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Growth and Instability Analysis of Rice Production in India: A Zone Wise Study

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

The present study was undertaken both comprehensively and intensively to study the growth rate and instability of rice production in India. Rice yields are also affected by pests, diseases like rice blast and weeds. Sustainable practices like integrated pest management and rice-duck farming help to mitigate these issues. India is the second largest producer of rice in the world after China. It is a staple food for nearly half of the global population, especially in Asia and Africa. The study was carried out based on secondary data which was collected for the period from 1990-91 to 2021-22. Trend analysis, growth rates and instability indices were computed. Global data related to area, production, and productivity of different selected crops was collected from Food and Agriculture Organization (FAO) stat. Results showed that the growth rate of area of rice was lower in all zones

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except negative growth in Southern and Eastern zones. The production growth rate was low in all zones except medium growth in Northern zone. The growth rate of productivity was low in all zones. Area, production and productivity showed low instability in rice. Therefore, it is essential to promote drought-resistant and flood-resistant rice varieties through agricultural research to reduce instability in rice due to over-reliance on monsoon rains and regional concentration (Punjab, Haryana for rice) and climate shocks (droughts, floods). Expand irrigation coverage and modernize irrigation systems to reduce dependence on erratic rainfall and ensures stable production across seasons.

Keywords: Growth; instability; rice; production; rice-duck farming.

1. INTRODUCTION

The growth of agriculture depends on the monsoon and the production of farm products. The growth rate of agriculture production is generally judged by the performance of food grains and non-food grains production. The transformations in the sector are being induced by factors like the new concept of the organized sector, new and improved technologies, mechanized farming, rapid growth of contract farming, easy credit facilities, etc (Jain, 2018). Rice (*Oryza sativa* for Asian rice and *Oryza glaberrima* for African rice) is a staple food for nearly half of the global population, especially in Asia and Africa. Asian rice was cultivated in China from around 13,500 to 8,200 years ago, while African rice was cultivated approximately 3,000 years ago. In 2023, global rice production was 1378.25 lakh MT. Despite its large production, only 8 per cent is traded internationally. China, India and Indonesia are the largest consumers of rice. Substantial post-harvest losses occur in developing nations due to poor storage and transportation. For higher growth of agriculture, a quantitative assessment of the contribution of different factors to agricultural output growth is important for reorienting the programmes and prioritizing agricultural development. Various factors affect the growth of agricultural output. Major of these factors is area and yield. These major sources of output growth have significance in finalizing programmes of agricultural development and priorities of investment in it (Jambhulkar et al., 2024). Rice yields are also affected by pests, diseases like rice blast and weeds. Sustainable practices like integrated pest management and rice-duck farming help to mitigate these issues (Xi et al., 2009). Rice grains are milled to produce different varieties (brown rice, white rice and parboiled rice), depending on how much of the outer layer of grain is removed (Abdullah et al., 2015). Rice is gluten-free, and provides protein, but it lacks all essential amino acids. Starch composition (amylose and amylopectin) determines the texture of rice. Rice is categorized into three types by grain length: Long-grain (Indica): It stays intact and fluffy when cooked (includes basmati and jasmine varieties); Medium-grain (Japonica or Indica): It is sticky and moist (varieties include Calrose, Carnaroli and black rice (also known as forbidden rice)); and Short-grain (Japonica): It is sticky and ideal for sushi, mochi, risotto and paella (Al Mamun et al., 2021).

A genetically modified variety of rice enriched with Vitamin A is Golden rice. In 2022, rice cultivation contributed to over 1 per cent of global greenhouse gas emissions. Rice yields face risks from climate change, varying by geography and socio-economic conditions. Beyond agricultural significance, it plays important cultural and religious roles, symbolizing prosperity and fertility in many traditions, including weddings. The present study was undertaken both comprehensively and intensively to study the growth rate and instability of rice production in India with following objectives.

1. To determine the trend and growth rate in area, production and productivity of rice
2. To measure the extent of instability in area, production and productivity of rice excessive detail on rice types (e.g., long/medium/short grain) and cultural aspects

2. MATERIALS AND METHODS

The present study is confined to six zones in India which are considered administrative zones of India by the Ministry of Home Affairs, Government of India. Six zones include Northern (Haryana, Himachal Pradesh, Jammu & Kashmir, Punjab, Rajasthan, Delhi, Chandigarh and Ladakh), Central (Chhattisgarh, Uttarakhand, Uttar Pradesh, and Madhya Pradesh), Eastern (Bihar, Jharkhand, Odisha, and West Bengal), Western (Goa, Gujarat, Maharashtra, and Union Territories of Daman & Diu and Dadra & Nagar

Haveli), Southern (Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Telangana, and the Union Territory of Puducherry) and North Eastern (Assam, Arunachal Pradesh, Manipur, Tripura, Mizoram, Meghalaya, Nagaland, and Sikkim). The study utilized time-series data for area, production and productivity of rice in India for a period of 32 years (1990-91 to 2021-22). Time-series data of area, production and productivity of rice was collected from various issues of Statistical Abstracts of India published by Central Statistical Organisation, Ministry of Statistics & Programme Implementation, GOI, New Delhi, Statistical Abstracts of different states from different websites of states, Agriculture statistics at a Glance published by Department of Economics & Statistics, Ministry of Agriculture & Farmers Welfare, GOI, New Delhi and Handbook of Statistics on Indian Economy published by Reserve Bank of India, Mumbai. Global data related to area, production, and productivity of different selected crops was collected from Food and Agriculture Organization (FAO) stat.

For studying growth, variability and the effect of various components on production, the overall study period (1990-91 to 2021-22) was divided into three decadal periods i.e., period-I (1990-91 to 1999-2000), period-II (2000-01 to 2009-10) and period-III (2010-11 to 2021-22).,

3. ANALYTICAL TOOLS/TECHNIQUES

3.1 Trend Analysis

Linear function: This function assumes a linear relationship between X and Y. The goal of linear trend analysis is to determine how well the data fits this linear model and to make predictions based on this relationship. The mathematical equation for a linear trend line (also known as regression line) is given by

$$Y_t = a + bX_t + \varepsilon_t$$

Where,

'Y_t' is the dependent variable (area or production or productivity),
'X_t' is the independent variable (time in years),
'a' is the intercept,
'b' is the regression coefficient,
'ε_t' is the error term.

The values of 'a' and 'b' were estimated by applying the ordinary least squares (OLS) approach.

Quadratic function: This function shows curved relationship between Y and X, rather than the straight-line relationship assumed in linear trend analysis. Quadratic data function is useful where there is peak or trough in the data of past periods i.e., when there is a non-linear trend in the data that can be approximated by a quadratic function. Quadratic fit (or quadratic regression) can be expressed by the following mathematical equation

$$Y_t = a + bX_t + cX_t^2 + \varepsilon_t$$

Where,

'Y_t' is the dependent variable (area or production or productivity),
'X_t' is the independent variable (time in years),
'a' is the intercept,
'b' and 'c' are regression coefficients of X,
'ε_t' is the error term

The values of 'a', 'b' and 'c' were estimated by applying the ordinary least squares (OLS) approach.

