is a critical geographic and economic zone. It supports the livelihoods of millions through agriculture, forestry, fisheries, and industry, and sustains rich biodiversity and cultural heritage. Revenue mapping of this basin is a crucial exercise aimed at aligning land use, ownership, and administrative classifications with hydrological boundaries to inform integrated water and land resource management.

This mapping provides a comprehensive understanding of how various land-revenue categories such as agricultural land, forest areas, barren lands, and built-up zones are distributed across the basin. It helps in identifying the area under forest, which is essential for maintaining ecological balance, and the agricultural land that supports food security and rural economies. Mapping of built-up areas helps in understanding urbanization trends and their implications on natural resources. The barren lands and degraded zones identified in the mapping highlight the regions needing ecological restoration and investment.

Figure 1: Land and Resource Indicators for Revenue Mapping

The study covers various land-revenue categories, including forest land, agricultural land, water bodies, barren lands, and built-up areas, offering a complete spatial profile of land use. Special attention has been given to agricultural dynamics, with separate mapping of cash and non-cash crop areas, as well as crop production data, which are critical for understanding economic dependencies and planning agricultural support. Furthermore, the study evaluates people-to-land ratios, highlights vulnerable zones prone to degradation, and identifies over-exploited areas, particularly in terms of groundwater and land stress.

Importantly, the mapping also focuses on identifying areas with developmental potential, which could benefit from sustainable land-use strategies, such as afforestation, crop diversification, or water conservation. By integrating hydrological data with revenue and land-use records, this sub-basin-wise mapping provides a valuable foundation for scientific planning, resource management, and policy interventions in the Mahanadi River Basin.

Furthermore, the mapping exercise identifies vulnerable areas in terms of environmental degradation and zones that are over-exploited, particularly in terms of groundwater extraction, mining, and deforestation. It also highlights areas of possibility—land parcels that offer potential for sustainable development through afforestation, crop diversification, or water conservation.

This analysis has been carried out sub-basin wise, enabling more granular insights into land classification, resource utilization, and vulnerability across different physiographic zones. Figure 1 presents the sub-basin divisions of the Mahanadi River Basin, which serve as the primary units of analysis throughout this study. Sub-basin level mapping helps in capturing localized land-use patterns, administrative overlaps, and environmental challenges, making the findings more relevant for planning and intervention at the district and block levels.

Most importantly, this study guides the formulation of development and sustainable land-use strategies, ensuring that interventions are equitable, ecologically sensitive, and aligned with both hydrological and administrative priorities. By integrating environmental, socio-economic, and administrative data, the revenue mapping of the Mahanadi River Basin becomes a powerful tool for sustainable basin management, climate resilience, and regional planning.

1.1 Study area

The Mahanadi River Basin (MRB), one of the major river systems in eastern India, is composed of several sub-basins that contribute to its overall hydrology and catchment characteristics. These sub-basins are distributed across the upper, middle, and lower reaches of the river, along with a number of key tributaries that join the main stem at various points.

Major Main Stem Sub-Basins

1. **Upper Mahanadi Main Sub-Basin (18,839.00 sq. km)**
   This sub-basin covers a large portion of upland central India, with a landscape dominated by mixed forest areas and plateau regions interspersed with plains. The area features rural settlements, agricultural fields, and forest-agriculture interfaces. Its terrain supports a patchwork of land use, reflecting both human habitation and natural land cover.
2. **Middle Mahanadi Main Sub-Basin (19,596.60 sq. km)**
   Characterized by expansive plains and fertile valleys, this sub-basin lies between two major regions of the basin. It features a mixture of cultivated lands, settlements, and infrastructure corridors. The land cover shows signs of long-term

human settlement and development, with diversified land use patterns across districts.

3. **Lower Mahanadi Main Sub-Basin (6,537.80 sq. km)**
   This region lies in the coastal and sub-coastal zone of eastern India. It includes densely settled areas, agricultural tracts, and urban-industrial clusters. The landscape is generally flat, with productive soils and intensive land utilization. The area also includes sections of infrastructure networks and peri-urban development zones.

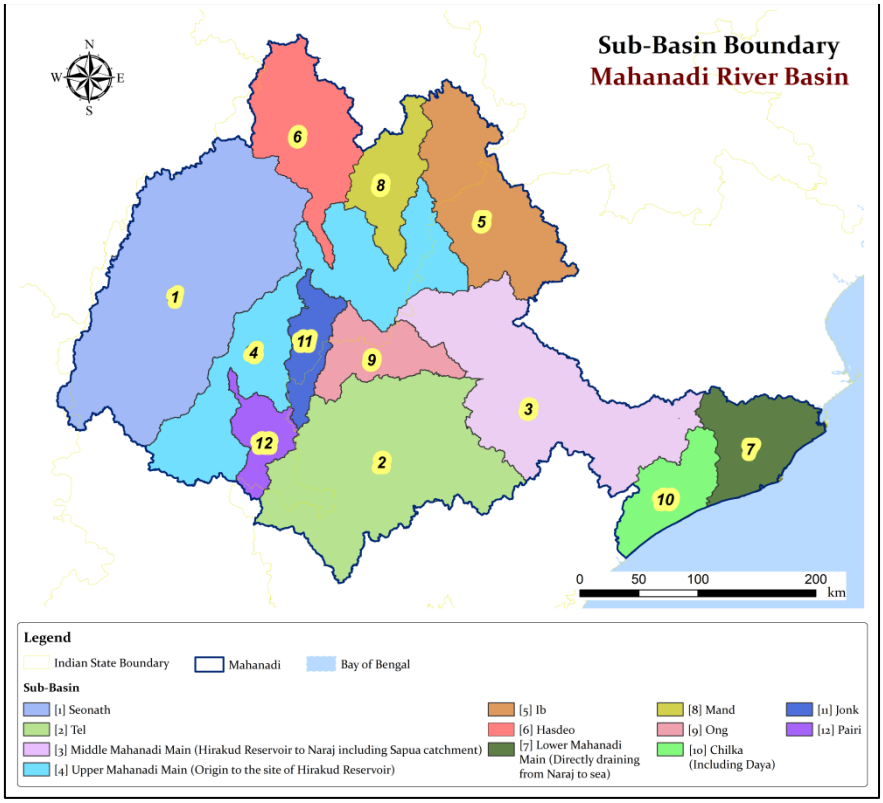

Figure 2: Sub-Basin Boundary of Mahanadi River Basin

Source: CGWRD

Major Tributary Sub-Basins

1. **Seonath Sub-Basin (30,950.00 sq. km)**
   The largest sub-basin in the region, Seonath includes diverse landscapes ranging from forested highlands to densely cultivated plains. It encompasses several major urban centers and a wide rural hinterland. The area shows a strong presence of road and rail networks, agricultural intensification, and growing built-up zones.
2. **Tel Sub-Basin (22,890.20 sq. km)**
   Spanning interior regions of western Odisha and eastern Chhattisgarh, this sub-basin includes a mix of uplands, farmlands, and forested zones. Settlements are interspersed with cultivated land, and traditional land use patterns are dominant. The area exhibits regional variations in land cover due to differences in terrain and development levels.

3. **Ib Sub-Basin (12,575.00 sq. km)**
   Located across mineral-rich and agriculturally active areas, this sub-basin includes plains, rolling terrain, and industrial belts. It features mixed land use, with zones under farming, mining, industry, and habitation. The area reflects a combination of resource-based development and traditional land occupation.
4. **Hasdeo Sub-Basin (9,918.10 sq. km)**
   This region includes parts of northern Chhattisgarh known for their resource extraction zones, forests, and farming settlements. The terrain is a combination of undulating land, flat valleys, and settlement clusters. The sub-basin shows contrasting land use, with dense vegetation in some areas and urban-industrial footprints in others.
5. **Mand Sub-Basin (5,329.10 sq. km)**
   Situated in a largely hilly and forested region, this sub-basin consists of rural and tribal-dominated zones with scattered agriculture. Settlements are sparse, and much of the land is under natural vegetation or mixed use. Development remains low-density and traditional in nature.
6. **Ong Sub-Basin (5,145.60 sq. km)**
   This sub-basin covers interior plains of western Odisha with moderate population density and cultivated land. The area includes small towns, rural markets, and open farmland. The landscape shows stable land use with moderate changes in built-up area over time.
7. **Chilika (Including Daya) Sub-Basin (5,004.30 sq. km)**
   This coastal sub-basin covers parts of the Odisha plains, including wetland zones, agricultural fields, and coastal villages. It includes areas surrounding a major lagoon and supports unique land cover types, including marshlands, reclaimed paddy fields, and aquaculture zones. Settlements are clustered near water bodies and transport routes.
8. **Jonk Sub-Basin (3,455.50 sq. km)**
   Covering parts of western Chhattisgarh and adjacent regions, the Jonk sub-basin is composed of rural land, cultivated patches, and mixed vegetation cover. The area has a moderate settlement density, with village clusters and agricultural zones distributed across varied terrain.
9. **Pairi Sub-Basin (3,242.60 sq. km)**
   This sub-basin lies in eastern Chhattisgarh and includes forested hills, small plains, and rural habitations. Land use is traditional, with a strong presence of community-managed resources and subsistence farming. The terrain includes valleys, highlands, and sparsely populated zones.

2. Land-revenue Categories

For the condition assessment and management of the Mahanadi River Basin (MRB), a comprehensive analysis of land revenue categories is essential. These categories offer valuable insights into land use, ownership, and productivity, which are critical for understanding the basin's environmental dynamics, planning water resources, and formulating sustainable development strategies.

The following analysis is based on land use statistics from the Directorate of Economics and Statistics (DES), Govt. Of Odisha and Commissioner Land Record, Chhattisgarh for the decades 2000-2001, 2010-2011, and 2020-2021. The report focuses on identifying major trends and changes across different subbasins in five key categories: Forest, Agricultural Land, Fallow Land, Net Sown Area, Build up area and Non-Cultivable Land.

An example village-level cadastral map is shown below for Paragaon Village, Tehsil Arang, District Raipur (Chhattisgarh), located on the banks of the Mahanadi River. The map highlights Khasara/Plot No. 1598/1872 and illustrates how such detailed plot-level information can be useful for river conservation and management work.

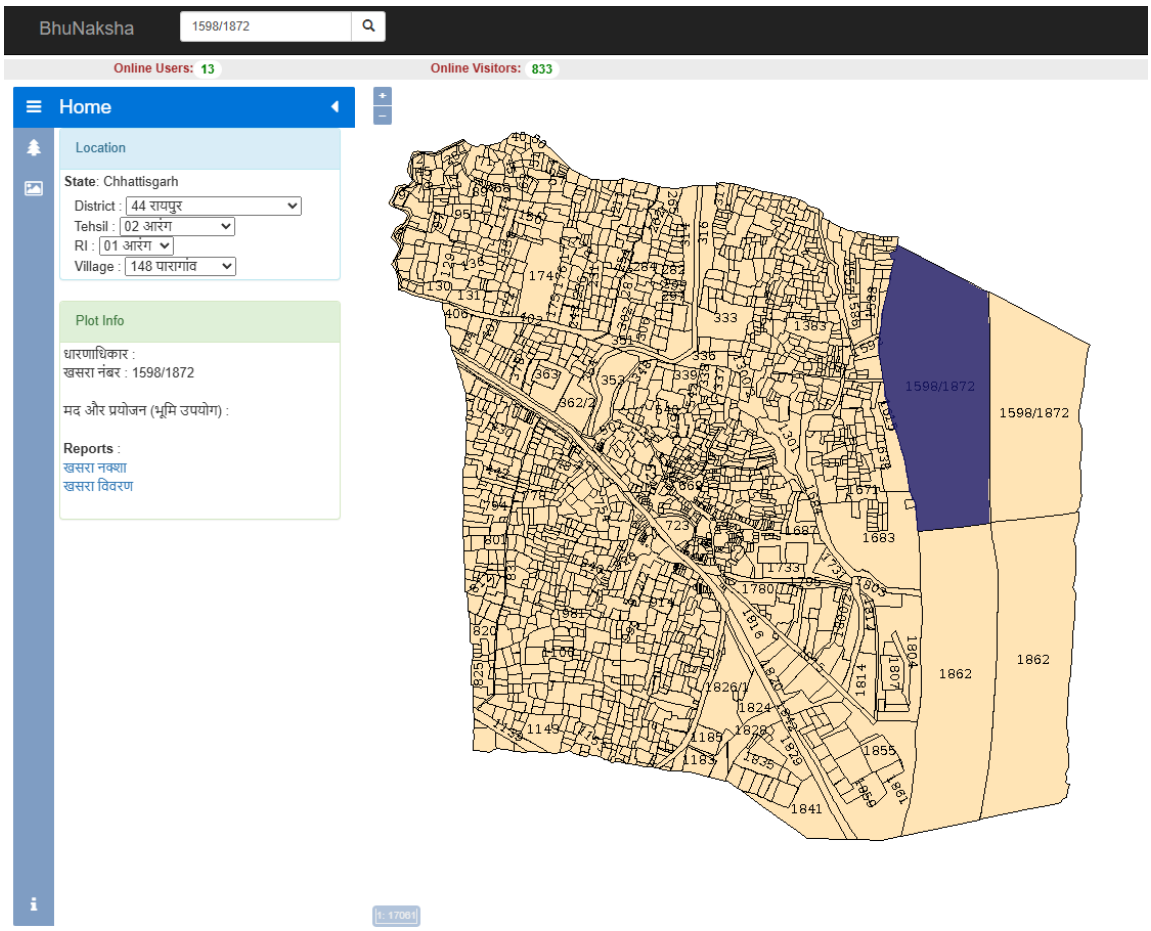

Figure 3: Example cadastral (revenue) map of Paragaon Village on the Mahanadi River bank, showing Plot No. 1598/1872.

Source: Bhunaksha Chhattisgarh, Government of Chhattisgarh (https://bhunaksha.cg.nic.in/)

Cadastral maps, when integrated into basin-level studies, provide several benefits:

- **Identifying encroachments:** Helps detect agricultural or built-up expansion into the riverbank and floodplain zones.
- **Planning riparian buffers:** Facilitates targeted interventions like afforestation or grass strip development along khasra boundaries adjoining the river.
- **Ownership-linked conservation:** Links land parcels with ownership records, enabling community participation and accountability in riverbank protection programs.
- **Conflict resolution:** Provides legal clarity in cases of disputes over floodplain land use or riverbank settlements.
- **Micro-to-macro integration:** Supports scaling up of village-level land management insights to sub-basin and basin-wide conservation strategies.

2.1 Land-revenue Categories under Chhattisgarh State

Table 1: Land Use Categories of MRB under the Chhattisgarh State.

