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Growth and Variability Dynamics of Groundnut Cultivation in Odisha: A Five-decade Statistical Analysis

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

Groundnut cultivation in Odisha has been subject to changes in cultivated area, yield and production, but their long-term patterns differ across periods and districts. This study assessed growth, trend direction and temporal variability in groundnut area, yield and production at the state level for 1974–75 to 2023–24 and across 30 districts for 1994–95 to 2023–24. Secondary agricultural statistics were analysed using simple and compound growth rates, the Mann–Kendall trend test, Sen's slope estimator, the coefficient of variation and one-way analysis of variance, with period-wise mean comparisons. State-level results indicated highly significant area expansion during 1974–75 to 1983–84 (simple growth rate, 11.92%; compound growth rate, 12.62%), followed by significant contraction during 1994–95 to 2003–04. Across the full 50-year period, yield increased significantly (simple growth rate, 1.03%; compound growth rate, 1.04%), whereas the overall area trend was not significant. The Mann–Kendall test confirmed a

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significant increasing trend in yield but a non-significant increasing trend in production. District-level results demonstrated increasing area and production trends in Koraput, Deogarh and Rayagada, alongside declining area trends in several established groundnut-growing districts. Yield variability was lower in the final decade than in the first, with coefficients of variation of 4.98% and 17.94%, respectively. The findings indicate a shift towards yield-led growth, together with marked spatial differences that warrant district-specific attention.

Keywords: Groundnut; CGR; Mann-kendall test; Sen's slope; temporal instability; spatial disparity; Odisha.

1. Introduction

India is one of the world's top oilseed producers, but it still imports a huge amount of edible oil every year, which is a big burden on the country's foreign exchange. Groundnut is the most important oilseed crop in Odisha, and it plays a big role in supplying edible oil and nutrition to rural areas. It has a high oil content of 48-50% and a significant amount of plant protein, around 25-28%. Groundnut is widely cultivated in many districts of Odisha, including Jajpur, Bargarh, Ganjam, Dhenkanal, Malkangiri, and Kalahandi. However, most of the groundnut cultivation in Odisha relies on rainfall, which makes it vulnerable to changes in the monsoon season. There are also some structural problems that have limited the productivity of groundnut in Odisha. For example, many farmers do not have access to certified seeds, and the extension services in tribal districts are weak. Additionally, the post-harvest infrastructure is inadequate, which means that a lot of the crop is wasted after it is harvested. Previous studies on oilseed production in Odisha are outdated and do not provide a detailed analysis of the situation at the district level. This study aims to fill these gaps by analyzing the trends and patterns of groundnut production in Odisha over a period of 50 years, as well as examining the situation in each of the 30 districts over the past 30 years. The study uses a range of statistical tools to evaluate the growth trends, temporal instability, and spatial disparities in groundnut production, including the area under cultivation, yield, and total production. By doing so, it hopes to provide a more comprehensive understanding of the challenges and opportunities facing groundnut farmers in Odisha, and to identify strategies for improving productivity and reducing the country's reliance on imported edible oil.

Recent analysis of agricultural production in Odisha has documented differences in the growth and instability of cultivated area, yield and production across crops (M. K. Das *et al*., 2024). Evidence from Indian groundnut cultivation also identifies rainfed production as an important consideration in interpreting yield performance (Gopinath *et al*., 2024). Reviews of groundnut production further discuss the relevance of climatic variability to productivity and yield stability (Chilwal *et al*., 2025; Pujar *et al*., 2025).

Although earlier studies have examined aspects of oilseed production in Odisha, an integrated comparison of groundnut growth, monotonic trends and temporal instability over the state-level and district-level study periods remains insufficiently addressed in the literature reviewed here.

The study is guided by the following specific research questions:

1. What has been the period-wise Simple Growth Rate (SGR%) and Compound Growth Rate (CGR%) of area, yield, and production of groundnut in Odisha across five decadal periods from 1974-75 to 2023-24, and are these growth rates statistically significant?
2. Do the magnitudes and directions of growth trends, as measured by the Mann-Kendall trend test and Sen's slope estimator, confirm or contradict the parametric SGR and CGR findings, and how do these trends vary across the 30 districts of Odisha?
3. How has the temporal instability in area, yield, and production of groundnut, as measured by CV% and tested through ANOVA, varied across the five state-level periods and the three district-level sub-periods?

The objective of the present study is to evaluate growth, trend direction, and temporal instability in groundnut area, yield and production in Odisha at the state level (1974-75 to 2023-24) and across its 30 districts (1994-95 to 2023-24), using the statistical measures specified in the study.

2. Review of Literature

Kaushik (1993) found positive oilseed production growth during the Technology Mission on Oilseeds (TMO) period driven by area expansion, while yield growth remained inconsistent across regions. Sawant and Achuthan (1995) noted that oilseeds lagged cereals in the post-Green Revolution era, emphasising the need for region-specific productivity interventions. Narayan (2017) reported accelerated CAGR of 3.70% in area and 6.97% in production during the TMO era (1986-87 to 1995-96), followed by near-stagnation after 1996-97 due to WTO-mandated removal of import restrictions. Dinesh *et al.* (2019) found moderate-to-high production instability in several regions due to climatic variability and shifting cropping patterns, stressing the need for region-specific strategies. Samal *et al*. (2017) reported that 20 of 30 Odisha districts recorded negative groundnut production growth in the first decadal period (1995-96 to 2014-15), with weather variability identified as the dominant driver of instability over price risk.

