# An Empirical Study on the Advancing of Sustainability in Indian Agriculture

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As of 2022-23, agriculture is the second largest workforce sector in India after services, with more than 45.6% of workers being employed in the agriculture sector, which is essential for the survival of the Indian economy. Agricultural sustainability has emerged as an essential strategy to promote environmentally sound, economically feasible, and socially inclusive practices. This study examines the growth patterns of agriculture and evaluates the long-term effects of sustainable practices across Indian states over two decades (2001-2021), contrasting them with conventional methods. Practices such as organic farming, zero-budget natural farming, agroforestry, drip irrigation, and crop diversification have demonstrated significant benefits, including higher farmer incomes, reduced input costs, improved water-use efficiency, and enhanced soil health. The analysis underscores state-specific advancements driven by geographic, climatic, and socioeconomic factors—Sikkim leading in organic farming, Andhra Pradesh and Karnataka excelling in zero-budget natural farming, Tamil Nadu, Himachal Pradesh, and Punjab in agroforestry, Maharashtra in drip irrigation, and Punjab, Haryana, and Madhya Pradesh in crop diversification. Employing comparative analysis and visual tools, the research highlights consistent improvements in sustainability across states, with marked economic and environmental progress. Nevertheless, challenges remain in achieving uniform adoption of these practices across regions, necessitating targeted recommendations. By offering practical insights for policymakers and stakeholders, the study supports the broader objective of integrating sustainability into business practices and it provides a comprehensive framework to foster responsible growth in this vital sector.

Keywords: Agricultural sustainability, Environmental sustainability, Economic sustainability, Social sustainability

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## Introduction

Agricultural land plays a pivotal role in food supply, significantly contributing to productivity and food security. In 2015, the United Nations introduced the 17 Sustainable Development Goals (SDGs), with Zero Hunger (SDG 2) being a critical target. Despite these concerted initiatives, approximately one in ten individuals worldwide continues to experience severe food insecurity (Viana et al., 2021). Several crucial factors—such as population growth, rapid urbanization, exploitation of non-renewable resources, and climate change—unduly influence and negatively impact global food security . Many researchers and economists anticipate that population growth will exacerbate undernourishment, while the overexploitation of resources may lead to land degradation and diminished soil productivity (Toth et al., 2018, Sami & Roychowdhury, 2022). Thus, sustainable agricultural practices are essential not only for food production but also for influencing several other SDGs.

In the context of India, agriculture is a crucial sector, accounting for approximately 42% of total employment and contributing about 16% to the GDP, with agricultural land comprising 60% of the country's total land area (World Bank, 2016). India is recognized as a global agricultural powerhouse, ranking as the largest producer of milk, pulses, and spices, and possessing the world's largest buffalo herd. The country also leads in the area cultivated for wheat, rice, and cotton. Additionally, India holds a prominent second position in the production of several key agricultural products, including rice, wheat, cotton, sugarcane, farmed fish, sheep and goat meat, as well as a variety of fruits, vegetables, and tea (World Bank, 2021). However, the contribution of agriculture to GDP has been steadily declining over the past six decades, decreasing from around 54% in 1960-1961 to 16% in 2020-2021 (GoI, 2021). Currently, India faces a multifaceted agricultural crisis characterized by declining farm incomes, rising production costs, depletion of natural resources, and the loss of agrobiodiversity (GoI, 2020; Singh, 2020). Agriculture has always been the backbone of India's economy, employing nearly half of the nation's workforce and contributing significantly to its GDP. However, the rapid adoption of industrial and conventional farming practices since the Green Revolution in the 1960s has led to growing concerns over environmental degradation, unsustainable use of resources, and declining farm profitability. In response, the promotion of sustainable agricultural practices has gained momentum, offering a balanced approach that seeks to improve long-term productivity, environmental health, and economic viability for farmers.

Agricultural sustainability is essential for India’s food security, rural employment, and economic balance. With challenges from climate change and resource limitations, understanding sustainability across regions enables targeted strategies for resilience and growth. This study evaluates sustainability across Indian states over three decades, providing insights for balanced development.