Sub basin Total	Decade	Land Use Categories [in Ha] in 2020-21												
		Hilly	Forest	Water Bodies	Barren & uncultivated land	Land under non agriculture use	Cultivable waste	Pasture or grazing land	Land under Misc. crops	Current Fallows	Other Fallows	Net Sown area	Area sown more than once	Gross cropped area
Upper Mahanadi	2000-01	18229.35	38899.87	0	4019.4	11394.39	4014.34	14877.55	0	4014.04	3987.64	65431.89	5382.08	70813.96
	2010-11	18229.35	38815.57	2579.87	2167.98	11027.04	2896.07	14210.97	0	5194.89	4925.37	64181.22	9233.15	73414.37
	2020-21	18229.35	38217.44	2579.87	2158.38	12032.15	2823.82	14472.37	0	6428.78	6314.87	61342.39	9877.95	71220.35

Seonath	2000-01	277536.15	703515.67	0	48284.17	233912.52	71814.79	235365.04	340.65	90430.2	71242.66	1470351.13	501731.02	1972082.15
	2010-11	277536.15	701333.4	84291.29	49294.25	138735.76	84643.29	237778.6	591.63	67560.33	61712.77	1579827.41	780796.68	2360624.09
	2020-21	277536.15	682630.26	84291.29	45368.08	161185.17	77828.24	239176.06	579.04	50660.92	62769.49	1715993.55	849095.05	2565088.6
Pairi	2000-01	277536.15	701333.4	84291.29	49294.25	138735.76	84643.29	237778.6	591.63	67560.33	61712.77	1579827.41	780796.68	2360624.09
	2010-11	31902.89	289016.94	7991.28	2419.15	5716.6	1984.66	9958.92	7.57	805.31	1327.36	55828.36	9842.18	65670.53
	2020-21	31902.89	282304.43	7991.28	2771.4	4894.46	1627.23	11779.61	6.79	1862.1	1867.29	59934.67	18039.63	77974.3
Hasdeo	2000-01	164285.66	646011.11	0	27010.18	45769.75	11715.21	60354.91	18.01	15974.47	16004.43	256127.32	44638.78	300766.11
	2010-11	164285.66	623843.07	17738.09	24069.87	26579.83	11170.72	60770.68	23.25	19408.53	19029	257354.47	43942.87	301297.34
	2020-21	162271.33	669053.16	17458.68	24606.86	27442.32	14622.91	64916.15	119.86	27280.45	19029.44	251935.34	39361.66	291297
Mand	2000-01	247706.03	226359.45	0	11370.6	27525.03	5527.26	45328.9	3.61	13683	11349.02	197939.13	26244.94	224184.07
	2010-11	247706.03	225458.57	4782.36	12248.35	22054.88	5308.12	46217.74	5.71	14669.61	11860.96	197167.29	32555.28	229722.57
	2020-21	247706.03	225675.78	4782.36	12211.64	25765.93	6688.47	49018.86	41.74	20661.87	15739.83	192822.99	29132.51	221955.51
Jonk	2000-01	11006.63	99144.04	0	2613.18	14241.95	2509.09	10499.43	8.8	4241.46	2630.27	112597.02	4932.6	117529.62
	2010-11	11006.63	92488.8	5940.31	3647.2	9495.99	2525.55	11969.44	5.51	3124.24	1655.78	118442.7	18203.77	136646.52

			6									5		
	2020-21	11006.63	102017.78	5940.31	3837.03	7977.94	2161.06	13136.72	4.04	3854.22	2163.25	122527.35	22381.49	144908.84
IB	2000-01	118694.34	151699.23	0	59483.41	21887.75	4607.87	37105.85	0	18244.33	11405.25	207781.59	17036.46	224818.05
	2010-11	118694.34	178712.57	1973.91	32820.69	15517.12	5613.11	36612.63	0	12471.04	18891.44	208283.49	20483.76	228767.26
	2020-21	118694.34	178719.2	1973.91	32558.79	15051.43	6434.86	37430.51	0	18650.82	12441.58	212076.01	19518.8	231594.81
Tel	2000-01	24005.52	105441.57	0	1527.03	7391.82	1898.83	6566.43	6.34	1213.1	1435.76	39967.83	1476.14	41443.96
	2010-11	24005.52	105441.57	1668.62	1266.13	2639.22	1841	7199.65	3.68	821.03	1246.46	37891.6	2154.31	40045.91
	2020-21	24005.52	105511.87	1668.62	1164.09	2380.61	1290.61	8102.18	4.24	2600.52	1042.11	40408.61	1296.14	41704.75
Ong	2000-01	9762.63	20357.87	0	1234.8	8831.24	1480.34	6274.79	5.55	3057.86	985.7	66193.79	2020.4	68214.19
	2010-11	9762.63	22429.16	2135.25	1659.04	5914.35	1418.54	6766.87	4.77	806.57	764.69	69353.12	5939.59	75292.71
	2020-21	9762.63	22457.56	2135.25	1067.97	4560.95	1397.03	7158.5	7.96	1660.55	1128.72	67982.35	10675.41	78657.76
Middle Mahanadi	2000-01	716.76	1754.08	0	173.96	841.38	82.38	841.59	0.06	138.68	113.61	5786.82	321.09	6107.9
	2010-11	716.76	1769.82	231.59	173.28	886.6	86.1	851.7	0.05	117.8	182.95	5992.06	1288.08	7280.14
	2020-21	716.76	1774.84	231.59	172.19	709.06	80.29	862.99	0.11	118.59	162.2	6215.98	1598.46	7814.43

2.1.1 Area under Forest

General Trend: Most sub-basins show either marginal decline or stable forest area, with some like IB and Jonk showing slight increases. The decrease in others (like Seonath and Pairi) likely reflects encroachment, deforestation for agriculture, and infrastructural expansion.

Seonath, the largest sub-basin, witnessed a drop of nearly 18,700 Ha, which is ecologically significant and may impact watershed functions.

Stability in smaller basins (like Tel and Middle Mahanadi) suggests either managed forest patches or limited human intervention.

Potential Causes:

- Agricultural expansion (cropland encroachment)
- Urban-industrial development
- Forest degradation not reflected in area (i.e., qualitative loss)

Implication: Need for forest conservation and afforestation, especially in sensitive ecological corridors of Seonath and Pairi.

2.1.2 Agricultural Land

a) Net Sown Area: Increased in high-performing basins like Seonath, IB, and Jonk, indicating robust agricultural practices, possibly due to irrigation, better inputs, and market access. Stagnation/Decline in Mand and Hasdeo may reflect soil exhaustion, groundwater limits, or socio-economic shifts (migration, labour shortages).

b) Area Sown More Than Once: A key indicator of cropping intensity, shows major increases in Seonath (+68,000 Ha) and Jonk (+4,000 Ha), pointing to improved irrigation and double cropping.

Implication: While agriculture is intensifying in many regions (particularly Seonath), sustainability is a concern in basins with declining trends like Mand and Hasdeo. These areas may benefit from soil health improvement, crop diversification, and better irrigation efficiency.

2.1.3 Area under Non-Agricultural Use

Most sub-basins (e.g., Upper Mahanadi, Seonath, Mand) show consistent increases, clearly indicating urban sprawl, road expansion, mining, and industrial growth.

Seonath leads this increase, with ~22,450 Ha more land under non-agriculture use from 2010–11 to 2020–21.

Even rural sub sub-basins like Kelo (Under Upper Main Mahanadi) show gradual growth in non-agricultural use, hinting at dispersed infrastructure development.

Implication: With development accelerating, there is a growing pressure on agricultural and forest land, emphasizing the need for land zoning, planning regulations, and safeguarding critical zones (e.g., floodplains, forests).

2.14 Area under Water Bodies (2010–11 and 2020–21)

Most sub-basins show no significant change, suggesting:

No major new reservoirs/dams constructed.

Seasonal and minor water bodies possibly not captured or consistent in definition.

Seonath (84,291 Ha) and Upper Mahanadi (46,125 Ha) continue to have the largest surface water extents.

Note: In 2000–01, water bodies were not separately classified; their area was included under 'Land under Non-Agricultural Use'.

Implication: While water availability appears stable, no net gain in surface water resources hints at the need for:

- Better rainwater harvesting
- Wetland protection
- Accurate mapping of seasonal vs. perennial water bodies

2.1.5 Area under Built-up Land

The built-up area of the whole MRB experienced a substantial increase of approximately threefold (+277%) between 1985 and 2023. Hotspots of built-up expansion (Linked to: urbanization, infrastructure projects, mining expansion, and township development) under CG State include:

- Seonath (Bilaspur-Durg region)
- Upper Mahanadi (Raipur-Raigarh belt)

Implication: Rapid and often unregulated built-up growth may lead to:

- Disruption of natural drainage
- Encroachment on farmland/wetlands
- Urban heat island effects
- Spatial land use planning and low-impact urban development should be prioritized.

A detailed discussion of the drivers and spatial patterns of this change, along with other LULC changes, based on remote sensing data, is presented in Section 2.3.

2.1.6 Area under Barren & Uncultivated Land

Mixed trends:

- Reduction in Seonath and Pairi suggests land reclamation for farming or settlements.
- Increase in Hasdeo (+500 Ha) and Jonk may point to land degradation or unsuitable terrain.
- Minor but persistent share in all basins (~1–3% of total area), these lands have potential for - 1. Silvipasture, 2. Renewable energy installations (solar farms), 3. Afforestation or eco-tourism zones.

Implication: Need to differentiate between true wasteland vs. recoverable degraded land for effective rehabilitation strategies.

2.1.7 Decadal Total - Land Revenue Categories

Table 2: Decadal Total (2000–2021) of Land Use Categories in the Mahanadi River Basin within Chhattisgarh State.

Decadal Total		2000-01	2010-11	2020-21
Geographical area of the Block		15787374.71	15787356.71	15886752.71
Geographical area of the Block lying in the Basin		7886013.69	7886004.75	7925795.81
Land use details of MRB (Chhattisgarh)	Hilly	992909.47	992909.47	990895.14
	Forest	2827933.4	2829724.73	2855650.47
	Water Bodies	NA	175457.95	175178.54
	Barren & uncultivated land	182426.09	161364.98	150294.55
	Land under non agriculture use	487434.48	311849.77	343848.33
	Cultivable waste	135352.32	147039.52	152683.52
	Pasture or grazing land	542014.46	546494.73	563450.66
	Land under Misc. crops	448.72	716.57	924.99
	Current Fallows	175757.82	152425.61	154848.38
	Other Fallows	144839.12	142155.3	146012.98
	Net Sown area	3255045.62	3397242.34	3539330.27
	Area sown more than once	711131.35	1101601.08	1179584.49
	Gross cropped area	3966176.97	4498843.42	4718914.76

2.2 Land-revenue Categories under Odisha State

The Odisha part of Mahanadi subbasin shows a concerning trend of decreasing forest cover and a continuous increase in both non-cultivable and build-up areas. This indicates a potential shift from natural and agricultural land towards development and non-arable uses. However, there is a positive trend in agricultural activity, with both Fallow Land and Net Sown Area increasing. The overall Agricultural Land (Cropped Area) shows a mixed trend, indicating fluctuations and instability.

2.2.1 Area Under Forest

Forest land is another critical category, classified into reserved forests, protected forests, and unclassified forests. Forests contribute significantly to regulating surface runoff, reducing soil erosion, maintaining base flow in rivers, and supporting biodiversity. Assessing forest cover changes helps in identifying deforestation trends, impacts of encroachments, and areas that need reforestation or conservation interventions. The trend for forest cover shows a general decline across most subbasins. The most significant decrease was in Tel, with a loss of over 800,000 hectares.

2.2.2 Agricultural land

Agricultural land remains one of the most significant categories, comprising irrigated land (including double or multi-cropped areas), unirrigated land (typically single-cropped), and fallow lands. Fallow lands are further divided into current fallows and long-term fallows. These indicate periods of non-cultivation due to soil recovery needs, water scarcity, or economic constraints. Monitoring fallow trends over time helps assess shifts in agricultural practices, land productivity, and the need for targeted agricultural support or soil fertility enhancement measures. Agricultural land, which includes both Fallow Land and Net Sown Area, shows a mixed but often negative trend across the subbasins.

a) Fallow Land:

A consistent trend of decreasing fallow land is observed in all subbasins. This could indicate either that this land is being brought into cultivation or is being converted to other non-agricultural uses. The most significant decrease was in Lower Mahanadi.

b) Net Sown Area:

Net Sown Area, an important measure of active cultivation, exhibits mostly declining or mixed patterns across the region. The most significant reduction is observed in the Lower Mahanadi sub-basin, indicating notable shifts in agricultural land use.

2.2.3 Area not available for cultivation

Cultivable waste land refers to land that is potentially arable but has not been brought under cultivation for several years due to constraints like poor soil, water availability, or economic viability. Despite being uncultivated, such land holds promise for reclamation and productivity improvement through soil conservation, irrigation infrastructure, and land development schemes. Its

Table 3: Land Use Categories of MRB under the Odisha State.

Sub basin Total	Decade	Classification of reporting Area(in hectares)										
		Forests	Not available for Cultivation		Other Uncultivated Land Excluding Fallow Land			Fallow Land		Agricultural land		
			Area under Non Agricultural Uses	Barren and Unculturable Land	Permanent Pasture and other Grazing Land	Land under Misc. Tree Crops and Groves not included in Net Area Sown	Culturable waste Land	Fallow Lands other than current Fallows	Current Fallow	Net Area Sown	Cropped Area	Area Sown More Than Once
Tel	2000-2001	1570150	980889	987606	964211	949008	957622	955746	960412	1281361	1408960.3	1058726.4
	2010-2011	767508	132690.04	106349.08	77788.88	13126.88	52261.84	52263.14	123724.6	595455	673809.41	101563.58
	2020-2021	314934	216184	254758.8	144536	17626.4	92396	134762.6	242926.8	730140	840833.96	110694.16
Middle Mahanadi	2000-2001	716741	127160.72	80619.86	62902.5	73721.92	77073.25	51264.46	59870.75	895931	1191302.6	333286.89
	2010-2011	834574	156546.52	92984.99	57481.96	56768.68	61904.12	66605.08	84031.59	606020	722135.32	116115.54
	2020-2021	384782	235004.38	119454.54	92130.98	23510.94	98466.68	115987.94	163575.5	672591	831541.19	158949.97
Lower	2000-	76799	109089.46	10757.66	20554.14	19875.35	35125.97	19481.52	38619.83	319993	476292.52	215124.65

Mahanadi	2001											
	2010-2011	76597	127769.35	9399.89	29845.16	13714.62	20626.45	22045.16	31512.15	294525	390574.54	96049.823
	2020-2021	25351	145155.5	10294.9	26603.4	14581.1	22260.05	24108.15	52622.55	261873	348124.63	86252.085
Chillika Subbasin	2000-2001	84520	55976.24	14860.56	13064.4	28659.48	23793.6	11925.04	19689.6	405429	476896.6	318687.04
	2010-2011	83299	72817.24	19095	18063.12	28116.8	14403.72	18024.16	16509	166043	211644.38	45601.584
	2020-2021	38386	86933	22818.2	19477.2	23333.8	21314.3	24513.3	30258.1	167555	216497.61	48942.262
Ib Subbasin	2000-2001	214062	39503.9	41605.99	34542.87	22783.9	27231.45	11089.36	24145.99	420050	487275.39	63086.79
	2010-2011	268175	68019.374	42391.687	41886.648	20438.432	47839.158	49837.001	61033.77	161920	169022.06	25056.272
	2020-2021	149365	71741.6	40352	33601.2	3468.2	43638.6	53637	58309.6	175654	187184.14	11529.743
Ong Subbasin	2000-2001	88650	31996	15199.6	10808.8	19432	9440.8	2178.8	10095.6	218614	278097.79	59484.192
	2010-2011	93419	38638.8	4874.8	16564	712.4	15192	14068.8	22487.2	191020	238964.96	47944.957
	2020-2021	20630	44362	8826	17702	710	16188	17422	28060	173428	226749.63	53321.804
Upper Mahanadi	2000-2001	67839	22205.4	9377.52	6039.86	12356.9	6219.7	999.68	6544.62	160651	195474.362	34823.958
	2010-2011	41509	17152.204	3961.094	7943.688	939.076	8697.44	8925.972	13168.142	59888.8	69430.9106	9542.07422

	2020-2021	20529.7	21345.82	6773.6	8317.94	625.74	10791.12	12404.5	13678.52	56019.6	67088.242	11069.02914
Jonk Subbasin	2000-2001	30092	2620	2005	2410	1469	1052	471	2443	42292	59490.43	17198.43
	2010-2011	43881	6136	2125	4152	1840	1644	1841	4273	31633	37249.392	5616.392
	2020-2021	9453	7418	2202	3933	241	1655	2345	4974	29361	33161.863	3801.101
Pairi Subbasin	2000-2001	7925.4	577.8	488.7	243.6	321	207	402.3	517.5	14039	19290.987	5251.787
	2010-2011	8182.5	816.21	398.52	491.31	563.4	332.91	280.08	849.87	7141.6	7602.5858	460.99575
	2020-2021	3530.8	1413.6	694	894.4	711.6	252.4	594.4	852.4	7980.7	8264.4412	283.7748

Source: Directorate of Economics and Statistics (DES), Govt. of Odisha

inclusion in condition assessment allows planners to identify opportunities for expanding agricultural land use sustainably. Area that are not available for cultivation includes built up areas, barren lands and sometimes waterbodies.