Logarithmic function: This equation reflects a logarithmic relationship between X and Y. It is commonly used when the rate of change in Y varies logarithmically with X i.e., Y changes by a certain proportion each time X increases by a constant ratio. The equation for a logarithmic trend line (or logarithmic regression) is

$$Y_t = a + b \ln(X_t) + \varepsilon_t$$

Where,

'Y_t' is the dependent variable (area or production or productivity),
'X_t' is the independent variable (time in years),
'a' is the intercept,
'b' is the regression coefficient,
'ε_t' is the error term

The values of 'a' and 'b' were estimated by the method of ordinary least squares (OLS)

Exponential function: This function signifies an exponential relationship between X and Y. It is used when the growth or decay of Y is proportional to its current value, leading to rapid changes over time or across values of X. The equation for an exponential trend line (or exponential regression) is typically represented as

$$Y_t = a \cdot e^{bX_t} + \varepsilon_t$$

Where,

'Y_t' is the dependent variable (area or production or productivity),
'X_t' is the independent variable (time in years),
'a' is the coefficient (also known as the initial value or constant multiplier),
'b' is the exponent (also known as the growth rate or decay rate),
'e' is the base of the natural logarithm, approximately equal to 2.71828.

The values of 'a' and 'b' were estimated by applying the ordinary least squares (OLS) approach.

Selection of the suitable function was done by using values of adjusted R-square.

3.2 Linear Growth Rate

Linear growth rate refers to a steady increase by the same amount over equal time intervals. In a linear growth model, the quantity increases or decreases by a constant value in each time step, resulting in a straight line when graphed. The defining characteristic of linear growth is that the change in the quantity per unit of time is constant, which is different from exponential growth where the growth rate is proportional to the current value.

The formula for linear growth is often written as:

$$y = ax + b$$

Where:

y is the quantity at a given time,
a is the constant growth rate (the slope of the line),
x is the time or independent variable, and
b is the initial value.

3.3 Compound Growth Rate

Compound growth rate was estimated to know the growth pattern of area, production, productivity of rice crop for the period 1990-91 to 2021-22 was calculated for India in six zones for the study period as mentioned earlier by fitting an exponential function of the form. The functional form is;

$$Y_t = A\, e^{bt} \quad \ldots\ldots (1)$$

Where,

Y_t = area, production and productivity of crop in the year t
a = intercept
b = regression coefficient
t = time variable

The equation (1) was transformed into log-linear and written as

$$\log_e Y_t = \log_e A + bt \quad \ldots\ldots (2)$$

Equation (2) was estimated by using Ordinary Least Square (OLS) technique.

The compound growth rate (r) was then estimated by using the equation (3)

$$r = (\text{antilog } b - 1)\ 100 \quad \ldots\ldots (3)$$

Where,

r = Estimated compound growth rate per annum in percentage.
b = regression coefficient value

3.4 Coefficient of Variation (CV)

To examine the stability, mean, standard deviation and CV was worked out. Standard deviation (σ) is a positive square root of the arithmetic mean of the square of the deviations of the given observation from their arithmetic mean. Standard deviation is an absolute measure of dispersion, given by the formula.

$$\sigma = \sqrt{\frac{1}{n}\sum (X - \bar{X})^2}$$

Where,

$\bar{X} = \frac{1}{n}\sum X$ = mean of sample observation,
n = number of observations.

For comparing the variability of two distributions, compute the coefficient of variation for each distribution. CV is percentage variation in mean, standard deviation considered as total variation in the mean.

$$CV = \frac{\sigma}{\bar{X}} \times 100$$

Where,

σ = standard deviation,
$\bar{X}$ = mean.

A distribution with a smaller CV is said to be more homogenous or uniform or less variable or more stable than the other and the series with greater CV is said to be heterogenous or more variable or less stable than the other.

3.5 Cuddy and Della Valle Index (CDVI)

It was proposed by John D. Cuddy and Peter A. Della Valle in 1978. The coefficient of variation is generally used as a measure of instability. But time series data often contain a trend component. In order to take care of the trend component and for meaningful measurement of instability, CV is modified and proposed by Cuddy and Della as the Cuddy and Della Valle Instability Index.

Instability is measured in relative terms by this index, which is commonly used as a measure of instability in time series data (Singh & Byerelee, 1990) since the simple coefficient of variation overestimates the level of instability in time series data characterized by long-term trends, the Cuddy-Della valle index corrects the coefficient of variation as follows:

$$CDVI = (CV^*) (1 - R^2)^{1/2}$$

$$CDVI = CV^* \sqrt{1 - R^2}$$

Where,

CDVI is the Cuddy-Della Valle index of instability
CV* is coefficient of variation without trend-adjusted data; and
R^2 is coefficient of multiple determination from a time trend regression adjusted by the number of degrees of freedom.
A linear trend was fitted to a time series data on area, production and productivity and wherever the trend was significant, the coefficient of variation (CV) for unadjusted data were multiplied by the square root of the unexplained portion of variation ($\sqrt{1 - R^2}$) in the trend.

The present study divided the CDVI value into three categories, which represent the different range of instability.

The ranges of CDVI as defined by Sihmar, 2014 is as under:

- Low instability = between 0 to 15
- Median instability = greater than 15 and lower than 30
- High instability = greater than 30

3.6 Coppock's Instability Index (CII)

It was proposed by J.B. (Joseph Bryan) Coppock in 1962. Coppock's Instability Index is a close approximation of a average year to year percentage variation adjusted for trend. In algebraic form:

$$CII = \left(\text{Antilog}\left(\sqrt{\text{Log V}}\right) - 1\right) \text{ x } 100$$

$$\text{Log V} = \frac{\sum\left(\frac{\log X_{t+1}}{X_t} - M\right)}{N}$$

$$M = (\log X_{t+1} - \log X_t) / N - 1$$

Where,

Log V = Logarithmic variance of the series (area/production/productivity),
N = Number of years minus one (n-1),
M = Arithmetic mean of difference between the logs of X_t and X_{t+1}, X_{t+1} and X_{t+2} etc.,
X_t = area/production/productivity in year 't'.

3.7 Ray Instability Index (RII)

The "Ray (1983) Instability Index" is used in analysis to quantify the instability or volatility of a time-series data related to area/production/productivity. It's based on the standard deviation of the natural logarithm of the ratio of successive agriculture values or returns over a certain period.

The Ray approach was employed in the current study to examine instability because it provides a fairly simple measurement of instability via standard deviation in annual growth rates. Instability index is calculated using the following formula:

$$RII = \text{Standard deviation}\left[\ln\left(\frac{Y_{t+1}}{Y_t}\right)\right] \text{ x } 100$$

Where,

Y_t denote the agriculture value at time t (current year), and
Y_{t+1} denote the agriculture value at time t+1 (next year).

This index helps in quantifying the volatility or instability of a time series. Higher values indicate greater instability or volatility, while lower values indicate more stable or predictable behaviour.