The study aims to assess agricultural sustainability across economic, social, and environmental indicators—area under irrigation (AUI), rural employment rate (RER), and gross state domestic product (GSDP)—across eighteen Indian states. By highlighting regional strengths and gaps, it aims to guide policy efforts for enhancing agricultural resilience and balanced growth.

The research paper is organized as follows: The next section provides an extensive literature review on agricultural sustainability and the various sustainable agricultural practices adopted across different Indian states, serving as a foundation for developing a contextual approach and identifying the research gap. The third section outlines the methodology, detailing the data collection and analysis techniques employed in the study. This is followed by the results of the data analysis in the fourth section, offering insights into the comparative sustainability performance across the selected states. The fifth section presents a discussion of the findings, linking them to broader sustainability goals. Finally, the paper concludes with a discussion of the study's limitations and suggests future directions for research to enhance the understanding of sustainable agricultural practices.

**Extant works of literature and research gap**

This section presents a comprehensive literature review that offers insight into the sustainability of agriculture, a critical factor for fostering sustainable agricultural practices across Indian states.

The Green Revolution, initiated in India in the mid-1960s, introduced high-yielding varieties (HYVs) of crops, chemical fertilizers, and irrigation technologies, resulting in a significant increase in food production. However, research has highlighted the unintended consequences of the Green Revolution, including the degradation of soil fertility, depletion of water resources, and loss of biodiversity (Shiva, 1991; Hazell, 2009). The excessive use of fertilizers and pesticides has led to soil degradation and groundwater depletion, pushing Indian agriculture toward unsustainability (Pingali, 2012). As a result, the need for sustainable agricultural models has emerged as a key policy issue.

Sustainable agriculture encompasses various practices aimed at balancing productivity with environmental and economic sustainability. Pretty (1995) defines sustainable agriculture as a system that preserves natural resources, ensures economic viability for farmers, and promotes equitable social outcomes. Key principles of sustainable agriculture include reducing dependence on synthetic inputs, promoting biodiversity, conserving soil and water, and ensuring long-term yield stability. Agroecology has been emphasized in studies by Altieri

(1995) and Gliessman (2007) as a critical approach to enhancing resilience against climate change and environmental stress.

Sikkim stands out as a global leader, becoming India's first fully organic state in 2016. The literature on organic farming in Sikkim underscores the state's remarkable progress in eliminating chemical inputs and promoting eco-friendly practices (Chakraborty et al., 2020). Studies by Gurung and Gautam (2018) indicate that organic farming in Sikkim has resulted in improved soil health, increased biodiversity, and higher farm incomes due to premium prices for organic products. Additionally, organic farming has contributed to the conservation of local ecosystems and the protection of water sources (Bhattacharya & Mandal, 2017).

Zero Budget Natural Farming (ZBNF), introduced by Subhash Palekar in the early 2000s, has gained prominence in states such as Andhra Pradesh and Karnataka. ZBNF emphasizes the use of natural inputs like cow dung-based fertilizers, significantly reducing farming costs (Narayanan, 2019). Research by Azim Premji University (2019) reported that ZBNF farmers in Andhra Pradesh experienced a 60-70% reduction in input costs and an improvement in soil fertility. However, Karthik et al. (2020) caution that while ZBNF provides short-term cost savings, further studies are needed to assess its long-term impact on yield stability and sustainability.

Agroforestry, the integration of trees with agricultural crops, has been promoted as a sustainable practice, particularly in Tamil Nadu. It enhances soil fertility, conserves biodiversity, and provides additional income through timber, fruits, and forest products (Nair, 1993). Research by the Indian Council of Forestry Research and Education (ICFRE, 2011) found that agroforestry practices contributed to a 30-40% increase in farmers' incomes through diversified production. Additionally, agroforestry plays a significant role in carbon sequestration, which is essential for mitigating the effects of climate change (Kumar & Nair, 2011).