Dash and Hansdah (2020) found that despite positive yield CGR in kharif oilseeds, significantly negative area CGR caused negative production CGR confirming that area decline is the primary production constraint in Odisha. Senthilnathan *et al.* (2023) showed that groundnut production growth in India was characterised by high instability driven primarily by yield variability, with yield effect dominating production changes. Mahapatra *et al.* (2024) found groundnut exhibited stronger yield improvement than sesamum in Odisha (1970-71 to 2019-20) using CDVII and CAGR. Das *et al.* (2024) and Dash & Panigrahi (2020) identified yield instability as the key challenge for consistent crop output in Odisha, calling for technology-led and climate-adaptive interventions.

3. Methods and Materials

3.1 Data

The secondary data on area (in '000ha), yield (in Kg/ha), and production (in '000MT) of groundnut at the state level were collected from various volumes of Agricultural Statistics published by Department of Agriculture & Farmer's Empowerment, Government of Odisha from 1974-75 to 2023-24. District-level data were obtained from the *District Statistical Handbook* and the *Season and Crop Reports* published by the Directorate of Agriculture and Food Production, Odisha from 1994-95 to 2023-24.

3.2 Periodization of Data

To capture the structural changes and growth trajectories in agricultural performance over time, the study period has been divided into distinct sub-periods. At the state level, the entire study period is divided into five sub-periods of ten years each, facilitating a comparative analysis of growth across different policy regimes and agricultural development phases. This periodization allows for identifying inflection points and policy impacts on agricultural growth patterns.

3.3 Simple Growth Rate (SGR)

The Simple Growth Rate (SGR) measures the percentage change in a variable from the base year value to the terminal year value. It is a straight forward measure that gives the absolute rate of change between two specific time points without accounting for the compounding effect.

$$\text{Simple Growth Rate in Percentage (SGR \%)} = \frac{b}{\bar{Y}} \times 100$$

where,

'Y' is the area, yield and production of groundnut
'b' is the linear regression coefficient and

3.4 Compound Growth Rate (CGR)

The Compound Growth Rate (CGR) measures the rate at which a variable grows over multiple periods, assuming the growth in each period is compounded on the previous period's value.

The Compound Growth Rate percentage (CGR%) can be expressed as

$$\text{CGR percentage} = [\text{Antilog } (\ln b)-1] \times 100$$

The significance of the growth rates can be tested by applying student's 't' test i.e.,

$$t = \frac{r}{SE(r)} \text{ with (N-2) degrees of freedom}$$

Where,

Y_t=Area, Yield, Production of Groundnut in year *t*;
't' is the time in years
'b' is the linear regression coefficient and
r is the growth rate
N is the total number of years considered under study
SE(r) is the standard error of growth rate

3.5 Trend Analysis

Trend analysis is one of the most commonly used tools for detecting changes in time series. Trend analysis is employed to detect the presence and direction of monotonic trends in the time series data.

3.5.1 Mann–Kendall (MK) Trend Test

The Mann–Kendall test is a rank-based non-parametric test used to identify whether a statistically significant monotonic trend (upward or downward) exists in a time series. It is the most suitable test for detecting the trend for data with high fluctuation.

Test Statistic (S): For a timeseries$\{x_1, x_2, \ldots . x_n\}$, the MK statistic *S* is calculated as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} Sign\ (T_j - T_i)$$

Where the sign function $Sign(T_j - T_i)$is defined as:

$$Sign(T_j - T_i) = \begin{cases} 1 & if\ (T_j - T_i) > 0 \\ 0 & if(T_j - T_i) = 0 \\ 1 & if(T_j - T_i) < 0 \end{cases}$$

where $T_i\ and\ T_j$ are the values in periods j and i respectively (MotieeandMcbean2009) where j > i. If fn<10, the value of |S| is compared directly to the theoretical distribution of S derived by Mann and Kendall.

3.5.2 Sen's Slope Estimator

Sen's slope estimator is a non-parametric method used to estimate the magnitude (rate) of a trend in a time series. It is more robust than ordinary least squares slope estimation as it is resistant to outliers and does not require normality of the data.

For a timeseries of *n* data values, the slopes of all possible pairs of observations are calculated as:

$$T_i = \frac{x_j - x_k}{j - k}, \quad i = 1,2,3,\ldots.N$$

Where $x_j\ and\ x_k$are data values at times *j* and *k* respectively (*j*>*k*). The total number of slope estimates is $N = \frac{n(n-1)}{2}$

Sen's slope is the median of all *N* slope estimates:

$$Q_{Med} = \begin{cases} T_{\frac{N+1}{2}} & N\ is\ odd \\ \frac{1}{2}\left(\frac{T_N}{2} + \frac{T_{N+2}}{2}\right) & N\ is\ even \end{cases}$$

In the end, T_{Med} is computed by a two- sided test at 100(1-α) % confidence interval and then a true slope can be obtained by this non-parametric test. A positive value of Q_{Med} indicates an increasing trend, while a negative value indicates a decreasing trend. The slope is interpreted as the change per unit time (e.g., per year).

3.6 Temporal Instability in Area, Yield and Production

Instability analysis measures the extent to which agricultural output fluctuates over time. Three statistical tools have been used for temporal instability analysis: The Coefficient of Variation (CV%), One-way Analysis of Variance (ANOVA), and the Critical Difference (CD) Test.