4. RESULTS AND DISCUSSION

4.1 Trend and Growth in Area, Production and Productivity of Rice in India

A second-degree polynomial trend line was fitted to the time-series data on area, production and

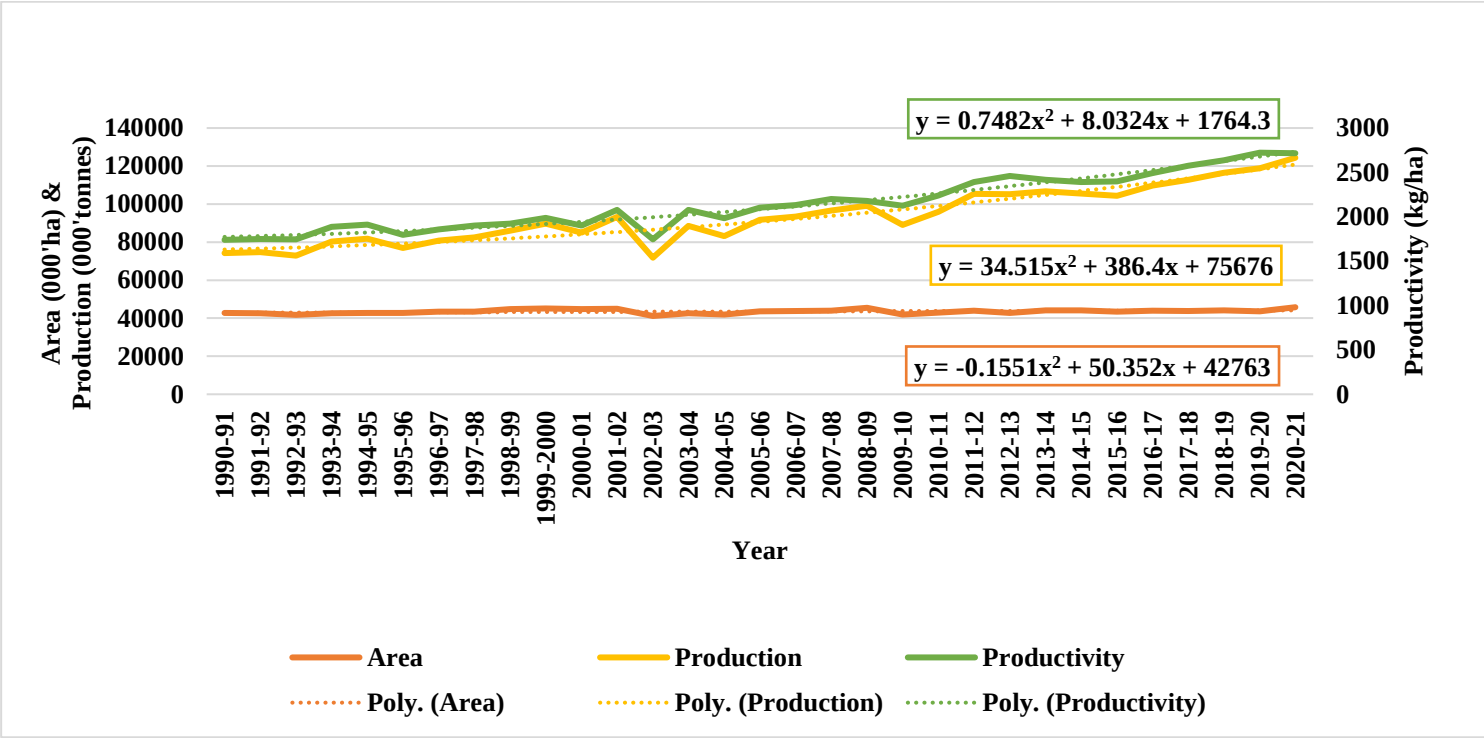

Fig. 1. Trend analysis of area, production and productivity of rice in India

Table 1. R-square of area, production and productivity of rice

Aspects	Area	Production	Productivity
Linear	0.14	0.87	0.91
Quadratic	0.14	0.90	0.94
Logarithmic	0.15	0.66	0.68
Exponential	0.14	0.87	0.92

productivity of rice from 1990 to 2021 as shown in Fig. 1. A quadratic trend line was selected by comparing R-square values of all functions (Table 1). The negative coefficient of the quadratic term indicated a concave (downward-opening) curve, suggesting that area under cultivation initially exhibited a slow but steady increase, followed by stabilization or marginal decline in later years. It implied that the expansion of cultivated area might be approaching towards saturation. The positive quadratic term indicated a convex (upward-opening) curve, reflecting a pattern of accelerating growth in production over time. The polynomial's positive curvature indicated accelerated productivity improvement over time. Although the rate of increase in productivity was moderate compared to production, the consistent upward trend led to an enhancement in efficiency and input use.

The linear and compound growth rates in area, production and productivity of rice are presented in Table 2. In Northern zone, area of rice constituted 10.55 per cent of total area under rice cultivation in India. Haryana and Punjab stand-out as major rice-producing states in Northern zone with a high share of area (2.90% and 6.40%) and production (3.56% and 10.28%) in India's total area (46.28 m ha) and production (129.47 m tonnes). The productivity of Haryana (3330 kg/ha) and Punjab (4193 kg/ha) was higher than the productivity of India (2798 kg/ha). Rice area of Northern zone, showed high growth in period-I (3.12% LGR) and (3.11% CGR). However, this growth declined in period-II to around 1.13 per cent (LGR) and 1.12 per cent (CGR) and remained stable in period-III at approximately 1.09 per cent (LGR) and 1.10 per cent (CGR). In the overall period, the area experienced a growth rate of 1.43 per cent (LGR) and 1.47 per cent (CGR). Rice production showed consistent growth throughout all periods, with period-I showing LGR of 2.72 per cent and CGR of 2.73 per cent. Period-II showed an increased growth rate (2.98% LGR, 3.04% CGR), while Period-III had a slight decline (2.10% LGR, 2.14% CGR) in the growth rate. During the overall period, production growth remained positive at 2.36 per cent (LGR) and 2.46 per cent (CGR). In terms of productivity, the region showed a decline in growth rate in period-I (-0.35% LGR, -0.36% CGR), but there was a substantial recovery in period-II (1.85% LGR, 1.90% CGR). The growth rate in period-III was at a slower pace, with a 1.01 per cent LGR and a 1.02 per cent CGR. In the overall period, productivity increased by 0.96 per cent (LGR) and 0.98 per cent (CGR). However, area, production and productivity in this zone showed a significant growth rate.