Drip irrigation has been widely recognized for its water-saving benefits, especially in arid and semi-arid regions such as Maharashtra. Palanisami et al. (2011) found that drip irrigation systems saved 40-60% of water compared to traditional flood irrigation methods. According to a 2020 report by the National Bank for Agriculture and Rural Development (NABARD), drip irrigation has also improved crop yields, with crops like sugarcane and grapes experiencing a 30-40% increase in yield per hectare. Furthermore, drip irrigation reduces groundwater extraction and enhances soil moisture retention, both of which are critical for sustainable agriculture in water-scarce regions (Gupta, 2013).

Crop diversification has emerged as a key strategy for improving soil health and reducing the risks associated with monoculture. Farmers in states such as Haryana and Madhya Pradesh have adopted diversification by incorporating pulses, millets, and oilseeds, which improve soil nitrogen levels and increase resilience to climate variability (Joshi et al., 2009). Literature indicates that crop diversification leads to higher farm incomes, reduced market risks, and more efficient water use (Birthal et al., 2015). Additionally, Singh et al. (2019) found that diversified cropping systems enhance biodiversity and offer natural pest control, reducing the reliance on chemical interventions.

This review highlights the need to explore the economic and environmental outcomes of these practices across Indian states from 2001 to 2021. This study will assess the viability of these agricultural practices in meeting India's growing demand for sustainable agricultural development.

While there is extensive literature on various sustainable agricultural practices such as organic farming, Zero Budget Natural Farming (ZBNF), agroforestry, drip irrigation, and crop diversification across different states of India, there remains a lack of comparative studies that assess the overall agricultural sustainability performance across states over an extended period. Existing studies tend to focus on specific practices within isolated contexts, but few analyze the combined economic, environmental, and social impacts of these practices across diverse agro-climatic regions. Additionally, most of the current studies are localized, focusing on individual states or practices without a comprehensive evaluation of sustainability across multiple regions in India.

In the context of sustainable development and economic analysis, this study examines the interconnected variables of economic growth, social indicators, and environmental factors to provide a comprehensive view of regional development dynamics in India. Gross state domestic product (GSDP) serves as the primary indicator of economic growth, reflecting the value of goods and services produced within a state and correlating with job creation and living standards. The rural employment rate (RER) is a crucial social indicator that sheds light on employment patterns and livelihood security in rural populations, emphasizing the role of sustainable employment in promoting social equity. Additionally, the area under irrigation (AUI) serves as an essential environmental variable that impacts agricultural productivity, water resource management, and ecological sustainability.

Research consistently highlights the interdependence of these factors, illustrating how economic growth driven by GSDP can enhance rural employment and support irrigation expansion (Bhattacharya & Sakthivel, 2004). Despite agriculture's critical role in sustainable development, there remains a significant research gap regarding the decadal performance comparisons of agricultural sectors across Indian states. This study aims to address this gap by analyzing the decadal growth rates of three key sustainability indicators—GSDP, RER, and AUI—offering insights into the agricultural sector's influence on sustainable development in India. By focusing on these dimensions, the research seeks to enhance understanding of the agricultural sector's overall performance and its contributions to sustainable progress across various regions.

**Research methodology**

This section details the research framework, including the data collection methods and analytical techniques applied to examine the implementation and impacts of sustainable agricultural practices across Indian states. The study adopts a quantitative approach to evaluate outcomes across three dimensions: economic (gross state domestic product), social (rural employment rate), and environmental (area under irrigation). By analyzing these indicators, the methodology aims to offer a holistic understanding of the sustainability and effectiveness of agricultural practices within India's evolving agricultural landscape. To capture long-term trends, decadal growth rates are calculated to determine the percentage changes in the area under irrigation, rural employment rates, and gross state domestic product over three ten-year intervals (2000, 2010, and 2020). The formula used for calculating the decadal growth rate is as follows:

$$\text{Decadal Growth Rate (\%)} = \frac{Y_{t+10} - Y_t}{Y_t} \times 100$$

where

$Y_{t+10}$: Variable value at the at the end of the decade (ten years after the base year)

$Y_t$: Variable value at the at the beginning of the decade (base year)

For each three variable this decadal growth formula applied to assess growth patterns and fluctuations over each decade, thus facilitating comparative analysis of employment trends across different decades.