3.6.1 Coefficient of Variation (CV%)

The Coefficient of Variation (CV) is a dimensionless measure of relative variability, defined as the ratio of the standard deviation to the mean, expressed as a percentage. It enables comparison of variability across variables with different units or magnitudes.

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

Where σ is the standard deviation of the observations

3.6.2 One-Way Analysis of Variance (ANOVA)

One-way Analysis of Variance (ANOVA) is a parametric statistical technique used to test whether there are significant differences in the mean values of a variable across different sub-periods (groups).

The Mathematical Model

$$Y_{ij} = \mu + \alpha_i + \epsilon_{ij}$$

where,

Y_{ij}= Observation of the jth year in the ith district.
μ= Grand mean of all observations.
α_i = Effect of the ith district.
ϵ_{ij} = Random error.

Calculation:

1. **Correction Factor (CF):** CF = $\frac{(G^2)}{N}$, where G is the Grand Total and N is the total number of observations.
2. **Total Sum of Squares (TSS):** $\sum {Y_{ij}}^2 -$ CF
3. **District Sum of Squares (TrSS):** $\sum \frac{({T_i}^2)}{n_i} - CF$, where T_i is the total for district i.
4. **Error Sum of Squares (ESS):** TSS –TrSS

Table 1. The ANOVA Table

Source of Variation	Degrees of freedom (df)	Sum of Squares (SS)	Mean Sum of Squares (MS)	F-ratio
Between Districts	k – 1	TrSS	$MS_{tr} = \frac{TrSS}{k-1}$	$F = \frac{MS_{tr}}{MS_e}$
Within Districts (Error)	N - k	ESS	$MS_e = \frac{ESS}{N-k}$	
Total	N - 1	TSS		

3.6.3 Critical Difference (CD) Test

The Critical Difference (CD) test, also known as the Least Significant Difference (LSD) test, is a post-hoc multiple comparison procedure applied after a significant F-ratio in ANOVA to identify which specific pairs of sub-period means differ significantly from each other.

The CD between any two group means ($\bar{X}_i$ and $\bar{X}_j$) is computed as:

$$CD = SE.(d) \times t_{(\alpha,df)}$$

where $t_{(\alpha, df)}$ is the critical value of Student's *t* distribution at significance level α with
$df = (N - k)$ error degrees of freedom;
SE_d is the standard error of the difference between two means

4. Results and Discussion

It is essential to understand the overall distributional characteristics of the data, so the descriptive statistics of all the parameter of groundnut is presented in the Table 2, indicates significance variability in area and production with high CV values of 30% and 31%, respectively, suggesting instability, Whereas the yield shows relatively lower variability supported by the lower CV value of 19%. Skewness values suggest slight asymmetry, while negative kurtosis across all variables indicates platykurtic distributions.

Table 2. Descriptive Statistics of groundnut in Odisha (1974-75 to 2023-24)

Statistic	Area (000' ha)	Yield (Kg/ha)	Production (000' MT)
Mean	245.61	1471.42	359.58
Median	245.53	1436.5	377.75
Standard Deviation	73.567	281.563	110.846
CV%	30%	19%	31%
Kurtosis	-0.273	-0.212	-0.238
Skewness	0.154	-0.190	-0.688

4.1 Period-wise Simple Growth Rate (SGR%) and Compound Growth Rate (CGR%) of Groundnut of Odisha (1974-75 to 2023-24)

Table 3 shows the period wise growth analysis of groundnut reveals substantial temporal variation in performance. Period I (1974-75 to 1983-84) was the most dynamic expansion phase, Groundnut area grew at a highly significant SGR of 11.92 per cent and CGR of 12.62 per cent per annum. Production surged significantly, confirming that this was an area-led growth phase. Yield growth was non-significant, indicating that production gains were driven by expansion rather than productivity. Period II (1984-85 to 1993-94) marked a consolidation phase. Groundnut area and production growth turned non-significant. Period III (1994-95 to 2003-04) was the most critical period of contraction. Groundnut area declined significantly at -4.84 per cent (SGR) and -4.74 per cent (CGR). Period IV (2004-05 to 2013-14) witnessed a notable groundnut recovery in area (1.67 per cent), yield (1.57 per cent), and production (3.21 per cent), all showing significant growth, likely driven by improved varieties and MSP support. Groundnut area declined significantly (-2.52 per cent) but yield improved significantly (1.08 per cent). Over the entire 50-year span, groundnut yield showed a highly significant upward trend (SGR: 1.03 per cent, CGR: 1.04 per cent) and production showed significant growth (SGR: 0.79 per cent, CGR: 1.25 per cent), while area declined non-significantly.

4.2 District-wise Simple Growth Rate (SGR%) and Compound Growth Rate (CGR%) of Groundnut of Odisha (1974-75 to 2023-24)

As per Table 4., district wise SGR and CGR analyses revealed substantial spatial heterogeneity in oilseed growth across Odisha. Groundnut area experienced wide declines during the first period, followed by partial recovery in several western and southern

districts during the second period. In the third period, coastal districts again recorded significant decline, whereas districts such as Koraput and Deogarh maintained strong expansion. Over the entire study period, Koraput, Boudh, Deogarh and Rayagada emerged as the most consistent growth regions for groundnut, while Jagatsinghpur, Kendrapara, Khordha and Bargarh exhibited persistent declines.