In Southern zone, area under rice constituted 20.03 per cent of total area under rice in India. Telangana and Andhra Pradesh were major rice-producing states in Southern zone with high share of area (6.96% and 5.08%) and production (8.22% and 6.34%) in India's total area (46.28 m ha) and production (129.47 m tonnes). The productivity of Telangana (3406 kg/ha) and Andhra Pradesh (3730 kg/ha) was higher than the productivity of India (2798 kg/ha). The southern zone showed a growth rate of 0.52 per cent (LGR) and 0.51 per cent (CGR) in the area in period-I (Table 2). This improved slightly in period-II (0.63% LGR, 0.76% CGR) but declined again in period-III (0.46% LGR, 0.40% CGR). In the overall period, the area under rice cultivation showed a negative trend with LGR and CGR at -0.16 and -0.17 per cent, respectively. Production growth in period-I was 1.45 per cent (LGR) and 1.29 per cent (CGR) and increased slightly in period-II (1.37% LGR, 1.69% CGR), and improved further in period-III (2.07% LGR, 1.93% CGR). However, the overall period showed a lower growth rate (0.91% LGR, 0.88% CGR). Productivity exhibited an increasing trend, with period-I showing 0.89 per cent (LGR) and 0.78 per cent (CGR) growth rate, and there was steady increase in period-II (0.88% LGR, 0.92% CGR), and period-III (1.55% LGR, 1.53% CGR). In the overall period, productivity almost remained stable with LGR and CGR of 1.05 per cent. Growth of area was non-significant, but growth of production and productivity was significant in this zone.

In Central zone, the share of rice area was 25.87 per cent of total area under rice in India. Uttar Pradesh and Chhattisgarh were major rice producing states in Central zone with high share of area (12.41% and 8.28%) and production (12.48% and 5.76%) in India's total area (46.28 m ha) and production (129.47 m tonnes). The productivity of Uttar Pradesh (2737 kg/ha) and Chhattisgarh (2602 kg/ha) was lower than productivity of India (2798 kg/ha). In Central zone, the area under rice cultivation showed high growth in period-I (3.94% LGR, 3.94% CGR), but the trend reversed in period-II, with negative growth rates (-0.53% for both LGR and CGR) (Table 2). There was a slight recovery in period-III (0.28% LGR, 0.29% CGR), but the overall period exhibited a minimal growth of 0.11 per

Table 2. Growth rates of area, production and productivity of rice in India: 1990-2021 (percent)

Aspect	Period	Northern Zone		Southern zone		Central zone		Eastern zone		Western zone		North Eastern zone		All India	
		LGR	CGR	LGR	CGR	LGR	CGR	LGR	CGR	LGR	CGR	LGR	CGR	LGR	CGR
Area	**Period-I**	3.12	3.11***	0.52	0.51	3.94	3.94***	0.28	0.28	0.07	0.07	0.12	0.12	0.68	0.68***
	Period-II	1.13	1.12***	0.63	0.76	-0.53	-0.53	-0.26	-0.27	0.77	0.78*	-0.58	-0.58	-0.02	-0.02
	Period-III	1.09	1.10***	0.46	0.40	0.28	0.29	0.25	0.27	0.34	0.33	-0.35	-0.36	0.34	0.34**
	Overall Period	1.43	1.47***	-0.16	-0.17	0.11	0.13	-0.39	-0.39***	0.44	0.43***	0.05	0.05	0.10	0.10**
Production	**Period-I**	2.72	2.73***	1.45	1.29	11.12	11.43***	1.70	1.69*	2.03	2.09***	1.17	1.15**	1.99	2.00***
	Period-II	2.98	3.04***	1.37	1.69	0.94	1.11	1.36	1.41	3.06	3.57	0.20	0.13	1.53	1.59
	Period-III	2.10	2.14***	2.07	1.93*	2.40	2.43***	2.06	2.24***	1.62	1.62***	0.85	0.85**	2.04	2.05***
	Overall Period	2.36	2.46***	0.91	0.88***	1.03	1.23**	1.48	1.50***	1.77	1.77***	1.94	1.93***	1.60	1.59***
Productivity	**Period-I**	-0.35	-0.36	0.89	0.78	7.14	7.20***	1.41	1.41	2.30	2.09*	1.03	1.03***	1.30	1.32***
	Period-II	1.85	1.90***	0.88	0.92	1.50	1.66	1.62	1.68**	2.39	2.77	0.75	0.71	1.56	1.61**
	Period-III	1.01	1.02***	1.55	1.53**	2.16	2.13***	1.88	1.96***	1.28	1.28**	1.20	1.21***	1.70	1.71***
	Overall Period	0.96	0.98***	1.05	1.05***	1.03	1.09***	1.88	1.90***	0.72	0.72***	1.88	1.88***	1.49	1.49***

Note 1: Period-I: (1990-91 to 1999-00); Period-II: (2000-01 to 2009-10); Period-III: (2010-11 to 2021-22)
Note 2: LGR = Linear Growth Rate, CGR = Compound Growth Rate
*Note 3: ***, ** and * are significant at 1%, 5% and 10%, respectively*

cent (LGR) and 0.13 per cent (CGR). Production was significantly high in period-I, with 11.12 per cent (LGR) and 11.43 per cent (CGR), but decreased sharply in period-II (0.94% LGR, 1.11% CGR). Period-III showed 2.40 per cent LGR and 2.43 per cent CGR. The overall period recorded growth rate of 1.03 per cent (LGR) and 1.23 per cent (CGR). The growth rate of productivity was exceptionally high in period-I (7.14% LGR, 7.20% CGR), declined in period-II (1.50% LGR, 1.66% CGR), and stabilized in period-III (2.16% LGR, 2.13% CGR). The overall period showed a productivity growth rate of 1.03 per cent (LGR) and 1.09 per cent (CGR). However, area, production and productivity in this zone showed a significant growth rate.

In Eastern zone, rice area share was 30.71 per cent of total area under rice in India. West Bengal and Odisha were vital rice-producing states in Easten zone with high share of area (12.20% and 8.82%) and production (13.29% and 7.08%) in India's total area (46.28 m ha) and production (129.47 m tonnes). The productivity of West Bengal (3057 kg/ha) was higher than India (2798 kg/ha) but Odisha's (2030 kg/ha) productivity was low compared to India. Eastern zone experienced minimal growth rate in area in period I, with LGR and CGR of 0.28 per cent. The growth rate was declined in period-II (-0.26% LGR, -0.27% CGR) but recovered slightly in period-III (0.25% LGR, 0.27% CGR). In the overall period, area growth remained negative at -0.39 per cent for both LGR and CGR. The growth rate of production in period-I was recorded at 1.70 per cent LGR, 1.69 per cent CGR, but a slight decrease was observed in period-II (1.36% LGR, 1.41% CGR). Period-III recorded stable growth rate (2.06% LGR, 2.24% CGR) and the overall period exhibited a growth rate of 1.48 per cent (LGR) and 1.50 per cent (CGR). The growth rate of productivity was relatively strong across all periods, with period-I at 1.41 per cent (LGR and CGR), increased in period-II (1.62% LGR, 1.68% CGR), and further increased in period-III (1.88% LGR, 1.96% CGR). The growth of productivity in overall period remained stable at 1.88 per cent (LGR) and 1.90 per cent (CGR). However, area, production and productivity in this zone showed significant growth rate (Table 2).