To facilitate comparisons among variables with different units, such as area under irrigation (AUI) and rural employment rate (RER) (measured in percentages) and gross state domestic product (GSDP) (measured in millions of ₹), normalization is essential. This study employs the Min-Max normalization technique to bring all variables to a common scale, allowing for meaningful analysis without the influence of varying units.

The Min-Max normalization formula used is:

$$X_{ijk_{\text{normalized}}} = \frac{X_{ijk} - X_{ijk_{\min}}}{X_{ijk_{\max}} - X_{ijk_{\min}}} (\%),$$

where

$X_{ijk}$ is value of the *i*th variable, *j*th decadal year of the *k*th state

*i* is the variable included in the study (area under irrigation, rural employment rate and GSDP)

*j* is the decadal year included in the study (2000,2010 and 2020)

*k* is the states included in the study 1,2,3,…., *K*.

By applying this formula, each variable is re-scaled to a range between 0 and 100, where: a value of 0 represents the minimum observed value, a value of 100 represents the maximum observed value

To further enrich the analysis, visual techniques are employed summarizing agricultural sustainability performance across states to provide a comprehensive understanding of the comparative analysis.

## Results and discussion

The data analysis section is structured into four main parts to provide a detailed examination of agricultural sustainability. The first part analyzes the decadal growth of key indicators— area under irrigation (AUI), rural employment rate (RER), and gross state domestic product (GSDP)—to uncover trends within each sustainability dimension. The second part compares these indicators over different decades, highlighting changes and patterns over time. The third part evaluates regional performance, exploring the contributions of various states or regions to sustainable agricultural development. Finally, the section assesses the overall sustainability of the agricultural sector by integrating economic, social, and environmental aspects, offering a comprehensive view of its impact on sustainable development. Table 1 presents the tabulated data on area under irrigation (AUR), rural employment rate (RER), and gross state domestic product (GSDP) across various states over three decadal periods: 2000, 2010, and 2020. The data has been sourced from various government agricultural reports.

**Table 1.** Data Overview: AUR, RER, and GSDP across states (2000-2020)

| | Area under irrigation (%) | | | Rural Employment Rate( %) | | | GSDP (₹ millions) | | |
|---|---|---|---|---|---|---|---|---|---|
| **State** | **2000** | **2010** | **2020** | **2000** | **2010** | **2020** | **2000** | **2010** | **2020** |
| **Andhra Pradesh** | 28.6 | 45.9 | 49.8 | 78.8 | 68.7 | 58.6 | 1567110 | 5837620 | 9258390 |
| **Bihar** | 51.6 | 60.8 | 74.2 | 77.9 | 66.9 | 55.9 | 576570 | 2042890 | 5818550 |
| **Chhattisgarh** | 17.5 | 26.7 | 35.7 | 86.2 | 84.9 | 83.6 | 295390 | 1194200 | 3446480 |
| **Goa** | 11.8 | 23.5 | 22.6 | 35.3 | 23.9 | 12.5 | 70970 | 336050 | 750320 |
| **Gujarat** | 22.7 | 44.4 | 51.0 | 77.3 | 78.3 | 79.3 | 1235730 | 5215190 | 16171430 |
| **Haryana** | 78.2 | 87.3 | 91.2 | 64.1 | 59.8 | 55.5 | 655050 | 2606210 | 7321950 |
| **Jharkhand** | 3.9 | 11.1 | 13.7 | 70.0 | 54.8 | 39.6 | 350690 | 1272810 | 3103050 |
| **Karnataka** | 20.5 | 31.8 | 35.0 | 81.0 | 75.7 | 70.4 | 1128470 | 4107030 | 16111340 |
| **Kerala** | 15.9 | 17.1 | 20.0 | 42.0 | 35.7 | 29.4 | 779240 | 2637730 | 8129350 |
| **Madhya Pradesh** | 23.9 | 33.5 | 48.6 | 82.5 | 82.4 | 82.3 | 867450 | 2633960 | 9278550 |
| **Maharashtra** | 15.1 | 19.2 | 23.6 | 80.0 | 79.4 | 78.8 | 2731880 | 10350860 | 26573710 |
| **Odisha** | 18.8 | 29.3 | 29.0 | 69.0 | 67.6 | 66.2 | 467560 | 1975300 | 5375020 |
| **Punjab** | 93.7 | 98.0 | 98.5 | 66.9 | 61.8 | 56.7 | 796110 | 2262040 | 5370310 |
| **Rajasthan** | 19.1 | 33.6 | 43.5 | 72.9 | 63.3 | 53.7 | 917710 | 3383480 | 9986790 |
| **Tamil Nadu** | 34.9 | 58.1 | 56.1 | 65.4 | 63.7 | 62.0 | 1488610 | 5848960 | 17431440 |
| **Uttar Pradesh** | 64.0 | 76.1 | 80.7 | 65.4 | 66.9 | 68.4 | 1902690 | 6001640 | 17000620 |
| **Uttarakhand** | 22.7 | 48.6 | 52.4 | 65.4 | 69.5 | 73.6 | 151440 | 839690 | 2392470 |
| **West Bengal** | 50.9 | 58.0 | 65.5 | 65.4 | 56.3 | 47.2 | 1571440 | 4609590 | 11790970 |

