A SCOPING STUDY

PART ONE

The Potential to Promote Climate Smart Agriculture for a Resilient Odisha

Resource Use and Greenhouse Gas Emission Profiles for the Agriculture and Allied Sector in Odisha

April 2025

CSTEP

Center for Study of Science, Technology and Policy (CSTEP)

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The Potential to Promote Climate Smart Agriculture for a Climate Resilient Odisha

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PART ONE

Resource Use and Greenhouse Gas Emissions profiles for districts of Odisha

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EXECUTIVE SUMMARY

Odisha's agricultural and allied sectors face severe threats from climate change. These sectors are crucial for the state's economy yet are increasingly at risk to climate extremes. This scoping report series is an exercise to identify the priority districts for intervention to build resilience sustainably in the agriculture and allied sectors of the state. It leverages three key components to investigate the nature, extent, and intensity of impacts on agriculture and allied sectors: Resource Use Profiling (RUP), Greenhouse Gas (GHG) Emissions Inventory, and Climate Risk Assessment (CRA). The result is a triangulated determination of top district(s) with inefficient resource use, high GHG emissions and extreme climate risks to the sector to guide the development of District-Level Climate Action Plans and implementing Climate Smart Agriculture (CSA) practices. This scoping study report series is split into three parts. Part 1 dives into the RUP and GHG emissions inventory, while Part 2 presents the Climate Risk Assessment, and the Scoping Study triangulates results from Part 1 and 2 to pinpoint priority districts to promote CSA interventions to maximise climate benefits.

Resource Use Profiling

The resource use profiling section of the study provides a detailed examination of the inputs required for paddy cultivation in Odisha, focusing on the intensity and efficiency of fertiliser, water, and mechanisation use. Paddy was selected for this assessment due to its extensive cultivation across all districts and its significant share of input usage, which includes fertilisers, water, and agricultural machinery.

- The study quantified the application rates of Nitrogen (N), Phosphorous (P), Potassium (K), manure, and pesticide in paddy cultivation. Balangir, Deogarh, Jajpur, Dhenkanal, and Ganjam were identified as having the highest input application rates (relatively high manure, fertiliser and pesticide application). Nabarangpur was identified as the district with the highest fertiliser (N, P & K) application rates, Balangir as the highest manure application rates, and Koraput as the district with highest pesticide application rates, potentially leading to inefficiencies and environmental risks.

- Water-Use Efficiency was measured as Biophysical Water Productivity, which is the amount of water required to produce one kilogram of paddy. Gajapati, Jajpur, Kandhamal, and Khordha exhibited low biophysical water productivity, meaning more water was used to produce the same amount of crop, highlighting inefficiencies in water usage.

- The study also evaluated mechanisation levels in paddy cultivation, which directly affect labour productivity and energy use. Balasore, Bhadrak, and Jajpur had higher percentages of operational holdings using agricultural machinery, indicating better mechanisation uptake. On the other hand, Koraput, Keonjhar, and Jagatsinghpur showed lower uptake, suggesting a need for enhanced mechanisation support to improve agricultural productivity.

In summary, the analysis reveals marked disparities in resource use intensity for paddy cultivation across Odisha's districts, as captured by the RUP Index. Districts such as Balangir, Khordha, Jajpur, Gajapati, and Kandhamal exhibit high RUP index scores, reflecting poor water-use efficiency, relatively high manure, fertiliser and pesticide application, and limited mechanisation –indicating the greatest need for resource optimisation through CSA practices. In contrast, districts such as Kalahandi, Nabarangpur, Subarnapur, Sambalpur, and Bargarh register low RUP index scores, reflecting higher water-use efficiency and better mechanisation, alongside lower organic manure use but elevated application of fertilisers and pesticides. This indicates that even districts with overall efficient resource use may require targeted improvements in specific areas, such as mechanisation or balanced input use. Taking into account both overall and component-level inefficiencies, Balangir, Nabarangpur, and Bargarh have been identified as priority districts for the implementation of resource-efficient CSA interventions in consultation with the Department of Agriculture and Farmers' Empowerment. Government of Odisha.

GHG Emission Inventory

The GHG emissions inventory section of the study focuses on the comprehensive calculation of GHG emissions from the agriculture and allied sectors between 2014 and 2023. While the RUP focused only on resource-use for paddy cultivation, this inventory tracks emissions from paddy cultivation; livestock (enteric fermentation and manure management); fertiliser use (nitrous oxide - N_2O emissions); and fuel consumption by farm machinery (carbon dioxide - CO_2 emissions) in general, i.e., for all crops in the district, based on the methodology used by the GHG Platform of India.

Paddy fields are the largest contributor to GHG emissions in the state, with methane (CH_4) emissions from flooded fields accounting for approximately 50% of the total agricultural emissions. Mayurbhanj district alone emitted 18.5 million tons of $CO_{2\text{-eq}}$ over the decade. The stable methane emissions from rice were punctuated by a notable dip during drought years, specifically in 2017 and 2018, which saw reduced water availability for paddy fields.

The state's second-highest contributor of methane emissions was livestock, particularly cattle. Enteric fermentation accounted for a large portion of these emissions, followed by manure management. Over the decade, livestock emissions declined gradually due to reduced livestock populations between 2012 and 2019. Despite this, livestock still accounted for over 45% of total agricultural GHG emissions in the state. Mayurbhanj and Keonjhar were among the highest contributors.

The study also tracked emissions from nitrogen-based fertilisers used for paddy cultivation. N_2O emissions have steadily increased over the last decade, driven by rising fertiliser application rates, particularly in districts like Bargarh and Nabarangpur. Although fertiliser use in Odisha is well below the national average, it accounts for 4% of the state's agricultural GHG emissions, signalling optimisation in high fertiliser use districts to mitigate GHG emissions.

CO_2 emissions from diesel-powered farm machinery, including tractors and pump-sets, were also assessed. Although the number of diesel pump-sets declined over the years, the overall fuel consumption increased due to the growing use of tractors in agricultural operations. Bargarh and Balasore were leading in fuel-related CO_2 emissions, with diesel consumption in tractors and other machinery driving this trend.

In 2023, total CO_2 emissions from farm machinery reached 0.5 million tons. In 2014, total GHG emissions from Odisha's agriculture and allied sectors were 24.2 million tons of $CO_{2\text{-eq}}$. By 2023, this figure had reduced to 22.2 million tons, reflecting a 9% decrease, largely attributed to the adoption of CSA practices like improved water management and crop diversification. Rice cultivation and livestock-dominated emissions account for 96% of total sectoral GHG emissions. Methane was the most significant gas emitted (largely from rice and livestock), followed by nitrous oxide (from fertilisers) and carbon dioxide (from machinery). Mayurbhanj, due to its extensive rice and livestock production, emerged as the largest emitter, while Jharsuguda emitted the least at 2.5 million tons over the decade. However, **Puri** and **Bhadrak lead the state in per-hectare GHG emissions**. These districts mainly contain lowlands with the highest fraction of areas under deep water and flood-prone rainfed rice ecosystems.

NEXT SPREAD: At the crack of dawn fishermen prepare to leave in their fishing boats. The beach becomes a hive of activity. Silhouette figures gradually appear on the golden sands of Puri beach, in Odisha, as the sun rises for another day at sea. Tim W Mills

Contents

1.	**Introduction**	**14**
2.	**Objective**	**16**
3.	**Methodology**	**17**
3.1.	Resource use profiling	17
3.1.1.	Fertiliser, manure and pesticide application rates (kg/ha)	20
3.1.2.	Mechanisation	22
3.1.3.	Water-use efficiency	23
3.2.	GHG inventory	23
3.2.1.	Rice cultivation	23
3.2.2.	Enteric fermentation of livestock	29
3.2.3.	Synthetic fertiliser use	29
3.2.4.	Diesel consumption by farm machinery	30
3.2.5.	Green House Gas Emissions Index	30
4.	**Results**	**32**
4.1.	Resource use profiling for paddy	32
4.1.1.	Fertiliser, manure and pesticide (kg/ha)	32
4.1.2.	Mechanisation	32
4.1.3.	Water use efficiency	32
4.1.4.	Key Takeaways for Resource use profiling for paddy	34
4.2.	GHG inventory	39
4.2.1.	Greenhouse gas emissions index	51
4.2.2.	Key takeaways of GHG emissions inventory	51
4.2.3.	Data and result validation	52
5.	**Conclusions**	**53**
6.	**References**	**56**

Tables

Table 1:	Major crops in each district based on area under cultivation	18
Table 2:	Data sources for assessing resource use intensity	19
Table 3:	Paddy systems in Odisha (Das, 2012)	20
Table 4:	Proportion of paddy area treated with fertiliser, manure and pesticides (Input Survey Report, 2015)	20
Table 5:	Farmer fertiliser application rates in different paddy systems and their proportions	21
Table 6:	Fertiliser (NPK) application rates in kg/ha at the districts level for different Paddy systems	24
Table 7:	Manure application rates (kg/ha) at the district level for different paddy systems	26
Table 8:	Pesticide application rates (kg/ha) at the district level for different paddy systems	27
Table 9:	Emission factors for agriculture - Rice	28

Table 10: National level proportion of different paddy areas 28

Table 11: Disaggregation of livestock types considered for the GHG inventory and their emission factors 29

Table 12: Factors assumed for daily usage, fuel consumption and emissions of tractors and pump sets (2014-2023) 30

Table 13: Distribution of weights for each source of emission 31

Figures

Figure 1: Advancing agriculture resilience and sustainability in Odisha 15

Figure 2: Major crops mapped at district level (Source: Odisha Agriculture Statistics, 2018) 19

Figure 3: Method used to quantify fertiliser, manure and pesticide application rates in kg/ha (Source: CSTEP research) 22

Figure 4: Aggregated indexed values of fertiliser, manure and pesticides applied to paddy at the district level 33

Figure 5: Percentage of operational holdings owning and renting machinery for crop cultivation 33

Figure 6: Percentage of implements supplied under various schemes (2018-23) 34

Figure 7: Biophysical water productivity map for paddy in Odisha 35

Figure 8: District level water-use efficiency for production of paddy 37

Figure 9: Resource use profile of districts for paddy cultivation 37

Figure 10: Resources contributing to the RUP index for different classes of RUP districts 38

Figure 11: Approach to estimating emissions inventory 39

Figure 12: Total annual emissions from the agriculture and allied sector of Odisha 40

Figure 13: District-wise emissions from the agriculture and allied sector of Odisha 40

Figure 14: Contribution of different emissions sources to the total emissions 41

Figure 15: Total Emissions of the top three highest emitting districts 42

Figure 16: Total annual emissions by various emission sources 44

Figure 17: Total district-wise emissions by various emission sources 46

Figure 18: District-wise per hectare emissions by various emission sources 48

Figure 19: Fraction of total area under each rice ecosystem (High, medium, and lowlands, average of 2014-2019) 50

Figure 20: District-wise comparison of greenhouse gas emissions (Kg $CO_{2\text{-eq}}$ per hectare per year) 50

Abbreviations

Abbreviated form	Expanded form
BWP	Biophysical Water Productivity
CRA	Climate Risk Assessment
CSA	Climate Smart Agriculture
ET	Evapotranspiration
FAO	Food and Agriculture Organisation
GEOGLAM-BACS	Global Best Available Crop Specific Masks
GHG	Greenhouse Gas
GHGPI	GHG Platform India
GVA	Gross Value Added
IR	Irrigated
MT	Million Tonnes
NATCOM	National Communication
NHP	National Hydrology Project
NPK	Nitrogen, phosphorus and potassium
RF	Rainfed
RUP	Resource Use Profiling
SAPCC	State Action Plan for Climate Change
UNFCCC	United Nations Framework Convention on Climate Change
WUE	Water-Use Efficiency

RIGHT: Rice is cultivated in all districts of Odisha

Manoranjan Mishra

1. Introduction

Odisha, India's eighth-largest state, spans 155,707 km^2 with a 450 km coastline along the Bay of Bengal, bordered by Chhattisgarh to the west and Andhra Pradesh to the south. Understanding the challenges faced by Odisha's agriculture and allied sectors requires a thorough understanding of the state's geographical and climatic context. Odisha's topography – fertile coastal plains, central highlands, and uplands – supported by major rivers like the Mahanadi, Subarnarekha and Brahmani, help realise the state's agriculture productivity. The state's tropical climate, marked by erratic rainfall (75-80% during the southwest monsoon) and increasing extreme weather events, make it particularly at risk to floods, droughts, heatwaves, cyclones, and coastal erosion, impacting the state's economy and food security (OSDMA, 2024; IANS, 2023; MoHHW, 2022; Shankar et al., 2022).

Agriculture and allied sectors sustain 80-85% of Odisha's rural population, with paddy, pulses, millets, and horticultural crops as major contributors (Caritas India, 2021; APEDA, 2023). Livestock in Odisha constitutes 3.4% of India's total livestock population (Livestock Census, 2019) and remains critical for landless laborers and small farmers (Singh & Sonwani, 2023), while fisheries have emerged as a fast-growing sector, driven by Odisha's coastline, inland water systems and enabling policies (Annual activities report, 2018-19).

Despite rising climate risks, agriculture's contribution to Odisha's Gross Value Added (GVA) increased from 18.9% in 2018-19 to 21% in 2023-24. Livestock, the second-largest sub-sector after crops, contributes to 16.7% of the Gross Value Added from agriculture and allied activities (Odisha Economic Survey, 2023-24).

Fisheries has been the fastest-growing sub-sector, with a 13% average annual growth rate over the past five years, supporting 15 lakh fishers and three lakh aquaculture farmers (World Bank, 2021). As highlighted in Odisha State Action Plan on Climate Change (2018), recurring disasters result in the annual loss of 900,000 hectares of agricultural land, exacerbating food insecurity and water stress.

With agriculture responsible for about a quarter of Odisha's total emissions (98.5 Mt $CO_{2\text{-eq}}$; CII, 2015), the sector holds immense potential for climate action. Climate Smart Agriculture (CSA) offers a way forward by aligning productivity with sustainability – improving resource use, reducing emissions, and building adaptive capacity. By embedding CSA into agricultural planning, Odisha can strengthen rural livelihoods, reduce climate risks, and move toward a more climate-resilient, future. Initiatives like the Shree Anna Abhiyan and the SAMRUDHI Agriculture Policy (2020) strengthen this approach by encouraging diverse cropping systems, efficient water use, and sustainable land management.

By integrating CSA into agricultural systems and leveraging supportive policies, the state has the opportunity to enhance the sustainability of agriculture sector, protect farmer livelihoods, and mitigate climate impacts. Transforming agriculture into a resilient, climate-adaptive sector is essential not only for achieving food security and economic stability but also for contributing meaningfully to global climate action.
The steps towards advancing agriculture resilience and sustainability in Odisha is detailed in Figure 1.

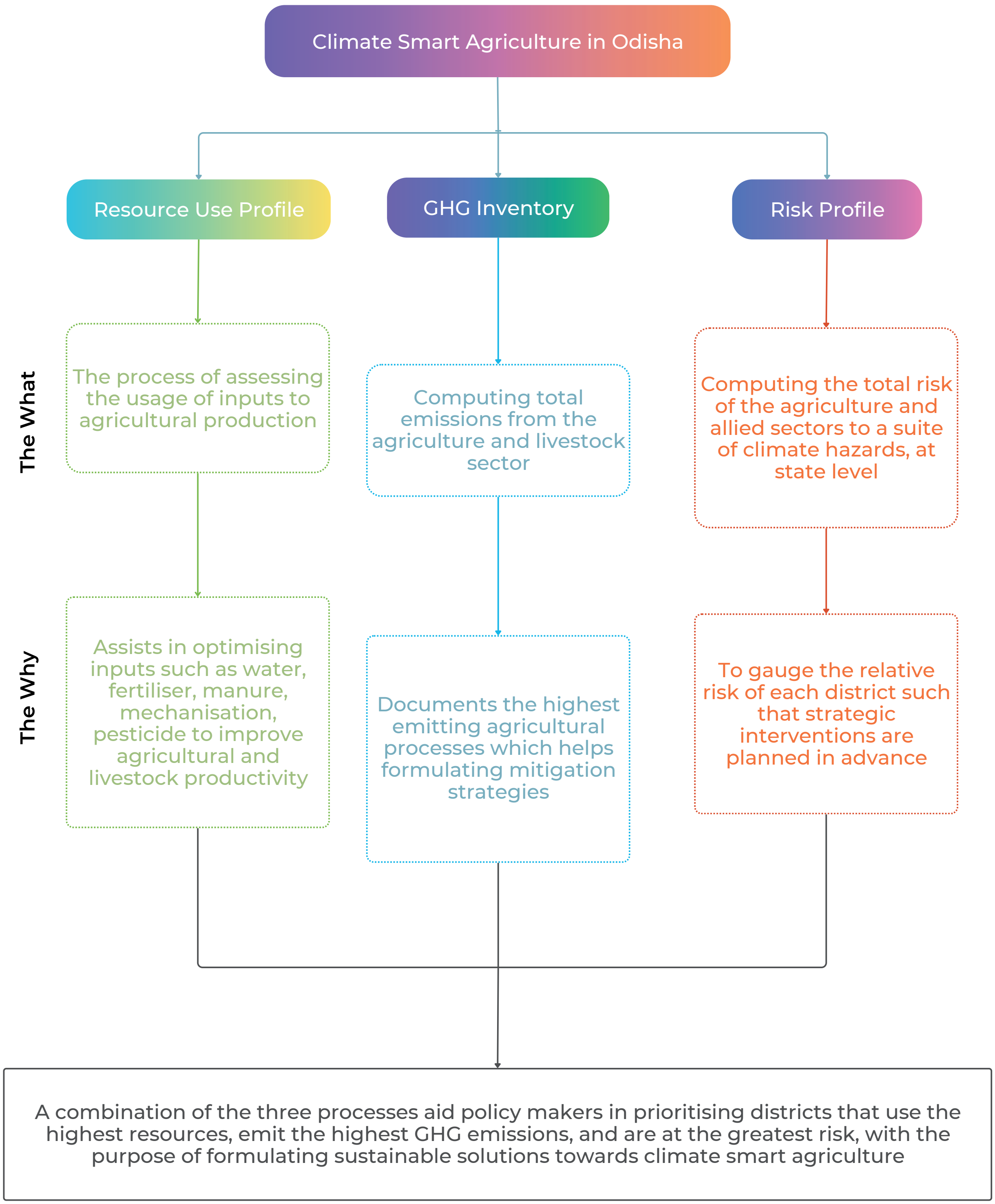


Figure 1: Steps taken towards generating baseline information to advance agriculture resilience and sustainability in Odisha

2. Objective

The primary objective of the scoping study is to identify districts in Odisha that require prioritisation for enhancing resilience, optimising resource use, and addressing emissions in the agriculture and allied sectors. By examining current patterns of resource consumption, GHG emissions, and sector-specific climate risks, it will inform the creation of targeted District Action Plans. These plans will not only focus on building long-term sustainability but also serve as a foundation for piloting CSA practices, ultimately strengthening the sector's resilience.

This report outlines the analytical approach adopted to assess resource consumption and GHG emissions across agriculture and allied sectors. By presenting the findings from these assessments, the report aims to support planners and policymakers in pinpointing districts with intensive resource use and high emissions. These insights are intended to inform the strategic deployment of CSA interventions, focusing on reducing inefficiencies and emissions in both crop and livestock systems. This approach ensures that interventions are data-driven and tailored to areas with the greatest potential for impact.

3. Methodology

This section provides a brief overview of the two assessments and the methodologies adopted to establish the resource use and GHG emission profiles for the districts of Odisha.