2.2.4 Area under water bodies

A detailed discussion of the drivers and spatial patterns of the changes in waterbodies, along with other LULC changes, based on remote sensing data, is presented in Section 2.3.

2.2.5 Area under built-up land

Built-up Area (Area under Non-Agricultural Uses): From the land use statistics all subbasins showed a clear and consistent increase in built-up areas. The most significant growth was in Lower Mahanadi. The Lower Mahanadi Consists of most of the coastal cities of the states including Cuttack, Kendrapara, Jagatsinghpur, Puri and Khordha. A detailed discussion of the drivers and spatial patterns of this change, along with other LULC changes, based on remote sensing data, is presented in Section 2.3.

2.2.6 Area under barren land

Barren and unculturable lands, often characterized by rocky terrain, poor soil, or adverse topography, represent areas with minimal to no productive potential. While not immediately suitable for cultivation, these lands are important to identify in order to prevent further environmental degradation and to explore potential uses such as afforestation or renewable energy installations.

Barren Land (Barren and Unculturable Land): Most subbasins show a mixed trend, with Jonk having the highest increase in barren land. A significant reason for the increasing trend of barren land in the Jonk subbasin is the ongoing deforestation in its constituent districts, Nuapada and Bargarh. Between 2020 and 2024, Nuapada lost 24 hectares of its natural forest, while Bargarh lost 11 hectares. This loss of tree cover is a major contributor to soil erosion and degradation, ultimately converting forested areas into barren, unproductive land.

2.2.7. Decadal Total - Land Revenue Categories

Table 4: Decadal Total (2000–2020) of Land Use Categories in the Mahanadi River Basin within Odisha State.

Decadal Total		2000-2001	2010-2011	2020-21
Geographical area of the district		10817562.35	10817562.35	10817562.35
Geographical area of the district lying in the Basin		6572489.42	6572489.42	6572489.42
Land use details of MRB	Forest	2856778.35	2217145.243	966961.17
	Area under Non-Agricultural Uses	1370018.54	620585.738	829557.9
	Barren and Unculturable Land	1162520.95	281580.061	466174.04
	Pasture and other Grazing Land	1114776.67	254216.766	347196.12
	Land under Misc. Tree Crops	1127627.25	136220.288	84808.78
	Culturable waste Land	1137765.27	224545.638	306962.15
	Other Fallows	1053558.58	233890.393	385774.89
	Current Fallow	1122338.63	361862.296	595257.51
	Net Area Sown	3758358.92	4593080.991	2105670.173
	Gross Cropped Area	2113646.103	2520433.566	447951.2172
	Area Sown More Than Once	2274601.768	2759445.703	484843.9344

2.3 Assessment of Land Use and Land Cover Change over MRB (1985–2023)

This assessment examines the spatial and temporal dynamics of Land Use and Land Cover (LULC) in the MRB over the period 1985 to 2023, utilizing Landsat 5 TM data for the year 1985 and Sentinel-2 MSI data for 2023.

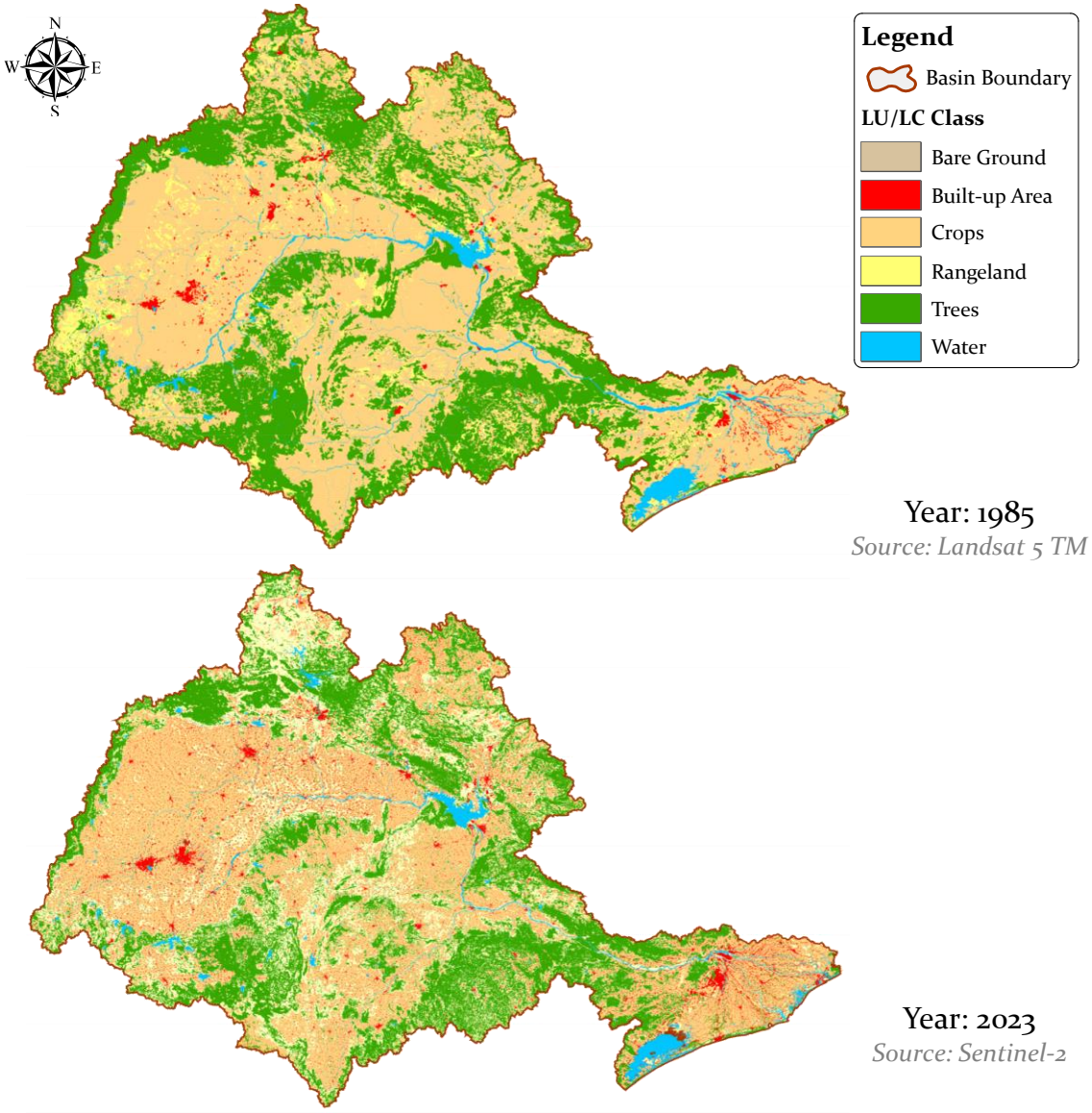

Figure 4: Spatial distribution of Land Use and Land Cover (LULC) in the MRB for 1985 and 2023, illustrating major changes over the 38-year period.

The Land Use and Land Cover (LULC) analysis of the MRB between 1985 and 2023 reveals substantial spatial transformations across the major land cover categories. The comparison of classified datasets indicates both expansion and contraction in various classes, reflecting the combined influence of anthropogenic activities, land management practices, and environmental change.

- Bare Ground decreased from 622.97 km² in 1985 to 334.30 km² in 2023, marking a 46.34% reduction. This decline suggests either natural revegetation, conversion to

agricultural or built-up land, or improved vegetation cover due to land restoration measures in certain areas.

Table 5: Area statistics of major Land Use and Land Cover (LULC) classes in the MRB for 1985 and 2023, with absolute and percentage changes.

Common Class	Area 1985 (km2)	Area 2023 (km2)	Change (km2)	Change (%)
Bare Ground	622.97	334.3	**-288.67**	**-46.34%**
Built-Up Area	1,946.75	7,342.11	**5,395.36**	**277.15%**
Crops	80,260.56	59,411.23	**-20,849.33**	**-25.98%**
Rangeland	9,648.42	31,826.17	**22,177.75**	**229.86%**
Trees	47,332.76	41,830.83	**-5,501.93**	**-11.62%**
Water Bodies*	5,165.46	4,669.97	**-495.49**	**-9.59%**
**Water Bodies also includes Flooded Vegetation.*				

- Built-up Area exhibited a pronounced increase, expanding from 1,946.75 km² to 7,342.11 km², representing a 277.15% growth. This sharp rise underscores rapid urban expansion, infrastructure development, and the transformation of rural landscapes into urban settlements over the past four decades.
- Crops showed a significant contraction, declining from 80,260.56 km² to 59,411.23 km², a 25.98% loss. This reduction may be attributed to conversion into built-up land, rangeland expansion, or abandonment due to declining agricultural viability in certain parts of the basin.
- Rangeland increased substantially from 9,648.42 km² to 31,826.17 km², marking a 229.86% growth. This trend may indicate land degradation, overgrazing, or a shift from intensive cultivation to more extensive land uses, possibly linked to socio-economic or climatic drivers.
- Tree Cover declined from 47,332.76 km² to 41,830.83 km², a 11.62% decrease. This loss reflects deforestation pressures, clearance for agriculture or settlement, and potential impacts of logging activities, though the magnitude of decline is moderate compared to other categories.
- Water Bodies (including Flooded Vegetation) declined from 5,165.46 km² in 1985 to 4,669.97 km² in 2023, a 9.59% reduction. This decrease could be linked to changes in hydrological regimes, increased water abstraction, sedimentation, or climate-induced variability in surface water extent.

Overall, the LULC change assessment highlights a clear pattern of urban expansion, agricultural decline, and rangeland growth, accompanied by moderate forest loss and slight contraction of water resources. These changes have important implications for biodiversity conservation, water security, and sustainable land management within the MRB.

3. Productions of different crops

The basin supports a wide diversity of crop production ranging from staple cereals and pulses to high-value cash crops, vegetables, fruits, and spices. Crop choice and productivity largely depend on landform, soil type, and irrigation availability, ensuring both subsistence needs and market-oriented farming. The next sections will highlight the classification of crops into cash and non-cash categories within the MRB.

3.1 Crop Categories in the MRB

Cash Crops:

- **Oilseeds:** Soybean, Groundnut, Linseed, Niger, Sesame, Sunflower, Rapeseed-Mustard, and Safflower are major oilseed crops grown primarily in rainfed uplands and midlands across Chhattisgarh and Odisha.
- **Sugarcane:** Sugarcane is cultivated as a high-value commercial crop in irrigated tracts of the basin, especially in fertile riverine and command areas.
- **Commercial Vegetables:** Brinjal, Tomato, Cauliflower, Cabbage, Bhindi, Onion, Potato, Pumpkin, and Bottlegourd are widely grown in peri-urban and irrigated areas during rabi and summer seasons.

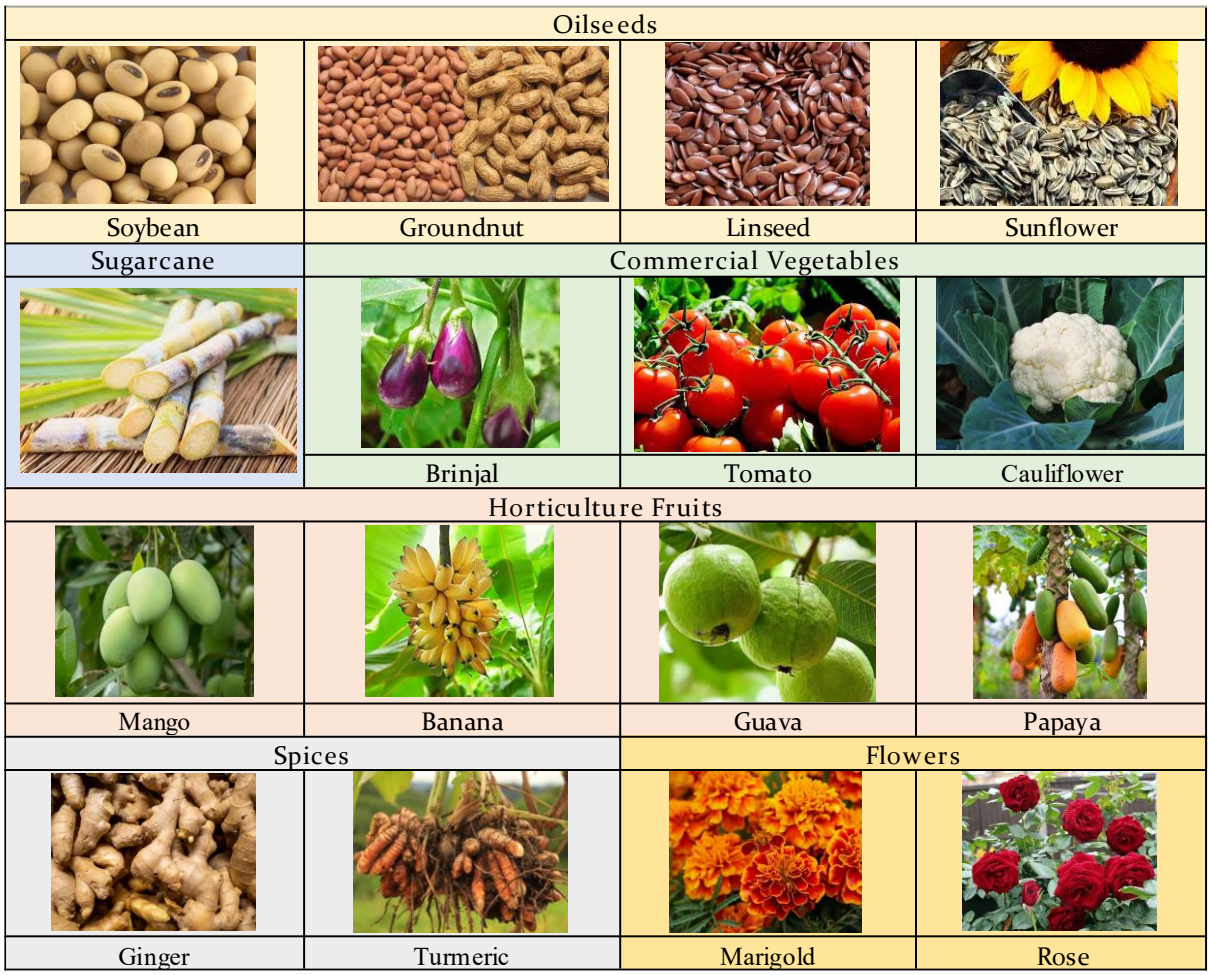

Figure 5: Major Cash Crops of MRB

- **Horticulture Fruits:** Mango, Banana, Guava, Papaya, Lemon, Jackfruit, Orange, Custard Apple, and Litchi are cultivated in homestead gardens, orchards, and upland areas with assured moisture regimes.