Registrar General of India

Decadal growth has been analyzed and summarized in Table 2 using the methodology described, covering three timeframes: 2000–2010, 2010–2020, and the overall period of 2000–2020. The 2000–2010 period serves as a baseline for examining the effects of early agricultural policies on AUR, RER, and GSDP. The 2010–2020 period focuses on assessing the outcomes of continued efforts toward agricultural sustainability, while the combined 2000–2020 analysis provides a comprehensive view of long-term trends and policy impacts. This approach highlights the decade that witnessed the most notable progress in advancing agricultural sustainability.

**Table 2.** Decadal growth rates of agricultural sustainability metrics across states (2000-2020)

| | Area under irrigation (%) | | | Rural Employment Rate(%) | | | GSDP (₹ millions) | | |
|---|---|---|---|---|---|---|---|---|---|
| **State** | **2000-10** | **2010-20** | **2000-20** | **2000-10** | **2010-20** | **2000-20** | **2000-10** | **2010-20** | **2000-20** |
| **Andhra Pradesh** | 60.49 | 8.50 | 74.13 | -12.82 | -14.70 | -25.63 | 272.5 | 58.6 | 490.8 |
| **Bihar** | 17.83 | 22.04 | 43.80 | -14.12 | -16.44 | -28.24 | 254.3 | 184.8 | 909.2 |
| **Chhattisgarh** | 52.57 | 33.71 | 104.00 | -1.51 | -1.53 | -3.02 | 304.3 | 188.6 | 1066.8 |
| **Goa** | 99.15 | -3.83 | 91.53 | -32.29 | -47.70 | -64.59 | 373.5 | 123.3 | 957.2 |
| **Gujarat** | 95.59 | 14.86 | 124.67 | 1.29 | 1.28 | 2.59 | 322.0 | 210.1 | 1208.7 |
| **Haryana** | 11.64 | 4.47 | 16.62 | -6.71 | -7.19 | -13.42 | 297.9 | 180.9 | 1017.8 |
| **Jharkhand** | 184.62 | 23.42 | 251.28 | -21.71 | -27.74 | -43.43 | 262.9 | 143.8 | 784.8 |
| **Karnataka** | 55.12 | 10.06 | 70.73 | -6.54 | -7.00 | -13.09 | 263.9 | 292.3 | 1327.7 |
| **Kerala** | 7.55 | 16.96 | 25.79 | -15.00 | -17.65 | -30.00 | 238.5 | 208.2 | 943.2 |
| **Madhya Pradesh** | 40.17 | 45.07 | 103.35 | -0.12 | -0.12 | -0.24 | 203.6 | 252.3 | 969.6 |
| **Maharashtra** | 27.15 | 22.92 | 56.29 | -0.75 | -0.76 | -1.50 | 278.9 | 156.7 | 872.7 |
| **Odisha** | 55.85 | -1.02 | 54.26 | -2.03 | -2.07 | -4.06 | 322.5 | 172.1 | 1049.6 |
| **Punjab** | 4.59 | 0.51 | 5.12 | -7.62 | -8.25 | -15.25 | 184.1 | 137.4 | 574.6 |
| **Rajasthan** | 75.92 | 29.46 | 127.75 | -13.17 | -15.17 | -26.34 | 268.7 | 195.2 | 988.2 |
| **Tamil Nadu** | 66.48 | -3.44 | 60.74 | -2.60 | -2.67 | -5.20 | 292.9 | 198.0 | 1071.0 |
| **Uttar Pradesh** | 18.91 | 6.04 | 26.09 | 2.29 | 2.24 | 4.59 | 215.4 | 183.3 | 793.5 |
| **Uttarakhand** | 114.10 | 7.82 | 130.84 | 6.27 | 5.90 | 12.54 | 454.5 | 184.9 | 1479.8 |
| **West Bengal** | 13.95 | 12.93 | 28.68 | -13.91 | -16.16 | -27.83 | 193.3 | 155.8 | 650.3 |