3.1. Resource use profiling

Resource Use Profiling in agriculture is an essential process for assessing and optimising inputs such as water, energy, fertilisers, and labour that contribute to agricultural productivity (Haque, 2006). This profiling helps identify inefficiencies and opportunities for improvement, ensuring that agricultural practices are sustainable and resilient, particularly in regions facing environ- mental challenges and resource constraints. In the context of Odisha, optimising resource use is critical for enhancing food security, reducing environmental impacts, and adapting to climate variability.

Odisha has diverse agro-climatic zones, soil types, and varying water availability, making a one-size-fits-all approach to agriculture ineffective and unsustainable. To address this diversity and variability, resource use profiling at the district level is adopted, wherein the dominant crops in each district were identified using data for the year 2023-24, provided by the Agriculture Statistics Department, Department of Agriculture and Farmers' Empowerment, Government of Odisha. Major crops across all 30 districts were identified based on the area under cultivation (Table 1). These were broadly grouped under food (Paddy, Pulses, Maize and Ragi), cash (Rapeseed, Mustard, Sesamum, Groundnut and Sugarcane) and horticulture (Banana, Guava, Litchi, Mango and Potato).

Among these, rice/paddy emerged as the most important system, prompting a detailed investigation of its subsystems, specifically highland, middle land, and lowland rice cultivation under irrigated and rainfed conditions. *Kharif* paddy was selected for this exercise due to significant coverage in terms of net sown area (66.17%) and, consequently, its share of input usage being the highest in the state (Odisha Input Survey Report, 2016). Additionally, as this assessment aids in prioritising districts with unbalanced (either overuse or under-use of resources) resource usage, the fact that paddy is cultivated in all districts, unlike other crops, allows for better comparison (Figure 2).

Resources considered for the analysis are fertiliser, manure, pesticide, water, and mechanisation. Data related to labour specific to paddy at a district level was unavailable and, therefore, not included in the assessment. The data sources are presented in Table 2.

OPPOSITE: Grains, vegetables and spices being sold in the Kunduli market, Odisha. Oscar Espinosa

SN	District Name	Food Crops			Oil Seeds			Horticulture	
1	Angul	Rice	Pulses	Potato	Groundnut	Sesamum	Rapeseed and Mustard	Mango	Banana
2	Balangir	Rice	Pulses	Maize	Groundnut	Rapeseed and Mustard	Sesamum	Mango	Banana
3	Balasore	Rice	Pulses	Potato	Groundnut	Rapeseed and Mustard	Sesamum	Mango	Banana
4	Bargarh	Rice	Pulses	Potato	Groundnut	Rapeseed and Mustard	Sesamum	Mango	Banana
5	Boudh	Rice	Pulses	Sugarcane	Rapeseed and Mustard	Groundnut	Sesamum	Mango	Banana
6	Bhadrak	Rice	Pulses	Maize	Rapeseed and Mustard	Sesamum	Groundnut	Mango	Banana
7	Cuttack	Rice	Pulses	Sugarcane	Groundnut	Rapeseed and Mustard	Sesamum	Mango	Banana
8	Deogarh	Rice	Pulses	Potato	Sesamum	Groundnut	Rapeseed and Mustard	Mango	Litchi
9	Dhenkanal	Rice	Pulses	Potato	Groundnut	Sesamum	Rapeseed and Mustard	Mango	Banana
10	Gajapati	Rice	Maize	Total pulses	Sesamum	Groundnut	Rapeseed and Mustard	Mango	Guava
11	Ganjam	Rice	Pulses	Maize	Sesamum	Groundnut	Rapeseed and Mustard	Mango	Banana
12	Jagatsinghapur	Rice	Pulses	Sugarcane	Groundnut	Rapeseed and Mustard	Sesamum	Mango	Banana
13	Jajpur	Rice	Pulses	Sugarcane	Groundnut	Rapeseed and Mustard	Sesamum	Mango	Banana
14	Jharsuguda	Rice	Pulses	Maize	Sesamum	Rapeseed and Mustard	Groundnut	Mango	Banana
15	Kalahandi	Rice	Pulses	Maize	Groundnut	Rapeseed and Mustard	Sesamum	Mango	Guava
16	Kandhamal	Rice	Pulses	Maize	Rapeseed and Mustard	Groundnut	Sesamum	Mango	Banana
17	Kendrapara	Rice	Pulses	Potato	Groundnut	Rapeseed and Mustard	Sesamum	Others	Banana
18	Keonjhar	Rice	Pulses	Maize	Rapeseed and Mustard	Groundnut	Sesamum	Mango	Guava
19	Khordha	Rice	Pulses	Sugarcane	Groundnut	Sesamum	Rapeseed and Mustard	Mango	Others
20	Koraput	Rice	Ragi	Others	Groundnut	Sesamum	Rapeseed and Mustard	Mango	Guava
21	Malkangiri	Rice	Pulses	Ragi	Sesamum	Groundnut	Rapeseed and Mustard	Mango	Guava
22	Mayurbhanj	Rice	Pulses	Maize	Groundnut	Rapeseed and Mustard	Sesamum	Mango	Banana
23	Nabarangpur	Rice	Maize	Total pulses	Groundnut	Sesamum	Sesamum	Mango	Guava
24	Nayagarh	Rice	Pulses	Maize	Rapeseed and Mustard	Sesamum	Groundnut	Mango	Banana
25	Nuapada	Rice	Pulses	Maize	Groundnut	Sesamum	Rapeseed and Mustard	Mango	Guava
26	Puri	Rice	Pulses	Potato	Groundnut	Sesamum	Rapeseed and Mustard	Mango	Banana
27	Rayagada	Rice	Pulses	Ragi	Sesamum	Rapeseed and Mustard	Groundnut	Mango	Banana
28	Sambalpur	Rice	Pulses	Potato	Rapeseed and Mustard	Sesamum	Groundnut	Mango	Litchi
29	Subarnapur	Rice	Pulses	Other cereals and millets	Groundnut	Rapeseed and Mustard	Sesamum	Mango	Banana
30	Sundargarh	Rice	Pulses	Maize	Rapeseed and Mustard	Sesamum	Groundnut	Mango	Banana

Table 1: Major crops in each district based on area under cultivation

Table 2: Data sources for assessing resource use intensity

Resource Category	Data Source and Remarks
Area under Paddy	Odisha Agriculture Statistics, 2018-19;
Fertiliser, manure, and pesticide use rates	Das, 2012, Sharma et al., 2019, SAMRUDHI Agriculture Policy, 2020
Total fertiliser, manure, and pesticide use	Odisha Input Survey Report (2016) and the Odisha Agriculture Statistics, 2018-19
Farm machinery/ mechanisation	Odisha Input Survey Report (2016) and the Odisha Agriculture Statistics, 2018-19, 2023 data by the Department of Agriculture and Farmers' Empowerment Statistics, Directorate of Agriculture and Food Production, Odisha
Water-use efficiency	Computed using total Evapotranspiration for *Kharif* months (2023) from the National Evaporative Flux Monitoring System (Bhuvan-NHP) and the *kharif* paddy yield data (2023-24) from the Department of Agriculture and Farmers' Welfare. For the purpose of ET data extraction, area under paddy shapefile (Becker-Reshef et al., 2022) from Global Best Available Crop Specific Masks (GEOGLAM-BACS) was used.

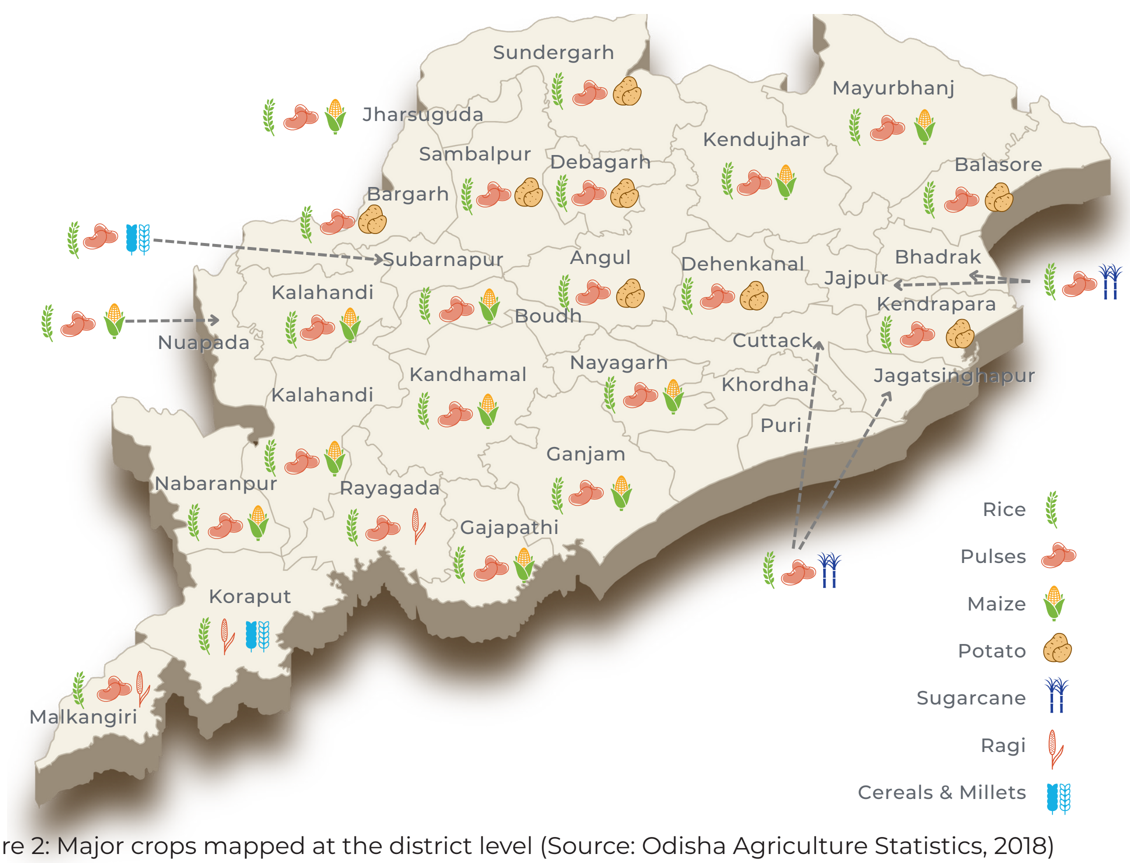


Figure 2: Major crops mapped at the district level (Source: Odisha Agriculture Statistics, 2018)

While data for area under paddy was available for 2023-24 (Department of Agriculture Statistics, Directorate of Agriculture and Food Production, Odisha), the data was not disaggregated into high, medium and lowlands. This disaggregation is crucial to consider as management practices used in these different paddy systems vary significantly. Therefore, data from 2018 was used for this assessment.

3.1.1. Fertiliser, manure and pesticide application rates (kg/ha)

The Odisha Agriculture Statistics, 2018-19 provides the area under cultivation of all crops, including *kharif* paddy, disaggregated by high, medium and lowlands. It also provides the total nutrient application in Million Tonnes (MT) at the district level, disaggregated by Nitrogen (N), Phosphorus (P) and Potassium (K) content of chemical fertilisers, and the total farmyard manure for irrigated and unirrigated lands.

Irrigation status significantly contributes to how paddy systems manage fertiliser application (FAO, 2005) and for the purpose of this assessment, the paddy systems in Odisha were classified into six broad types based on Das, 2012 (Table 3). Column A provides the proportion of area under the six paddy systems; Column B aggregates irrigated and unirrigated for high, medium and lowlands;

Table 3: Paddy systems in Odisha (Das, 2012)

SN	Paddy system: Land class	Paddy system: Irrigation status	A: Proportion of area under each system	B: Total propo-rtion under each system (A)	C: Proportion of B
1	High land	Irrigated	5%	24.1%	20.7%
2		Unirrigated	19.1%		79.3%
3	Medium land	Irrigated	24.7%	37.1%	66.6%
4		Unirrigated	12.4%		33.4%
5	Lowland	Irrigated	5%	38.8%	12.9%
6		Unirrigated	33.8%		87.1%
7	Total	Irrigated	35%	100%	300%
8		Unirrigated	65%		

Table 4: Proportion of paddy area treated with fertiliser, manure and pesticides (Input Survey Report, 2015)

Area under paddy treated with fertiliser		Area under paddy treated with manure		Area under paddy treated with pesticides	
Irrigated	**Un-irrigated**	**Irrigated**	**Un-irrigated**	**Irrigated**	**Un-irrigated**
68%	84%	31%	50%	2.06%	2.73%

ABOVE: Farmers operating a power tiller in a paddy field, in Odisha Manoranjan Mishra

Column C disaggregates Column B again, but on a scale of 100. Column C was used to disaggregate it into the six paddy classes. This disaggregated area was then used to compute the area under paddy treated with fertilisers and manure (Table 4).

The total NPK, manure and pesticide application (in MT) was disaggregated to the different paddy systems by multiplying it with the application rates sourced from literature—the fertiliser application rates by farmers in upland (high) paddy systems was sourced from Dass et al., 2009, for medium land, which is the major land type in Odisha, the state average NPK application rate published in SAMRUDHI Agriculture Policy, 2020, and for lowlands, data from Sharma et al., 2019, were used (Table 5).

The disaggregated total input (MT) was then divided by the area under *Kharif* paddy that was treated by either fertiliser, manure or pesticide (converting MT to Kg at this stage) to arrive at a per unit application rate for each district in Kg/ha.

Table 5: Farmer fertiliser application rates in different paddy systems and their proportions

SN	Paddy System	Application rate (Kg/ha) N	P	K	Total	Proportion N	P	K	Total
1	High land	26.8	16.9	12.5	56.2	47.7%	30.1%	22.2%	100%
2	Medium land	41.4	17.5	9.2	68.0	60.8%	25.7%	13.5%	100%
3	Low land	80.0	17.0	33.0	130.0	61.5%	13.1%	25.4%	100%

Figure 3 presents the approach adopted to compute fertiliser, manure and pesticide application rates. The fertiliser (Table 6), manure (Table 7) and pesticide (Table 8) application rates at the district level are provided below.

3.1.2. Mechanisation

Mechanisation data specific to paddy was unavailable for the state at the district level. Considering the area under paddy is significant, and the type of machines and tools reported in the Input Survey Report (2016) and the Odisha Agriculture Statistics, 2018-19, such as reapers/reaper binders, post-harvest equipment, transplanters, power-driven equipment (tractors/power tillers), laser-guided land levellers, diesel/electric/petrol/kerosene pump set, etc., which are used in the cultivation of paddy, it is assumed that all mechanisation reported applies to paddy in the absence of disaggregated data.

The number of operational holdings that owned and rented agricultural machinery for

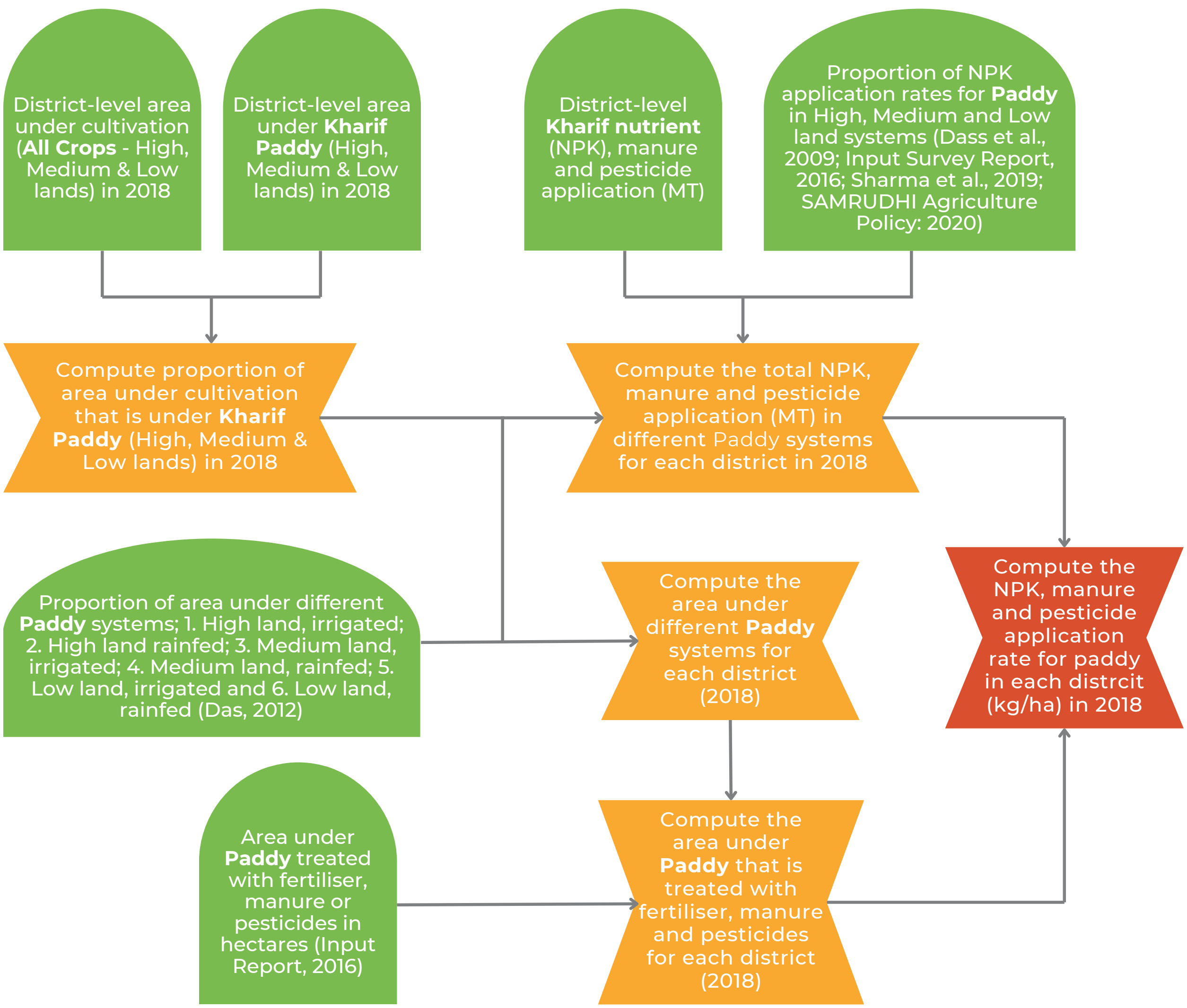


Figure 3: Method used to quantify fertiliser, manure and pesticide application rates in kg/ha (Source: CSTEP research)

cultivation, as reported in Input Survey Report, 2016, was considered and the percentage of total operational holdings using machinery was computed. According to this data, there is no significant variation in mechanisation across the state. Additionally, efforts by the state to promote mechanisation of agriculture and the data representing the same was used to rank the districts with the most implements supplied under various schemes between 2018 and 2023.

3.1.3. Water-use efficiency

Water-use efficiency was measured as the Biophysical Water Productivity (BWP), which describes the agricultural output (crop yield) per unit of water used in a given area. FAO report suggests that optimising this dimension of water productivity means producing more crop for every drop of water (FAO, 2022). This dimension was computed for paddy using variables represented in Equation 1.

Equation 1: $$BWP = \frac{\text{Crop Yield}}{\text{Water-use (ET)}}$$

These variables were quantified using different data sources and methods:

- A *kharif* crop yield in kg/ha was considered for this assessment retrieved from the Department of Agriculture Statistics, Directorate of Agriculture and Food Production, Government of Odisha (2023-24).
- The total evapotranspiration for the *kharif* months (June, July, August, and September) of 2023 (in mm) was sourced from the National Hydrology Project's (Bhuvan-NHP) satellite-based Regional Evaporative Flux Monitoring System and represents the water-use component in the BWP equation above.