Non-Cash Crops:

- **Cereals:** Paddy (Kharif and Summer), Wheat, and Maize are the major staple cereals cultivated across all landforms depending on water availability and soil type.
- **Pulses:** Gram, Moong, Urad, Tur, Lathyrus, Horse Gram, Pea, and Lentil are largely cultivated in upland and rainfed areas, often in mixed or sequential cropping systems, enhancing soil fertility and food security.
- **Millets & Minor Cereals**: Kodo, Kutki (Little Millet), Foxtail Millet, Bajra (Pearl Millet), Ragi (Finger Millet), and Jowar (Sorghum) primarily cultivated in upland, rainfed, and tribal-dominated regions of Chhattisgarh and Odisha.

Figure 6: Major Non-Cash Crops of MRB

The rice (paddy) coverage for the 2023–2024 kharif season was obtained from the Mahalanobis National Crop Forecast Centre (MNCFC) and used to prepare a spatial map of the Mahanadi River Basin. Rice, the principal non-cash crop of the basin,

dominates agricultural production in large tracts, with the Upper Mahanadi Basin in Chhattisgarh often referred to as the "Dhan ka Katora" (Bowl of Rice) due to its extensive paddy fields. Significant rice-growing zones are also evident in the Odisha part of the basin. Figure 1 shows the spatial distribution of Kharif rice coverage for the 2023–2024 season, highlighting these core production areas.

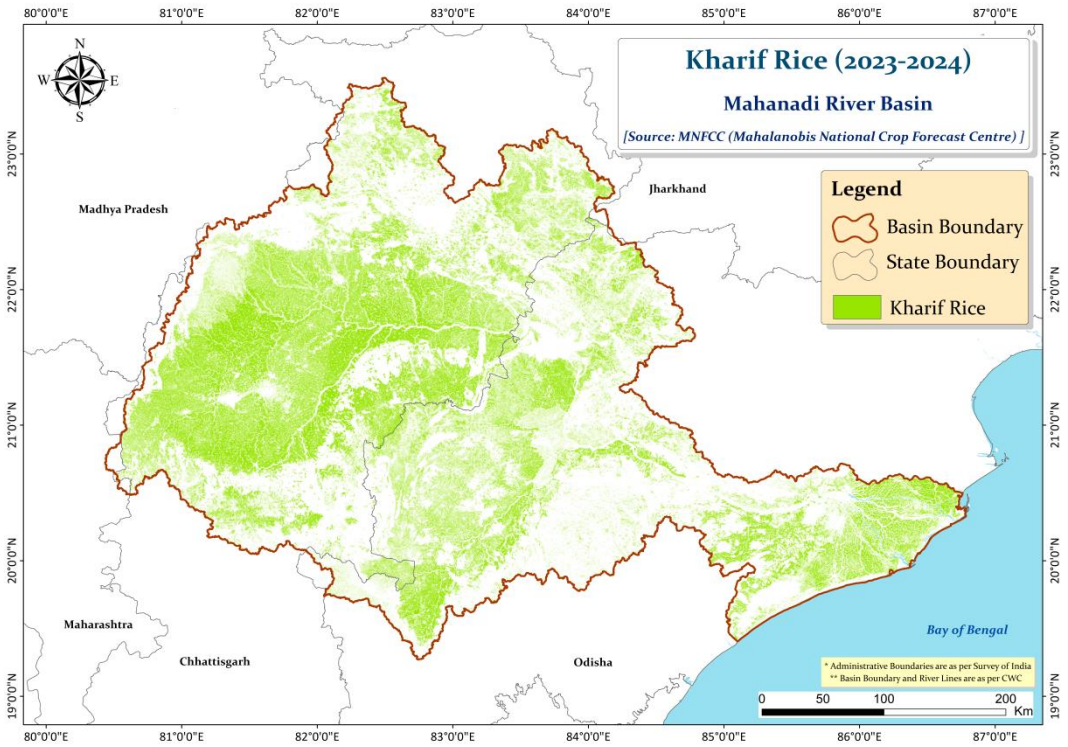

Figure 7: Kharif Rice Coverage (2023–2024) in the Mahanadi River Basin, highlighting major production zones in Chhattisgarh's "Dhan ka Katora" and Odisha.

3.2 Crop Categories at Sub-Basin Level for Chhattisgarh State

The analysis of crop production has been carried out for the sub-basins of the Mahanadi River Basin that fall within the geographical extent of **Chhattisgarh state**. These include the **Upper Mahanadi**, **Middle Mahanadi**, **Seonath**, **Hasdeo**, **Mand**, **Ib**, **Ong**, **Tel**, **Jonk**, and **Pairi** sub-basins. The production statistics for various crops under these sub-basins have been compiled and analyzed to understand decadal trends, spatial variation, and cropping patterns. The assessment integrates both field crops and horticultural crops across kharif, rabi, and summer seasons, reflecting the agricultural dynamics within the Chhattisgarh part of the basin.

3.2.1 Data Preparation Methodology at Sub-Basin Level

- **Primary Data Sources**

  Field Crops: Data is sourced from the *Commissioner Land Record*, which maintains district and block-level statistics on agricultural land use.

Horticulture Crops: Data is obtained from the **HAPIS (Horticulture Area Production Information System)**, a web portal maintained by the Government of India.

- For **2013–14 to 2020–21**: Data is taken directly from the HAPIS portal.
- For **2001–02 to 2012–13**: Data is based on primary records from the Horticulture Department.

- **Spatial Mapping to Sub-basins**

  - The raw crop area data is originally available at block-level. The areas under different crops in sub-basin are populated as per the sub-basin/block wise GIS data provided by CG WRD.

- **Seasonal Context for Vegetables**
  In Chhattisgarh:

  Kharif Season: Vegetables are mainly grown in uplands due to monsoon rainfall.

  Rabi and Summer Seasons: With availability of irrigation, vegetables are cultivated in uplands, midlands, and lowlands — leading to higher total vegetable areas in these seasons compared to kharif.

3.2.2 Crop Area Under - Seonath Sub-Basin

Table 6: Area Under Cash Crops – Seonath Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2020–21 (ha)	Major Crops Included
Oilseeds	49,259	92,175	78,426	Soybean, Groundnut, Sesamum, Linseed, Mustard, etc.
Sugarcane	1,066	376	438	Sugarcane
Spices	1,352	16,610	14,555	Ginger, Garlic, Coriander, Turmeric, Chilli
Flowers	378	1,287	1,796	Marigold, Rose
Fruits	9,887	39,888	55,468	Mango, Guava, Papaya, Banana, etc.
Vegetables	33,309	1,11,807	1,43,901	Tomato, Brinjal, Cabbage, Cauliflower, Onion, etc.

Table 7: Area Under Non-Cash Crops – Seonath Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2020–21 (ha)	Major Crops Included
Cereals	14,53,654	14,90,562	15,61,537	Paddy, Wheat, Maize, Sorghum, Barley, etc.
Pulses	1,32,327	2,09,859	2,10,228	Gram, Urd, Moong, Tur, Pea, Lentil, Lathyrus, etc.

- **Expansion of Cropped Area:** Net cropped area rose by ~9% and gross cropped area by ~17% over two decades, showing intensified land use.
- **Dominance of Cash Crops:** Significant increase in vegetables, fruits, and oilseeds (especially soybean in 2010–11), marking a shift towards high-value cropping.
- **Pulse Crop Growth:** Pulses like gram and lathyrus expanded, suggesting diversification for nutrition and income.
- **Horticultural Rise:** Fruits (mango, banana, guava) and vegetables grew steadily, indicating agribusiness linkages and input availability.
- **Higher Cropping Intensity:** Cropping intensity surpassed 150% by 2020–21, reflecting better irrigation, adoption of short-duration crops, and policy support.
- **Marginal but Notable Sectors:** Sugarcane saw minor expansion, while floriculture (marigold, rose) gained pace near urban clusters.

3.2.3 Crop Area Under - Upper Mahanadi Sub-Basin [CG Part]

Table 8: Area Under Cash Crops – Upper Mahanadi Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2020–21 (ha)	Major Crops Included
Oilseeds	10,858	10,918	7,353	Groundnut, Sesamum, Soybean, Niger, Sunflower, Rapeseed-Mustard, Linseed, Safflower
Sugarcane	502	381	170	Sugarcane
Spices	788	22,658	17,059	Ginger, Coriander, Chilli, Garlic, Turmeric, others
Flowers	91	1,097	7,863	Marigold, Rose, others
Vegetables	16,437	67,660	1,82,510	Cauliflower, Tomato, Onion, Brinjal, etc.
Fruits	3,870	40,748	1,02,440	Mango, Banana, Papaya, Guava, Citrus, etc.

Table 9: Area Under Non-Cash Crops – Upper Mahanadi Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2020–21 (ha)	Major Crops Included
Cereals & Pulses	8,48,562	8,65,928	8,90,387	Paddy, Maize, Wheat, Gram, Moong, Urd, Lentil, Kodo, Kutki, Ragi, Jowar, Bajra, Kulthi, other cereals and pulses

Cash Crops Expansion:

- **Vegetables:** Increased by more than 1,000% from 16,437 ha in 2000–01 to 182,510 ha in 2020–21, marking a major shift towards high-value, short-duration crops within the basin's cash crop portfolio.
- **Fruits:** Expanded by over 2,500% from 3,870 ha in 2000–01 to 102,440 ha in 2020–21, reflecting large-scale adoption of orchard-based farming systems over the past two decades.
- **Spices and Flowers:** Showed noticeable additions in cultivated area, with much of the recorded gain occurring in the latest period (2020–21), signalling recent diversification within the cash crop category.
- **Oilseeds:** Displayed only minor net change over the 20-year period, with totals largely fluctuating within a narrow range, suggesting limited expansion compared to other cash crops.

Non-Cash Crops

- **Paddy:** Maintained its position as the dominant crop by area throughout the two decades, underscoring its central role in both subsistence and commercial farming in the basin.
- **Pulses:** Retained a significant share of cultivation, though the proportion decreased slightly over time, indicating marginal substitution by other crops.

Cropping Intensity: Increased from 114% to over 127% when including the Kelo sub-basin, pointing to a higher frequency of cropping per unit area and greater land-use intensity in recent years.

3.2.4 Crop Area Under - Hasdeo Sub-Basin

Table 10: Area Under Cash Crops – Hasdeo Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2020–21 (ha)	Major Crops Included
Oilseeds	13,565	13,742	12,443	Groundnut, Sesamum, Soybean, Niger, Sunflower
Sugar Crops	73	126	708	Sugarcane

Vegetables	5,995	25,458	28,504	Tomato, Brinjal, Cauliflower, Bhindi, Onion
Fruits	524	15,470	19,233	Mango, Banana, Papaya, Guava, Litchi, Aonla
Spices	404	5,797	5,931	Ginger, Garlic, Turmeric, Chilli, Coriander
Flowers	91	413	673	Marigold, Rose

Table 11 :Area Under Non-Cash Crops – Hasdeo Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2020–21 (ha)	Major Crops Included
Cereals & Pulses	2,14,463	2,14,522	2,18,637	Paddy, Wheat, Maize, Tur, Urd, Gram

- Steady Rise in Cash Crops: From just over 20,000 ha in 2000–01 to nearly 68,000 ha by 2020–21, the share of cash crops has seen a strong rise, especially due to expansion in fruits, vegetables, and spices. This indicates increasing market orientation and diversification in farming.
- Oilseeds Shrinking: While still significant, oilseed crop area has decreased over the last decade. The reduction in mustard, linseed, and sesamum cultivation might reflect shifting climatic, economic, or input-related preferences.
- Fruits & Vegetables Boom: Massive growth in fruits (especially mango, papaya, banana) and vegetables (cauliflower, tomato, brinjal) suggests a shift to high-value horticulture, likely driven by market demand, government incentives, and increased irrigation coverage.
- Stability in Foodgrains: Area under cereals and pulses has remained relatively stable, with Paddy continuing to dominate kharif cultivation. Some marginal shifts are visible in wheat and gram.
- Improved Cropping Intensity (but stagnating): Cropping intensity increased from 113.4% to 119% in 2010–11 but slightly fell to 116.7% in 2020–21, which may indicate limits to double cropping or rising mono-cropping in some zones.
- Spices & Floriculture Rise: Area under spices (especially ginger, turmeric) and flowers (marigold, rose) rose sharply, reflecting niche diversification. This may be related to market linkages or peri-urban influences.
- Sugarcane Still Minor: Despite a rise from 73 ha to 708 ha in two decades, sugarcane remains minor in Hasdeo, likely due to soil-moisture constraints or lack of processing infrastructure.

3.2.5 Crop Area Under - Mand Sub-Basin

Table 12: Area Under Cash Crops – Mand Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2020–21 (ha)	Major Crops Included
Field Crops	33,512	35,327	30,636	Groundnut, Sesamum, Niger, Sunflower, Linseed, Mustard
Fruits	3,262	12,043	16,393	Mango, Cashew Nut, Guava, Aonla, Banana, Litchi
Vegetables	4,663	13,664	19,977	Cauliflower, Tomato, Brinjal, Bhindi, Potato
Spices	435	4,471	2,042	Ginger, Turmeric, Chilli, Coriander, Garlic
Flowers	19	154	301	Marigold, Rose

Table 13: Area Under Non-Cash Crops – Mand Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2020–21 (ha)	Major Crops Included
Field Crops	1,53,292	1,64,507	1,70,590	Paddy, Maize, Tur, Urd, Moong, Gram, Wheat

- **Increasing Cropping Intensity:** The Mand sub-basin has shown a consistent increase in cropping intensity over two decades—from 107.9% in 2000–01 to 113.3% in 2020–21—reflecting improved agricultural practices, irrigation, and possibly multiple cropping in selected zones.
- **Shift Toward Cash Crops:** There is a notable expansion in area under fruits and vegetables—particularly Mango, Cashew Nut, Tomato, and Cauliflower. This shift indicates a diversification trend toward higher-value crops likely due to market demand or government promotion.
- **Stable Non-Cash Crop Base:** Paddy remains dominant in kharif season across all years, and pulses like Urd and Tur show consistent presence. However, slight declines in Horse Gram and Lathyrus may suggest shifting preferences or water/resource constraints.
- **Oilseed Dynamics:** Niger has consistently remained the top oilseed crop by area. Other oilseeds like Groundnut and Linseed show fluctuations, while Mustard maintains moderate growth.
- **Vegetable Surge:** Vegetables as a group more than quadrupled in gross area from 2000–01 (4,663 ha) to 2020–21 (19,977 ha), with significant contributions from Potato, Tomato, Brinjal, and Bhindi. This may indicate peri-urban market linkages or nutritional awareness.

- **Emerging Fruit Crops:** Cashew Nut and Mango expanded drastically, with total fruit area under net cropping rising from 3,262 ha to 16,393 ha. This long-term plantation-based cropping may also reflect subsidy-based schemes or local agro-climatic suitability.
- **Spice Sector Volatility:** Ginger and Turmeric have risen sharply, but Chilli and Coriander remain low or fluctuating. This could relate to market pricing or agronomic requirements.

3.2.6 Crop Area Under - Ib Sub-Basin [CG Part]

Table 14: Area Under Cash Crops – Ib Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2020–21 (ha)	Major Crops Included
Oilseeds	18,263	17,448	12,303	Groundnut, Sesamum, Soybean, Niger, Rapeseed, Mustard, Linseed, Safflower
Sugar Crops	140	189	802	Sugarcane
Spices	202	3,083	692	Ginger, Coriander, Chilli, Garlic, Turmeric
Flowers	0	32	46	Marigold, Rose

Table 15: Area Under Non-Cash Crops – Ib Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2020–21 (ha)	Major Crops Included
Cereals & Pulses	1,94,230	1,97,330	1,94,850	Paddy, Maize, Urd, Tur, Gram, Wheat, Lentil etc.
Vegetables	3,384	8,658	12,179	Cauliflower, Tomato, Potato, Onion, Brinjal etc.
Fruits	1,281	6,828	10,932	Mango, Banana, Guava, Cashew, Litchi etc.