Table 3. Simple Growth Rate (SGR%) and Compound Growth Rate (CGR%) of groundnut of Odisha (1974-75 to 2023-24)

Time	SGR			CGR		
	Area (000 ha)	Yield (Kg/ha)	Production (000 MT)	Area (000 ha)	Yield (Kg/ha)	Production (000 MT)
Period I	11.92**	0.98NS	13.54**	12.62**	0.77NS	13.5**
Period II	1.14NS	0.4NS	1.52NS	1.23NS	0.37NS	1.6NS
Period III	-4.84**	-0.0NS	-5.05NS	-4.74**	0.09NS	-4.66NS
Period IV	1.67**	1.57**	3.21**	1.7**	1.61**	3.34**
Period V	-2.52*	1.08*	-1.37NS	-2.35*	1.05*	-1.32NS
Overall	-0.1NS	1.03**	0.79**	0.21NS	1.04**	1.25**

*** Significant at 1% level (p<0.01); * Significant at 5% level (p<0.05); NS = Non-Significant*

Table 4. The SGR and CGR of groundnut district wise across Odisha during 1994-95 to 2023-24

Districts	Area		Yield		Production	
	SGR%	CGR%	SGR%	CGR%	SGR%	CGR%
Angul	-0.14NS	-0.12NS	2.17**	2.35**	2.07**	2.22**
Balasore	1.07NS	1.14*	1.20**	1.29**	2.08**	2.44**
Bargarh	-3.03**	-3.07**	1.42**	1.41**	-1.90**	-1.71**
Bhadrak	-3.08**	-6.35**	1.52**	1.70**	-1.75NS	-4.78**
Bolangir	-2.30**	-2.13**	2.59**	2.69**	0.43NS	0.51NS
Boudh	4.04**	4.45**	2.18**	2.49**	5.50**	7.05**
Cuttack	-1.89**	-1.66**	2.49**	2.62**	0.57NS	0.92NS
Deogarh	4.96**	5.34**	1.27**	1.33**	6.12**	6.74**
Dhenkanal	-1.94**	-1.78**	2.73**	3.01**	1.19**	1.17**
Gajapati	-0.00NS	-0.03NS	1.63**	1.63**	1.72**	1.60*
Ganjam	-0.87NS	-1.01NS	1.92**	1.98**	0.81NS	0.96NS
Jagatsinghpur	-4.39**	-4.75**	1.42**	1.83**	-2.61**	-3.00**
Jajpur	-1.43**	-1.59**	1.67**	2.14**	0.15NS	0.51NS
Jharsuguda	-0.28NS	-0.91NS	1.07**	1.16**	0.58NS	0.23NS
Kalahandi	1.38**	1.41**	1.54**	1.64**	2.91**	3.07**
Kandhamal	0.87NS	0.67NS	1.09**	1.30**	2.16NS	1.98NS
Kendrapara	-5.08**	-5.47**	1.10*	1.39**	-3.57**	-4.16**
Keonjhar	-1.43NS	-1.07NS	1.42*	1.46*	-0.52NS	0.38NS
Khordha	-3.68**	-4.97**	2.11**	2.40**	-2.22NS	-2.69NS
Koraput	7.89**	8.77**	2.36**	2.55**	9.27**	11.54**
Malkangiri	1.27NS	1.56NS	1.10**	1.33**	2.15NS	2.91NS
Mayurbhanj	0.89NS	0.78NS	2.21**	2.27**	2.75**	3.07**
Nabarangapur	0.34NS	-0.10NS	0.87NS	1.19*	1.52NS	1.08NS
Nayagarh	-1.33*	-1.26NS	1.16**	1.21**	-0.09NS	-0.06NS
Nuapada	-0.10NS	-0.14NS	1.80**	2.03**	1.72**	1.89*
Puri	-1.62*	-2.57**	1.44**	1.54**	-0.35NS	-1.07NS
Rayagada	2.68**	2.69**	2.36**	2.80**	4.83**	5.57**
Sambalpur	1.47*	1.61*	1.69**	1.74**	3.06**	3.38**
Subarnapur	1.62NS	1.64*	0.94**	1.07**	2.59**	2.73**
Sundargarh	-1.96**	-1.58**	1.12**	1.13**	-1.01NS	-0.46NS

*** Significant at 1% level (p < 0.01); * Significant at 5% level (p < 0.05); NS = Non-Significant (p > 0.05)*

4.3 To Assess the Temporal Instability in Area, Yield and Production of Groundnut in Odisha

At the state level over 50 years, the Mann-Kendall test confirmed that Groundnut yield showed the strongest and most significant increasing trend, the most robust positive trend in the entire dataset. Groundnut production showed a positive but statistically non-significant trend. Groundnut area exhibited a non-significant decreasing trend in Table 5.

Table 5. Mann-Kendall (Tau) and Sen's Slope estimator for area, yield and production of groundnut in Odisha

Statistic	Area (000' ha)	Yield (Kg/ha)	Production (000' MT)
Z Value	-1.288	6.55**	1.757
Tau (τ)	-0.1265	0.64	0.1722
Trend	Decreasing	Increasing	Increasing
Sen's Slope	-1.46	14.9333	2.5187
p-value	0.198	<0.001	0.079

*** Significant at 1% level (p<0.01); * Significant at 5% level (p<0.05); NS = Non-Significant*

Table 6. Mann-Kendall (Tau) and Sen's Slope Estimator for area, yield and production covered by groundnut in different districts of Odisha