3.2. GHG inventory

Greenhouse gas emissions inventory was computed for the agriculture and allied sector of Odisha for the period 2014-2023. The methodology used to calculate emissions follows the method adopted by GHG Platform of India (GHGPI) from 2005 to 2018. This is based on the IPCC Guidelines for National Greenhouse Gas Inventories, 1996. The inventory provides district-wise emissions in tonnes of $CO_{2\text{-eq}}$ per annum of the following sources:

- Rice cultivation
- Enteric fermentation of livestock
- Manure management
- Synthetic fertiliser use
- Fuel consumption by farm machinery.

The inventory presents total district-wise emissions from various sources rather than emissions normalised per hectare. This is because the emission factors used in the IPCC Guidelines, India's Third National Communication to the UNFCCC (NATCOM 3), and other literature are standardised by the area under cultivation, typically in units of "$kgCO_{2\text{-eq}}$ per hectare." These emission factors are applied uniformly across districts for each source, resulting in identical emissions per hectare for a given source across all districts. This approach is the best available method and follows standard procedures for calculating emissions.

3.2.1. Rice cultivation

The data used to estimate emissions were obtained from the Odisha Agricultural Statistics reports for 2014-2019. The area under rice cultivated for this period is disaggregated into three major types of rice ecosystems, namely rainfed, irrigated and deep-water. However, the total area cultivated is available for 2019-2022. Therefore, the disaggregation of paddy cultivation across the three rice ecosystems was based on the

DISTRICT	High land							
	Irrigated			Un-irrigated			Irrigated	
	N	P	K	N	P	K	N	P
Angul	0	0	0	0	0	0	15	4
Balangir	0	0	0	0	0	0	40	7
Balasore	0	0	0	0	0	0	50	13
Baragarh	34	13	4	28	10	3	44	11
Bhadrak	0	0	0	0	0	0	59	16
Boudh	25	7	2	20	6	2	32	6
Cuttack	0	0	0	0	0	0	41	5
Deogarh	28	19	2	22	15	2	35	16
Dhenkanal	0	0	0	0	0	0	17	3
Gajapati	24	5	1	19	4	1	31	4
Ganjam	38	6	2	30	4	1	48	5
Jagatsinghapur	0	0	0	0	0	0	44	10
Jajpur	40	14	6	32	11	5	51	12
Jharsuguda	25	8	2	20	7	2	31	7
Kalahandi	30	10	3	24	8	2	39	8
Kandhamal	5	4	0	4	4	0	6	4
Kendrapara	22	7	1	18	5	1	28	6
Keonjhar	22	6	2	17	5	1	28	5
Khordha	31	6	3	25	5	2	39	5
Koraput	21	7	3	17	5	2	26	6
Malkangiri	20	4	1	16	3	1	25	4
Mayurbhanj	22	6	1	17	4	1	28	5
Nabarangpur	94	15	7	76	12	6	120	13
Nayagarh	22	5	2	17	4	1	28	4
Nuapada	21	7	2	17	6	1	26	6
Puri	0	0	0	0	0	0	28	5
Rayagada	28	7	2	23	6	2	36	6
Sambalpur	44	12	6	35	9	5	56	10
Subarnapur	23	8	3	19	6	2	30	7
Sundargarh	15	5	2	12	4	1	20	5

Table 6: Fertiliser (NPK) application rates in kg/ha at the districts level for different Paddy systems

Medium land				Lowland					
	Un-irrigated			Irrigated			Un-irrigated		
K	N	P	K	N	P	K	N	P	K
1	12	3	1	15	2	1	12	2	1
2	32	6	2	40	4	4	33	3	3
3	40	11	3	50	7	6	40	5	5
3	35	9	2	44	6	5	36	5	4
3	48	13	3	60	8	6	48	6	5
1	26	5	1	33	3	3	26	3	2
2	33	4	1	41	2	3	33	2	2
1	28	13	1	36	8	2	29	7	2
1	13	3	1	17	2	2	14	1	1
1	25	3	1	31	2	2	25	2	1
1	39	4	1	49	2	2	39	2	2
3	35	8	2	45	5	5	36	4	4
3	41	10	3	51	6	7	41	5	5
1	25	6	1	32	4	3	26	3	2
2	31	7	1	39	4	3	31	3	2
0	5	3	0	6	2	1	5	2	0
1	23	5	1	28	3	1	23	2	1
1	22	4	1	28	3	2	22	2	1
2	32	4	1	40	3	3	32	2	3
2	21	5	1	27	3	3	21	2	2
1	20	3	1	25	2	1	20	1	1
1	22	4	1	28	2	2	22	2	1
4	97	10	4	122	6	8	98	5	7
1	22	3	1	28	2	2	23	2	2
1	21	5	1	27	3	2	21	3	2
1	23	4	1	28	2	3	23	2	2
1	29	5	1	36	3	3	29	3	2
4	45	8	3	57	5	7	46	4	5
2	24	5	1	30	3	3	24	3	3
1	16	4	1	20	2	2	16	2	2

	High land		Medium land		Low land	
DISTRICT	Irrigated	Un-irrigated	Irrigated	Un-irrigated	Irrigated	Un-irrigated
Angul	0	0	427	1126	2205	432
Balangir	0	0	1741	7423	8993	2848
Balasore	632	165	197	5698	1017	2186
Baragarh	0	0	1283	598	6627	230
Bhadrak	0	0	58	3058	301	1173
Boudh	2937	769	915	2986	4728	1146
Cuttack	0	0	674	2389	3484	916
Deogarh	1673	438	521	9754	2694	3742
Dhenkanal	0	0	395	9958	2040	3821
Gajapati	864	226	269	584	1391	224
Ganjam	3831	1003	1194	2206	6167	846
Jagatsinghapur	0	0	106	41	547	16
Jajpur	1701	445	530	7680	2738	2946
Jharsuguda	1575	412	491	1080	2535	414
Kalahandi	282	74	88	1424	454	546
Kandhamal	261	68	81	2866	420	1099
Kendrapara	272	71	85	32	438	12
Keonjhar	2007	525	625	4592	3230	1762
Khordha	2828	740	881	1340	4552	514
Koraput	1501	393	468	713	2416	274
Malkangiri	313	82	98	1104	504	423
Mayurbhanj	1009	264	314	5276	1624	2024
Nabarangpur	61	16	19	1667	97	639
Nayagarh	472	124	147	4312	760	1654
Nuapada	145	38	45	576	234	221
Puri	0	0	565	667	2917	256
Rayagada	1139	298	355	944	1833	362
Sambalpur	206	54	64	1227	331	471
Subarnapur	38	10	12	299	60	115
Sundargarh	23	6	7	2193	37	841

Table 7: Manure application rates (kg/ha) at the district level for different paddy systems

	High land		Medium land		Lowland	
DISTRICT	Irrigated	Un-irrigated	Irrigated	Un-irrigated	Irrigated	Un-irrigated
Angul	0.000	0.000	0.002	0.012	0.004	0.020
Balangir	0.000	0.000	0.014	0.013	0.011	0.010
Balasore	0.032	0.025	0.038	0.030	0.047	0.037
Baragarh	0.000	0.000	0.030	0.005	0.019	0.003
Bhadrak	0.000	0.000	0.003	0.040	0.003	0.034
Boudh	0.000	0.000	0.000	0.000	0.000	0.000
Cuttack	0.000	0.000	0.116	0.000	0.075	0.000
Deogarh	0.003	0.007	0.005	0.013	0.009	0.026
Dhenkanal	0.000	0.000	0.000	0.000	0.000	0.000
Gajapati	0.016	0.008	0.025	0.012	0.031	0.015
Ganjam	0.035	0.008	0.019	0.004	0.021	0.005
Jagatsinghapur	0.000	0.000	0.031	0.001	0.023	0.001
Jajpur	0.000	0.020	0.000	0.015	0.000	0.017
Jharsuguda	0.000	0.000	0.000	0.000	0.000	0.000
Kalahandi	0.182	0.007	0.075	0.003	0.095	0.004
Kandhamal	0.000	0.000	0.000	0.000	0.000	0.000
Kendrapara	0.037	0.023	0.005	0.003	0.007	0.005
Keonjhar	0.001	0.010	0.000	0.005	0.001	0.012
Khordha	0.153	0.124	0.019	0.015	0.016	0.013
Koraput	0.217	0.113	0.033	0.017	0.055	0.029
Malkangiri	0.001	0.018	0.003	0.033	0.004	0.045
Mayurbhanj	0.001	0.003	0.002	0.004	0.001	0.004
Nabarangpur	0.003	0.009	0.009	0.024	0.012	0.031
Nayagarh	0.000	0.069	0.000	0.025	0.000	0.025
Nuapada	0.000	0.012	0.000	0.022	0.000	0.023
Puri	0.000	0.000	0.000	0.000	0.000	0.000
Rayagada	0.106	0.066	0.051	0.032	0.047	0.029
Sambalpur	0.020	0.021	0.014	0.014	0.024	0.025
Subarnapur	0.047	0.014	0.044	0.013	0.049	0.014
Sundargarh	0.003	0.013	0.002	0.008	0.004	0.014

Table 8: Pesticide application rates (kg/ha) at the district level for different paddy systems

average ratio computed for 2014-2018 (Table 9 and Table 10). The data for 2023 is extrapolated from previous years' data due to a lack of access to the latest estimates. The total emissions were calculated using the emission factors listed in the GHGPI National Emissions Estimates, based on IPCC guidelines and scientific literature (Table 9).

Table 9: Emission factors for agriculture - Rice

Rice system	Emission Factor (kg CH_4 per hectare)
Continuous Flooding	159.74
Single Aeration	66.2
Multiple Aeration	19.3
Flood Prone	189
Drought Prone	66.84
Deep Water	190
Upland	0

Additionally, the proportion of areas presented in (Table 3) was also considered for computation (Source: Das, 2012).

The total area under rice cultivation is available in the Odisha Agricultural Statistics reports for three types of rice cultivation, namely Low, Medium and High. Lowlands mainly consist of deep-water ecosystems (EF: 190 kg CH_4 per hectare) as well as flood-prone rainfed ecosystems (EF: 189 kg CH_4 per hectare). Table 10 above shows that almost 90% of lowlands are unirrigated. Therefore, the total low land area is multiplied with the deep-water rice emission factor to obtain the total emissions.

High and Medium lands are a mix of rainfed and irrigated rice ecosystems. Table 3 above shows that high lands are a mixture of about 80% rainfed and 20% irrigated lands, whereas medium lands comprise 33% rainfed and 67% irrigated lands. Therefore, the total area under high lands is divided into two-thirds rainfed and one-third irrigated lands. Conversely, the total area under medium lands was divided into one-third rainfed and two-thirds irrigated lands.

The irrigated lands are divided further into continuously flooded, single-aerated, and multiple-aerated lands according to the proportions listed in Table 10, and their respective emission factors are applied (Table 9). The rainfed parts of high and medium lands are assumed to be drought-prone rainfed lands since flood-prone rainfed lands are mainly lowlands. Therefore, the emission factor for a drought-prone rainfed ecosystem is applied to rainfed land that comes under high and medium.

Table 10: National-level proportion of different paddy areas

Area Break-up by National Data	Proportion	Source
Rainfed		
- RF Flood Prone	27.10%	Huke and Huke 1997
- RF Drought Prone	72.90%	
Irrigated		
- IR Continuous Flooded	26.90%	
- IR Single Aeration	35.70%	Gupta et al. 2009
- IR Multiple Aeration	37.40%	

Table 11: Disaggregation of livestock types considered for the GHG inventory and their emission factors

Category	Subcategory	Emission Factor – Enteric Fermentation (kg CH4 per hectare per year)	Emission Factor – Manure Management (kg CH4 per hectare per year)
Dairy Cattle	Indigenous Exotic	37 45	4 4
Non-Dairy cattle (Indigenous)	0 – 1 Years Adult	24 29	2.4 2.4
Non-Dairy cattle (Exotic)	0 – 1 Years 1 – 2.5 Years Adult	14 26 29	1.5 2.3 2.5
Dairy Buffalo Non-dairy Buffalo Sheep Goats Pigs		53 45 4 4 1	4.7 4.4 0.3 0.2 4

3.2.2. Enteric fermentation of livestock

Livestock are a source of methane emissions due to two phenomena. Firstly, methane is emitted as a result of the digestion of food in animals, predominantly bovines such as cattle and buffaloes but also other herbivores such as sheep, goats, and horses. Secondly, methane is emitted from the anaerobic decomposition of manure.

To calculate livestock emissions in Odisha, district-level populations of various livestock, such as cattle, buffaloes, sheep, goats, and pigs, were obtained from the 19th and 20th National Livestock Census, conducted in 2012 and 2019, respectively. The population for the intervening years (2014-2018) was interpolated, and populations for subsequent years (2020-2023) were computed by extrapolating from the two-census data.

Emission factors for the different livestock varieties (Table 11) are obtained from the IPCC Guidelines, the third National Communication of India to the UNFCCC (NATCOM 3) and Samal, 2024. Annual emissions from livestock are calculated by multiplying the livestock populations with their respective emission factors. The disaggregation of livestock types considered for the inventory is detailed in Table 11.

3.2.3. Synthetic fertiliser use

Fertiliser use in agriculture leads to N_2O emissions due to nitrification and denitrification of the nitrogen present in fertilisers. Additionally, there are indirect N_2O emissions from volatilisation, leaching and runoffs. The total nitrogen present in the fertiliser applied to the soil is obtained from Odisha Agricultural Statistics (2014-2019) reports. Data for the period (2020-2023) is obtained from “District at a Glance” reports published by the state’s Department of Agriculture and Farmers' Empowerment for the respective years.

The N_2O emission factor is obtained from IPCC Guidelines as well as H. Pathak, 2002, and A. Garg, 2006. The value of the emission factor is 0.76 kg N_2O per 100 kg of nitrogen for urea-based fertiliser. The total annual district-wise emissions are calculated by multiplying the amount of nitrogen applied to the soil via fertiliser with the emission factor.

3.2.4. Diesel consumption by farm machinery

Diesel use, in farm implements such as pump sets and tractors, leads to CO_2 emissions. To calculate the total emissions from diesel use, the total number of pump sets and tractors are considered. The district-wise number of pump sets was obtained from Odisha Agricultural Statistics reports from 2014-2019, and the same was extrapolated for the subsequent years (2020-2023). Out of the total pump sets, the share of diesel pump sets was assumed to be 7% in 2014, decreasing to 5% by 2024 with a compound annual growth rates (CAGR) of -3%. Since the share of diesel pump sets is not directly available, it is inferred from data available for other states, namely Karnataka and Tamil Nadu State Energy Calculators TANGEDCO (2021). The assumptions and factors used for computing annual emissions from pump sets and tractors is presented in Table 12.

The total diesel consumed is calculated per diesel pump set and tractor per year and summed for the district in a year. The total district-wise annual emissions are then computed by multiplying the diesel consumption by number of pump sets and tractors separately with the respective emission factors and summed to obtain total emissions from diesel consumed by farm machinery.

3.2.5. Green House Gas emissions index

An aggregated GHG emissions index was developed using the average emissions data from 2014 to 2023. The total emissions for each district, measured in $kgCO_2$ per hectare per year, include contributions from livestock enteric fermentation and manure management, rice cultivation, diesel consumption by farm machinery, and synthetic fertiliser use. Values from each source were normalised to a 0 to 1 scale for ease of comparison, and weighted according to its contribution to the Index. Given that rice cultivation accounted for a substantial portion of Odisha’s emissions – averaging 3,453 $kgCO_2$ per hectare per year – a weight of 80% was assigned to it. Emissions from livestock enteric fermentation and manure management, synthetic fertilisers, and diesel use in farm machinery were weighted at 18%, 1.5%, and 0.5%, respectively, as presented in Table 13. The districts were then ranked accordingly.

Table 12: Factors assumed for daily usage, fuel consumption and emissions of tractors and pump sets (2014-2023)

Variable	Diesel pump sets	Tractors
Hours of use/day	5	7.5
Fuel consumption per hour (litres)	2.5	4.2
Share of Agricultural Tractors in use	-	80%
Emission factor ($kgCO_2$/litre)	2.7	2.7

Table 13: Distribution of weights for each source of emission

Components	Emissions from rice cultivation	Emissions from enteric fermentation of livestock and manure management	Emissions from synthetic fertiliser usage	Emissions from diesel consumption by farm machinery	Total
Average GHG emissions ($kgCO_2$ per ha per year)	3453	761.2	79.13	20.08	4313
Weight (in %)	80	18	1.5	0.5	100
Weight (0-1)	0.8	0.18	0.015	0.005	1

BELOW: Harvesting rice with a tractor-mounted paddy threshing machine in Bhadrak, Odisha Manoranjan Mishra

4. Results

4.1. Resource use profiling for paddy

This section presents the resources used to cultivate one kilogram of a paddy crop during the *Kharif* season of 2018 across the districts of Odisha. It allows us to identify districts with high resource use and with potential for optimisation.

4.1.1. Fertiliser, manure and pesticide use (kg/ha)

The detailed fertiliser, manure and pesticide use profiles for different paddy systems are provided in Table 6, Table 7 and Table 8. The disaggregated results are:

Fertiliser

- Nabarangpur, Sambalpur and Jajpur districts have the highest fertiliser application rates.
- Kandhamal, Angul, Dhenkanal, Malkangiri and Sundargarh have the lowest fertiliser application rates.

Manure

- Boudh, Deogarh, Ganjam, Jajpur, and Keonjhar have the highest manure application rates.
- Jagatsinghapur, Kendrapara, Nuapada, Subranapur and Sundargarh have the lowest manure application rates.

Pesticide

- Balasore, Rayagada, Koraput, Subranapur and Khordha have high pesticide application rates compared to the other districts in the state.
- Boudh, Dhenkanal, Jharsuguda, Kandhamal, and Puri do not apply any pesticides for paddy cultivation.

These results were aggregated, and the values are presented here for visualisation (Figure 4). Index values range from zero (having the least aggregate input value) to 1 (most aggregate input value).

Balangir, Deogarh, Jajpur, Dhenkanal and Ganjam have the highest cumulative input application rates while Malkangiri, Nuapada, Kendrapara, Jagatsinghapur and Subranapur, have the least input application rates as compared to other districts in Odisha.

4.1.2. Mechanisation

Balasore, Bhadrak, Cuttack, Baragarh, and Jajpur have 31% to 37% of operational holdings using machinery for crop cultivation. On the other end of this spectrum, Koraput, Jagatsinghpur, Keonjhar, Jharsuguda, and Kandhamal have 18% to 23% of operational holdings using machinery for crop production (Figure 5).

About 5-10% of implements supplied by the state are to Baragarh, Malkangiri, Ganjam, Sambalpur, Kalahandi, Jajpur, Sundargarh and Balasore (Figure 6).

4.1.3. Water-use efficiency

The water-use efficiency (WUE) measured as Biophysical Water Productivity (BWP) (kg/m3) of paddy crop is presented in Figure 7·
The resulting BWP values indicate that on an average 0.28 kg of paddy is produced using 1 m^3 of water. This translates to an average use of 3,667 litres of water to produce one kg of paddy— significantly higher than the national average of 2,500 litres per kg, as reported by ICAR (2021).