Based on author's own calculation



From Table 2, it is evident that there are significant disparities among states in terms of irrigation coverage, rural employment rates, and GSDP over the two decades analyzed.

*Area Under Irrigation (AUI):*

Goa emerged as the top performer in irrigation coverage, achieving an impressive 99.15% during the 2000–2010 period. Although it experienced a slight decline of 3.83% in the subsequent decade, it still maintained the highest overall percentage. In contrast, Haryana was the poorest performer, starting with an irrigation coverage of 11.64% in 2000–2010 and only showing a marginal increase of 4.47% in 2010–2020, indicating minimal progress. Madhya Pradesh showed moderate improvement, with its AUI increasing from 40.17% in the first decade to 45.07% in the second, reflecting a positive trend in expanding irrigation facilities.

*Rural Employment Rate (RER):*

In the category of rural employment rates, Bihar stood out as the best performer despite recording negative growth, with RER improving from -15.10% in 2000–2010 to -18.63% in 2010–2020, showcasing efforts to address rural employment challenges. Haryana, however, ranked the lowest, with a steady decline in RER from -24.11% in the first decade to -19.21% in the second, highlighting worsening employment conditions in rural areas. Madhya Pradesh demonstrated moderate progress, with RER rising from 7.74% to 21.69% over the two decades, indicating an increase in job opportunities for rural communities.

*Gross State Domestic Product (GSDP):*

Gujarat led in economic performance, with its GSDP growing significantly from ₹322.0 million during 2000–2010 to ₹210.1 million in 2010–2020, reflecting robust economic growth. Haryana again performed the worst, with its GSDP declining sharply from ₹297.9 million in the first decade to ₹180.9 million in the second, indicating an economic downturn. Uttarakhand showed moderate growth, with its GSDP increasing from ₹454.5 million to ₹184.9 million over the two decades, demonstrating economic progress, albeit at a slower pace compared to Gujarat.

To enable a clearer comparison across variables, the decadal growth rates for AUI, RER, and GSDP have been normalized.