District	Area				Yield				Production			
	M-K test			Sen's	M-K test			Sen's	M-K test			Sen's
	Z_{mk}	Tau (τ)	Trend	Slope	Z_{mk}	Tau (τ)	Trend	Slope	Z_{mk}	Tau (τ)	Trend	Slope
Angul	-0.21	-0.0299^{NS}	Decreasing	-0.014	3.6	0.4667**	Increasing	30.4	3.5	0.4529**	Increasing	0.342
Balasore	2	0.2598*	Increasing	0.0952	3.6	0.4667**	Increasing	19.3333	2.85	0.3701**	Increasing	0.3265
Bargarh	-5.32	-0.6874**	Decreasing	-0.9216	3.68	0.4759**	Increasing	18.4444	-2.85	-0.3701**	Decreasing	-0.6758
Bhadrak	-2.2	-0.2851*	Decreasing	-0.0348	3.71	0.4805**	Increasing	23.3333	-1.11	-0.1448^{NS}	Decreasing	-0.0348
Bolangir	-4.69	-0.6069**	Decreasing	-0.2	5	0.646**	Increasing	33.6667	0.39	0.0529^{NS}	Increasing	0.04
Boudh	4.5	0.5816**	Increasing	0.0172	4	0.5172**	Increasing	30.3333	4.37	0.5655**	Increasing	0.0389
Cuttack	-2.36	-0.3057*	Decreasing	-0.1582	5.67	0.7333**	Increasing	30	0.86	0.1126^{NS}	Increasing	0.1122
Deogarh	5.44	0.7034**	Increasing	0.0871	4.44	0.5747**	Increasing	18.5	5.54	0.7149**	Increasing	0.15
Dhenkanal	-3.87	-0.5011**	Decreasing	-0.2633	6.6	0.8529**	Increasing	38.0714	3.43	0.4437**	Increasing	0.3014
Gajapati	0.32	0.0437^{NS}	Increasing	0.0024	5.35	0.692**	Increasing	24	2.36	0.3057*	Increasing	0.0576
Ganjam	-1.46	-0.1908^{NS}	Decreasing	-0.1625	5.69	0.7356**	Increasing	28.7857	1.25	0.1632^{NS}	Increasing	0.1824
Jagatsinghpur	-3.64	-0.4713**	Decreasing	-0.2732	2.5	0.3241*	Increasing	15.3	-2.57	-0.3333*	Decreasing	-0.3689
Jajpur	-4.98	-0.6437**	Decreasing	-0.2775	4.05	0.5241**	Increasing	20.1818	-0.32	-0.0437^{NS}	Decreasing	-0.165
Jharsuguda	0.14	0.0207^{NS}	Increasing	0.0019	3.07	0.3977**	Increasing	16.125	0.29	0.0391^{NS}	Increasing	0.0093
Kalahandi	2.94	0.3816**	Increasing	0.1906	4.6	0.5954**	Increasing	26.2	5	0.646**	Increasing	0.6885
Kandhamal	0.37	0.0506^{NS}	Increasing	0.0071	2.28	0.2966*	Increasing	12.3333	2.03	0.2644*	Increasing	0.0579
Kendrapara	-5.41	-0.6989**	Decreasing	-0.4052	2.16	0.2805*	Increasing	14.6667	-3.1	-0.4023**	Decreasing	-0.5889
Keonjhar	-0.34	-0.046^{NS}	Decreasing	-0.01	2.21	0.2874*	Increasing	25	1.39	0.1816^{NS}	Increasing	0.0973
Khordha	-3.18	-0.4115**	Decreasing	-0.0945	4.6	0.5954**	Increasing	30.2759	-1.87	-0.2437^{NS}	Decreasing	-0.0911
Koraput	6.16	0.7954**	Increasing	0.0836	5.46	0.7057**	Increasing	28.6842	6.08	0.7862**	Increasing	0.125
Malkangiri	1.53	0.2NS	Increasing	0.2133	2.11	0.2736*	Increasing	19.6842	1.75	0.2276^{NS}	Increasing	0.6325
Mayurbhanj	1.03	0.1356^{NS}	Increasing	0.06	4.62	0.5977**	Increasing	33.8889	3.09	0.4**	Increasing	0.215
Nabarangapur	-1.05	-0.1379^{NS}	Decreasing	-0.01	2.21	0.2874*	Increasing	15.5	-0.04	-0.0069^{NS}	Decreasing	-0.0009
Nayagarh	-1.93	-0.2506^{NS}	Decreasing	-0.0146	3.14	0.4069**	Increasing	16.7391	-0.3	-0.0414^{NS}	Decreasing	-0.0029
Nuapada	-0.37	-0.0506^{NS}	Decreasing	-0.0115	4.07	0.5264**	Increasing	23.3182	2.96	0.3839**	Increasing	0.2909
Puri	-1.5	-0.1954^{NS}	Decreasing	-0.2155	2.09	0.2713*	Increasing	16.4167	0.25	0.0345^{NS}	Increasing	0.0981
Rayagada	5.32	0.6874**	Increasing	0.0314	5.14	0.6644**	Increasing	30	5.73	0.7402**	Increasing	0.0858
Sambalpur	2.27	0.2943*	Increasing	0.0187	4.16	0.5379**	Increasing	29.1818	3.23	0.4184**	Increasing	0.0579
Subarnapur	1.53	0.2NS	Increasing	0.0338	1.86	0.2414NS	Increasing	14.0625	2.75	0.3563**	Increasing	0.115
Sundargarh	-2.05	-0.2667*	Decreasing	-0.0647	3.84	0.4966**	Increasing	14.3333	-0.82	-0.108^{NS}	Decreasing	-0.0529