- Nabarangpur, Sambalpur, and Boudh have the highest BWP for paddy, meaning less water is used to produce one kg of crop, suggesting better water-use efficiency (Figure 8).
- Gajapati, Jajpur, Kandhamal, and Khordha have the lowest BWP for paddy (Figure 8).

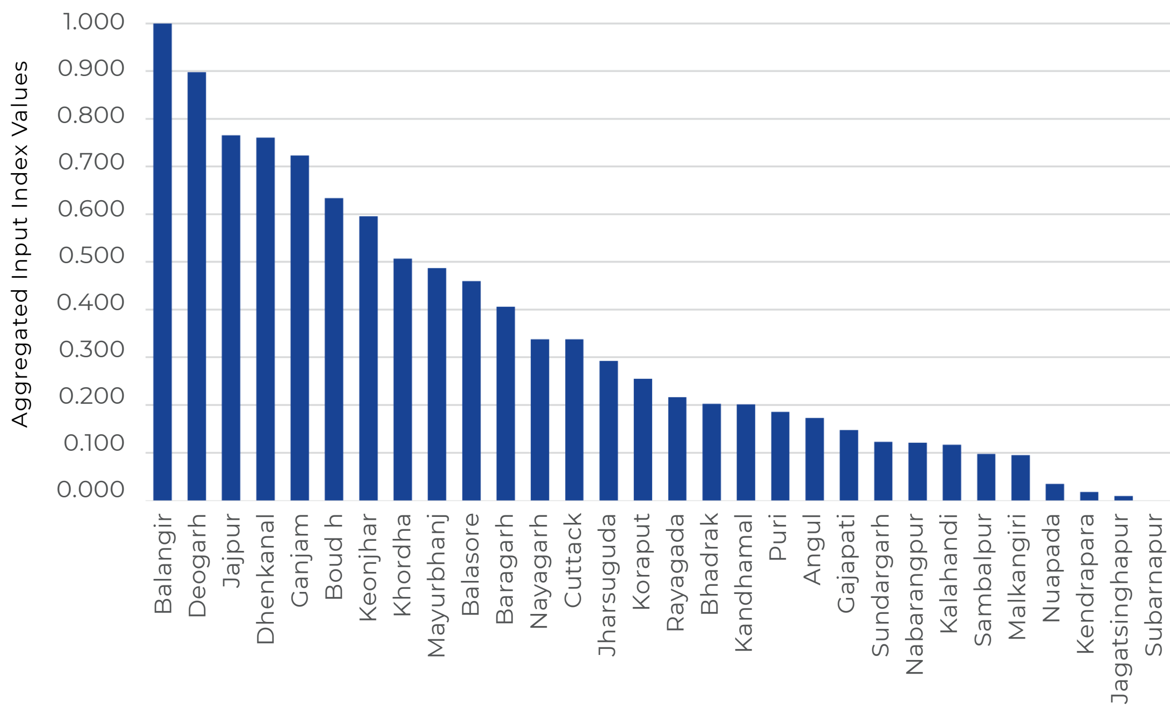


Figure 4: Aggregated indexed values of fertiliser, manure and pesticides applied to paddy at the district level

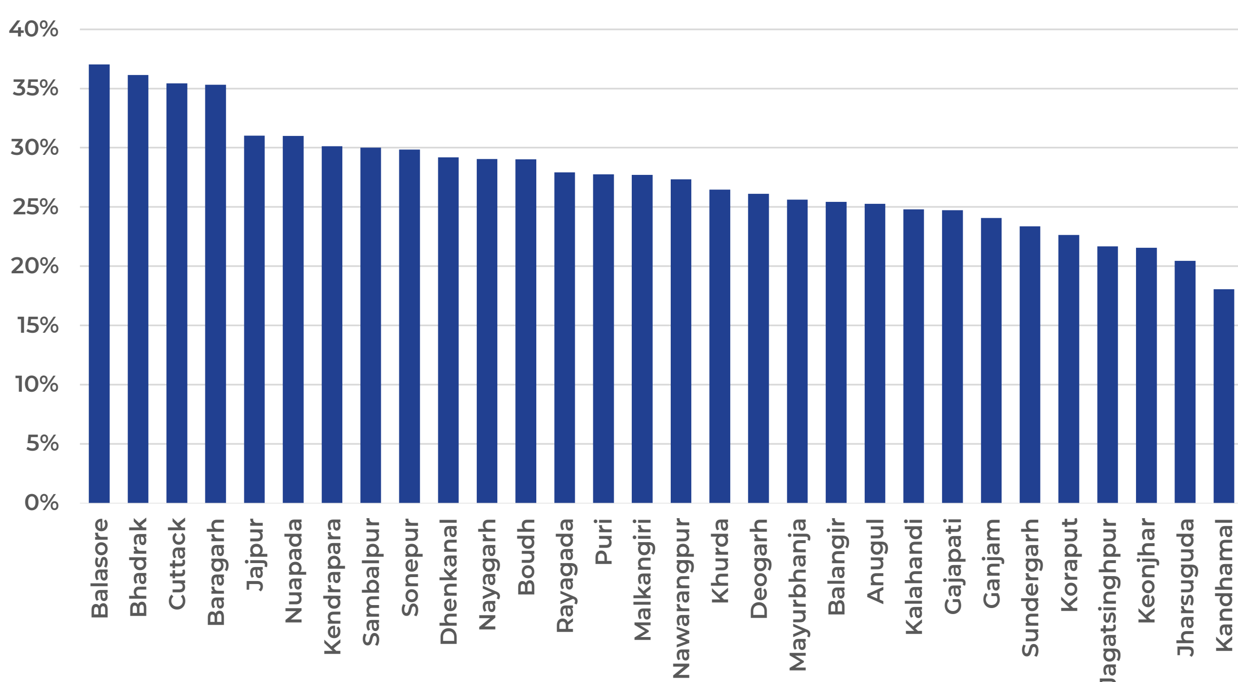


Figure 5: Percentage of operational holdings owning and renting machinery for crop cultivation

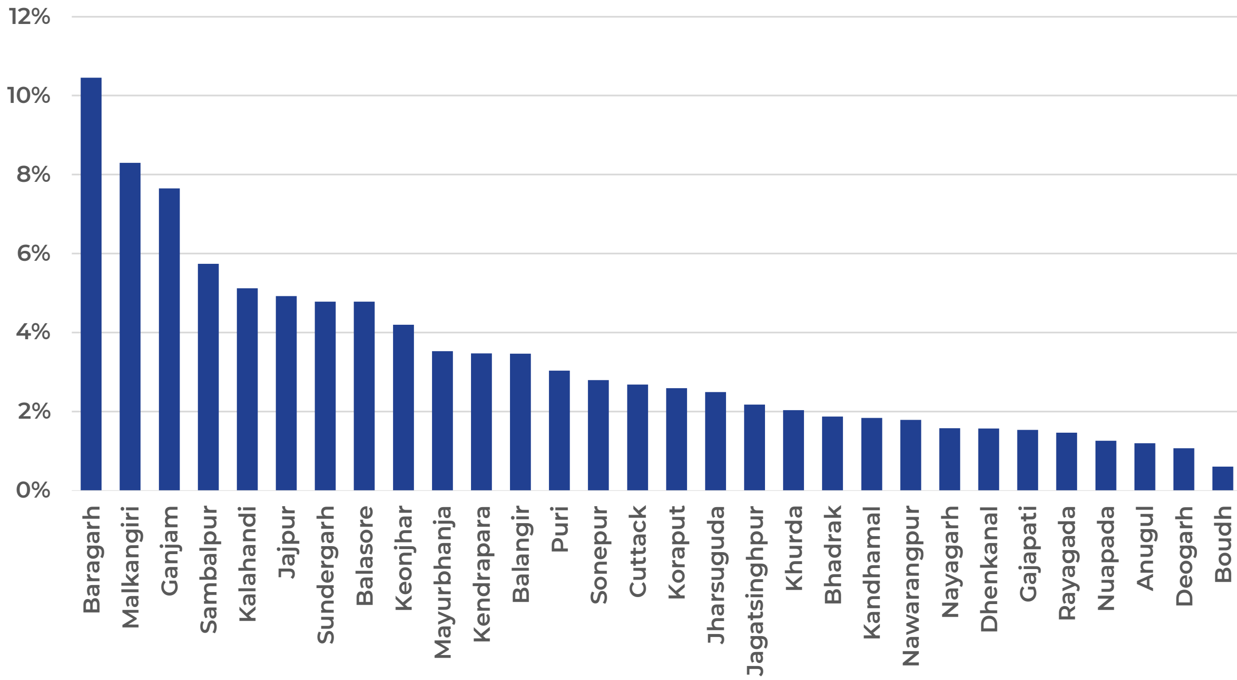


Figure 6: Percentage of implements supplied under various schemes (2018-23)

Districts with low BWP mentioned above have high rainfall and low irrigation coverage (27 to 46). Because they rely primarily on rainfall for agriculture, it can lead to inefficiencies in water-use. Rainfed systems tend to have lower control over water supply and use, leading to lower BWP. Additionally, due to lack of efficient irrigation infrastructure, water distribution is uneven, limiting the ability of farmers to optimise water-use for crop growth. Additional factors such as drought stress, soil health and structure, high soil temperatures and evapotranspiration, socio-economic constraints and poor management practices can lower BWP further (Nangia & Oweis, 2017; Sekhon et al., 2010; and Sharma et al., 2009).

- In contrast, districts with higher BWP have higher irrigation coverage (41% to 67%) and are benefiting from consistent and controlled water supply. This controlled water application helps reduce the dependency on erratic rainfall and enhances crop yields, improving water-use efficiency in districts.

4.1.4. Key takeaways from resource use profiling for paddy

All resources considered for this exercise were normalised and aggregated to provide a resource use index to facilitate comparison between districts (Figure 9). High fertiliser, manure, and pesticide use increase RUP index values, while high mechanisation and water use efficiency lower RUP index values. According to the assessment, Balangir, Khordha, Jajpur, Gajapati, and Kandhamal districts have highest RUP index values. Conversely, Kalahandi, Nabarangpur, Subranapur, Sambalpur, and Bargarh are ranked as having the least RUP index scores.

The RUP index reflects a pattern where districts have high cumulative manure, fertiliser and pesticide application rates,

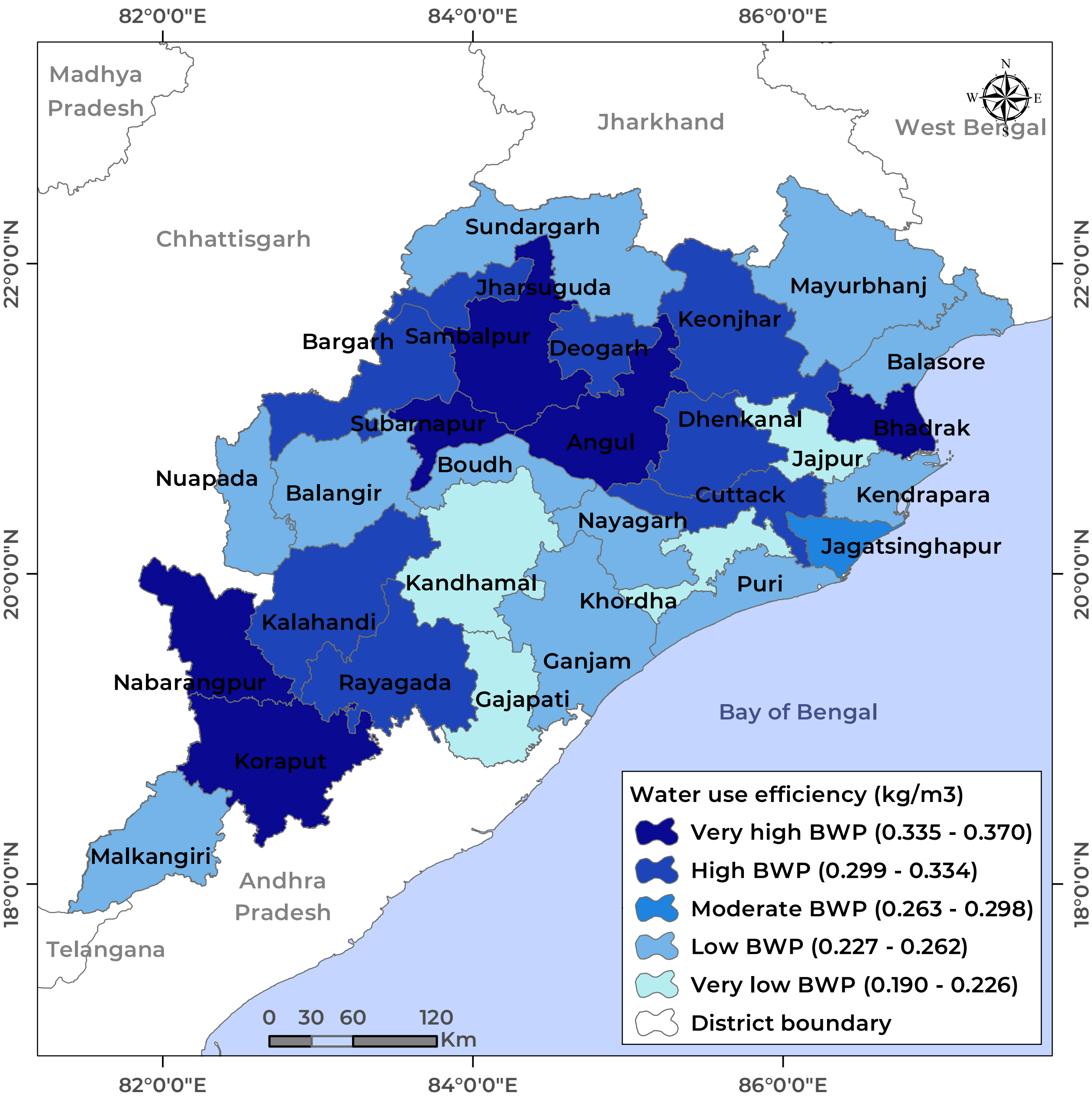


Figure 7: Biophysical water productivity map for paddy in Odisha

Agricultural workers using a tractor-mounted paddy threshing machine or harvester to extract rice grains in Bhadrak, Odisha

Manoranjan Mishra

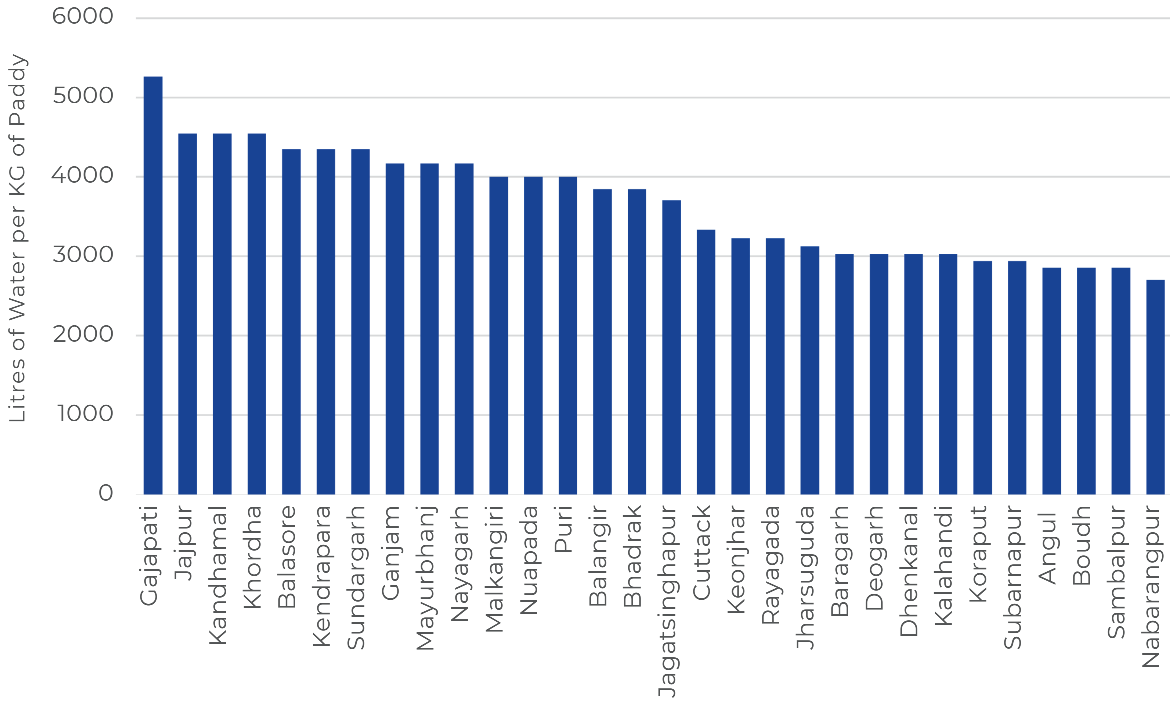


Figure 8: District level water-use efficiency for production of paddy

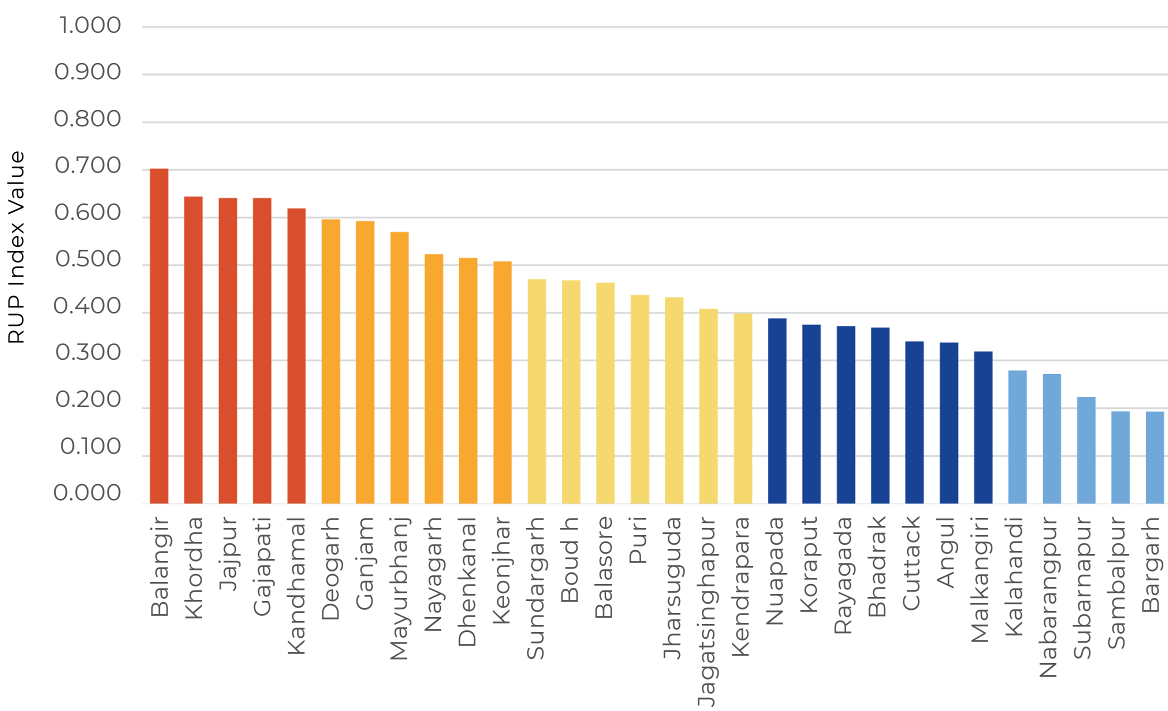


Figure 9: Resource use profile of districts for paddy cultivation

lower mechanisation, and lower water-use efficiency. This highlights the need to enhance input efficiency, promote mechanisation, and improve water productivity in these districts. Consequently, the district with the highest RUP index score (Balangir) should be prioritised for piloting CSA practices aimed at optimising input utilisation. Furthermore, the lack of mechanisation emerges as a significant driving factor influencing resource use across all districts, indicating that promoting mechanisation could be a focus across Odisha.