In Western zone, the share of rice area was 5.50 per cent of total area under rice in India. Maharashtra and Gujarat were major rice producing states in Western zone with high share of area (3.41% and 1.98%) and production (2.65% and 1.73%) in India's total area (46.28 m ha) and production (129.47 m tonnes). The productivity of Maharashtra (2110 kg/ha) and Gujarat (2370 kg/ha) was higher than the productivity of India (2798 kg/ha). Western zone recorded very low growth rate in area in period-I (0.07% LGR and CGR), which improved in period-II (0.77% LGR, 0.78% CGR) but decreased in period-III (0.34% LGR, 0.33% CGR). The growth rate of area in overall period remained at 0.44 per cent (LGR) and 0.43 per cent (CGR). Production showed growth rate of 2.03 per cent (LGR) and 2.09 per cent (CGR) in Period-I, followed by a significant rise in period-II (3.06% LGR, 3.57% CGR). In period-III, the growth rate was stabilized at 1.62 per cent for both LGR and CGR. The overall period showed a consistent growth rate in production with 1.77 per cent (LGR and CGR) (Table 2). Growth rate of productivity was highest in period-II (2.39% LGR, 2.77% CGR), but decreased in Period-III (1.28 per cent for both LGR and CGR). The growth rate of productivity remained at 0.72 per cent (both LGR and CGR) in the overall period. However, area, production and productivity in this zone showed significant growth rate.

In North Eastern zone, rice area constituted 7.33 per cent of total area under rice in India. Assam was highest rice producing state in this zone with high share of area (5.16%) and production (4.19) in India's total area (46.28 m ha) and production (129.47 m tonnes). The productivity of Assam (2210 kg/ha) low compared to productivity of India (2798 kg/ha). North Eastern zone showed positive growth rate in area in period-I (0.12% LGR and CGR) but turned negative in period-II (-0.58% LGR and CGR) (Table 2). A slight decline of growth rate was observed in period-III (-0.35% LGR, -0.36% CGR), with growth rate in overall period close to zero (0.05% LGR and CGR). Growth rate of production in period-I was 1.17 per cent (LGR) and 1.15 per cent (CGR), slightly decreased in period-II (0.20% LGR, 0.13% CGR), and remained stable in period-III (0.85% for both LGR and CGR). The overall period showed slight improvement with 1.94 per cent (LGR) and 1.93 per cent (CGR). Productivity remained steady in all periods, with period-I at 1.03 per cent (LGR and CGR), period-II at 0.75 per cent LGR and 0.71 per cent CGR, and period-III at 1.20 per cent LGR and 1.21 per cent CGR. The growth rate of productivity was stable at 1.88 per cent (LGR and CGR). Growth of area was non-significant, but growth of production and productivity was significant in this zone.

For All India, growth rate of area was positive in period-I (0.68% LGR and CGR), but negative in period-II (-0.02% LGR and CGR), and recovered in period-III (0.34% LGR and CGR) (Table 2). In the overall period, growth rate of area was minimal at 0.10 per cent (LGR and CGR). Production showed consistent positive growth rate across all periods, with 1.99 per cent (LGR) and 2 per cent (CGR) in period-I, followed by 1.53 per cent (LGR) and 1.59 per cent (CGR) in period-II, and 2.04 per cent (LGR) and 2.05 per cent (CGR) in period-III. The overall period exhibited steady growth rate of 1.60 per cent (LGR) and 1.59 per cent (CGR). Growth rate of productivity in overall period was also stable with 1.49 per cent (LGR and CGR), indicating continuous improvement in rice productivity across India. However, area, production and productivity in country showed significant growth rate.

The growth pattern of rice cultivation in India demonstrated considerable regional variation, particularly in the area, production and productivity aspects. The area under rice cultivation showed a low growth rate in Northern, Central, Western, North-Eastern zones and at All India level. This reflects a general stagnation or marginal increase in land devoted to rice, possibly due to urbanization, soil degradation or crop diversification. More notably, the Southern and Eastern zones experienced negative growth, indicating a decline in rice-growing area, which could be attributed to water scarcity, shifts to more profitable or less water-intensive crops, or loss of agricultural land to non-farm uses (Savadatti, 2018). In terms of production, the growth was moderate in most zones. Southern, Central, Eastern, Western and North-Eastern zones recorded relatively low growth, with All India production growth at 1.59 percent. Only Northern zone showed a moderate production growth rate, likely due to better irrigation infrastructure, adoption of high-yielding varieties, and effective government support. These modest gains in production across most zones indicate reliance on yield increases rather than area expansion (Laitonjam *et al.,* 2018).

Productivity growth remained low in all zones, with All India recording a growth rate of just 1.49 percent. This reflects a plateau in efficiency gains, possibly due to overuse of inputs, declining soil fertility, or climate-related challenges. Although yield growth has sustained national production to some extent, the slowing pace raises concerns about long-term sustainability (Dey *et al.,* 2020). Overall, rice area, production and productivity in India followed a quadratic increasing trend. Initially, during the Green Revolution and subsequent decades, rice cultivation expanded rapidly in area and yield due to policy support and improved technology. However, this growth has tapered in recent years, with declining or stagnant area and only modest productivity improvements (Savadatti, 2018).

4.2 Instability in Area, Production and Productivity of Rice in India

The instability in area, production and productivity of rice is present in Table 3.

Northern Zone: In terms of CV, Northern zone exhibited considerable instability in production of rice in overall period with 21.79 per cent, which was much higher compared to the period-I (9.51%), period-II (9.49%), and period-III (7.66%) (Table 3). Productivity was relatively stable across all periods i.e., period-I (4.40%), period-II (6.33%) and period-III (4.43%). The highest instability in productivity (9.82%) was observed in overall period, which reflected some long-term fluctuations. Area showed moderate instability in overall period with 13.44 per cent compared to significantly lower values in period-I (10.13%), period-II (4.55%) and period-III (4.32%). The trend in CV suggested that production instability dominates in the long term compared to area and productivity which remained relatively stable. Concerning CDVI, which adjusts for trends, the production instability for overall period (3.78%) was only slightly higher than period-I (5.07%), period-II (3.12%) and period-III (3.37%). Productivity showed modest instability in period-I (4.53%), period-II (3.11%) and period-III (3.03%) with overall period reaching 4.49 per cent. For the area, CDVI values decreased progressively from period-I (3.91%) to period-III (2.47%), which indicated a stabilization of area usage over time. CDVI confirmed the relative stability of productivity and area while capturing the higher variability in production.