- **Stable Dominance of Paddy**: Paddy continues to dominate the field crop landscape with consistent area over the three decades, indicating minimal shift in staple crop preference.

- **Decline in Oilseeds**: Although Niger and Groundnut had significant presence in 2000–01 and 2010–11, their area reduced by 2020–21, suggesting either reduced demand or crop replacement.
- **Rise in Fruits and Vegetables**: Dramatic increase in area under fruit crops like Mango and Litchi and vegetables like Tomato, Onion, and Cauliflower indicates diversification and a probable shift toward horticultural practices for income enhancement.
- **Expansion of Spices & Flowers**: Spices such as Ginger and Turmeric gained considerable area by 2010–11. However, flower crops still occupy negligible area.
- **Increase in Cropping Intensity**: A steady rise in cropping intensity shows better utilization of land and possible support from irrigation or improved agronomy.
- **Cashew and Mango Boom**: A significant increase in area under perennial fruit trees like Cashew and Mango points to the growing interest in orchard-based systems, likely aided by government schemes or market demand.

3.2.7 Crop Area Under - Pairi Sub-Basin [CG Part]

Table 16: Area Under Cash Crops – Pairi Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2020–21 (ha)	Major Crops Included
Oilseeds	251	563	114	Groundnut, Sesamum, Niger, Rapeseed-Mustard, Linseed, Sunflower, Safflower
Commercial Crops	10	24	41	Sugarcane, Marigold, Rose
Spices	83	538	570	Ginger, Coriander, Chilli, Garlic, Turmeric
Flowers	19	26	38	Marigold, Rose
Vegetables (High-Value)	2,149	3,009	2,735	Cauliflower, Tomato, Brinjal, Onion, Capsicum, Chilli
Fruits	574	1,689	1,898	Mango, Banana, Papaya, Guava, Lemon, Aonla

Table 17: Area Under Non-Cash Crops – Pairi Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2020–21 (ha)	Major Crops Included
Cereals & Pulses	50,782	52,844	61,901	Paddy, Wheat, Maize, Tur, Gram, Pea, Urd, Moong

Coarse Grains	2,492	1,826	1,114	Kodo-Kutki, Horsegram, Lathyrus, Lentil
Summer Crops	355	1,467	4,662	Summer Paddy

- Rise in Cash Crops Share: From 2000 to 2020, the net area under cash crops increased by 75%, indicating a shift toward high-value and commercial crops. Spices and fruits saw major increases, suggesting a diversification in cropping choices.
- **Expansion of Summer Crops:** The cultivation of summer paddy expanded significantly from 355 ha in 2000–01 to 4,662 ha in 2020–21, pointing to intensification using irrigation.
- **Decline in Pulses:** Traditional pulses like Lathyrus, Moong, and Gram show a significant reduction, possibly due to lower economic returns compared to high-value crops.
- **Vegetable Boom:** Vegetables maintained a consistent share, particularly cauliflower, tomato, and brinjal. Onion and green peas increased notably in the last decade.
- Improvement in Cropping Intensity till 2010–11: The cropping intensity peaked in 2010–11 at ~114% but saw a slight decline in 2020–21 despite higher gross cropped area, due to a sharper increase in net sown area.
- **Fruit Orchards Expansion:** Plantation fruits like mango, guava, and aonla nearly tripled in area from 2000 to 2020. This is likely due to agroforestry and orchard-based diversification strategies.
- **Policy Implications:** The trend toward cash crops and summer paddy indicates irrigation dependency. There is a need for monitoring water sustainability and supporting pulse cultivation for nutrition security.

3.2.8 Crop Area Under - Jonk Sub-Basin [CG Part]

Table 18: Area Under Cash Crops – Jonk Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2020–21 (ha)	Major Crops Included
Field Crops (Oilseeds)	2052	1401	770	Groundnut, Sesamum, Soybean, Sunflower, Mustard, Linseed, Safflower
Spices	43	698	632	Ginger, Coriander, Chilli, Garlic, Turmeric
Flowers	0	37	340	Marigold, Rose

Fruits	44	1103	3713	Mango, Banana, Papaya, Guava, Lemon, Jackfruit, Custard Apple
Vegetables	372	1520	6264	Cauliflower, Tomato, Brinjal, Cabbage, Onion, Bittergourd, Bhindi

Table 19: Area Under Non-Cash Crops – Jonk Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2020–21 (ha)	Major Crops Included
Field Crops	113877	117377	118110	Paddy, Maize, Kodo-Kutki, Tur, Moong, Urd, Wheat, Gram, Pea, Lathyrus
Summer Paddy	3472	9797	14770	Summer Paddy

- Steady Increase in Total Cropped Area: Net cropped area increased from ~114k ha in 2000–01 to ~124k ha in 2020–21, indicating expanding agricultural activity.
- Rising Cropping Intensity: A clear upward trend is seen from 107.4% to 116.6%, driven by increased multiple cropping and intensification, especially in vegetables and summer paddy.
- Vegetable Boom: The gross area under vegetables exploded from just 372 ha in 2000–01 to over 6264 ha in 2020–21, showing market orientation and diversification.
- Fruit Orchard Expansion: Significant rise in fruits like mango, banana, custard apple, guava, and lemon reflects perennial investment by farmers and diversification toward high-value crops.
- Oilseed Shrinkage: Area under oilseeds like groundnut and sesamum declined consistently over the decades, replaced possibly by vegetables or summer crops.
- Shift Toward Commercial Crops: Overall cash crop area (especially vegetables, fruits, and flowers) grew fourfold, indicating commercialization of agriculture in the Jonk sub-basin.
- Sustainability Note: The growing intensity and diversification may improve income but will require careful water and soil management, especially with expanding summer paddy and water-intensive vegetables.

3.2.9 Crop Area Under - Tel Sub-Basin [CG Part]

Table 20: Area Under Cash Crops – Tel Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2020–21 (ha)	Major Crops Included
Oilseeds	682	541	298	Groundnut, Sesamum, Niger
Pulses (cash)	1600	1610	962	Moong, Urd, Tur
Spices	2	8	97	Ginger, Coriander, Chilli
Vegetables	12	232	679	Cauliflower, Brinjal, Tomato
Flowers	0	2	1	Marigold, Rose

Table 21: Area Under Non-Cash Crops – Tel Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2020–21 (ha)	Major Crops Included
Cereals	36547	38614	44099	Paddy, Maize, Kodo-Kutki
Pulses (non-cash)	267	797	883	Horse Gram, Gram, Pea, Lentil, etc.
Fruits	8	89	358	Mango, Guava, Lemon, etc.
Other Field Crops	14	15	27	Wheat, Barley, Others

- **Cereals dominate** the Tel sub-basin, with paddy alone occupying over 40,000 ha in 2020–21, marking a steady increase from 2000–01.
- **Cash crops**, though present, constitute a relatively smaller share of total cropped area (~4.4% in 2020–21), mainly comprising oilseeds, pulses, vegetables, and spices.
- **Vegetables have seen the most growth** in cash crops — from 12 ha in 2000–01 to 679 ha in 2020–21 — showing potential market-driven intensification.
- **Fruits expanded significantly**, especially mango and lemon plantations, likely driven by horticulture schemes.

- **Spices (mainly ginger and coriander)** also increased in area but remain limited in absolute terms.
- **Overall cropping intensity** has remained stable around 102%, indicating limited multiple cropping practices, with scope for enhancing through improved irrigation and inter-cropping systems.
- **Floriculture is negligible**, but there's a slight presence of marigold in recent years, which may grow under market-linked programs.
- The data shows a **gradual shift towards diversification**, especially in vegetables and fruits, but cereals continue to dominate both in net and gross terms.

3.2.10 Crop Area Under - Ong Sub-Basin [CG Part]

Table 22: Area Under Cash Crops – Ong Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2020–21 (ha)	Major Crops Included
Oilseeds	1794	1427	1508	Groundnut, Sesamum, Linseed, Safflower
Sugarcane	97	85	100	Sugarcane
Spices	26	421	351	Ginger, Coriander, Chilli, Garlic, Turmeric
Flowers	0	22	214	Marigold, Rose
Vegetables	227	792	3691	Cauliflower, Brinjal, Tomato, Onion, etc.

Table 23: Area Under Non-Cash Crops – Ong Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2020–21 (ha)	Major Crops Included
Cereals/Pulses	50160	54196	54106	Paddy, Wheat, Maize, Pulses, Summer Paddy
Fruits	28	640	2251	Mango, Guava, Papaya, Lemon, Jackfruit

Observations and Trends and Insights

- **Cash Crop Expansion**: There is a noticeable increase in vegetable cultivation, with gross area rising from 227 ha (2000–01) to 3691 ha (2020–21), indicating diversification and market orientation. Spices, particularly ginger, garlic, and turmeric, saw a significant rise post-2010, showing commercial intensification.
- **Fruit Orchards Growth**: Fruit cultivation expanded drastically from 28 ha (2000–01) to over 2250 ha (2020–21), especially mango, guava, and papaya, indicating agro-ecological and economic shifts.
- **Stable Cereal Base**: Paddy remains the dominant crop, occupying over 45,000 ha consistently across decades. Introduction and growth of summer paddy (4419 ha by 2020–21) reflects improved irrigation or multiple cropping trends.
- **Cropping Intensity Rise**: Increased from 103.8% to 115.2%, suggesting improved input access, irrigation, and cropping system optimization.
- **Oilseeds Static**: Area under oilseeds remains largely stagnant (~1400–1800 ha), signaling either agro-climatic limitations or policy/market disincentives.
- **Floriculture Entry**: Emergence of marigold and rose post-2010, with area growing to 214 ha by 2020–21, indicates diversification into high-value crops.

3.2.11 Crop Area Under - Middle Mahanadi Sub-Basin [CG Part]

Table 24: Area Under Cash Crops – Middle Mahanadi Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2020–21 (ha)	Major Crops Included
Oilseeds	260	195	121	Groundnut, Sesamum
Sugar Crop	51	45	8	Sugarcane
Spices	22	238	46	Ginger, Turmeric, Coriander, Garlic, Chilli
Flowers	0	0	12	Marigold, Rose
Fruits	43	230	432	Mango, Banana, Papaya, Guava, Lemon, Cashew, etc.
Vegetables	234	643	926	Cauliflower, Cabbage, Tomato, Brinjal, Bhindi, etc.

Table 25: Area Under Non-Cash Crops – Middle Mahanadi Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2020–21 (ha)	Major Crops Included
Cereals	5027	4938	5191	Paddy, Maize, Kodo-Kutki, Wheat
Pulses	257	242	172	Moong, Urd, Tur, Gram,

				Lentil, Pea, etc.
Other Field Crops	100	148	30	Other kharif/rabi crops

- **Steady Increase in Cropping Intensity:** Cropping intensity increased from **107.8%** (2000–01) to **129.4%** (2020–21), indicating more efficient land use and double cropping in many areas.
- **Vegetables and Fruits Expansion:** Area under vegetables rose from **234 ha** in 2000–01 to **926 ha** in 2020–21. Fruit orchards increased tenfold, showing market-oriented diversification.
- **Spices as Emerging Segment:** Notable increase in **ginger** and **turmeric** cultivation by 2020–21, suggesting growing commercial potential in spice farming.
- **Cash Crop Share Rising:** Cash crop net area more than doubled from **610 ha** in 2000–01 to **1545 ha** in 2020–21, accounting for nearly **25%** of net cropped area.
- **Surge in Summer Paddy:** Hot weather (summer) paddy rose drastically in 2020–21 to **943 ha**, indicating irrigation facility or water availability during summer months.
- **Oilseeds on Decline:** Groundnut and sesamum showed a consistent decline, possibly due to low yield, input costs, or competition from other crops.
- **Sugarcane Losing Ground:** Area under sugarcane fell sharply from **51 ha** to **8 ha**, possibly due to water needs, market risks, or shifting priorities.
- **Diversification in Cropping System:** Rise in crops like papaya, capsicum, leafy vegetables, and chilli suggests farmer inclination toward high-value horticulture.

3.3 Crop Categories at Sub-Basin Level for Odisha State

The analysis of crop production has been carried out for the sub-basins of the Mahanadi River Basin that fall within the geographical extent of **Odisha state**. These include the **Upper Mahanadi**, **Middle Mahanadi**, **Lower Mahanadi**, **Tel**, **Ib**, **Chillika region**,**Ong**,**Jonk**, **and Pairi** sub-basins. The production statistics for various crops under these sub-basins have been compiled and analysed to understand decadal trends, spatial variation, and cropping patterns. The assessment integrates both field crops and horticultural crops across kharif, rabi, and summer seasons, reflecting the agricultural dynamics within the Odisha part of the basin.

In Odisha part of Mahanadi, rice is the primary crop during the Kharif season, occupying 71% (1738 thousand hectares) of the area sown. However, the area dedicated to rice cultivation has been decreasing over time. The Kharif area under rice in the Odisha part of the basin fell by approximately 178 thousand hectares between 1993-94 and 2013-14, from 2011 to 1833 thousand hectares.

Since the year 2000, the gross cereals cropped area has seen a marginal decline in the state. In contrast, the area under pulses has experienced an increase. The area for vegetables, however, has also fallen.

For the Rabi crop season in Odisha part of Mahanadi, pulses are the dominant crop group, accounting for 55% of the total Rabi area, followed by oilseeds, vegetables, and cereals.

3.3.1 Data Preparation Methodology at Sub-Basin Level

- **Primary Data source** -Annual reports have been collected from Odisha Agricultural Department for 3 decades i.e. 2000-2001,2010-2011 and 2019-2020. The Report for the year 2020-2021 has not been updated by the department.
- **Spatial Evaluation to Sub-basins-** The raw crop area data is originally available at **District-level**. The areas under different crops in sub-basin are populated as per the sub-basin by using finding the percentage area within the Odisha part of basin. To assess land use statistics, the values for each land category are multiplied by the percentage of the district's area that falls within the Mahanadi basin. While this approach has limitations—since land use types are not evenly distributed across districts it still offers a fairly good approximation for understanding broader patterns.

3.3.2 Crop Area Under – Tel Sub-Basin [OD Part]

Table 26: Area Under Cash Crops –Tel Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2019–20 (ha)	Major Crops Included
Oilseeds	2,76,549	1,43,192	1,10,699	Groundnut, Sesamum, Soybean, Niger, Rapeseed, Mustard, Linseed, Safflower
Fibres	41878.15	75143	155565.1	Jute, Mesta, Sunhemp, cotton
Spices	22054.11	27,702	33818.79	Ginger, Coriander, Chilli, Garlic, Turmeric
Sugarcane	9537.29	8,378	5096.8	Sugarcane
Tobacco	-	1308.63	130	Tobacco

Table 27: Area Under Non Cash Crops –Tel Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2019–20 (ha)	Major Crops Included
Cereals & Pulses	12,61,439	14,69,146	13,11,945	Paddy, Maize, Urd, Tur, Gram, Wheat, Lentil etc.
Vegetables	55,340	1,25,426	1,18,190	Cauliflower, Tomato, Potato, Onion, Brinjal etc.
Fruits	-	91,252	93,984	Mango, Banana, Guava, Cashew, Litchi etc.

Oilseeds show a consistent and sharp decline (60%), indicating reduced cultivation, possibly due to market, soil suitability, or irrigation issues. Sugarcane, though smaller in area, also shows a steady decrease (46%).Fibres (Jute, Mesta, Cotton) expanded massively (increased by 271.5%), reflecting a growing textile industry demand. Spices exhibit a moderate increase (53%), indicating shifting focus to high-value, low-water crops.Tobacco shows a slight presence with fluctuations but overall decreased recently.