*** Significant at 1% level (p ≤ 0.01); * Significant at 5% level (p ≤ 0.05); NS = Non-Significant (p > 0.05) | Z > 0 → Increasing; Z < 0 → Decreasing | Sen's Slope = median rate of change per year*

At the district level over 30 years, the Mann-Kendall analysis revealed pronounced spatial heterogeneity. For Groundnut area, highly significant increasing trends were recorded in Koraput, Deogarh, Rayagada, Boudh, and Kalahandi, signifying emerging growth frontiers. In contrast, highly significant decreasing trends were found in Kendrapara, Bargarh, Bolangir, Jajpur, and Dhenkanal, indicating structural area contraction in these traditionally important districts. For groundnut yield, the MK test revealed predominantly positive trends across most districts, reflecting broad-based technological progress. The production results suggest Koraput, Deogarh, Rayagada, Boudh, and Kalahandi all recorded strong and significant increasing production trends, benefiting from simultaneous gains on both fronts in Table 6.

4.4 Period-wise Comparison of the Mean and CV% in Area, Yield and Production of Groundnut of Odisha

Table 7 shows period wise comparison of Mean and CV% of groundnut in Odisha during 1974-75 to 2023-24. Groundnut area increased sharply from period I to peak in period II reaching 354.92 thousand ha, followed by a gradual decline in subsequent periods, with highest instability observed in period I and greater stability in period II and IV. In contrast, yield instability declined from 17.94% to 4.98%, while mean yield increased across the study period indicating improved stability and technological process. Production peaked in period II to 472.11 thousand MT due to maximum area allocation, while period IV and V maintained relatively high production levels despite reduced area, supported by increased yield, production variability also declined over time. Collectively, the findings indicate a structural shift from area expansion to yield led growth, accompanied by enhanced stability in recent decade.

Table 7. Period-wise Comparison of Mean and CV% of area, yield and production of groundnut in Odisha

Time period	Area (000 ha)		Yield (Kg/ha)		Production (000 MT)	
	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)
Period I (1974-75 to 1983-84)	167.53^{e}	37.94	1240.5^{cd}	17.94	209.89^{e}	46.72
Period II (1984-85 to 1993-94)	354.92^{a}	8.69	1332.0^{c}	6.57	472.11^{a}	9.57
Period III (1994-95 to 2003-04)	253.65^{b}	16.31	1274.8^{c}	15.62	325.31^{d}	25.84
Period IV (2004-05 to 2013-14)	247.49^{b}	5.82	1674.4^{b}	5.87	415.61^{b}	11.38
Period V (2014-15 to 2023-24)	204.47^{d}	11.47	1835.4^{a}	4.98	375.02^{b}	11.66
Overall Period (1974-75 to 2023-24)	245.62	29.95	1471.42	19.14	359.59	30.83
F-value	33.184*		31.032*		21.655*	
CD (5%)	34.793		136.5097		60.919	

*CV = Coefficient of Variation (%); CD = Critical Difference at 5% level of significance; *Significant at 5% level of significance; Means followed by same letter(s) are not significantly different by DMRT (p=0.05)*

The study of the temporal variation in area, yield and production covered by groundnut across three periods for different districts were performed using one-way ANOVA and CV% and the results are presented in the Tables 8, 9,10 respectively. Groundnut area exhibited significant variations in most districts, with some districts showing consistent expansion while others recorded marked declines. Yield improvements were observed in nearly all districts, with the highest yields generally occurring during the most recent period, indicating significant gains in productivity.

Table 8. Period-wise Comparison of Mean and CV% of area under groundnut across districts in Odisha

District	Period I (1994-95 to 2003-04)		Period II (2004-05 to 2013-14)		Period III (2014-15 to 2023-24)		Overall Period (1994-95 to 2023-24)		F-value	CD (5%)
	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)		
Angul	12.05^{a}	13.43	11.1^{abc}	13.81	11.92^{ab}	10.33	11.69	12.68	1.235^{NS}	1.3491
Balasore	7.78^{c}	12.1	12.69^{a}	24.09	9.88^{b}	14.96	10.11	28.02	14.666*	1.8661
Bargarh	35.79^{a}	21.54	30.83^{b}	10.09	19.12^{c}	12.92	28.58	30.07	29.225*	4.5935
Bhadrak	1.27^{b}	14.58	1.53^{a}	25.51	0.49^{c}	81.65	1.1	50.81	25.526*	0.3113
Bolangir	12.64^{a}	26.49	9.93^{b}	6.15	8.4^{c}	14.59	10.32	26.08	10.585*	1.9167
Boudh	0.29^{c}	31.13	0.56^{b}	13.1	0.7^{a}	37.26	0.52	45.47	15.875*	0.1519
Cuttack	10.44^{a}	37.99	9.94^{ab}	9.07	7.25^{c}	14.97	9.21	29.79	4.985*	2.2306
Deogarh	0.86^{c}	24.71	1.75^{b}	27.5	2.63^{a}	29.71	1.75	51.54	26.299*	0.4988
Dhenkanal	18.89^{a}	12.37	12.22^{bc}	9.02	12.85^{b}	15.91	14.65	24.33	37.441*	1.7454
Gajapati	2.19^{ab}	24.23	1.91^{bc}	18.21	2.32^{a}	22.68	2.14	22.96	1.957^{NS}	0.4371
Ganjam	17.8^{b}	21.32	22.18^{a}	15.84	15.08^{c}	28.92	18.35	26.17	8.427*	3.5836
Jagatsinghpur	11.14^{a}	46.08	7.79^{b}	8.59	4.78^{c}	51.61	7.91	52.43	9.22*	3.0384