Figure 10 provides the drivers of resource use intensity ranked across the different classes of resource use.

- A lack of mechanisation consistently contributes highly to the index across all RUP classes.
- For the districts classified as having very high RUP index scores – low water-use efficiency is the most significant driver. However, a lack of mechanisation also significantly contributes to the index.
- Cumulative input application rates are significantly lower and water-use efficiency is significantly higher in the districts with the lowest RUP index scores. This is predominantly due to low manure application rates; however, these districts have the highest fertiliser and pesticide application rates in the state, and as such, Nabarangpur and Bargharh have been prioritised in consultation with the Department of Agriculture and Farmers' Empowerment to build resource use efficiency.

The resource use profiling relies solely on data provided by the Department of Agriculture Statistics, Directorate of Agriculture and Food Production, or data published by the Government of Odisha.

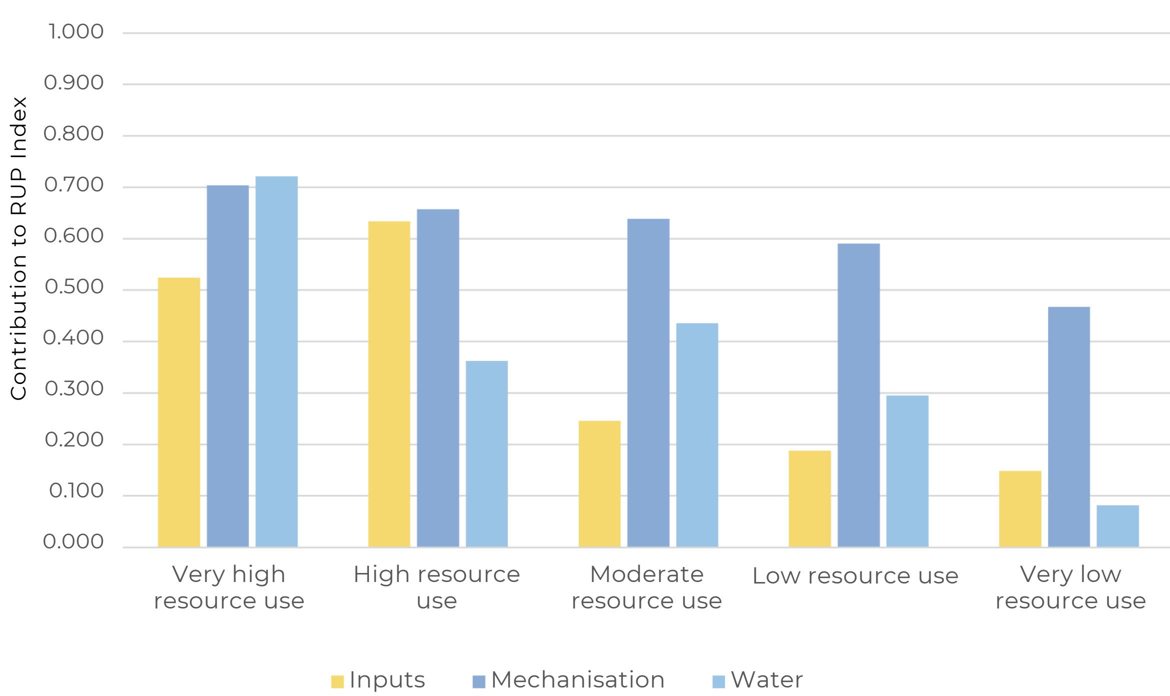


Figure 10: Resources contributing to the RUP index for different classes of RUP districts

4.2. GHG inventory

The general approach to estimate emissions is presented in Figure 11. The GHG emissions inventory for the agriculture and allied sector computed for the decade spanning 2014-2023 encompasses the following sources:

1. Rice cultivation (CH_4 emissions)
2. Livestock (CH_4 emissions)
   - Enteric fermentation
   - Manure and manure management
3. Fertilise usage (N_2O emissions)
4. Diesel consumption by farm machinery (CO_2 emissions)
   - Diesel pump-sets
   - Diesel tractors

The total annual district-wise emissions from the aggregated sources are presented in Figures 12 and 13. It is evident from Figure 12 that there has been a significant decrease in the overall emissions from the agriculture and allied sector over the past decade. The total annual emissions from the afore-mentioned sources in 2014 was 24.2 million tonnes of $CO_{2\text{-eq}}$ and in 2023, it had reduced to 22.2 million tons of $CO_{2\text{-eq}}$. **This decrease is likely due to the adoption of CSA practices such as improved crop diversification through the Shree Anna Abhiyan (Directorate of Agriculture and Food Production, 2019), increased adoption of solar pumps (Odisha Renewable Energy Development Agency, 2019), etc.**

Identify emission sources

- Literature review

Quantify individual emissions sources

- Literature review and interpolation methods for years with missing data

Compile emission factors for the different emission sources

- IPCC emissions factor database and other relevant India-specific data sources

Calculate the total emissions

- Using emission factors for individual sources, compute emissions

Figure 11: Approach to estimating emissions inventory

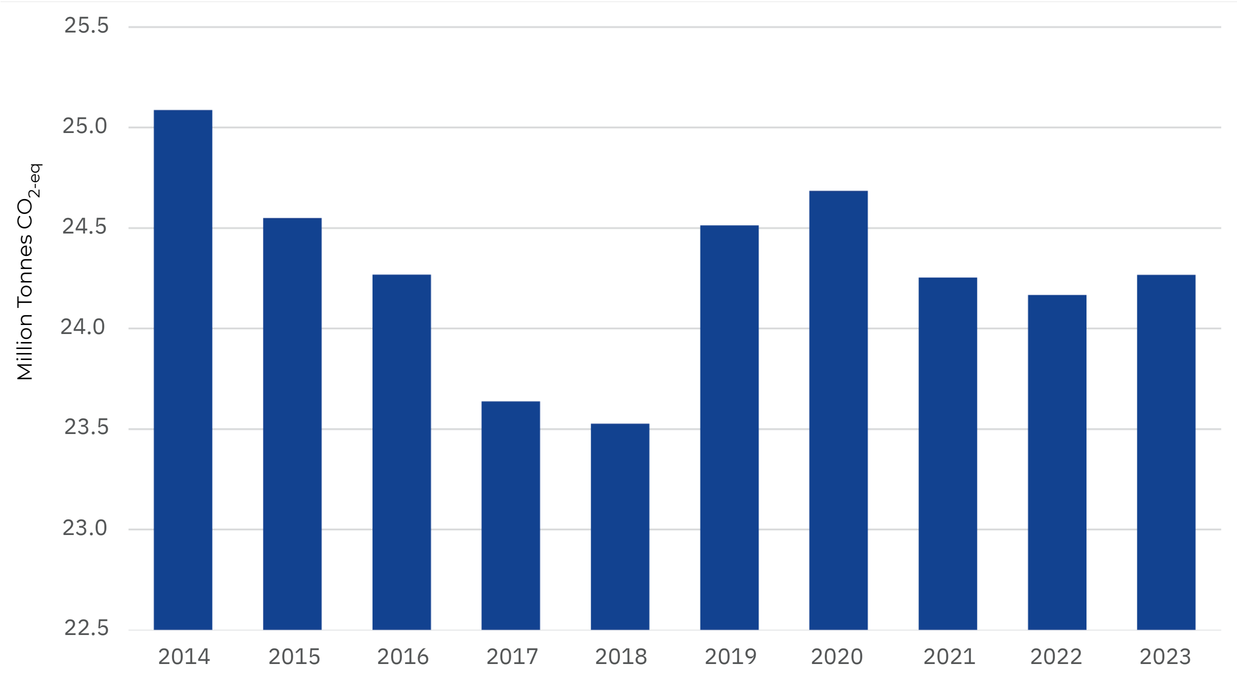


Figure 12: Total annual emissions from the agriculture and allied sector of Odisha

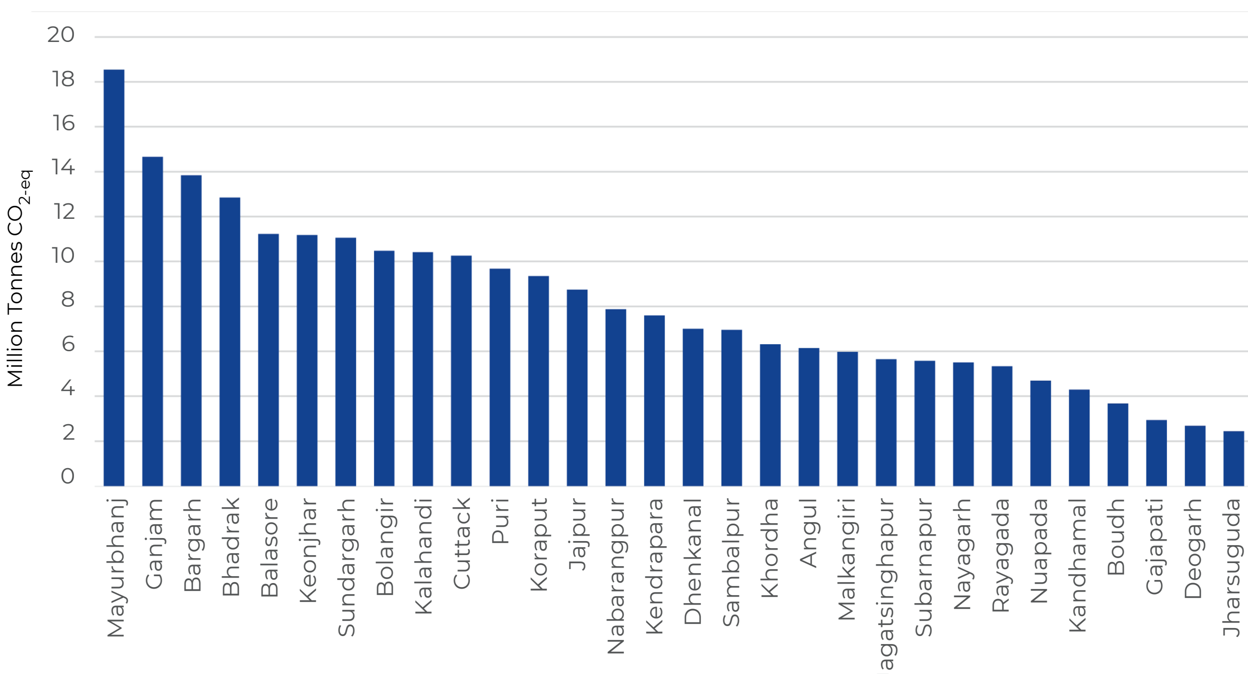


Figure 13: District-wise emissions from the agriculture and allied sector of Odisha

Along with being the district with the highest total area in Odisha, Mayurbhanj also has the highest area under rice cultivation and highest livestock population. **Consequently, in terms of district-wise emissions, Mayurbhanj was found to be the largest contributor to the total emissions of the state, having contributed 18.5 million tons of $CO_{2\text{-eq}}$ from 2014 to 2023.** Jharsuguda was found to be the lowest emitting district in the state with a total contribution of 2.5 million tons of $CO_{2\text{-eq}}$ over the past decade.

The shares of the various emissions sources to the total emissions from the agriculture and allied sector in Odisha are presented in Figure 14. The GHG emissions from this sector is found to be largely dominated by two key sources, namely rice cultivation and livestock, which account for over 96% of the total emissions. This finding is in agreement with GHGPI's national level estimates (GHGPI, September 2019). However, the share of rice cultivation and livestock is lower at the national level, due to the inclusion of another significant emissions source, namely crop residue burning. While crop residue burning contributes notably to national emissions, it is negligible in Odisha. Further, it can be seen from Figure 19 that the vast majority of the sectoral emissions are CH_4 (from rice cultivation and livestock), followed by N_2O (from fertiliser use) and lastly, CO_2 (from diesel consumption).

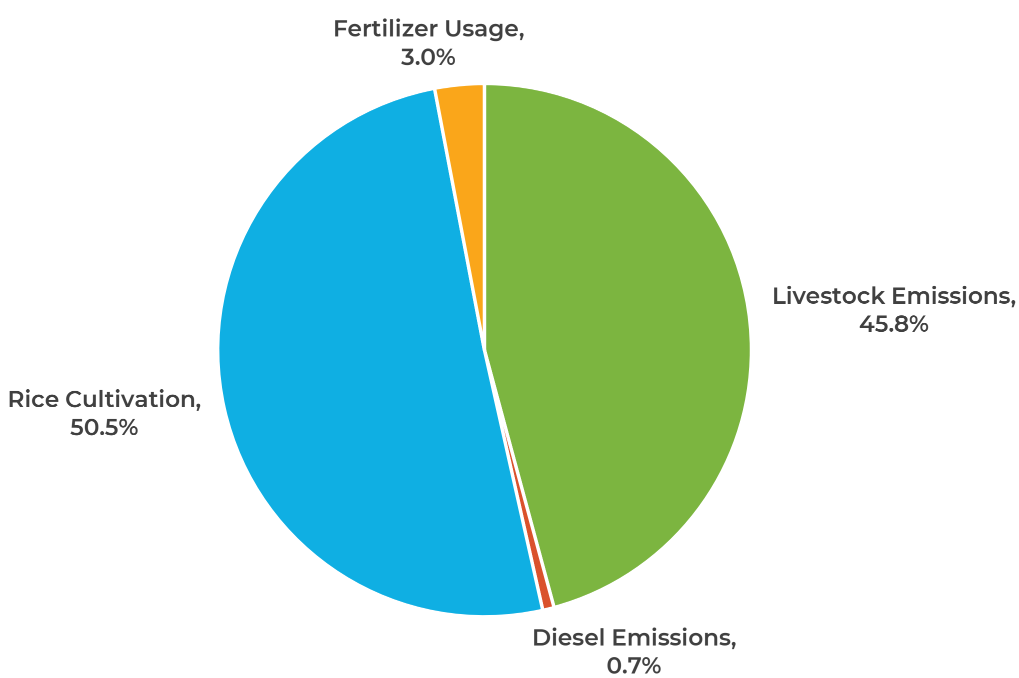


Figure 14: Contribution of different emissions sources to the total emissions

The source-wise total emissions on an annual basis and district-wise are presented in Figure 12 and Figure 13. The contribution of emissions from different sources is presented in Figure 14.

Per-hectare emissions are calculated by standardising total emissions from different sources based on relevant land areas. The method for normalising emissions for each source is as follows:

1. **Rice emissions**: Total rice emissions in each district is divided by the district's area under rice cultivation to obtain emissions per hectare.
2. **Livestock emissions**: Total livestock emissions in each district is divided by the total land area of a district, as livestock emissions are generally spread across all land types and not limited to croplands.
3. **Fertiliser emissions**: Total fertiliser emissions in a district is divided by the district's gross cropped area to calculate fertiliser emissions per hectare, given that fertiliser is applied across various crops.
4. **Diesel emissions**: Total diesel emissions is divided by the district's gross cropped area, as the use of irrigation pumps and tractors is not restricted to specific crop varieties.

The per hectare rice emissions reflect a combination of several factors across districts. Along with the total area under paddy cultivation and yearly changes, the total emissions also account for the different types of rice ecosystems. Lowland areas which fall under deep water or flood prone rainfed rice ecosystems have the highest methane emissions per hectare due to the soil being continuously inundated. Therefore, districts with the largest fractions of deep water or flood-prone rainfed rice cultivation have the highest per-hectare emissions. This has been represented in Figure 18.

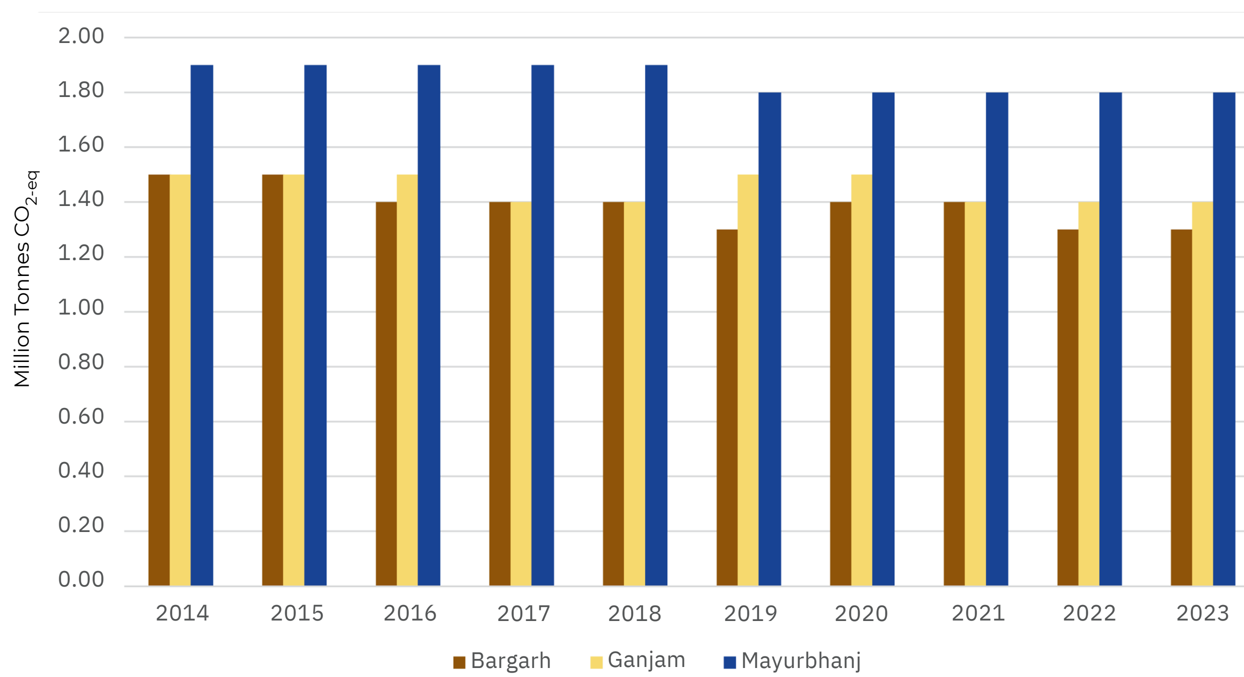
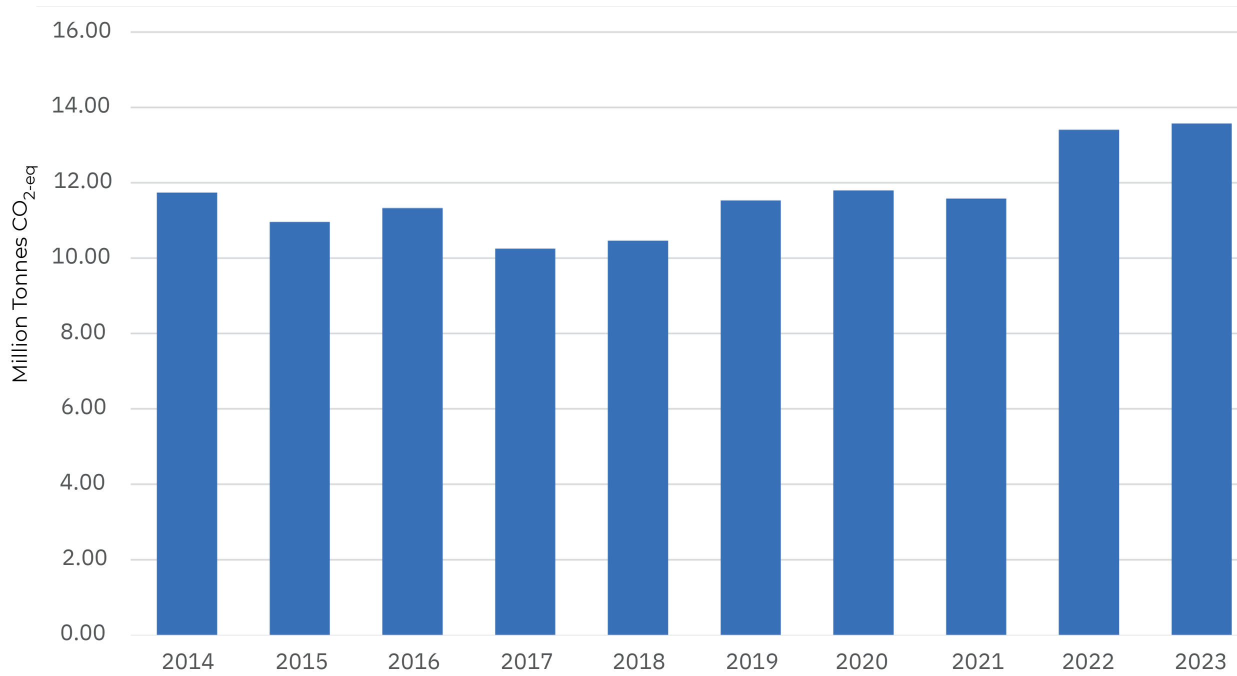