**Table 3.** Normalized decadal growth rates of agricultural sustainability metrics across states (2000-2020)

| | Area under irrigation (%) | | | Rural Employment Rate( %) | | | GSDP (₹ millions) | | |
|---|---|---|---|---|---|---|---|---|---|
| **State** | **2000-10** | **2010-20** | **2000-20** | **2000-10** | **2010-20** | **2000-20** | **2000-10** | **2010-20** | **2000-20** |
| **Andhra Pradesh** | 31.05 | 25.21 | 28.03 | 50.51 | 61.56 | 50.51 | 32.69 | 0.00 | 0.00 |
| **Bihar** | 7.35 | 52.90 | 15.71 | 47.13 | 58.32 | 47.13 | 25.96 | 54.01 | 42.30 |
| **Chhattisgarh** | 26.65 | 76.76 | 40.17 | 79.83 | 86.14 | 79.83 | 44.44 | 55.63 | 58.24 |
| **Goa** | 52.52 | 0.00 | 35.10 | 0.00 | 0.00 | 0.00 | 70.05 | 27.68 | 47.16 |
| **Gujarat** | 50.55 | 38.23 | 48.56 | 87.10 | 91.38 | 87.10 | 51.01 | 64.82 | 72.58 |
| **Haryana** | 3.92 | 16.97 | 4.67 | 66.35 | 75.58 | 66.35 | 42.07 | 52.35 | 53.28 |
| **Jharkhand** | 100.00 | 55.73 | 100.00 | 27.44 | 37.24 | 27.44 | 29.15 | 36.46 | 29.73 |
| **Karnataka** | 28.07 | 28.41 | 26.65 | 66.78 | 75.93 | 66.78 | 29.52 | 100.00 | 84.62 |
| **Kerala** | 1.64 | 42.51 | 8.39 | 44.85 | 56.07 | 44.85 | 20.11 | 64.02 | 45.75 |
| **Madhya Pradesh** | 19.76 | 100.00 | 39.90 | 83.43 | 88.77 | 83.43 | 7.22 | 82.87 | 48.42 |
| **Maharashtra** | 12.53 | 54.69 | 20.79 | 81.80 | 87.58 | 81.80 | 35.05 | 41.99 | 38.62 |
| **Odisha** | 28.47 | 5.74 | 19.96 | 78.48 | 85.13 | 78.48 | 51.17 | 48.57 | 56.50 |
| **Punjab** | 0.00 | 8.87 | 0.00 | 63.98 | 73.60 | 63.98 | 0.00 | 33.72 | 8.47 |
| **Rajasthan** | 39.62 | 68.08 | 49.82 | 49.60 | 60.70 | 49.60 | 31.28 | 58.44 | 50.30 |
| **Tamil Nadu** | 34.38 | 0.79 | 22.60 | 77.00 | 84.01 | 77.00 | 40.24 | 59.66 | 58.66 |
| **Uttar Pradesh** | 7.95 | 20.19 | 8.52 | 89.69 | 93.18 | 89.69 | 11.58 | 53.35 | 30.61 |
| **Uttarakhand** | 60.83 | 23.82 | 51.07 | 100.00 | 100.00 | 100.00 | 100.00 | 54.06 | 100.00 |
| **West Bengal** | 5.20 | 34.27 | 9.57 | 47.66 | 58.84 | 47.66 | 3.40 | 41.59 | 16.13 |

Based on author's own calculation

The data analysis highlights clear distinctions among states based on their performance in three key indicators: area under irrigation, rural employment rate, and GSDP. High-performing states, such as Chhattisgarh and Gujarat, demonstrate significant improvements across all three metrics, reflecting successful agricultural practices and economic growth. States like Karnataka and Madhya Pradesh, which fall into the average-performing category, show mixed results, with notable progress in rural employment and GSDP but more modest gains in irrigation. On the other hand, some states, such as Punjab and Goa, exhibit stagnant or declining performance. For example, Punjab struggles with low irrigation coverage and GSDP, showing no significant change, which may indicate underlying economic issues. Additionally, states like Haryana, despite having a relatively high GSDP, show little improvement in irrigation, suggesting a need for targeted measures to enhance agricultural efficiency and increase rural employment opportunities. Overall, the data highlights the diverse performance across states, emphasizing the need for focused policy interventions to address areas of concern and foster sustainable growth.

*Regional Comparison:*

The study also includes a region-wise comparison to provide a broader understanding of agricultural sustainability in India. Bar charts were used to visualize performance trends in agricultural sustainability across the four regions—north, south, east, and west—over the past decades. Figure 1 shows that there is no consistent pattern of agricultural performance within any region, as each region includes a mix of top-performing, average-performing, and underperforming states. This variation illustrates that progress in sustainability is uneven, with no region uniformly achieving significant advancements in agricultural practices.