District	Period I (1994-95 to 2003-04)		Period II (2004-05 to 2013-14)		Period III (2014-15 to 2023-24)		Overall Period (1994-95 to 2023-24)		F-value	CD (5%)
	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)		
Jajpur	32.26^{a}	6.98	31.89^{ab}	2.56	24.08^{c}	20.75	29.41	16.75	20.863*	2.9351
Jharsuguda	1.16^{b}	22.43	1.97^{a}	25.52	1.02^{bc}	53.32	1.38	44.05	12.649*	0.4161
Kalahandi	11.4^{c}	24.85	13.8^{ab}	10.43	15.31^{a}	19.24	13.5	21.6	6.216*	2.2959
Kandhamal	1.96^{b}	32.82	1.19^{c}	25.09	2.52^{a}	45.12	1.89	49.3	7.489*	0.7103
Kendrapara	15.98^{a}	46.11	10.2^{b}	4.92	5.84^{c}	53.34	10.67	57.59	12.074*	4.2466
Keonjhar	4.44^{a}	43.05	2.86^{bc}	11.55	3.74^{ab}	42.8	3.68	42.1	2.992^{NS}	1.3324
Khordha	2.69^{b}	42.65	3.47^{a}	32.92	0.95^{c}	48.67	2.37	60.17	17.694*	0.8912
Koraput	0.41^{c}	13.51	0.97^{b}	38.81	2.33^{a}	32.73	1.23	76.69	40.35*	0.4505
Malkangiri	11.9^{abc}	51.85	15.82^{a}	38.06	14.17^{ab}	41.66	13.96	43.3	1.064^{NS}	5.535
Mayurbhanj	4.01^{c}	17.59	7.38^{a}	16.53	5.49^{b}	47.66	5.63	38.57	9.699*	1.5748
Nabarangapur	1.48^{ab}	32.04	1.41^{abc}	34.43	1.8^{a}	78.81	1.56	57.2	0.533^{NS}	0.8341
Nayagarh	1.18^{a}	23.95	0.78^{c}	36.55	1.0^{b}	22.35	0.99	31.02	5.843*	0.2432
Nuapada	11.96^{a}	20.45	11.7^{abc}	13.75	11.74^{ab}	25.44	11.8	19.77	0.032^{NS}	2.2152
Puri	12.43^{ab}	21.73	12.83^{a}	24.35	9.44^{c}	59.22	11.57	36.02	2.13^{NS}	3.6821
Rayagada	0.93^{c}	19.64	1.12^{b}	8.06	1.64^{a}	11.22	1.23	27.71	53.677*	0.145
Sambalpur	0.93^{c}	43.06	1.17^{ab}	22.93	1.36^{a}	27.87	1.15	33.51	3.791*	0.3248
Subarnapur	2.21^{bc}	29.67	2.72^{ab}	52.98	3.02^{a}	26.99	2.65	39.55	1.584^{NS}	0.9433
Sundargarh	5.21^{a}	34.72	3.8^{b}	30.95	3.59^{bc}	12.02	4.2	34	4.817*	1.1662

*CV=Coefficient of Variation (%) CD=Critical Difference at 5% level of significance, *Significant at 5% level of significance*

Table 9. Period-wise Comparison of Groundnut yield (Kg/ha)