Cereals & Pulses show a peak in 2010–11, followed by a slight reduction by 2019–20, but overall remain stable with a net increase. Vegetables have more than doubled (114%), indicating a shift towards horticulture diversification. Fruits saw notable introduction post-2010, with steady growth.

- Decreasing Crops: Oilseeds decreased by 59.9 %, Sugarcane decreased by 46.5%, recent decline in Tobacco.
- Increasing Crops: Fibres (increased by 271.5%), Spices (increased by 53.3%), Vegetables (increased by 113.6%), Fruits (introduced & growing).
- Mixed/Stable: Cereals & Pulses show a small net increase (increased by 4%) but with a slight dip in recent years.

3.3.3 Crop Area Under – Lower Mahanadi Sub-Basin

Table 28: Area Under Cash Crops –Lower Mahanadi Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2019-20 (ha)	Major Crops Included
Oilseeds	42,099	37,179	26,707	Groundnut, Sesamum, Soybean, Niger, Rapeseed, Mustard, Linseed, Safflower
Fibres	3775.6	1145.614	1354.3	Jute, Mesta, Sunhemp, cotton
Spices	8005.65	15,963	8785.2	Ginger, Coriander, Chilli, Garlic, Turmeric
Sugarcane	2156.17	3,234	3028.2	Sugarcane

Table 29: Area Under Cash Crops –Lower Mahanadi Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2019–20 (ha)	Major Crops Included
Total Food grains (Cereals & Pulses)	4,94,153	5,78,491	9,01,153	Paddy, Maize, Urd, Tur, Gram, Wheat, Lentil etc.
Vegetables	33,520	63,985	49,986	Cauliflower, Tomato, Potato, Onion, Brinjal etc.
Fruits	-	29,019	23,176	Mango, Banana, Guava, Cashew, Litchi etc.

Oilseeds saw a consistent decline of 36.5%, mirroring the trend in Tel sub-basin, possibly due to market preferences and water constraints.

Fibres (Jute, Mesta, Cotton) witnessed a sharp fall of 64%, unlike the increase seen in Tel sub-basin, likely due to unsuitable agro-climatic factors in Lower basin.

Spices showed an initial surge till 2010, but a moderate net increase (9.7%) over the two decades. Sugarcane expanded steadily by 40%, suggesting better irrigation support in this part of the basin. Food Grains (Cereals & Pulses) expanded massively by 82%, indicating major cultivation focus on staples. Vegetables nearly doubled over two decades but show a slight dip after 2010.Fruits entered as a new crop group, but witnessed a decline from 2010 to 2020.

- Decreasing Crops: Oilseeds (decreased by 36.5%), Fibres (decreased by 64.1%), recent dip in Fruits & Vegetables.
- Increasing Crops: Sugarcane (increased by 40.4%), Food Grains (increased by 82.3%), moderate increase in Spices (increased by 9.7%).
- Distinct Shift: Unlike Tel sub-basin, Fibres decreased here, while Sugarcane improved — highlighting sub-basin-specific dynamics.

3.3.4 Crop Area Under – Middle Mahanadi Sub-Basin [OD Part]

Table 30: Area Under Cash Crops –Middle Mahanadi Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2019–20 (ha)	Major Crops Included
Oilseeds	1,26,029	1,66,464	1,38,460	Groundnut, Sesamum, Soybean, Niger, Rapeseed, Mustard, Linseed, Safflower
Fibres	6665	4797.20436	6381.31	Jute, Mesta, Sunhemp, cotton
Spices	24855.61	39,229	43596.7	Ginger, Coriander, Chilli, Garlic, Turmeric
Sugarcane	8533.9	12,740	2415.1	Sugarcane
Tobaco	-	90	-	Tobaco

Table 31: Area Under Non Cash Crops –Middle Mahanadi Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2019–20 (ha)	Major Crops Included
Total Food grains (Cereals & Pulses)	23,15,908	11,57,596	9,67,055	Paddy, Maize, Urd, Tur, Gram, Wheat, Lentil etc.
Vegetables	69,334	1,33,186	1,31,965	Cauliflower, Tomato, Potato, Onion, Brinjal etc.
Fruits	-	1,61,440	1,13,637	Mango, Banana, Guava, Cashew, Litchi etc.

Oilseeds increased significantly till 2010 but slightly decreased afterwards; net growth of 10%. Fibres witnessed a drastic decline of nearly 90%, suggesting a major shift away from fibre cultivation. Spices expanded consistently, with a 75% increase, highlighting a clear preference for high-value crops. Sugarcane rose till 2010 but plummeted by 72% in 2020, indicating water scarcity or market-driven reduction. Tobacco appeared briefly but did not sustain. Food grains show a steep decline (58%), indicating a massive reduction in cereal and pulse cultivation. Vegetables nearly doubled (90%), showing a diversification towards horticulture. Fruits were introduced post-2000 but have shown a decline of 30% from 2010 to 2020.

- Decreasing Crops: Fibres (decreased by 89.7%), Sugarcane (decreased by 71.7%), Food Grains (decreased by 58.2%), Fruits declining after 2010.
- Increasing Crops: Spices (increased by 75.4%), Vegetables (increased by 90.4%), Oilseeds marginal increase (increased by 9.9% but declining post 2010).

3.3.5 Crop Area Under –Chilika Sub-Basin

Table 32: Area Under Cash Crops - Chilika Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2019–20 (ha)	Major Crops Included
Oilseeds	56,242	65,702	47,293	Groundnut, Sesamum, Soybean, Niger, Rapeseed, Mustard, Linseed, Safflower
Fibres	7168.08	4366.972	1688.34	Jute, Mesta, Sunhemp, cotton
Spices	8234.48	7,598	10302	Ginger, Coriander, Chilli, Garlic, Turmeric
Sugarcane	3782.09	5,552	803.96	Sugarcane

Table 33: Area Under Non Cash Crops -Chillika Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2019–20 (ha)	Major Crops Included
Total foodgrains (Cereals & Pulses)	7,25,857	8,60,281	7,34,418	Rice, Wheat, Jowar, Bajra, Maize, Ragi, Small Millets, Arhar, Mung, Other Pulses etc.
Vegetables	40,733	84,185	60,371	Cauliflower, Tomato, Potato, Onion, Brinjal etc.
Fruits	-	69,842	61,731	Mango, Banana, Guava, Cashew, Litchi etc.

Oilseeds followed a bell curve trend: increased till 2010 but fell by 2020, with an overall net decline of 16%. Fibres continued a steep decline (76%), reflecting state-wide trends. Spices fluctuated but showed a net growth of 25%, indicating niche market adaptation. Sugarcane surged initially but collapsed (79%) in the last decade, likely

due to water scarcity and reduced support price. Foodgrains showed a marginal net increase (1.2%), but the post-2010 decline may reflect urban expansion and water stress. Vegetables nearly doubled till 2010, but slightly declined afterwards, retaining a healthy net gain (48%).Fruits were introduced after 2000 but have shown a 11.6% decline from 2010 to 2020.

- Decreasing Crops: Oilseeds (decreased by 15.9%), Fibres (decreased by 76.4%), Sugarcane (decreased by 78.7%), Fruits (decline post-2010).
- Increasing Crops: Spices (increased by 25.1%), Vegetables (increased by 48.2%), marginal gain in Foodgrains (increased by 1.2%).

3.3.6 Crop Area Under –Ib Sub-Basin [OD Part]

Table 34: Area Under Cash Crops –IB Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2019–20 (ha)	Major Crops Included
Oilseeds	30,379	71,873	60,012	Groundnut, Sesamum, Soybean, Niger, Rapeseed, Mustard, Linseed, Safflower
Fibres	2803.964	338.941	857.81	Jute,Mesta,Sunhemp,cotton
Spices	10651.36	10,336	13369	Ginger, Coriander, Chilli, Garlic, Turmeric
Sugarcane	830.5	195	98.25	Sugarcane

Table 35: Area Under Non Cash Crops –IB Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2019–20 (ha))	Major Crops Included
Total foodgrains (Cereals & Pulses)	3,98,493	4,27,603	4,19,036	Paddy, Maize, Urd, Tur, Gram, Wheat, Lentil etc.
Vegetables	25,901	46,767	53,439	Cauliflower, Tomato, Potato, Onion, Brinjal etc.
Fruits	-	32,935	38,089	Mango, Banana, Guava, Cashew, Litchi etc.

Oilseeds saw a near doubling in area (97% increase) though with a slight dip post 2010.Fibres drastically fell (69%) but showed a small recovery by 2020.Spices remained stable initially but increased by 25% in 20 years. Sugarcane declined continuously, losing almost 90% of its area. Foodgrains remained mostly stable with a small net increase (5.2%).Vegetables more than doubled (106%), reflecting a strong diversification trend. Fruits introduced after 2000, showing a healthy growth of 16% in the last decade.

- Decreasing Crops: Fibres (decreased by 69.4%), Sugarcane (decreased by 88.2%).
- Increasing Crops: Oilseeds (increased by 97.5%), Spices (increased by 25.5%), Vegetables (increased by 106.3%), Fruits (increased by 15.6%), Foodgrains (increased by 5.2%).

The Ib Sub-basin, being an industrial and tribal belt, shows distinct trends Reduction in water-intensive and low-profit crops and diversification into oilseeds, spices, vegetables & fruits for higher returns and sustainability.

3.3.7 Crop Area Under –Ong Sub-Basin [OD Part]

Table 36: Area Under Cash Crops –Ong Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2020–21 (ha)	Major Crops Included
Oilseeds	22,832	24,883	23,751	Groundnut, Sesamum, Soybean, Niger, Rapeseed, Mustard, Linseed, Safflower
Fibres	1689.91	3347.9	6093.48	Jute,Mesta,Sunhemp,cotton
Spices	3598.88	2,890	2483.42	Ginger, Coriander, Chilli, Garlic, Turmeric
Sugarcane	1227.4	842	49.15	Sugarcane
Tobaco	-	1.44	-	Tobaco

Table 37: Area Under Non Cash Crops –Ong Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2019–20(ha)	Major Crops Included
Cereals & Pulses	17,41,480	2,65,743	1,66,743	Paddy, Maize, Urd, Tur, Gram, Wheat, Lentil etc.
Vegetables	11,032	14,577	13,892	Cauliflower, Tomato, Potato, Onion, Brinjal etc.
Fruits	-	7,075	7,448	Mango, Banana, Guava, Cashew, Litchi etc.

Fibres showed a significant surge likely due to policy incentives or market demand. Oilseeds remained largely stable with minor gains (4%). Spices declined by 31%, possibly due to shift to other profitable crops. Sugarcane faced a severe drop (96%), indicating unsustainability or water scarcity issues. Cereals & Pulses dropped alarmingly (90%), indicating possible water/stress shifts, or misreporting. Vegetables expanded by 26%, indicating preference towards diversified cropping. Fruits introduced after 2000, saw a small rise of 5% in the decade.

- Decreasing Crops: Spices (decreased by 30.9%), Sugarcane (decreased by 96%), Cereals & Pulses (decreased by 90.4%).

- Increasing Crops: Fibres (increased by 260.6%), Vegetables (increased by 25.9%), Fruits (increased by 5.3%).
- Stable: Oilseeds (increased by 4%).

The Ong Sub-basin reflects a shift towards fibre cultivation, replacing traditional staples like cereals, sugarcane & spices, likely due to economic returns and water issues. Vegetables & Fruits cultivation is slowly gaining space, reflecting market-oriented agriculture.

3.3.8 Crop Area Under –Upper Mahanadi Sub-Basin [OD Part]

Table 38: Area Under Non Cash Crops –Upper Mahanadi Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2019–20 (ha)	Major Crops Included
Oilseeds	5,482	9,573	5,951	Groundnut, Sesamum, Soybean, Niger, Rapeseed, Mustard, Linseed, Safflower
Fibres	288.727	146.953	344.7	Jute,Mesta,Sunhemp,cotton
Spices	295.47	1,200	1159.53	Ginger, Coriander, Chilli, Garlic, Turmeric
Sugarcane	9537.29	179	9.35	Sugarcane

Table 39: Area Under Non Cash Crops –Upper Mahanadi Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2019–20 (ha)	Major Crops Included
Cereals & Pulses	68,017	74,405	67,879	Paddy, Maize, Urd, Tur, Gram, Wheat, Lentil etc.
Vegetables	3,932	1,25,426	5,072	Cauliflower, Tomato, Potato, Onion, Brinjal etc.
Fruits	-	3,021	3,701	Mango, Banana, Guava, Cashew, Litchi etc.

Oilseeds expanded strongly until 2010–11 (+82%), then declined but remained well above 2000–01 levels, suggesting a lasting cropping shift despite fluctuations. Fibres dropped sharply by 2010–11 but recovered close to original levels by 2019–20, indicating renewed interest or market revival. Spices experienced a steep reduction after 2000–01, stabilising at much lower levels in recent years.

Sugarcane declined drastically from a major irrigated crop in 2000–01 to minimal area by 2019–20, reflecting a move towards less water-intensive crops, possibly due to water use concerns, soil limitations, or economic factors.

Cereals & Pulses remained broadly stable over two decades, maintaining their central role in food security.Vegetables showed a sharp temporary peak in 2010–11 before settling above baseline, signalling long-term growth in horticulture.Fruits emerged after 2010–11 and have grown steadily, pointing to diversification into orchard-based farming and adaptation to market or climatic opportunities.

- **Decreasing Crops:** Sugarcane (drastic decline; near disappearance)
- **Increasing Crops:** Fruits (new & steadily growing), Vegetables (long-term rise), Fibres (recovery to near baseline)
- **Mixed/Stabilized Crops:** Oilseeds (volatile but above baseline), Spices (sharp fall then stable), Cereals & Pulses (stable).

3.3.9 Crop Area Under –Jonk Sub-Basin [OD Part]

Table 40: Area Under Cash Crops –Jonk Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2019–2020 (ha)	Major Crops Included
Oilseeds	8,606	10,692	7,546	Groundnut, Sesamum, Soybean, Niger, Rapeseed, Mustard, Linseed, Safflower
Fibres	654.7	885.47	2535.4	Jute,Mesta,Sunhemp,cotton
Spices	401.7	1,200	1089.4	Ginger, Coriander, Chilli, Garlic, Turmeric
Sugarcane	53.5	141	14.66	Sugarcane

Table 41: Area Under Non Cash Crops –Jonk Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2019–20 (ha)	Major Crops Included
Cereals & Pulses	80,585	91,892	55,457	Paddy, Maize, Urd, Tur, Gram, Wheat, Lentil etc.
Vegetables	3,140	4,325	3,675	Cauliflower, Tomato, Potato, Onion, Brinjal etc.
Fruits	-	2,981	2,712	Mango, Banana, Guava, Cashew, Litchi etc.

Oilseeds show a net decline (12%) over 20 years after peaking in 2010.Fibres have surged significantly (287%), suggesting a major cropping shift.Spices grew remarkably (171%), despite a slight fall after 2010.Sugarcane collapsed (73%), becoming almost negligible. Cereals & Pulses experienced a decline of 31% since 2000, indicating land shift to cash crops. Vegetables grew modestly (17%), suggesting limited

diversification.Fruits, introduced after 2000, saw a mild decline (9%) in the last decade.

- Decreasing Crops: Oilseeds (decreased by 12.3%), Sugarcane (decreased by 72.6%), Cereals & Pulses (decreased by 31.2%), Fruits (decreased by 9%).
- Increasing Crops: Fibres (increased by 287.2%), Spices (increased by 171.3%), Vegetables (increased by 17%).