CII provides another perspective, focusing on long-term instability by incorporating growth rates and deviations. In Northern zone, CII values of rice remained high and consistent across all periods for all aspects. Production instability showed a notable peak in overall period (46.09%) (Table 3). In contrast, period-I (40.45%), period-II (40.51%) and period-III (39.73%) displayed slightly lower production

Table 3. Instability in area, production and productivity of rice in India: 1990 – 2022 (percent)

Zone	Aspects	Period - I			Period - II			Period - III			Overall period		
		A	P	Y	A	P	Y	A	P	Y	A	P	Y
Northern	**CV**	10.13	9.51	4.40	4.55	9.49	6.33	4.32	7.66	4.43	13.44	21.79	9.82
	CDVI	3.91	5.07	4.53	3.19	3.12	3.11	2.47	3.37	3.03	3.62	3.78	4.49
	CII	40.60	40.45	38.48	38.49	40.51	39.23	38.41	39.73	38.45	42.25	46.09	40.65
	RII	0.04	0.074	0.07	0.036	0.04	0.03	0.02	0.05	0.04	0.03	0.053	0.05
Southern	**CV**	3.74	11.48	9.90	12.18	17.31	6.72	11.10	14.66	8.49	9.89	16.03	11.99
	CDVI	3.60	11.26	10.11	12.76	17.82	6.55	11.59	13.66	7.12	9.95	13.98	7.43
	CII	38.18	41.27	40.88	41.80	44.54	39.50	40.97	42.66	40.05	40.76	43.41	41.62
	RII	0.06	0.13	0.134	0.14	0.20	0.08	0.11	0.16	0.11	0.11	0.16	0.10
Central	**CV**	13.35	38.09	24.74	3.84	12.96	10.92	2.40	10.12	9.46	8.11	26.68	19.52
	CDVI	6.33	18.87	12.80	3.70	13.40	10.53	2.33	6.58	6.52	8.19	25.43	17.41
	CII	41.93	53.22	46.77	38.24	42.07	41.23	37.69	40.73	40.40	39.79	47.74	44.72
	RII	0.07	0.23	0.17	0.06	0.26	0.21	0.03	0.10	0.09	0.06	0.25	0.19
Eastern	**CV**	2.04	9.27	8.45	2.88	9.15	7.63	3.34	9.54	7.61	4.89	15.38	18.15
	CDVI	1.97	8.19	7.74	2.94	8.67	6.20	3.41	7.01	4.58	3.42	7.57	6.18
	CII	37.56	40.48	40.13	37.88	40.36	39.79	38.08	40.85	39.84	38.67	43.00	44.13
	RII	0.03	0.14	0.13	0.042	0.15	0.11	0.04	0.09	0.06	0.041	0.12	0.10
Western	**CV**	1.41	7.05	11.96	4.25	18.52	15.56	2.79	7.32	6.30	4.91	19.30	14.06
	CDVI	1.48	3.68	10.32	3.77	17.00	14.60	2.69	5.24	4.91	2.94	10.79	12.68
	CII	37.31	39.59	40.89	38.41	45.06	43.50	37.83	39.58	39.18	38.64	44.93	42.69
	RII	0.02	0.06	0.11	0.06	0.30	0.25	0.04	0.09	0.09	0.04	0.19	0.21
North Eastern	**CV**	1.55	4.94	4.05	3.68	7.64	5.14	2.49	4.28	5.50	2.89	19.16	18.06
	CDVI	1.60	3.65	2.74	3.43	8.07	4.89	2.32	3.39	3.98	2.90	7.72	5.95
	CII	37.36	38.60	38.30	38.19	39.76	38.70	37.73	38.39	38.88	37.89	44.42	43.91
	RII	0.02	0.05	0.04	0.04	0.08	0.05	0.03	0.05	0.06	0.03	0.06	0.05
All India level	**CV**	2.42	6.74	4.67	3.35	8.80	6.82	1.81	7.28	6.09	2.58	15.51	14.20
	CDVI	1.35	3.19	2.64	3.56	7.93	5.21	1.48	2.81	2.45	2.44	5.58	4.30
	CII	37.69	39.34	38.55	38.05	40.35	39.50	37.46	39.55	39.10	37.75	42.91	42.33
	RII	0.01	0.05	0.04	0.05	0.14	0.10	0.02	0.032	0.03	0.03	0.08	0.06

Note 1: Period-I: (1990-91 to 1999-00); Period-II: (2000-01 to 2009-10) and Period-III: (2010-11 to 2021-22)
Note 2: A = Area; P = Production and Y = Productivity
Note 3: CV = Coefficient of Variation; CDVI = Cuddy-Della Valle Index; CII = Coppock's Instability Index and RII = Ray Instability Index

instability levels. Productivity exhibited the least variation among the three aspects, with 38.48 per cent, 39.23 per cent and 38.45 per cent in period-I, period-II and period-III respectively and overall period shown instability of 40.65 per cent. While area showed a comparable range, with 42.25 per cent in overall period. This consistency in CII values underscored the persistent instability in production and area over time, despite some stabilization in productivity. Finally, RII was typically more sensitive to minor fluctuations, Across all periods and aspects, the values remained minimal, with production instability peaked at 0.053 per cent in overall period compared to production (0.05%) and area (0.03%). Instability in area decreased from period-I (0.04%) to period-II (0.036%) and further in period-III (0.02%). Production instability also decreased from period-I (0.074%) to period -II (0.04%) but increased slightly in period-III (0.05%). Similarly, RII of productivity also decreased from period-I (0.07%) to period-II (0.03%) but increased in period-III (0.04%). The low RII values suggested that dynamic fluctuations were not a significant concern in Northern zone, despite the higher values observed in CV and CII.

Southern Zone: With CV, which reflects the extent of variability relative to the mean, it was observed that there was moderate instability in area of rice during period-I (3.74%), increased to a peak in period-II (12.18%) before slightly declining in period-III (11.10%) (Table 3). Production exhibited the highest CV in period-II (17.31%), highlighting significant variability during that time, followed by period-III (14.66%) and period-I (6.72%). Productivity started with a relatively high value in period-I (9.90%), decreased in period-II (6.72%) and increased slightly in period-III (8.49%). Overall period showed moderate variability in area (9.89%) and productivity (11.99%), while production (16.03%) remained highly unstable, indicating greater fluctuations in output compared to input usage. CDVI provided a similar picture. Area instability increased from period-I (3.60%) to period-II (12.76%) but slightly decreased in period-III (11.59%). Production instability peaked in period-II (17.82%) with a significant rise in period-III (13.66%) and tapering off in Period-I (11.26%). Productivity showed a similar trend, started with high instability in period-I (10.11%), drop in period-II (6.55%), and rise slightly in period-III (7.12%). CDVI mirrored CV patterns in overall period, with production (13.98%) showing the highest long-term instability compared to area (9.95%) and productivity (7.43%).

CII, a more robust measure of instability, presented consistent and relatively high instability across all aspects. Area instability of rice increased slightly from period-I (38.18%) to period-II (41.80%) and stabilized in period-III (40.97%) (Table 3). Production showed slightly higher instability, peaked in period-II (44.54%) and reduced marginally in period-III (42.66%) and period-I (41.27%). Productivity displayed consistent instability across the periods, with a slight peak in period-I (40.88%). In overall period, production remained most unstable (43.41%) compared to area (40.76%) and productivity (41.62%), which reflected its susceptibility to external shocks. RII showed that area instability rose from 0.06 per cent in period-I to a peak of 0.14 per cent in period-II and fall slightly in period-III (0.11%). Production followed a similar trajectory, with its highest value in period-II (0.20%) followed by period-III (0.16%) and period-I (0.13%). Productivity instability was high in period-I (0.134%) followed by period-III (0.11%) and period-II (0.08%). Over the long term (overall period), RII was highest for production (0.16%) but lowest for area (0.11%) and productivity (0.10%). It indicated that production remained most dynamically unstable.