Figure 15: Total Emissions of the top three highest emitting districts


Sunrise at Chilika Lake, Odisha, India WIRESTOCK

Rice Cultivation



Livestock

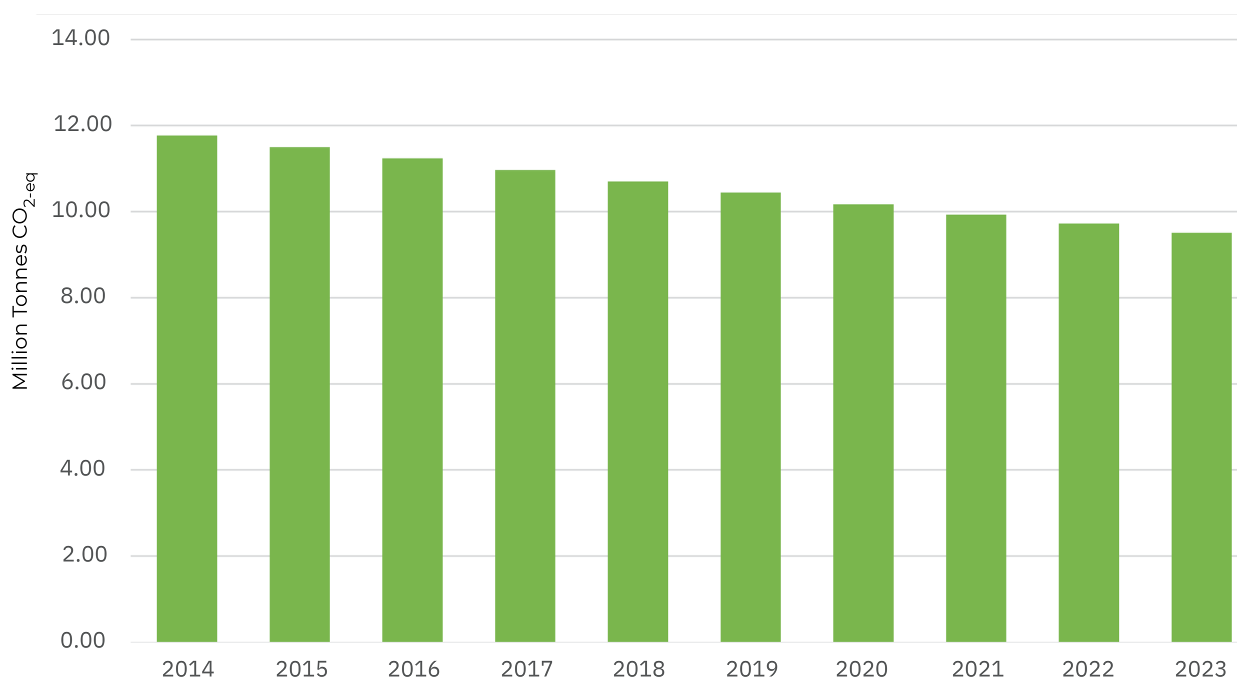
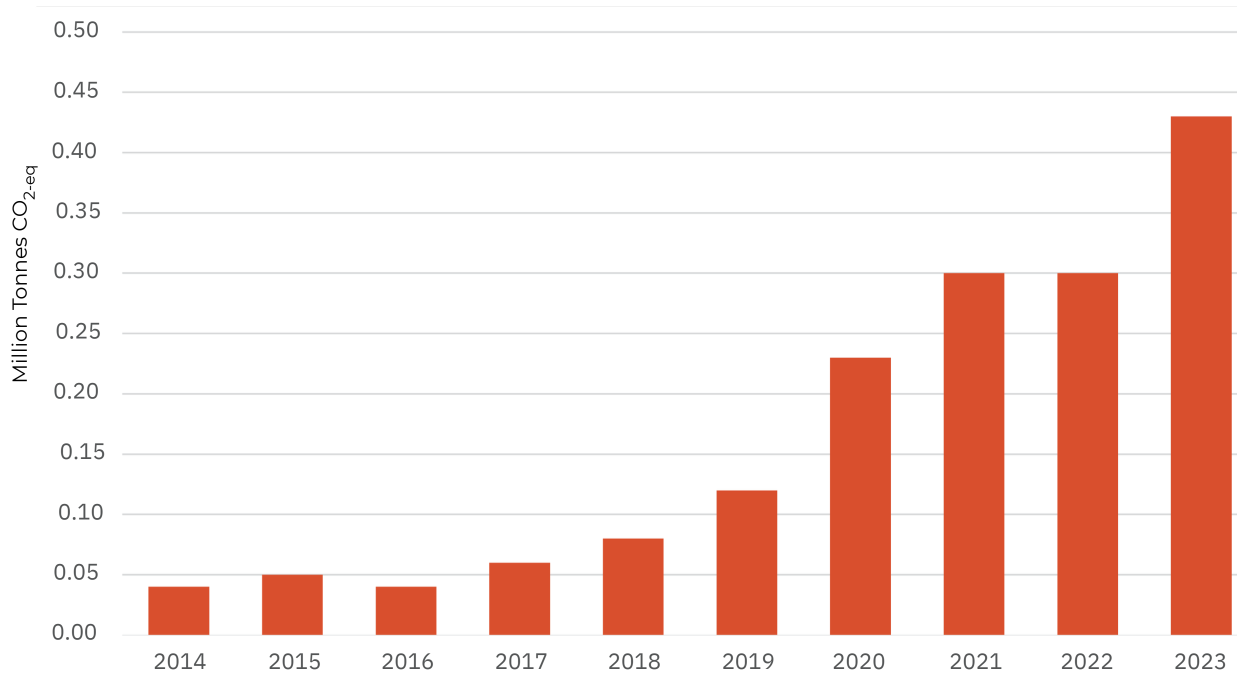
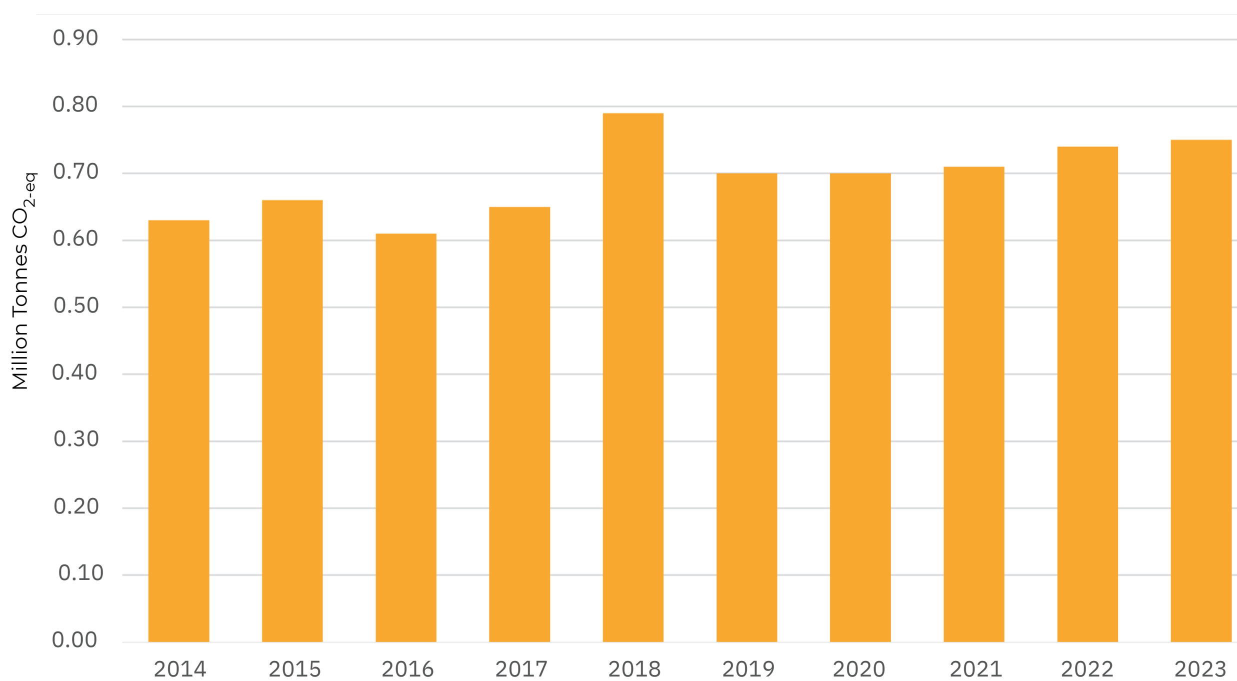


Figure 16: Total annual emissions by various emission sources (Above and facing page)

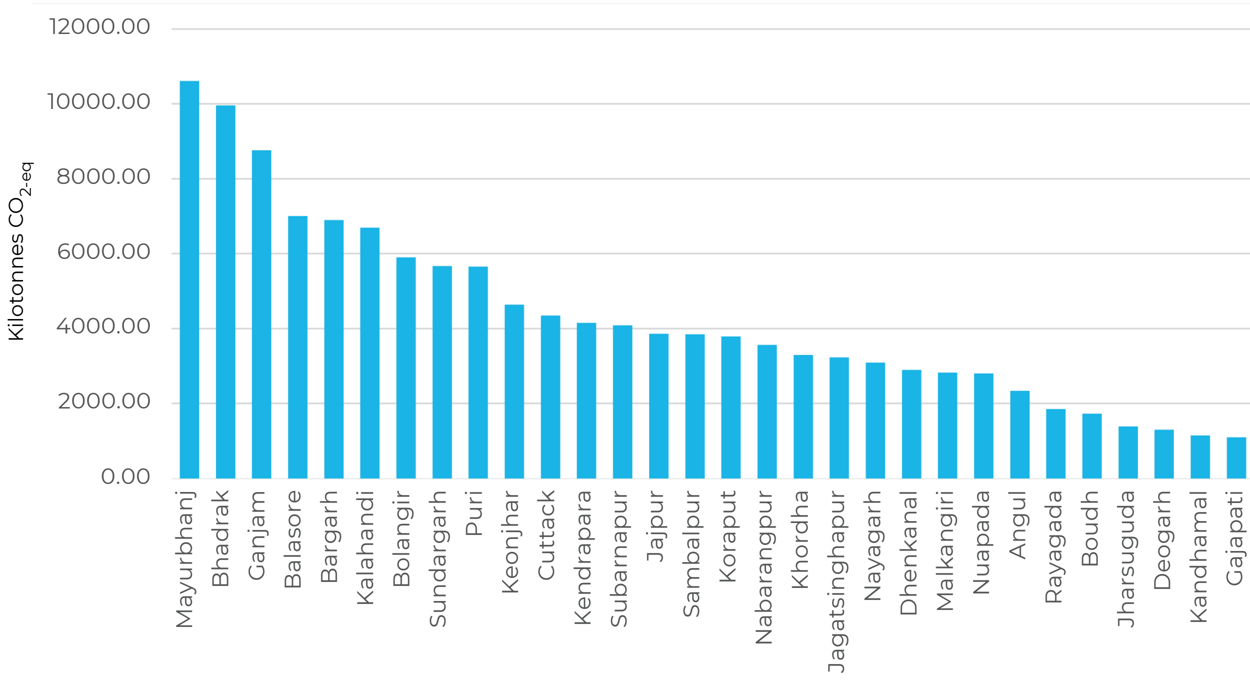
Diesel Consumption



Fertiliser Use



Rice Cultivation



Livestock

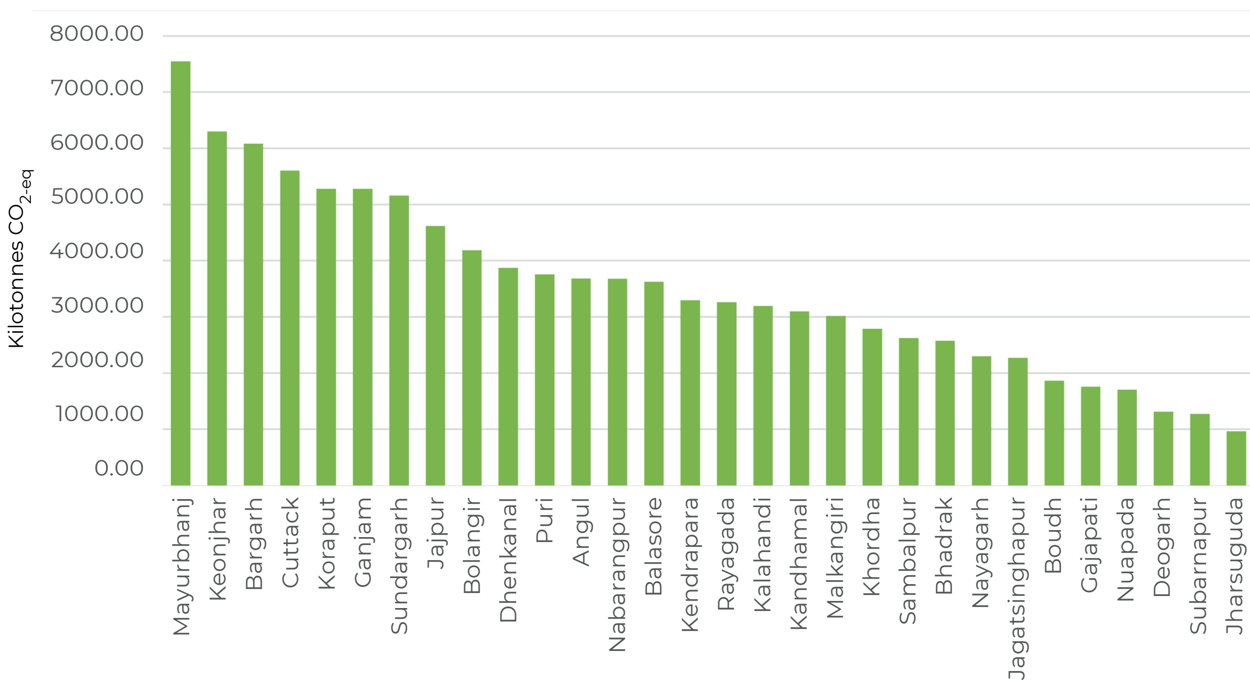
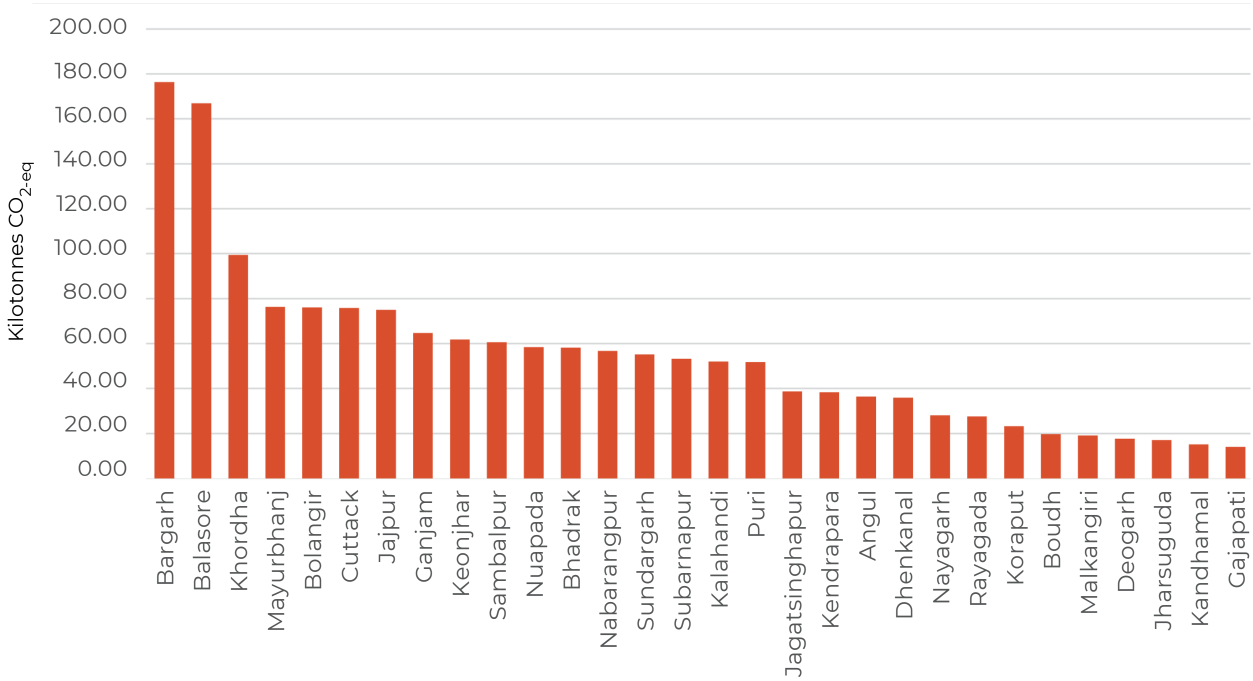
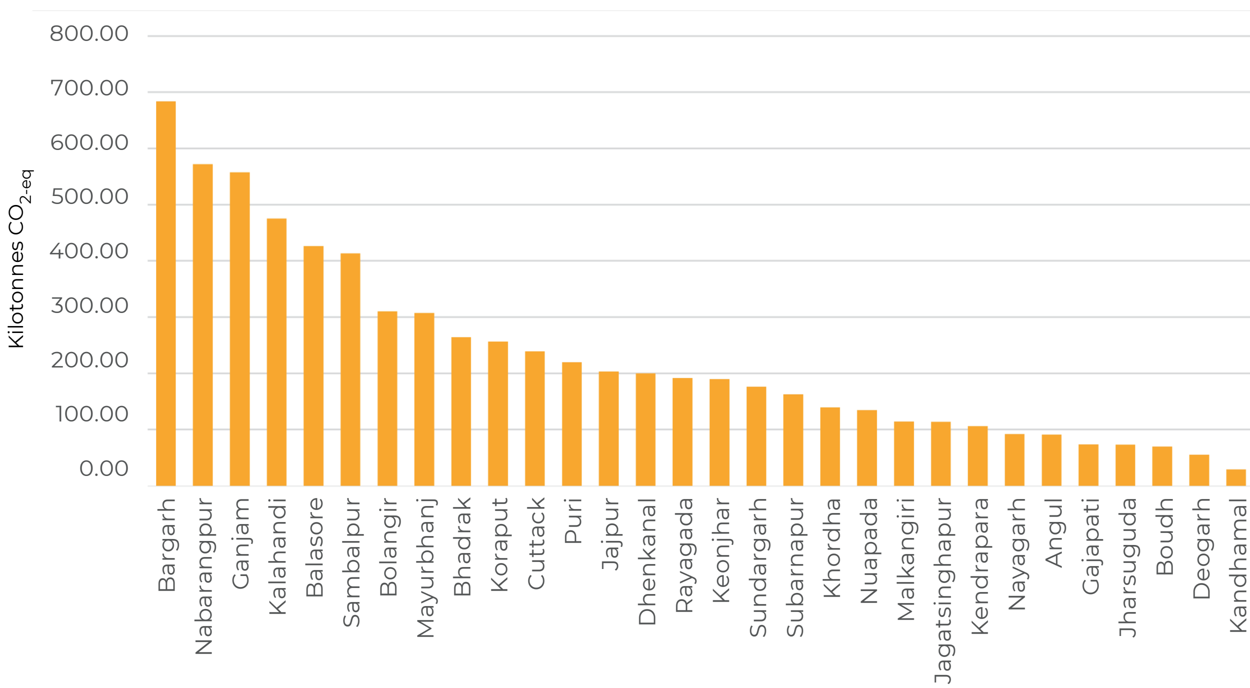