The Jonk Sub-basin reflects a clear transformation toward fibre and spice cultivation, likely due to crop diversification efforts. However, food security crops like cereals are declining, posing risks for local subsistence unless managed sustainably.

3.3.10 Crop Area Under –Pairi Sub-Basin [OD Part]

Table 42: Area Under Non Cash Crops –Pairi Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2019–20 (ha)	Major Crops Included
Oilseeds	2,167	976	827	Groundnut, Sesamum, Soybean, Niger, Rapeseed, Mustard, Linseed, Safflower
Fibres	339.15	86.544	169.8	Jute,Mesta,Sunhemp,cotton
Spices	226.03	262	164.9	Ginger, Coriander, Chilli, Garlic, Turmeric
Sugarcane	267.5	343	407.66	Sugarcane
Tobaco	-	0.837	-	Tobaco

Table 43: Area Under Non Cash Crops –Pairi Sub-basin

Crop Group	2000–01 (ha)	2010–11 (ha)	2019–20 (ha)	Major Crops Included
Cereals & Pulses	20,372	23,116	22,164	Paddy, Maize, Urd, Tur, Gram, Wheat, Lentil etc.
Vegetables	1,534	1,736	945	Cauliflower, Tomato, Potato, Onion, Brinjal etc.
Fruits	-	1,790	1,301	Mango, Banana, Guava, Cashew, Litchi etc.

Sharp decline (62%) over 20 years, indicating reduced cultivation in oilseeds. Fibres declined drastically by 2010–11 but partly recovered by 2019–20, still below 2000–01 levels. Spices got slight rise by 2010–11 but dropped by 2019–20; overall decline. Sugarcane has a consistent increase (52%) suggesting growing importance

- Decreasing Crops: Oilseeds (decreased by 61.8%), Fibres (decreased by 50%), Spices (decreased by 27%), Vegetables (decreased by 38%)
- Increasing Crops: Sugarcane (increased by 52.4%), Cereals & Pulses (increased by 8.8%), Fruits (new and growing)
- Stable/Minor Change: Cereals & Pulses mostly stable with minor fluctuations.

The Pairi Sub-basin shows a mixed cropping trend, with a decline in many traditional non-cash crops (Oilseeds, Fibres, Spices, Vegetables), but an increase in sugarcane and fruits, indicating a gradual shift in cropping patterns towards more water-intensive and high-value crops. Cereals & pulses remain stable, maintaining food security focus.

3.4 Cropping Intensity in the Mahanadi River Basin

he analysis of cropping intensity in the Mahanadi River Basin (MRB) over the last two decades reveals a consistently high level of land-use efficiency, underpinned by extensive adoption of multiple cropping practices. In 2000–01, the Net Sown Area (NSA) of the basin was estimated at 7.67 million hectares, while the Gross Cropped Area (GCA) reached 9.82 million hectares, resulting in a cropping intensity (CI) of 128.1%.

Table 44: Decadal Cropping Intensity (%) in the Mahanadi River Basin

Year	Net Sown Area (ha)	Gross Cropped Area (ha)	Cropping Intensity (%)
2000–01	76,65,604.06	98,22,189.59	128.1
2010–11	56,61,717.77	79,73,552.19	140.9
2020–21 *	64,01,854.08	83,86,087.55	131
** Note: For Odisha portion of the basin, crop area statistics are taken from 2019–20 due to the unavailability of 2020–21 data*			

By 2010–11, the NSA declined notably to 5.66 million hectares, although the GCA remained comparatively high at 7.97 million hectares. This shift elevated cropping intensity to its highest recorded value of 140.9%, suggesting that farmers compensated for reduced cultivable area through intensified land use, aided by factors such as expanded irrigation coverage, adoption of short-duration crop varieties, and favourable market conditions.

In 2020–21, the NSA partially recovered to 6.40 million hectares, with GCA increasing to 8.39 million hectares, resulting in a cropping intensity of 131%. This moderation

from the 2010–11 peak reflects an adjustment in cultivation patterns, potentially influenced by variations in water availability, crop diversification strategies, and concerns over resource sustainability.

The Chhattisgarh part of the MRB exhibits consistently high cropping intensity levels over the two decades, maintaining around 134.6% in 2000–01 and rising slightly to 136.6% by 2020–21. This stability in cropping intensity alongside a steady increase in Gross Cropped Area, despite relatively stable Net Sown Area (~4.12 million hectares), indicates a mature agricultural system with efficient land use and sustained adoption of multiple cropping patterns. It reflects favorable conditions such as effective irrigation, technology adoption, and stable market demand enabling farmers to intensify production without expanding cultivation area.

In contrast, the Odisha part shows more variability. The cropping intensity started lower at 120.6% in 2000–01 but surged sharply to a peak of 154.2% in 2010–11, reflecting a period of aggressive multiple cropping likely driven by government interventions, improved water availability, or cash crop incentives. However, by 2020–21, this intensity decreased substantially to 121%, indicating a moderation or possible constraints emerging in land or water resources, or market adjustments guiding farmers back to less intensive cropping systems.

Together, these trends reveal important regional differences within the MRB. The CG part's stable high intensity underscores strong agricultural resilience and optimized resource use, while the OD part's spike and subsequent decline illustrate how external factors such as policy shifts, resource availability, and economic conditions can rapidly impact cropping practices. Overall, while the basin as a whole shows effective multiple cropping, these insights highlight the need for spatially tailored approaches to sustain productivity, manage water demand, and ensure long-term environmental sustainability across diverse sub-regions of the MRB.

4. People to land ratio

4.1 For Odisha State part of MRB

People to land ratio

The people-to-land ratio, or population density, has seen a significant increase in the Mahanadi basin over the decade.

- **2001 Population**: 32.49 million
- **2011 Population**: 38.66 million
- **Decadal Population Growth**: Approximately 19%

Given the basin's total population density of 273 persons per square kilometer in 2011, a simple calculation shows that the density in 2001 was approximately **229 persons per square kilometer**. This increase of roughly 44 persons per square kilometer over ten years indicates a substantial rise in the people-to-land ratio, placing more pressure on the basin's resources.

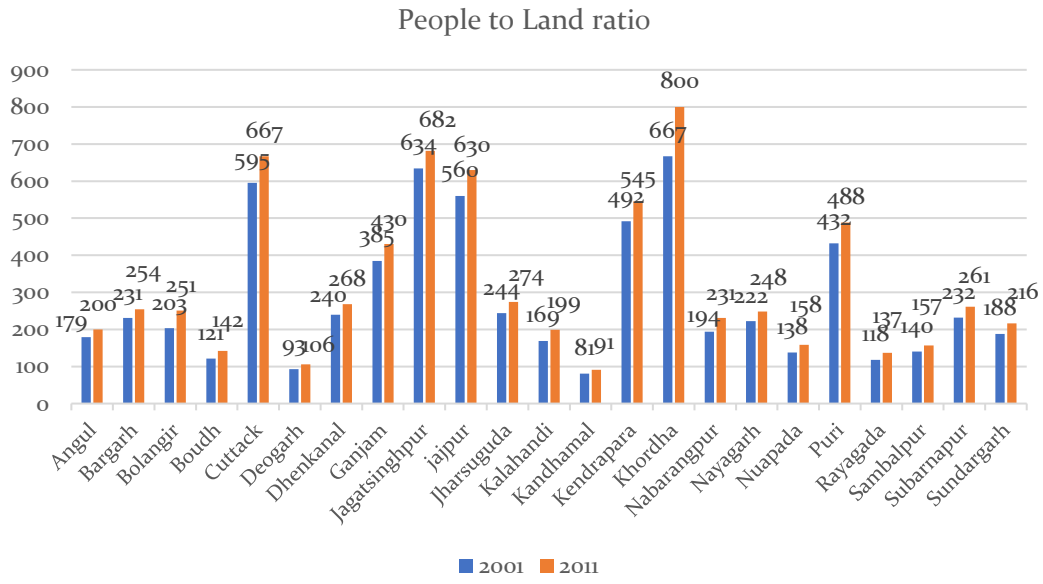

Figure 8: People to land Ratio under MRB for Odisha State

Source:-Odisha Census Data 2011

Analysis of People to Land Ratio Changes (2001-2011)

The most significant increase in population density was observed in Khordha district, with a growth rate of 66.5%. This is largely attributed to the presence of Bhubaneswar, the state capital, which acts as a major hub for employment, education, and services, attracting a high influx of people. Following this, Cuttack district also experienced a substantial population density increase of 36%, likely due to its status as a major commercial and urban centre.

Observed Reasons for High Growth in Khordha and Cuttack:

- **Urbanization and Economic Magnetism**: As the state capital and a major city, Bhubaneswar (in Khordha) and Cuttack are powerful economic magnets. They offer a greater concentration of job opportunities in the formal and informal sectors, better educational facilities, advanced healthcare, and a higher standard of living, which attracts migrants from rural areas and other districts.
- **Infrastructure Development**: Continuous investment in infrastructure, such as roads, housing, and commercial spaces, supports urban growth and further draws in a larger population. This is a common pattern for capital cities and major urban centers.

Conversely, the lowest rates of population density increase were recorded in Kandhamal and Deogarh districts, with growth rates of 5% and 6.5% respectively.

Observed Reasons for Low Growth in Kandhamal and Deogarh:

- **Economic Stagnation**: A low population growth rate can indicate a lack of robust economic opportunities. These districts may have fewer industries or urban centers to attract new residents or retain their existing population, leading to out-migration.
- **Geographical and Accessibility Factors**: The topography and remote nature of some of these areas could limit infrastructure development and connectivity, making them less attractive for settlement and economic activity.
- **Dependency on Subsistence Agriculture**: If the local economy is heavily dependent on traditional, subsistence-level agriculture, it may not be able to support a significant increase in population, leading to either stable or decreasing numbers as people move away.

Decade-wise Average Household (Landholding) Size in MRB, Odisha

During the first decade under consideration, landholdings were relatively larger, but a clear decline is evident in the following census years, reflecting increasing fragmentation of agricultural land. After this phase of contraction, the trend appears to stabilize, with the average size remaining unchanged in the most recent assessment.

Table 45: Decade-wise Average Household Size data of MRB Odisha part

Decade	Average Landholding Size (Area/no. of operational holdings in ha)
2005	0.803
2010	0.646
2015	0.646

Source: District-wise Average operational holding Size (ha) [Agricultural Census, Odisha 2005, 2010 & 2015]

4.1 For Chhattisgarh State part of MRB

Population Dynamics and Land Holding Size in the Mahanadi Basin (1991-2011)

Over the three decades from 1991 to 2011, the Total Mahanadi Basin experienced significant demographic changes. The data reveal a clear trend of rising population pressure on land, as indicated by both increasing population density and shrinking average landholdings.

Table 46: Decade-wise Average Household Size data of MRB CG part[a]

Decade	Population	Population Density (/sq km)	Number of Households	Average Household Size
1991	13,668,512	180.7	2,585,852	5.29
2001	16,099,112	212.8	3,157,351	5.10
2011	19,965,326	263.96	4,416,844	4.52

Source: Population Census 1991, 2001 & 2011

Table 47: Decade-wise Average Household Size data of MRB CG part [b]

Decade	Average Landholding Size (ha)
2005	1.22
2010	1.00
2015	0.75

Source: District-wise Average Landholding Size (ha) [Agricultural Census 2005, 2010 & 2015]

Key Observations and Comparisons (1991 vs. 2001 vs. 2011):

- ***Rising Population and Density:*** The basin's population grew by over 6.2 million from 1991 to 2011, which pushed the density up from 180.7 to 263.96 people per sq km.
- **Overall Population Growth and Urbanization:** The Mahanadi Basin witnessed substantial population growth across the two decades, increasing from 13,668,512 in 1991 to 16,099,112 in 2001 and further to 19,965,326 in 2011. Simultaneously, the proportion of the urban population increased from 20.11% in 1991 to 23.52% in 2001 and reached 26.26% in 2011, indicating a significant trend towards urbanization.

- **Declining Average Household Size:** The average household size consistently decreased from 5.29 in 1991 to 5.10 in 2001 and further to 4.52 in 2011, suggesting a trend towards nuclear families.
- **Accelerated Decline in Average Land Holding Size:** The average size of land holding per household continued its downward trajectory, falling from 1.22 Ha in 2005 to 1.00 Ha in 2010 and significantly to 0.75 Ha in 2015. This reinforces the trend of increasing land fragmentation, likely influenced by population growth and inheritance patterns, potentially more acutely felt in rural areas.

The data shows that the people-to-land ratio in the total Mahanadi Basin has become increasingly skewed over recent decades. More people are sharing less land per household, underscoring mounting land pressure due to demographic growth and subdivision. This trend highlights the need for sustainable land management strategies to address future challenges in the region.

5. Vulnerable areas in terms of Environmental Degradation

The Mahanadi River, spanning 851 km through Chhattisgarh and Odisha, is under mounting pressure from industrialization, rapid urban growth, and intensive agriculture. This has created multiple environmental degradation hotspots and high-risk zones, with the potential for further deterioration if unaddressed. The following synthesis draws from multiple literature sources to identify both current over-exploited areas and regions vulnerable to future stress.

5.1 Over-Exploited Areas and Pollution Hotspots

Several locations across the basin exhibit severe environmental degradation from high pollutant loads, untreated sewage, and unsustainable resource extraction.

- Sambalpur (Odisha): Discharges ~130 kilolitres/day of untreated sewage through 12 outfalls, with contamination peaking in the dry season when reduced releases from Hirakud Dam leave the river dominated by sewage flow. High faecal coliform levels pose acute health risks.
- Jharsuguda & Brajarajnagar (Odisha): Coal mining and thermal power plants release heavy metals and fly ash into the IB River, along with 80–100 kilolitres/day of urban waste.
- Cuttack (Odisha): Generates 7.5 lakh litres/day of domestic sewage. BOD levels exceed the permissible 3 mg/l limit, with heavy metals and high coliform counts.
- Paradeep (Odisha): Fertilizer and chemical industries discharge effluents with fluoride concentrations up to 6.44 mg/l (well above the 1–2 mg/l limit).
- Hirakud (Odisha): Industrial plants, including Hindalco, discharge over 5,000 kilolitres/day containing cyanide and fluoride—up to 18 times the permissible limit.
- Korba Coalfield (Chhattisgarh): Extensive coal mining produces significant particulate air pollution and contaminates water sources with mining effluents.
- Raigarh (Chhattisgarh): Industrial units discharge untreated effluents, affecting both surface and groundwater quality.
- Raipur (Chhattisgarh): Urban sewage and industrial waste flow into local streams feeding the Mahanadi, reducing water quality and increasing health risks.
- Angul & Talcher (Odisha): Coal-based industries and power plants contribute to both air and water pollution.
- Sundargarh, Rayagada, Koraput, Malkangiri, and Nabarangpur (Odisha): Mining, deforestation, and unregulated land use contribute to soil erosion, habitat loss, and water contamination.