Central Zone: CV in Central zone showed a sharp decline over the periods. During period-I, production of rice exhibited an exceptionally high variation (38.09%), indicating significant variability in rice production. However, it reduced significantly in period-II (12.96%) and further to 10.12 per cent in period-III, showing improvements in production stability (Table 3). Productivity followed a similar pattern, with high variation in period-I (24.74%), decreased to 10.92 per cent and 9.46 per cent in period-II and period-III, respectively. Area demonstrated much lower variation across all periods, with decreasing variation from 13.35 per cent in period-I to 3.84 per cent and 2.40 per cent in periods-II and period-III, respectively, which reflected significant stabilization in area under cultivation. Overall period showed high variation in production (26.68%) and productivity (19.52%) compared to area (8.11%). CDVI mirrors the trends of CV but provides a more nuanced measure of instability. Production in period-I recorded the highest instability (18.87%), highlighting the extreme fluctuations in rice production. It reduced in period-II (13.40%) and further to 6.58 per cent in period-III, indicated a trend toward greater stability. Productivity

showed a similar trend, with a high instability of 12.80 per cent in period-I, which decreased steadily in period-II (10.53%) and period-III (6.52%). Area has shown lowest instability, with 6.33 per cent in period-I and dropped significantly in period-II (3.70%) and period-III (2.33%). Overall period exhibited high instability for production (25.43%) followed by productivity (17.41%). While area (8.19%) remained relatively stable in overall period.

For CII, which captures both magnitude and trends in variability, Central zone displayed consistently high instability across all periods for rice. Production recorded highest instability in period-I (53.22%), which decreased slightly in period-II (42.07%) and period-III (40.73%), indicated persistent production fluctuations despite some improvements (Table 3). Productivity showed similarly high instability in period-I (46.77%) and decreased in period-II (41.23%) and period-III (40.40%). Area displayed slightly lower instability, with 41.93 per cent in period-I and stabilized in period-II (38.24%) and period-III (37.69%). Across overall period, CII remained high for production (47.74%) and productivity (44.72%), which emphasized their vulnerability to fluctuations, while area (39.79%) appeared more stable comparatively. RII, which focused on dynamic instability and was sensitive to small-scale fluctuations, revealed relatively low levels of instability compared to other indices. Production in period-II recorded the highest instability (0.26%), which reduced to 0.23 per cent in period-I and further to 0.10 per cent in period-III. Productivity followed a similar pattern, with 0.21 per cent in period-II and declined in period-I (0.17%) and period-III (0.09%). Area showed the least instability, at 0.07 per cent in period-I and reduced to 0.06 per cent and 0.03 per cent in period-II and period-III respectively. For overall period, production (0.25%) and productivity (0.19%) exhibited high instability, while area (0.06%) remained very stable.

Eastern Zone: In Eastern zone, the instability indices for rice production, area and productivity presented a nuanced picture of fluctuations over different periods. CV, a measure of relative variability, indicated moderate instability across aspects. In period-I, area showed minimal variability with a CV of 2.04 per cent, while production and productivity displayed higher variability (9.27% and 8.45%, respectively). In period-II, CV for production remained stable at 9.15 per cent, and productivity decreased slightly (7.63%), while the area increased marginally (2.88%) (Table 3). In period-III, there was a slight rise in CV across all aspects, area reached 3.34 per cent, production increased to 9.54 per cent and productivity stabilized at 7.61 per cent. In overall period, CV of area, production and productivity reached 4.89 per cent, 15.38 per cent and 18.15 per cent, respectively, indicated increasing variability, especially in productivity. CDVI, which adjusts for trends in time-series data showed that, in period-I, area has the lowest instability with a CDVI of 1.97 per cent, while production and productivity exhibited higher CDVI (8.19% and 7.74%, respectively). In period-II, CDVI for area increased slightly (2.94%), while production remained high (8.67%) and productivity dropped (6.20%). During period-III, area increased further (3.41%), while production and productivity decrease (7.01% and 4.58%, respectively), which showed slight stabilization. In overall period, CDVI of area was 3.42 per cent, 7.57 per cent for production and 6.18 per cent for productivity. It reflected moderate instability across all aspects with production remaining relatively unstable.

In terms of CII, area instability of rice was high in period-III (38.08%) followed by slight decrease in period-II (37.88%) and further in period-I (37.56%) (Table 3). Whereas, production instability was high in period-III (40.85%) followed by period-I (40.48%) and period-II (40.36%). Instability of productivity was high in period-I (40.13%) and decreased slightly in period-II (39.79%) and period-III (39.84%). In overall period, productivity (44.13%) showed high instability followed by production (43.00%) and area (38.67%) indicated a small but steady increase in instability over time, particularly in productivity. RII, which accounts for dynamic instability showed that area instability remained nearly same in period-I (0.03%), period-II (0.042%) and period-III (0.04%). Instability in production increased slightly from period-I (0.14%) to period-II (0.015%) but decreased further in period-III (0.09%). Productivity RII decreased slightly from period-I (0.13%) to period-II (0.11%) and further to period-III (0.06%). In overall period, RII of area, production and productivity was 0.04 per cent, 0.12 per cent and 0.10 per cent, respectively.

Western Zone: For CV, variation of rice area increased from period-I (1.41%) to period-II (4.25%) but decreased in period-III (2.79%). CV of production also increased drastically from period-I (7.05%) to period-II (18.52%) but decreased in period-III (7.32%) (Table 3). Similarly, productivity variation also increased from period-I (11.96%) to period-II (15.56%) but

decreased drastically in period-III (6.30%). For overall period, area showed moderate variability with a CV of 4.91 per cent, while production and productivity remained highly unstable, with CV of 19.30 per cent and 14.06 per cent, respectively. CDVI showed relatively lower instability in period-I in terms of area (1.48%), production (3.68%) and productivity (10.32%). But CDVI increased for area (3.77%), production (17.00%) and productivity (14.60%) in period-II. Again, instability of area (2.69%), production (5.24%) and productivity (4.91%) decreased in period-III. In overall period, area remained relatively stable with CDVI of 2.94 per cent, while production and productivity exhibited significant instability, with CDVI of 10.79 per cent and 12.68 per cent respectively.

CII of rice signified persistent instability in all aspects. In Period-I, CII of area (37.31%), production (39.59%) and productivity (40.89%) indicated moderate instability (Table 3). In contrast, period-II showed a sharp rise in the instability of production (45.06%) and productivity (43.50%), while area showed a slight increase to 38.41 per cent. In period-III, CII stabilized slightly, with CII of 37.83 per cent for area, 39.58 per cent for production and 39.18 per cent for productivity. In overall period, CII confirmed high instability, particularly for production (44.93%) and productivity (42.69%), while area remained moderately stable at 38.64 per cent. RII showed that during period-I, instability was extremely low for area (0.02%), moderate for production (0.06%) and slightly higher for productivity (0.11%). In period-II, RII increased significantly, especially for production (0.30%) and productivity (0.25%), reflected heightened instability during the period and area also increased slightly (0.06%). In period-III, RII decreased again, showing relative stability, with 0.04 per cent for area, 0.09 per cent for production and 0.09 per cent for productivity. Across overall period, RII captured significant instability in production (0.19%) and productivity (0.21%), while area remained relatively stable at 0.04 per cent.