In the southern region, Karnataka and Kerala have shown progress in GSDP and irrigation, although rural employment has decreased, suggesting growth in sectors outside agriculture. In contrast, Tamil Nadu and Andhra Pradesh have seen declines in both irrigation and rural employment, signaling challenges in maintaining rural economic stability. The eastern region presents mixed results: Bihar and Odisha have experienced slight GSDP gains despite reductions in rural employment and irrigation, while Chhattisgarh has shown consistent growth in all areas. In the northern region, Uttar Pradesh has led with stable GSDP growth and steady rural employment, while Rajasthan and Uttarakhand have improved in GSDP but continue to face issues with rural employment and irrigation. Haryana and Punjab, with declines in both irrigation and rural employment, appear to be shifting away from agriculture toward other sectors. In the west, Gujarat and Maharashtra have seen strong GSDP growth, along with stable rural employment and irrigation, whereas Goa has experienced significant declines in all areas, indicating deep economic challenges.

**Table 4.** Evolution of sustainable practices over 2001, 2011 and 2021

| Sustainable practices | State(s) | 2001 | 2011 | 2021 |
|---|---|---|---|---|
| Organic farming | Sikkim, Kerala | -Very few organic farms (<1%) | -Sikkim declared 10% organic farms | -Sikkim became 100% organic state |
| | | -High dependency on chemical inputs | -Moderate adoption, some market access | -15-20% higher prices for organic produce |
| | | -Soil degradation, low biodiversity | -Improved soil health, low pesticide use | -Significant environmental benefits, enhanced soil health |
| Zero budget natural farming (ZBNF) | Andhra Pradesh, Karnataka | -Not widely known to the farmers-High input costs for fertilizers | -Pilot survey started with small farmers to study the impact of ZBNF | -Adopted by 6 million farmers in Andhra Pradesh |
| | | | -50% reduction in chemical inputs | -Reduced input costs by 60-70%, improving soil health |
| Agroforestry | Tamil Nadu | Limited adoption, few awareness programs | Growing interest in farm forestry | High adoption, contributing to carbon sequestration |
| | | Income solely from crops | Income diversification starting | 30-40% increase in farmer income due to wood, fruits |
| Drip irrigation | Maharashtra, Gujarat | 1-2% of farms using drip irrigation | 15-20% farms under drip irrigation | 40-50% of farms use micro-irrigation |
| | | High water wastage, flood irrigation | 20-30% water savings | 40-60% water savings, improved yields |
| Crop diversification | Haryana, Madhya Pradesh | Monoculture farming | Beginning of diversification | Pulses, millets widely cultivated |

As seen in Table 4, this period has seen significant shifts in agriculture policies and farming practices, including the increased focus on sustainability. The key sustainable agricultural practices in Indian states, as seen in previous discussion, include organic farming, zero budget natural farming, agroforestry, drip irrigation and micro irrigation, crop diversification etc., which have been extensively adopted in the states of Sikkim & Kerala, Andhra Pradesh & Karnataka, Tamil Nadu, Maharashtra & Gujarat, and Madhya Pradesh & Haryana, respectively.

## Conclusion

In summary, this study provides an in-depth analysis of agricultural sustainability across Indian states, examining economic, social, and environmental factors over three decades. The findings highlight significant regional variations, showing that while some states excel in specific areas, sustainability does not follow a consistent pattern across regions. Goa excels in irrigation, while Gujarat and Maharashtra show strong GSDP growth and stable employment, indicating successful economic diversification. Conversely, states like Haryana and Goa have experienced declines in several sustainability indicators, suggesting broader economic challenges. In the southern region, Karnataka and Kerala show promising economic growth despite declines in rural employment, reflecting a shift toward non-agricultural sectors. The eastern and northern regions present mixed results, with states like Bihar and Uttar Pradesh balancing modest GSDP growth against challenges in rural employment and irrigation. These findings underscore the importance of region-specific interventions to address unique challenges and promote sustainable agricultural development.

However, the study has limitations. It focuses on only three indicators, which may not fully capture the complexities of agricultural sustainability. The analysis includes only eighteen states, which may restrict the generalizability of the findings. Additionally, the use of decadal data may overlook short-term fluctuations or the impacts of annual policies.

Future research could expand the scope to include more states, particularly from Northeast India, with a bigger time frame and explore additional indicators such as soil health, crop diversification, and climate resilience. Incorporating more detailed, annual data and conduct panel data analysis which would provide a more dynamic understanding of state-level progress and help policymakers better address shifts in agricultural sustainability.

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