5.1.1 Polluted Tributaries

Several tributaries show significant contamination, further degrading mainstem water quality:

Table 48: Water Quality Status of Identified Polluted Stretches (2023)

Priority Category during 2022			Priority during Jan-May, 2023	SourceTown(s)	Approx. Length (km)
Priority Category	No. of Stretches	Name of Polluted River Stretch	BOD (mg/L)		
Chhattisgarh					
IV	1	(Korba to Urga) Hasdeo	3.6 - 7.0	Korba	20
IV	1	(Bundari to Raipur)Kharun	3.3 - 7.2	Raipur	20
IV	1	(Sihawa to Arrang) Mahanadi	3.3 - 8.0	Kanker, Dhamtari, Nawapara, Rajim	70
IV	1	(Bemta to Simga)Seonath	3.4 - 8.4	Simga	10
V	1	(Raigarh to Kanaktora)Kelo	3.8 - 3.8	Raigarh	15
IV	1	(Arpa river D/S of Bilaspur) Arpa	3.8- 7.0	Bilaspur	40
Odisha					
I	1	Gangua Nallah along Bhubaneswar	18 - 39	Bhubaneswar	13
IV	3	Daya along Narankheta to Kanas	4.8 - 15	Bhubaneswar	37
IV		Kuakhai along Bhubaneswar	3 - 8.4	Bhubaneswar	7
IV		Mangala along Golasahi	2.8 - 4.5	Golasahi	6
V	3	Kathajodi along Cuttack	4.2 - 7.5	Cuttack	23
V		Serua along Sankhatrasa	3.6 - 6.0	Sankhatrasa	7
V		Brahmani along Rourkela	5.3 - 7.8	Rourkela	22

Source: CPCB,2023 & CECB 2020

- IB River and Bheden (Jharsuguda, Odisha): Receives untreated industrial wastewater from mining and thermal plants. Recent CGWB investigations highlight severe contamination from industrial effluents and municipal waste, with high levels of nitrate, fluoride, and dissolved solids, particularly near Safainala and Katikela. Only about half the sampled water met drinking standards, underscoring serious pollution risks in these rivers.
- Daya & Gangua Nalla (Bhubaneswar, Odisha): Coliform levels exceed permissible standards; BOD reaches 4.2 mg/l.

- Serua & Kathajodi (Cuttack, Odisha): High BOD and bacterial loads surpass CPCB standards.
- Seonath River (Chhattisgarh): Subject to pollution from industrial discharges in Durg-Bhilai and Raipur industrial clusters.
- Kharun and Arpa River (Raipur & Bilaspur, Chhattisgarh): Receives untreated domestic sewage, urban runoff, and industrial effluents from both respective cities and nearby industrial areas, contributing to nutrient enrichment, high coliform counts, and reduced dissolved oxygen levels.
- Mahanadi River stretch near Rajim town which continues downstream until it enters Odisha comes under polluted stretch (BOD between 3& 6 mg/l)
- Kelo River (Raigarh, Chhattisgarh): 15-km stretch of the Kelo with BOD levels at 3.7 mg/L downstream compared to 3.3 mg/L upstream.
- Untreated municipal sewage is the major contributor to river pollution in Hasdeo, Kharoon, Mahanadi, Seonath, and Kelo rivers.

5.2 Areas at Risk of Future Degradation

Beyond existing hotspots, several regions are vulnerable to intensified exploitation, climate stress, and urban expansion:

- Nuapada District (Odisha – Jonk River Sub-Basin): High vulnerability score (0.505). Projected temperature rise of 4–4.5°C by 2050 increases flood and drought risk.
- Bargarh District (Odisha): Over half the land is susceptible to desertification.
- For Bargarh district shallow aquifers in blocks like Bijepur, Gaisilet, Bheden, Paikmal, Padampur, and Bhatli show localized fluoride contamination. Deeper aquifers remain a safer, fluoride-free alternative source.
- Coastal Urban Clusters (Bhubaneswar, Paradeep, Cuttack): Projected domestic and industrial water demand to exceed treatment capacity by 2030.
- Jagatpur Industrial Area (Odisha): Elevated heavy metal contamination threatens aquatic life.
- Hirakud Reservoir (Odisha): Faces cumulative impacts from industrial effluents and agricultural runoff.
- Raipur City (Chhattisgarh): Growing untreated sewage discharges risk worsening waterborne disease outbreaks.
- Bilaspur & Janjgir-Champa (Chhattisgarh): Intensifying thermal power generation and mining may raise air and water pollution levels without stricter controls.

6. Development and sustainable land-use strategies

The Mahanadi River Basin (MRB) has undergone extensive land use and land cover (LULC) changes driven by demographic growth, irrigation expansion, industrialization, and climate variability. These shifts have profound implications for landholding patterns, resource availability, and sustainable development. In the following sections, we will further discuss these dynamics in detail, focusing on watershed-level land use changes, irrigation impacts, land fragmentation, environmental challenges, and ongoing restoration and adaptation initiatives.

Land Use Dynamics in the Hasdeo River Watershed

A geospatial study of the Hasdeo River watershed, covering approximately 10,396.37 km², used CA-Markov chain-based modeling to assess LULC changes from 2000 to 2050 (Sharma et al., 2021). Key findings included:

- A projected decrease in dense forest cover by over 15% by 2050 due to agricultural encroachment and coal mining expansion.
- An increase in agricultural land, particularly in northern and central watershed zones, driven by both irrigation infrastructure and land conversion.
- A notable rise in built-up land, especially near urbanizing pockets such as Korba, Ambikapur, and Champa, due to population pressure and industrial growth.
- These shifts are likely to alter land tenure dynamics, potentially reducing per capita landholding and increasing marginalization of small farmers.

Impact of Irrigation and Infrastructure Development

Large-scale irrigation projects like the Gangrel Dam (Ravishankar Sagar Dam), completed in 1979 on the Mahanadi River near Dhamtari, have significantly reshaped land use (Kumar & Sinha, 2020). The dam supplies irrigation water across multiple districts including Dhamtari, Raipur, and Durg. Its influence includes:

- A shift from rainfed to irrigated paddy and high-value crops such as sugarcane and vegetables.
- Induced double or triple cropping patterns, improving gross cropped area but also stressing water and soil resources.
- Expansion of agricultural boundaries into fallows and upland zones, occasionally resulting in land disputes and forest encroachment.
- Moreover, rural electrification and pump subsidies have led to uncontrolled groundwater extraction, reinforcing land use intensification and, at times, degradation.

Land Fragmentation and Rural Pressure

- Landholding data show a stark trend of shrinking average land size. Between 2005 and 2015, the average operational landholding size in rural Chhattisgarh fell from 1.22 ha to 0.75 ha (Agricultural Census, 2005, 2010, 2015). This reflects:

- Inheritance-based fragmentation without consolidation mechanisms.

- Increased landlessness and marginal holdings, especially among Scheduled Tribes and landless labourers.

- Limited access to land leasing mechanisms, leaving many unable to scale operations.

- The average landholding size in the Odisha part of the Mahanadi River Basin declined from 0.803 ha in 2005 to 0.646 ha in 2010, reflecting fragmentation due to population pressure and land use change.

- The value remained constant at 0.646 ha in 2015, suggesting a stabilization effect, possibly due to limits on further subdivision, policy measures, or rural out-migration reducing pressure on land.

Environmental and Policy Concerns

- Encroachment into forest land, especially in the northern and eastern districts of MRB, poses risks to biodiversity and ecosystem services.

- Open-cast coal mining in Hasdeo Arand and other areas causes irreversible land degradation and displacement (Rathore et al., 2023).

- Climate change projections suggest increased risk of land degradation due to erratic rainfall and prolonged dry spells (Ghosh et al., 2020).

Recommendations for Sustainable Land Use

- **Zoning regulations** to demarcate agricultural, forest, and industrial-use areas to minimize unplanned sprawl.

- **Agroforestry and integrated farming systems** to balance productivity with sustainability.

- **Digitization of cadastral records and GIS mapping** to enhance land governance, reduce disputes, and enable land banks.

- **Strengthening community-based natural resource management (CBNRM)** to empower local stakeholders in managing CPRs like grazing lands, tanks, and minor forest produce zones.

- **Promoting climate-resilient cropping systems**, water-use efficiency technologies, and crop diversification through policy and financial support.

Ongoing Restoration and Adaptation Initiatives

- **Green Mahanadi Mission (Odisha)**

Launched on 24 July 2023 with a budget of ₹5,000 crore, this mission targets soil erosion control and groundwater recharge over five years:

  - Plantation Goal: 2 crore saplings, including 63 lakh in the first phase.
  - Coverage: 16,500 ha across 1,303 villages in 15 districts along the Mahanadi.
  - Avenue Plantation: 500 km of roadside tree planting.
  - Species Focus: Fruit trees like mango, jackfruit, and jamun to provide both ecological and livelihood benefits.
  - Implementation: Jointly by the Forest, Horticulture, and Watershed Development departments.

- **CAMPA Afforestation Projects (Kanker, Chhattisgarh; Koraput, Odisha)**

Funded by the Compensatory Afforestation Fund Management and Planning Authority (CAMPA), these projects restore forestland diverted for mining and infrastructure. Implemented by respective State Forest Departments, they focus on biodiversity recovery, community participation, and soil-moisture conservation.

- **MGNREGS Watershed Development (Korba, Chhattisgarh)**

Supported and funded by the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS), this program builds check dams, farm ponds, and contour trenches to improve water retention and soil conservation while providing rural employment. Implemented by local Panchayats and block development offices.

- **Odisha Millet Mission (Tribal districts of Odisha)**

Funded by the Government of Odisha's Agriculture Department with supplementary support from National Food Security Missions, this initiative promotes drought-tolerant millet cultivation for nutrition and climate resilience. Extension services and training are provided through Krishi Vigyan Kendras (KVKs).

- **NABARD WADI Program (Nuapada and Kalahandi, Odisha)**

The National Bank for Agriculture and Rural Development (NABARD) funds this agroforestry program promoting orchard-based farming systems. Implemented by local NGOs and Agriculture Departments, it aims to improve livelihoods and restore degraded lands through fruit plantations.

7. Challenges in revenue mapping

Access to Updated Land Records

Delayed or restricted access to digitized land ownership details particularly khasra (plot-level) or cadastral data in geospatial format remains a critical bottleneck for integrated basin studies. Although platforms such as Bhulekh/Bhunaksha/Bhuiyan, and other state land records portals have digitized ownership details, they generally provide only tabular or single-plot information, rather than spatially linked cadastral layers compiled for larger administrative units.. The lack of readily accessible geospatial cadastral datasets limits accurate analysis of landholding distribution and constrains their integration with land-use and hydrological data. For the Mahanadi River Basin, such datasets are indispensable for assessing people–land relationships, identifying encroachments in floodplains, and designing sustainable river-space management strategies. Without streamlined access to updated cadastral information in GIS-compatible formats, condition assessment and planning efforts remain significantly constrained, reducing the precision and practical relevance of recommendations for sustainable basin development.

7.1. Shortcomings and Gaps

- Existing revenue maps are not spatially integrated with key environmental datasets, such as pollution hotspots or industrial zones.
- Lack of time-series data limits the ability to track land degradation or productivity loss over time.
- Weak coordination between land record systems and environmental data platforms creates fragmented information and data silos.

7.2. Proposed solutions

To overcome these limitations, a shift towards an integrated, digital approach is required.

- **GIS Integration:** Implementing GIS-based platforms to spatially overlay land-use, pollution, and vulnerability maps with district revenue records.
- **Vulnerability Indices:** Integrating vulnerability indices, such as drought/flood hazard maps and coliform exceedance zones, into the digital mapping platforms.
- **Digital Cadastral Platforms:** Building advanced digital platforms that tag discharge points, water quality data, and soil health indicators directly to cadastral records.
- **Climate Risk Zoning:** Including climate risk zones in land classification schemes to guide future urban planning and investments.

8. Conclusion and recommendations

8.1 Summary of the key findings

A) Land Use and Land Cover Changes (1985–2023)

- Urban Expansion: Built-up area surged by 277%, driven mainly by coastal cities in Odisha (e.g., Cuttack, Khordha, Puri) and industrializing zones in Chhattisgarh.

- Agricultural Land: Crop area declined by around 26%, with net cropped area fluctuations regionally. In Odisha, marginal decline in net sown area; Chhattisgarh showed relatively stable net sown area but increased cropping intensity.

- Rangeland: Enlarged by nearly 230%, indicating increased grazing land or degraded lands.

- Tree Cover: Reduced by about 12%, signaling ongoing deforestation and land clearance.

- Water Bodies: Contracted by close to 10%, revealing hydrological changes and possible water stress.

B) Crop Production and Diversity

Odisha:

- Rice dominates Kharif cropping with 71% area share but has declined by 178,000 ha from 1993-94 to 2013-14.

- Pulses increased in Rabi season (55% share).

- Decline in oilseed crops (e.g., 60% drop in Tel sub-basin) and sugarcane.

- Significant rise in fibre crops like jute (271.5% increase in Tel).

- Horticultural crops, vegetables, spices, and fruits are growing steadily.

Chhattisgarh:

- Upper Mahanadi sub-basin saw over 1,000% increase in vegetables and 2,500% rise in fruits cultivation (2000–21).

- Pulses and cereals remained stable; oilseeds declined nationally.

- Cropping intensity high at ~135%, reflecting multiple cropping enabled by irrigation.

- Expansion of cash crops including vegetables, spices, flowers, and fruit orchards.

C) Cropping Intensity Trends

- Peak cropping intensity in MRB reached 140.9% in 2010–11, declining to 131% by 2020–21.
- Chhattisgarh maintains higher and more stable cropping intensity (~136%) compared to Odisha.
- Odisha shows fluctuations tied to irrigation availability, policy, and resource constraints.

D) Demographic and Land Pressure

Population Growth (2001–2011):

- Odisha part: Population grew by ~19%, from 32.49 million to 38.66 million; population density rose from ~229 to 273 persons/km².
- Chhattisgarh part: Population grew from 16.1 million to nearly 20 million (1991–2011), density increased from 181 to 264 persons/km².

Landholding Size:

- Odisha: Average operational holdings declined from 0.803 ha (2005) to 0.646 ha (2015).
- Chhattisgarh: Average holding shrank significantly from 1.22 ha (2005) to 0.75 ha (2015).
- Urbanization concentrated in Odisha districts like Khordha (66.5% population increase) and Cuttack (36% increase).

E) Environmental Challenges and Vulnerabilities

Pollution hotspots include urban-industrial centers such as:

- Odisha: Sambalpur (untreated sewage ~130 kl/day), Hirakud (industrial cyanide and fluoride discharge up to 18 times permitted levels), Paradeep (high fluoride).
- Chhattisgarh: Korba coalfields (air and water pollution), Raipur and Raigarh (industrial and sewage contamination).
- Major tributaries face contamination from industrial and domestic sources.

8.2 Recommendations and improvements

To address these challenges, the following actions are recommended:

A) Integrated GIS-Based Revenue Mapping

- Develop GIS-integrated cadastral platforms linking land ownership with land use, pollution, groundwater, soil degradation, and climate risk data.
- Overlay environmental datasets onto revenue maps to create a comprehensive land–environment management tool.

B) Improved Data Accessibility and Coordination

- Streamline access to updated, spatially linked digital land records at the basin scale.
- Establish joint monitoring and coordination systems between Odisha and Chhattisgarh for water sharing and pollution control.

C) Use of Vulnerability Indices for Planning

- Incorporate drought, flood, pollution, and land degradation hazard maps into digital land platforms.
- Embed climate resilience and sustainability indicators into land zoning and development frameworks.

C) Sustainable Land Use and Agricultural Practices

- Promote agroforestry, crop diversification, and water-efficient technologies for sustainable intensification.
- Encourage land consolidation and climate-resilient cropping systems to reduce fragmentation and vulnerability.

D) Strengthening Restoration and Adaptation Efforts

- Expand the Green Mahanadi Mission for afforestation, soil erosion control, and groundwater recharge.
- Strengthen community-based monitoring and resource management through village-level committees and livelihood-linked schemes.

E) Revenue Mapping Enhancements for Sustainable Basin Development

- Tag revenue plots with environmental data (pollution hotspots, soil health, groundwater status).
- Develop a Mahanadi River Health Index, updated quarterly with real-time monitoring data for transparent ecological assessment.

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