North Eastern Zone: CV of rice indicated a relatively low variability during period-I for area (1.55%), production (4.94%) and productivity (4.05%), reflecting stable trends (Table 3). In period-II, instability increased, particularly in production (7.64%) and productivity (5.14%) and slight increase in area (3.68%), suggested a phase of greater variability. During period-III, CV of area (2.49%) and production (4.28%) slightly decreased compared to period-II, but productivity showed a marginal increase in instability (5.50%). For overall period, instability sharply increased for production (19.16%) and productivity (18.06%), while the area remained relatively stable (2.89%). It indicated that production and productivity have experienced substantial fluctuations over the long term compared to area. CDVI provided a slightly different perspective. In period-I, CDVI was very low for area (1.60%), production (3.65%) and productivity (2.74%), which supported the observation of stability during the phase. In period-II, the index reflected increased instability, particularly in production (8.07%) and productivity (4.89%) and low increase in area (3.43%). During period-III, CDVI declined slightly for area (2.32%) and production (3.39%), with a modest increase in productivity (3.98%), which highlighted a partial recovery in stability. For overall period, CDVI confirmed significant instability in production (7.72%) and productivity (5.95%), while the area (2.90%) remained stable, consistent with CV observations.

In terms of CII, period-I showed nearly equal CII for area (37.36%), production (38.60%) and productivity (38.30%) of rice indicating balanced and moderate instability (Table 3). In period-II, instability marginally increased for area (38.19%), production (39.76%) and productivity (38.70%). In period-III, the instability remained consistent for area (37.73%), production (38.39%) and productivity (38.88), showing a relatively stable pattern. In overall period, CII revealed a noticeable rise in instability for production (44.42%) and productivity (43.91%), while area (37.89%) remained steady, confirming that production and productivity have become more unpredictable in the long term. Considering RII, period-I showed low RII for area (0.02%), production (0.05%) and productivity (0.04%) indicated negligible fluctuations. In period-II, RII increased slightly for production (0.08%) and productivity (0.05%), while area remained stable (0.04%). In period-III, RII was stable and low for area (0.03%), production (0.05%) and productivity (0.06%), reflected limited dynamic instability. For overall period, RII for area (0.03%), production (0.06%), and productivity (0.05%) remained low, indicated that while variability exists, it does not show large or erratic shifts over time.

All-India Level: With CV, it was observed that variation in area of rice remained low in period-I (2.42%), period-II (3.35%) and period-III (1.81%) (Table 3). While production exhibited low instability in period-I (6.74%) but increased

slightly in period-II (8.80%) and period-III (7.28%). Similarly, productivity showed lower variation in period-I (4.67%) but increased in period-II (6.82%) and period-III (6.09%). For overall period, production (15.51%) and productivity (14.20%) showed higher variation while area (2.58%) remained relatively stable. CDVI was consistently low for area in period-I (1.35%), period-II (3.56%) and period-III (1.48%). Instability of production showed steady rise from period-I (3.19%) to period-II (7.93%) but decreased in period-III (2.81%). Productivity followed a similar trend with CDVI increasing from period-I (2.64%) to period-II (5.21%) but decreased again in period-III (2.45%). However, in overall period, production (5.58%) and productivity (4.30%) reflected high instability compared to area (2.44%).

CII of rice area remained relatively same in period-I (37.69%), period-II (38.05%) and period-III (37.46%) (Table 3). Similarly, production and productivity also exhibited same level of instability in period-I (39.34% and 38.55%, respectively), period-II (40.35% and 39.50%, respectively) and period-III (39.55% and 39.10%, respectively). Nonetheless, overall period demonstrated high instability in production (42.91%) and productivity (42.33%) compared to area (37.75%). Finally, RII captured low instability in period-I for area (0.01%), production (0.05%) and productivity (0.04%). But RII increased in period-II, especially for production (0.14%) and productivity (0.10%) and normally for area (0.05%). However, in period-III, instability decreased for area (0.02%), production (0.032%) and productivity (0.03%) compared to period-II. Overall period exhibited high level of instability in production (0.08%) and productivity (0.06%) and low in area (0.03%).

In Northern zone, the area under rice cultivation showed low instability (3.62%), which indicated that land allocation to rice remained consistent over time. This reflected strong cropping traditions and reliable irrigation infrastructure that minimized fluctuations (Faldu *et al.,* 2024). However, production (13.98% and productivity (4.49%) remained stable in Northern zone with low instability. Southern Zone experienced low instability in area (9.95%), production (13.98%), and productivity (7.43%). Although the region was sensitive to climatic variability, especially due to dependence on monsoons, the use of hybrid rice varieties, technological advancements and irrigation expansion helped maintain stability (Jambhulkar *et al.,* 2020). Central zone showed low instability in area (8.19%), but high instability in production (25.43%) and medium instability in productivity (17.41%). This inconsistency reflected the impact of erratic rainfall, delayed sowing, and low irrigation coverage. District-level study in Maharashtra (a key part of Central zone) reported that rice production exhibited major fluctuations due to agro-climatic constraints. In Eastern zone, low instability in area (3.42%), production (7.57%), and productivity (6.18%) signified a well-established and stable rice cultivation system. This could be attributed to fertile alluvial soils and water availability. Eastern states, particularly Odisha and Bihar, experienced relatively uniform rice yields despite seasonal variations (Jambhulkar *et al.,* 2020).

Western zone recorded low instability in area (2.94%), production (10.79%), and productivity (12.68%). Although not traditionally known for rice cultivation, Western zone maintained consistency due to regulated water supply via canal irrigation and focussed policy support interventions (Faldu *et al.,* 2024). In the North-Eastern Zone, all three parameters, area (2.90%), production (7.72%), and productivity (5.95%) reflected low instability. Zone is dominated by smallholder farming and traditional rice varieties, benefited from relatively stable agro-ecological systems (Jambhulkar *et al.,* 2020). At India level, rice cultivation showed low instability in area (2.44%), production (5.58%), and productivity (4.30%). These aggregate values confirmed the resilience of India's rice sector due to continued technological adoption and policy support (Faldu *et al.,* 2024; Anonymous, 2023).

5. CONCLUSIONS

India is second largest producer of rice in the world after China. It is a staple food for nearly half of global population, especially in Asia and Africa. Results showed that growth rate of area of rice was low in all zones except negative growth in Southern (-0.17%) and Eastern (-0.39%) zones. Production growth rate was low in all zones except medium growth in Northern zone (2.46%). Growth rate of productivity was low in all zones. Area, production and productivity showed low instability in rice (2.44%, 5.58%, 4.30%). Therefore, it is essential to promote drought-resistant and flood-resistant rice varieties through agricultural research for reducing instability in rice is due to over-reliance on monsoon rains and regional concentration (Punjab, Haryana for rice) and climate shocks (droughts, floods). Expand irrigation coverage and modernize irrigation systems to reduces

dependence on erratic rainfall and ensures stable production across seasons.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTSS

Authors have declared that no competing interests exist.

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