Figure 17: Total district-wise emissions by various emission sources

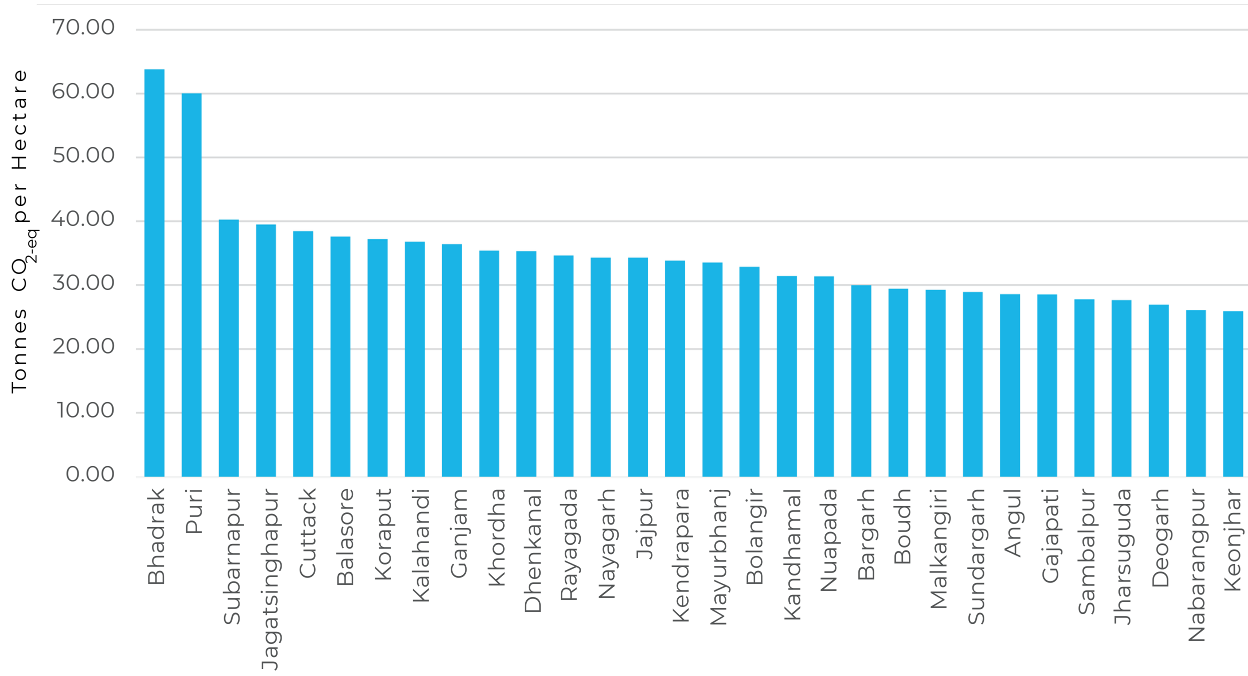
Diesel Consumption



Fertiliser Use



Rice Cultivation



Livestock

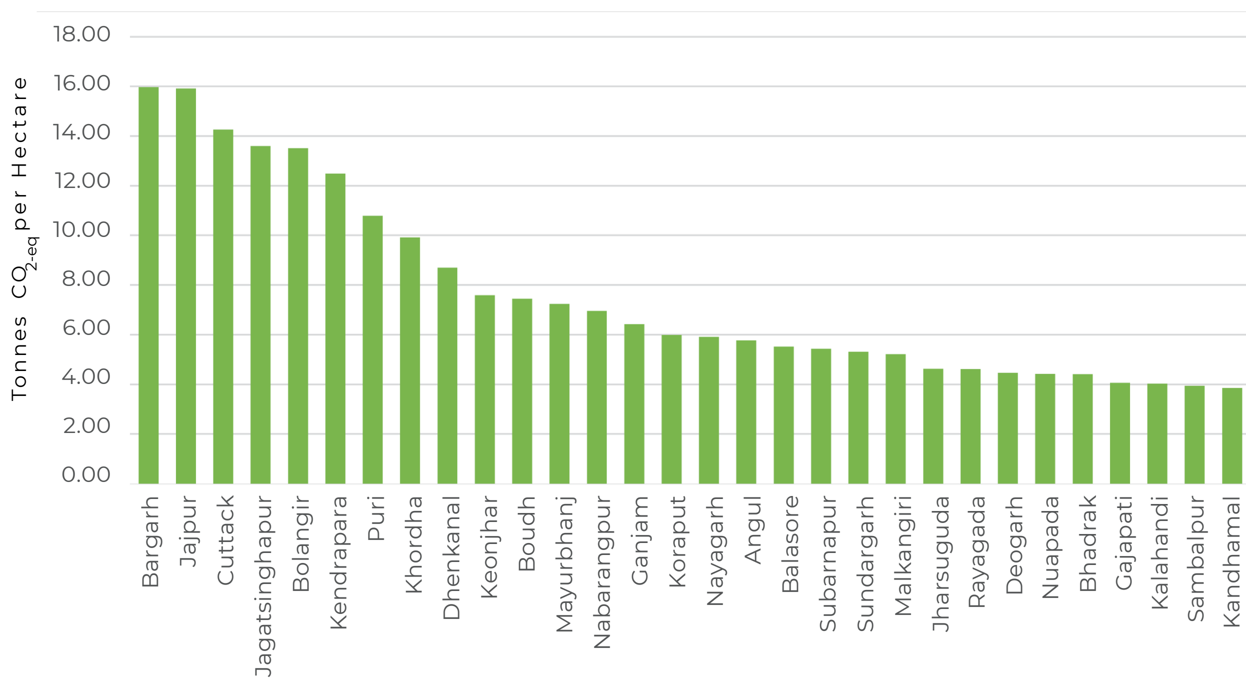
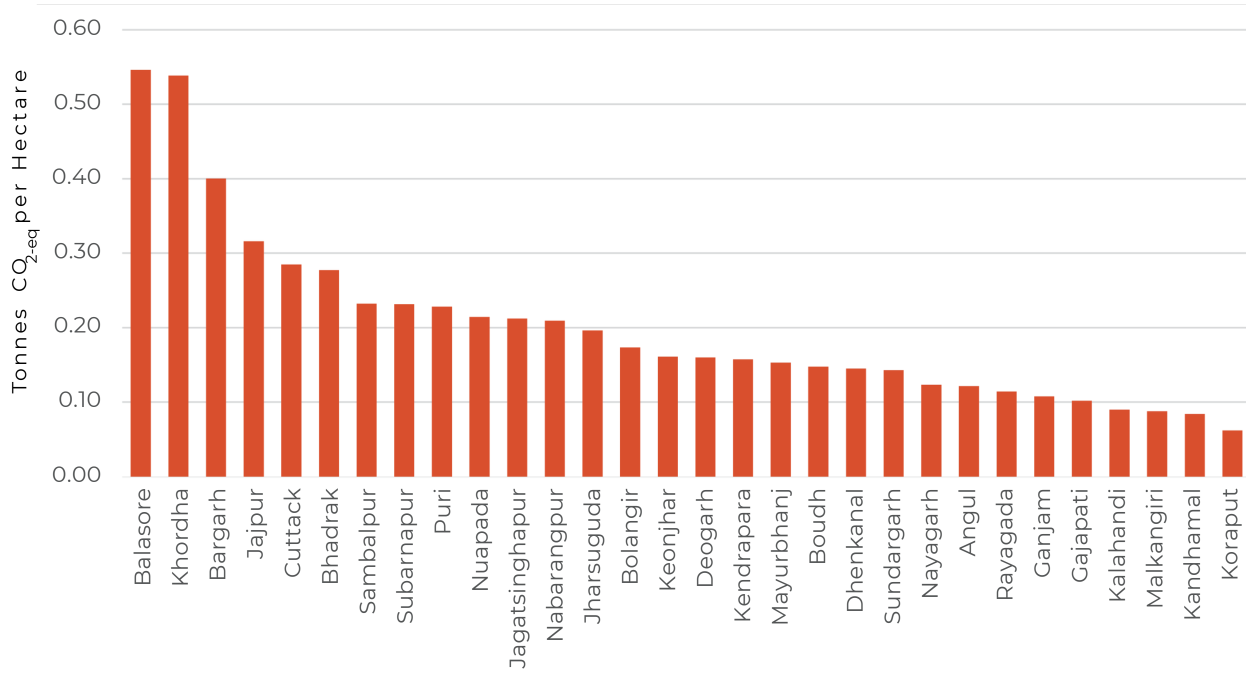
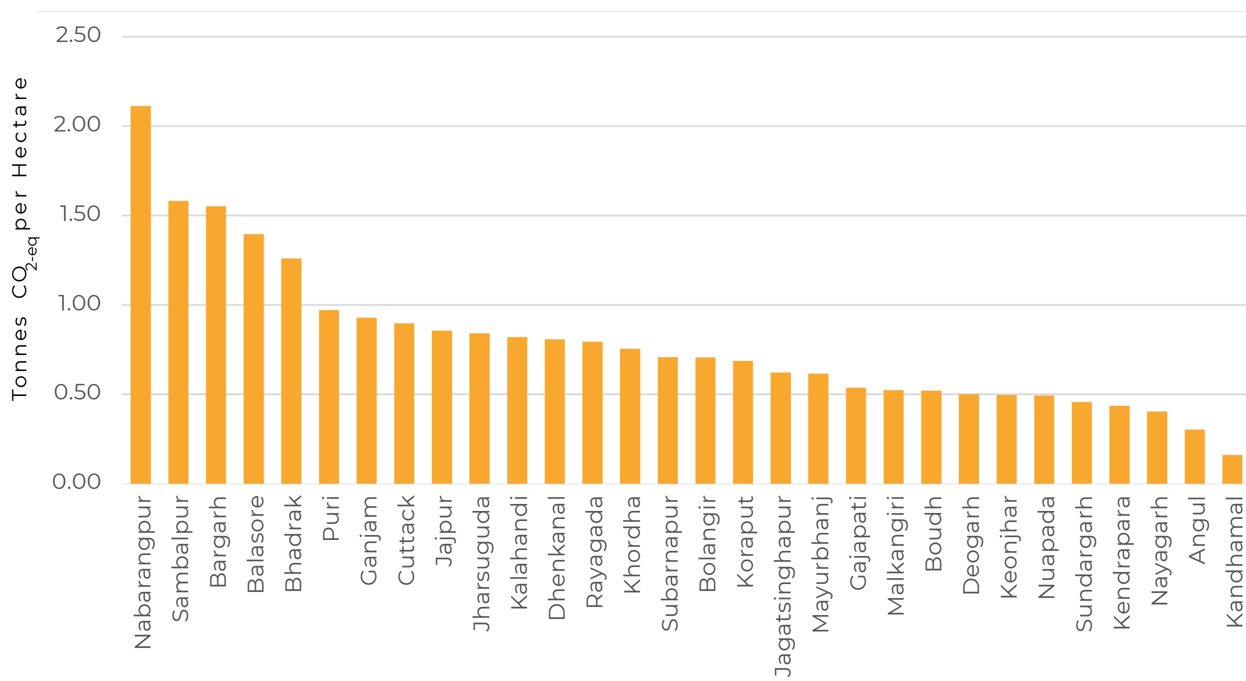


Figure 18: District-wise per hectare emissions by various emission sources

Diesel Consumption



Fertiliser Use



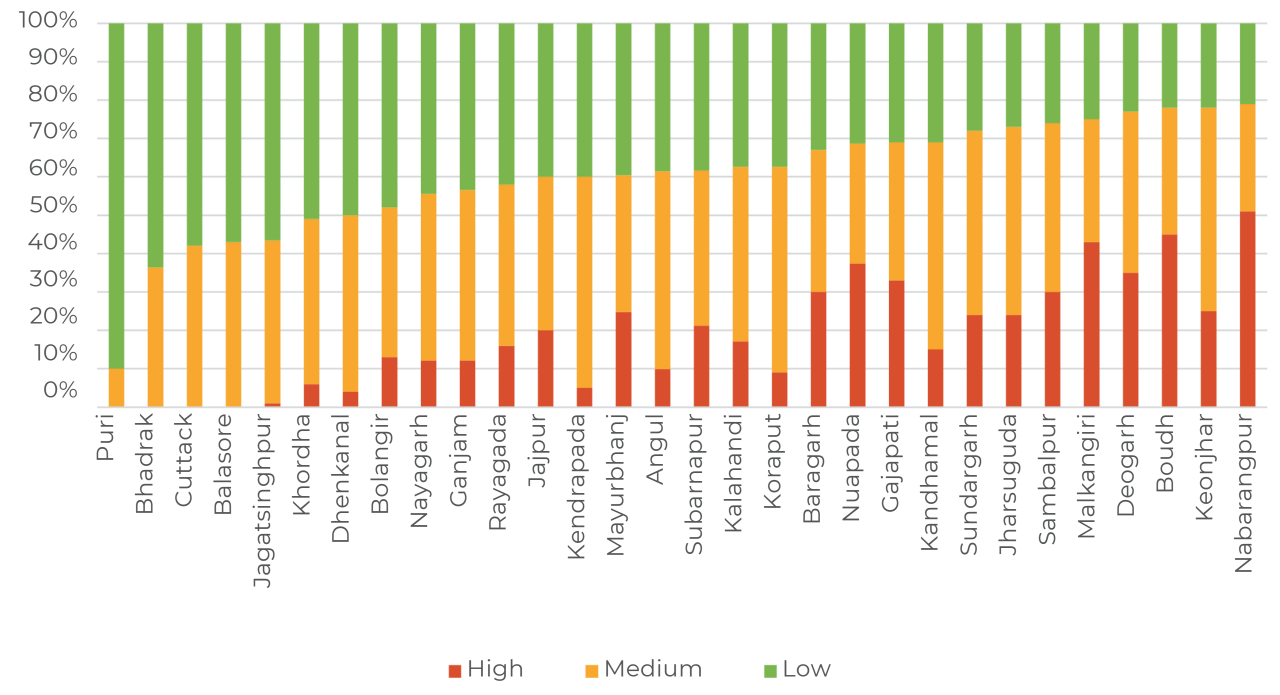


Figure 19: Fraction of total area under different rice ecosystems (High, medium, and lowlands, average of 2014-2019)

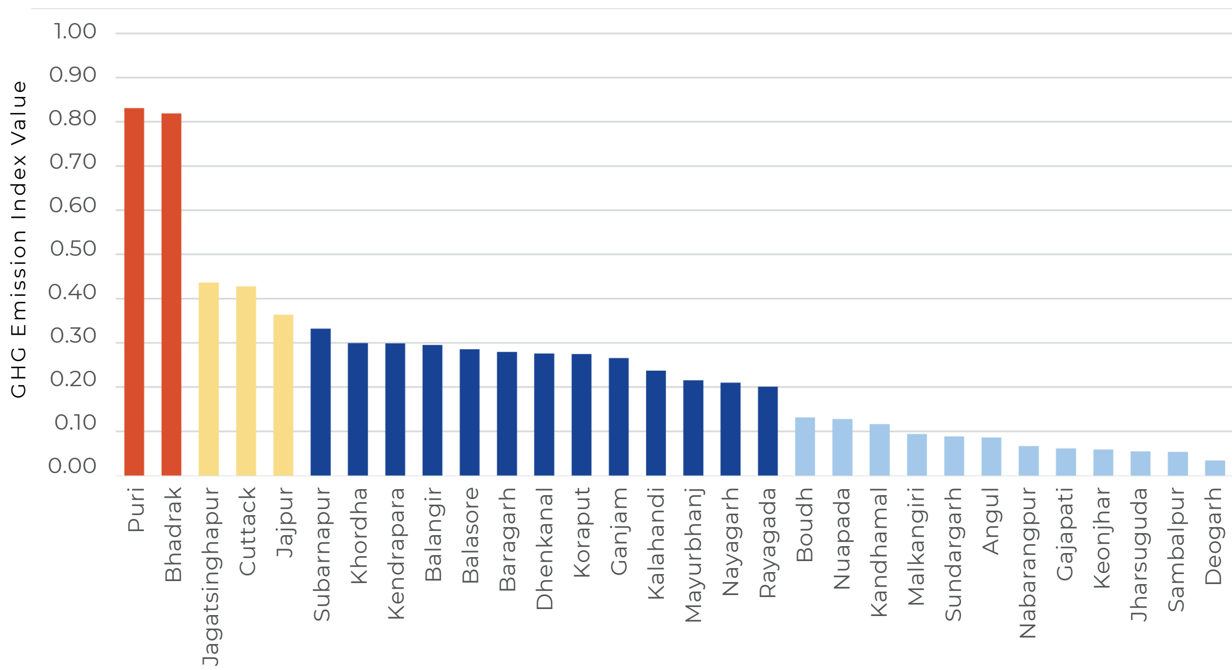


Figure 20: District-wise comparison of greenhouse gas emissions (Kg$CO_{2\text{-eq}}$ per hectare per year)

4.2.1. Greenhouse gas emissions index

This index aggregates all identified emission sources in the inventory, expressed in $kgCO_{2\text{-}eq}$ per hectare per year, enabling comparison of emissions across districts. As shown in Figure 20, **Puri and Bhadrak** emerge as the districts with the highest emissions per hectare annually. Mayurbhanj, however, has the highest total emissions from rice cultivation and livestock, attributed to its large geographical area. The disparity between these high-emitting districts and those in lower emission categories is notably wide, highlighting a significant concentration of emissions in specific areas.

4.2.2. Key takeaways of GHG emissions inventory

Some of the key takeaways of compiling a GHG inventory for the agriculture and allied sector in Odisha based on results presented in Figure 16 and Figure 17 are:

- Annual emissions from rice cultivation have remained relatively stable over the past decade, except for a significant drop in 2017 and 2018, due to droughts (Revenue and Disaster Management Department, 2017 and 2018).
- Annual livestock emissions have seen a gradual decline in the past decade. This reflects the decline in livestock population between the 19th and 20th National Livestock Censuses conducted in 2012 and 2019, respectively.
- Nitrogenous fertiliser usage has gradually increased over the past decade, resulting in a rise in total N_2O emissions.
- Although the emissions per unit area from fertiliser use has not increased significantly, there has been an increase in the total area under cultivation, increasing the total overall N_2O emissions.
- Diesel emissions have significantly increased in the past decade, even though the number of diesel pump sets has declined. This is due to an increase in the total number of agricultural tractors in the state, resulting in higher overall diesel consumption.
- Mayurbhanj district leads the state in terms of total emissions from rice cultivation and livestock, followed by Bhadrak and Ganjam in rice emissions and Keonjhar and Balasore in livestock emissions.
- Bargarh is the highest contributor to Odisha's total fertiliser and diesel emissions, followed by Nabarangpur and Ganjam in fertiliser emissions and Balasore and Khordha in diesel emissions.
- Bargarh and Nabarangpur lead the state in fertiliser use even though other districts, such as Mayurbhanj, has a larger area under cultivation. This is due to better access to fertilisers as well as awareness among farmers about fertiliser use (Rath, 2018).
- Bargarh and Balasore have high diesel emissions due to having a relatively high area under agriculture. Khordha, on the other hand, ranks 20th in Odisha in terms of total emissions but 3rd in terms of diesel emissions. A disproportionately high number of agricultural tractors are present in this district as a result of farmers having increased access to mechanisation by virtue of their proximity towards a large urban centre – Bhubaneswar.

Some of the key takeaways from the per-hectare emissions for the agriculture and allied sector in Odisha based on results presented in Figure 18 and Figure 20 are:

- **Puri** and **Bhadrak** lead the state in per-hectare emissions from rice cultivation. These districts mainly have lowlands with the highest fraction of areas under deep water and flood-prone rainfed rice ecosystems.

- **Bargarh** and **Jajpur** contribute the highest to per-hectare livestock emissions due to highest livestock population densities.
- **Nabarangpur**, **Sambalpur**, and **Bargarh** lead in terms of per-hectare fertiliser emissions due to comparatively high fertiliser application rates.
- **Balasore** and **Khordha** districts have the highest emissions from diesel consumption in the state, mainly due to the fact that they contain the highest number of agricultural tractors which are the main emitters.

4.2.3. Data and result validation

The results of the GHG inventory analysis were verified with the emissions estimated under GHGPI. Since GHGPI's estimates cover the period 2005-2015, the validations are conducted specifically for the years 2014 and 2015.

For these years, GHG emissions are validated with GHGPI's Greenhouse Gas Estimates (2005-2015) for the Agriculture, Forestry and Other Land Use (AFOLU) Sector (Dhingra, 2019). GHGPI's methodology includes both total and disaggregated emissions by source. A comparison of the results for 2014 and 2015 is provided in the table below:

(Values in $MtCO_{2\text{-eq}}$)	2014	2015
This Study	25.1	24.5
GHGPI Estimates	17.15	16.9

Although both estimates align reasonably well, the GHG estimates from this study are higher than those of GHGPI (2005-2015).

Several factors explain this disparity:

GHGPI's estimates exclude diesel usage from agricultural pumps and tractors as an emissions source, resulting in lower total emissions estimates. While diesel emissions contribute a relatively small amount, their omission still affects the total.

The CAGR used for estimating emissions from livestock, fertiliser, and rice cultivation differ between this study and the GHGPI methodology due to the different time periods considered (2005–2015 for GHGPI vs. 2014–2023 in this study).

There is a difference in the granularity of data which influences the total emissions. In this study, emissions are calculated at the district level, whereas in the GHGPI methodology, it is calculated at the state level.

In the case of emissions from rice cultivation, GHGPI relies on water management regime ratios derived from scientific literature (Pathak, et al., 2010; Bhatia, et al., 2013; Huke & Huke, 1997) and national-level data. In contrast, this study uses actual district-level ratios obtained from the Odisha Agricultural Statistics reports, which can lead to significant differences in rice emissions estimates.

The GHG emissions estimates from this study are also validated against the Odisha Climate Change Action Plan (SAPCC) 2021–2030. The SAPCC report provides an annual emissions estimate of 25.07 $MtCO_{2\text{-eq}}$ for 2015–2020, which is in agreement with the GHG inventory estimates from this study, calculated at 24.20 $MtCO_{2\text{-eq}}$ for the same period.

5. Conclusions

The resource use profiling index developed for this study highlights significant inter-district variations in Odisha. Districts such as Balangir, Khordha, Jajpur, Gajapati, and Kandhamal exhibit high RUP index scores, driven by manure application rates, relatively high fertiliser and pesticide use, poor water-use efficiency and limited mechanisation. These characteristics reflect inefficiencies in both input application and resource use, particularly in how water and nutrients are managed. In contrast, districts like Nabarangpur, Kalahandi, Subranapur, Sambalpur, and Bargarh report low RUP index scores, characterized by more efficient water use, better mechanisation, but lower organic manure application and high fertiliser and pesticide application rates. Overall, this analysis points to the need for tailored interventions. Districts with high RUP index scores require focused strategies to improve mechanisation, optimise manure use, and boost water-use efficiency. Meanwhile, districts with low RUP index scores may benefit from optimising specific inputs such as fertilisers to improve sustainability in agriculture. While Nabarangpur and Bargarh registers low RUP index scores they stand out for having the highest fertiliser application rate in the state, and these districts have been selected in consultation with the Department of Agriculture and Farmers' Empowerment for targeted efforts to optimise fertiliser use in these otherwise resource-efficient districts.

Greenhouse gas inventory findings reveal stable annual emissions from rice cultivation over the past decade, with notable exceptions during drought years. Livestock emissions have declined due to reduced livestock populations, while fertiliser usage has increased, contributing to higher N_2O emissions. Diesel emissions have risen due to an increase in agricultural tractor use, even as diesel pump sets have declined. Mayurbhanj leads in total average annual emissions from rice cultivation and livestock, while Bargarh is the highest contributor to fertiliser and diesel emissions. Puri and Bhadrak lead in per-hectare rice emissions, reflecting lowland rice ecosystems prone to flooding, while Bargarh and Jajpur have the highest per-hectare livestock emissions due to dense livestock populations.

Both assessments relied exclusively on data provided by the Department of Agriculture Statistics, Directorate of Agriculture and Food Production, Odisha, and other publicly available government datasets. The data and results were validated either by the stakeholders from respective departments or by comparing them with previous studies, such as the GHGPI and SAPCC reports, which indicated reasonable alignment. The use of standardised, government-sourced data provides a reliable foundation for inter-district comparisons and prioritisation of interventions.

The findings from both assessments underline the importance of prioritising resource use optimisation and emissions reduction in agriculture through Climate Smart Agriculture (CSA) practices tailored to district-specific needs, especially in high-resource-use and high-emission districts.

Terraced rice fields around Deomali, Odisha

Ravikanth Bora

6. References

1. APEDA. (2023). E-Catalogue For Export of Millets and Value-Added Products. Retrieved from APEDA_Govt_of_India: https://apeda.gov.in/milletportal/files/Odisha_Millet_Value_Added_Products_Catalogue.pdf
2. Becker-Reshef, I., Barker, B., Whitcraft, A., Oliva, P., Mobley, K., Justice, C., & Sahajpal, R. (2022). GEOGLAM Best Available Crop Type Masks (1.0.0) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.7230863
3. Bhatia, A., Jain, N., & Pathak, H. (2013). Methane and nitrous oxide emissions from Indian rice paddies, agricultural soils and crop residue burning. Greenhouse Gases: Science and Technology, 3(3), 196-211. https://doi.org/10.1002/ghg.1339
4. Caristas_India. (2021). Documentation of Traditional Climate Resilient Crops and Agricultural Practices in the Selected Blocks of Odisha. Retrieved from Caritas_India: https://caritasindia.org/GlobalProgramIndia/wp-content/uploads/2022/03/Documentation-of-Traditional-Climate-Resilient-Crops-and-Agricultural-practices-in-the-selected-blocks-of-Odisha.pdf
5. Confederation of Indian Industry, CII. (2015). Estimation of Odisha's carbon footprint. Final_Odisha_Carbon_Footprint_Report.pdf (climatechangecellodisha.org)
6. Das S R. (2012). Rice in Odisha. IRRI Technical Bulletin No. 16. Los Baños (Philippines): International Rice Research Institute. pp. 31.
7. Dass A., Sudhishri S., & Lenka N.K. (2009). Integrated nutrient management for upland rice in eastern ghats of Orissa. Oryza. 46(3), 20-226.
8. Department of Agriculture and Farmers' Empowerment. Government of Odisha(2014-15). Odisha Agriculture Statistics. https://agri.odisha.gov.in/sites/default/files/2022-09/AGRICULTURE%20STATISTICS_2014-15.pdf
9. Department of Agriculture and Farmers' Empowerment. Government of Odisha(2015-16). Odisha Agriculture Statistics. https://agri.odisha.gov.in/sites/default/files/2022-09/AGRICULTURE%20STATISTICS_2015-16.pdf
10. Department of Agriculture and Farmers' Empowerment. Government of Odisha(2016-17). Odisha Agriculture Statistics. https://agri.odisha.gov.in/sites/default/files/2022-09/ODISHA%20AGRICULTURE%20STATISTICS_2016-17.pdf
11. Department of Agriculture and Farmers' Empowerment. Government of Odisha(2017-18). Odisha Agriculture Statistics. https://agri.odisha.gov.in/sites/default/files/2022-04/ODISHA%20AGRICULTURE%20STATISTICS1_2017-18.pdf
12. Department of Agriculture and Farmers' Empowerment. Government of Odisha(2018-19). Odisha Agriculture Statistics. https://agri.odisha.gov.in/sites/default/files/2022-10/ODISHA%20AGRICULTURE%20STATISTICS%202018-19.pdf
13. Department of Agriculture and Farmers' Empowerment. Gov of Odisha. (2018, Sep 20). Odisha_Organic_Farming_Policy. Retrieved from The Odisha Gazette: https://startupodisha.gov.in/wp-content/uploads/2023/01/Odisha-Organic-Farming-Policy-2018.pdf
14. Department of Agriculture and Farmers' Empowerment. Government of Odisha. (2020). Executive Summary of SAMRUDHI- Agriculture Policy 2020. https://agri.odisha.gov.in/sites/default/files/2021-05/Executive%20Summary%20of%20SAMRUDHI%20-Agriculture%20Policy%202020%20in%20English_0.pdf
15. Dhingra, S., Singh, D., and Mehta, R. (2019). Greenhouse Gas Emission Estimates from AFOLU (Agriculture, Forestry and Other Land Use) Sector in India at the Subnational Level (Version/edition 3.0). New Delhi. GHG Platform India Report – Vasudha Foundation. Available at: http://www.ghgplatform-india.org/methdolo-afolu-sector
16. Directorate of Agriculture and Food Production. (October 2019). *Odisha Millets Mission*. Government of Odisha.
17. Directorate of Economics & Statistics, Odisha, Bhubaneswar, Government of Odisha. (2015-2016). *Agricultural Census, 2015-16: Odisha*.
18. Directorate of Economics & Statistics. *Report on Input Survey, 2016-17*, Odisha, (Phase – III). Directorate Of Economics & Statistics. Government of Odisha, Bhubaneswar.

19. Food and Agriculture Organization of the United Nations. (2005). *Fertiliser use by crop in India and plant nutrition management service, land and water development division.* Rome: FAO. Retrieved from https://krishi.icar.gov.in/jspui/bitstream/123456789/32459/1/54%20%20Nutrient%20ratios%20and%20crop%20response%20in%20relation%20to%20soil%20reserve%20K%20in%20India..pdf
20. Food and Agriculture Organization of the United Nations. (2022). The dimensions of water productivity. FAO. Retrieved from: https://openknowledge.fao.org/server/api/core/bitstreams/c813b0e0-1102-40ff-9d29-bd113c9c2846/content
21. Garg, P. S. (2006). *The sectoral trends of multigas emissions inventory of India.* Atmospheric Environment.
22. GHGPI. (September 2019). *National Level Greenhouse Gas Estimates (20050-2018) - AFOLU Sector.* New Delhi: GHG Platform of India.
23. Govt of India. (2012). 19th Livestock census-2012, All India Report. Ministry of Agriculture, Department of Animal Husbandry, Dairying, and Fisheries. https://dahd.nic.in/sites/default/filess/Livestock%20%205.pdf
24. Govt of India. (2019). 20th Livestock census-2019, All India Report. Ministry of Agriculture, Department of Animal Husbandry, Dairying, and Fisheries. https://dahd.nic.in/sites/default/filess/20thLivestockCensus2019AllIndiaReport.pdf
25. Government of Odisha. (2018). Climate_Change_Cell_Odisha. Retrieved from Odisha_State_Aaction_Plan_on_Climate_Change: https://climatechangecellodisha.org/pdf/State%20Action%20Plan%20on%20Climate%20Change%202018-23.pdf
26. Government of Odisha. (2018-19). Fisheries Sector. Retrieved from Annual Activities Report: https://fisheries.odisha.gov.in/upload/files/06_34_50pm88f4d58b395801f700bd2bb2cdda3d73.pdf
27. Gupta, P. K., Gupta, V., Sharma, C., Das, S. N., Purkait, N., Adhya, T. K., ... & Iyer, C. S. P. (2009). Development of methane emission factors for Indian paddy fields and estimation of national methane budget. Chemosphere, 74(4), 590-598.
28. Haque, T. (2006). Resource use efficiency in Indian agriculture. Indian Journal of Agricultural Economics, 61, 65–76.
29. H. Pathak, A. B. (2002). *Emission of Nitrous Oxide from Rice-Wheat Systems of Indo-Gangetic Plains of India.* Environmental Monitoring and Assessment.
30. Huke, R.E., and E.H. Huke, Rice Area by Type of Culture.' South, Southeast and East Asia, a Revised and Updated Data Base, 59 pp., Int. Rice Res. Inst., Los Banos, Philipp., 1997
31. IANS. (2023). 10 cyclones in 12 years; eroding coastline: Odisha impacted by climate change. https://timesofindia.indiatimes.com/india/10-cyclones-in-12-years-eroding-coastline-odisha-impacted-by-climate-change/articleshow/99005986.cms
32. Intergovernmental Panel on Climate Change (IPCC). (1996). *IPCC guidelines for national greenhouse gas inventories*. Retrieved from: https://www.ipcc-nggip.iges.or.jp/public/gl/invs6c.html
33. K Chandrasekar, NidhiMisra, Anurag Mishra, Mohammed Ahamed J., Madhavi P, Abdul Hakeem K & VV Rao; 2021, Evapotrative Flux Estimation Over Indian Region Using S-Npp Optical And Thermal Data; IEEE India Geoscience and Remote Sensing Symposium (InGARSS) – 2021, 06-10 December 2021, Ahamedabad, India. https://bhuvan-nhp.nrsc.gov.in/nhp, Last accessed: 25-03-2025 https://bhuvan.nrsc.gov.in/nhp/webgis-et/map
34. MoEFCC. (2023). India: Third National Communication and Initial Adaptation Communication to the United Nations Framework Convention on Climate Change. New Delhi: Ministry of Environment, Forest and Climate Change, Government of India. Retrieved from: India. National Communication (NC). NC 3. | UNFCCC
35. MoHHW. (2022). State Action Plan for Climate Change and Human Health—Odisha. https://ncdc.mohfw.gov.in/wp-content/uploads/2024/05/19.SAPCCHH-VERSION-1-Odisha.pdf
36. The Odisha Economic Survey. (2023-24). Government of Odisha. Accessed at https://odisha.neva.gov.in

37. Nangia, V., and Oweis, T. (2017). Supplemental irrigation: A promising climate-resilience practice for sustainable dryland agriculture. Innovations in Dryland Agriculture. 10.1007/978-3-319-47928-6_20
38. Nayak AK, Kumar A, Tripathi R, Panda BB, Mohanty S, Md. Shahid, Raja R, Khanam R, Bhaduri D, Satapathy BS, Lal B, Gautam P, Nayak PK, Vijayakumar S, Panneerselvam P and Swain P (2021). Improved Water Management Technologies for Rice Production System. NRRI Research Bulletin No. 32, ICAR-National Rice Research Institute, Cuttack 753006, Odisha, India. pp-40.
39. Odisha Renewable Energy Development Agency. (2019). *Solar Pump for Irrigation*. Retrieved from https://oredaodisha.com/solar-pump-for-irrigation/
40. OSDMA. (2024). Odisha State Disaster Management Authority. Retrieved from osdma.org: https://www.osdma.org/state-profile/#gsc.tab=0
41. Pathak, H., Jain, N., Bhatia, A., Patel, J., & Aggarwal, P. K. (2010). Carbon footprints of Indian food items. Agriculture, ecosystems & environment, 139(1-2), 66-73. https://doi.org/10.1016/j.agee.2010.07.002
42. Revenue and Disaster Management Department. (2017). *Drought Notification - 2017*. Retrieved from https://srcodisha.nic.in/2017%20Drought%20Notification/1st%20Drought%20Notification%20dated%2030.12.2017.pdf
43. Revenue and Disaster Management Department. (2018). *Drought Notification - 2018*. Retrieved from https://srcodisha.nic.in/2018%20Drought%20Notification/1st%20Additional%20%20Drought%20Notification%20dated%2028.11.2018.pdf
44. Samal, A. S. (June 2024). *Assessment and Quantification of Methane Emission from Indian Livestock and Manure Management*. Aerosol and Air Quality Research.
45. Sekhon H.S., Singh G., Sharma P. and Bains T.S. (2010). Water-use efficiency under stress environments. Climate Change and Management of Cool Season Grain Legume Crops. 10.1007/978-90-481-3709-1_12
46. Shankar, S., Dutta, A., & Singh, A. (2022). Understanding Changing Climate And Food Security In Rural Odisha. https://tigr2ess.globalfood.cam.ac.uk/news/understanding-changing-climate-and-food-security-rural-odisha
47. Sharma K.L., Ramakrishna Y.S., Samra J.S., Sharma K.D., Mandal U.K., Venkateswarlu B., Korwar G.R. and Srinivas K. (2009). Strategies for improving the productivity of rainfed farms in India with special emphasis on soil quality improvement. Journal of Crop Improvement. 23(4), 430-450. 10.1080/15427520903013431
48. Sharma S., Rout K.K., Khanda C.M., Tripathi R., Shahid M., Nayak A., Satpathy S., Banik C N., Iftikar W., Parida N., Kumar V., Mishra A., Castillo R. L., Velasco T., Buresh R. J. (2019). Field-specific nutrient management using Rice Crop Manager decision support tool in Odisha, India. Field Crops Research. 241, 107578, ISSN 0378-4290, https://doi.org/10.1016/j.fcr.2019.107578.
49. Singh, V., & Sonwani, S. (2023). Entrepreneurship and Self-employment through Livestock among Scheduled Tribes. *Journal of Livestock Science*, (14)
50. TANGEDCO (2021). Tamil Nadu State Energy Calculator 2050. http://tnsec2050.tangedco.org/pathways/222022222222222202222222220202222022222222112022202222022222/primary_energy_chart. Retrieved September 2024. Tamil Nadu State Energy Calculator 2050.
51. World Bank. (2021). Dealing with the Pandemic. https://agri.odisha.gov.in/sites/default/files/2021-05/Covid-19Covid-19-%20Impacton%20Agriculture-Allied-Sectors-Odisha_%20Dealing-with_the-pandemic.pdf

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