District	Period I (1994-95 to 2003-04)		Period II (2004-05 to 2013-14)		Period III (2014-15 to 2 023-24)		Overall Period (1994-95 to 2023-24)		F-value	CD (5%)
	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)		
Angul	1082.1^{c}	21.68	1528.9^{b}	21.71	1739.0^{a}	4.4	1450.0	24.93	19.738*	219.1172
Balasore	1527.3^{bc}	22.03	1654.2^{b}	15.63	1957.9^{a}	1.57	1713.13	17.5	8.116*	225.3682
Bargarh	1154.3^{c}	18.61	1304.3^{b}	13.53	1547.0^{a}	16.82	1335.2	20.11	8.127*	201.7065
Bhadrak	1528.6^{c}	21.06	1999.2^{ab}	13.04	2113.2^{a}	3.36	1880.33	18.5	16.311*	222.6562
Bolangir	1040.2^{c}	13.44	1598.6^{b}	11.72	1821.5^{a}	20.45	1486.77	27.87	25.131*	232.9638
Boudh	1015.2^{c}	13.62	1648.4^{ab}	7.56	1685.8^{a}	5.1	1449.8	22.98	101.417*	108.5815
Cuttack	1230.1^{c}	26.71	1796.0^{b}	9.67	2103.0^{a}	23.05	1709.7	29.3	15.764*	323.6198
Deogarh	1188.7^{c}	19.57	1333.4^{b}	14.62	1557.9^{a}	5.15	1360.0	17.16	10.534*	166.3178
Dhenkanal	1050.2^{c}	22.04	1575.6^{b}	12.57	1889.1^{a}	4.68	1504.97	26.17	53.559*	168.0703
Gajapati	1253.9^{c}	10.14	1397.2^{b}	8.82	1738.4^{a}	7.98	1463.17	16.52	36.722*	119.182
Ganjam	1195.0^{c}	10.93	1547.6^{b}	8.29	1791.3^{a}	10.61	1511.3	19.13	38.724*	139.7983
Jagatsinghpur	1360.8^{c}	31.44	2092.7^{a}	15.75	1950.6^{ab}	2.69	1801.37	24.53	15.349*	287.4484
Jajpur	1376.8^{c}	39.84	1786.8^{ab}	7	1970.9^{a}	2.08	1711.5	23.55	8.722*	298.8192
Jharsuguda	1096.1^{bc}	23.98	1213.1^{b}	13.66	1395.2^{a}	7.82	1234.8	17.99	6.283*	174.4814
Kalahandi	1343.3^{c}	15.5	1729.2^{b}	9.88	1875.5^{a}	7.85	1649.33	17.3	24.067*	162.6237
Kandhamal	1174.9^{c}	28.05	1565.1^{a}	5.82	1546.1^{ab}	7.5	1428.7	19.02	11.141*	191.2572
Kendrapara	1492.6^{c}	25.95	2156.2^{a}	11.28	1957.7^{b}	9.11	1868.83	21.05	14.437*	260.1231
Keonjhar	1244.8^{b}	32.41	1044.9^{c}	20.43	1703.6^{a}	13.98	1331.1	30.14	12.906*	272.7852
Khordha	1211.5^{c}	30.14	1817.8^{ab}	14.41	1983.4^{a}	13.91	1670.9	26.78	17.811*	279.4071
Koraput	866.2^{c}	17.7	1242.1^{b}	9.87	1450.8^{a}	11.15	1186.37	23.93	40.694*	134.7606
Malkangiri	1484.0^{c}	25.89	2066.4^{a}	10.92	1872.0^{b}	11.59	1807.47	20.47	10.74*	262.5475
Mayurbhanj	1201.7^{bc}	20.57	1337.8^{b}	19.08	1900.7^{a}	8.79	1480.07	25.51	26.715*	208.0458
Nabarangapur	1324.4^{bc}	35.04	1328.5^{b}	9.02	1619.9^{a}	13.96	1424.27	22.96	3.067^{NS}	280.7607
Nayagarh	1268.9^{c}	13.09	1526.1^{ab}	16.35	1588.5^{a}	8.81	1461.17	15.87	7.868*	175.2519
Nuapada	1066.9^{c}	28.67	1554.5^{ab}	10.9	1657.6^{a}	6.49	1426.33	23.27	22.306*	193.8515
Puri	1623.0^{c}	22.85	2182.3^{ab}	6.63	2210.4^{a}	20.83	2005.23	21.77	8.892*	322.4024
Rayagada	985.5^{c}	31.9	1453.3^{b}	10.23	1633.3^{a}	8.93	1357.37	25.65	23.589*	199.7795
Sambalpur	1190.9^{bc}	23.12	1304.5^{b}	15.05	1725.8^{a}	6.55	1407.07	21.82	18.743*	188.8851
Subarnapur	1572.1^{c}	14.82	2143.2^{a}	8.56	1940.8^{b}	3.87	1885.37	15.63	26.876*	162.0718
Sundargarh	1315.3^{bc}	16.95	1362.8^{b}	15.59	1636.1^{a}	8.66	1438.07	16.5	7.827*	179.5757

*CV=Coefficient of Variation (%) CD=Critical Difference at 5% level of significance, *Significant at 5% level of significance*

Table 10. Period-wise comparison of groundnut production (000 MT)

District	Period I (1994-95 to 2003-04)		Period II (2004-05 to 2013-14)		Period III (2014-15 to 2023-24)		Overall Period (1994-95 to 2023-24)		F-value	CD (5%)
	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)		
Angul	13.06^{c}	25.19	17.02^{b}	27.72	20.68^{a}	8.3	16.92	27.2	12.071*	3.1804
Balasore	11.98^{c}	28.65	21.4^{a}	35.82	19.35^{ab}	15.04	17.58	36.62	9.306*	4.7095
Bargarh	42.45^{a}	38.34	40.13^{ab}	16.54	29.64^{c}	22.64	37.41	31.86	3.95*	9.9675
Bhadrak	1.94^{b}	25.46	3.1^{a}	32.93	1.04^{c}	81.79	2.02	57.56	16.005*	0.7497
Bolangir	13.23^{abc}	34.34	15.91^{a}	14.94	15.3^{ab}	24.8	14.81	25.25	1.452^{NS}	3.3796
Boudh	0.3^{c}	38.38	0.93^{b}	18.31	1.19^{a}	39.73	0.81	59.14	23.604*	0.2741
Cuttack	13.35^{bc}	58.57	17.94^{a}	16.22	15.5^{ab}	37.05	15.59	38.19	1.541^{NS}	5.3649
Deogarh	1.04^{c}	35.24	2.34^{b}	30.9	4.12^{a}	33.25	2.5	62.34	28.225*	0.8439
Dhenkanal	19.84^{b}	24.77	19.09^{bc}	7.32	24.36^{a}	19.11	21.1	21.43	5.112*	3.6622
Gajapati	2.73^{b}	23.98	2.7^{bc}	26.06	4.04^{a}	25.23	3.16	31.92	8.996*	0.7428
Ganjam	21.51^{c}	29.87	34.57^{a}	21.68	26.77^{b}	25.99	27.62	31.37	8.881*	6.3985
Jagatsinghpur	14.91^{ab}	52.66	16.18^{a}	12.56	9.31^{c}	51.12	13.47	44.97	4.544*	4.9822
Jajpur	44.82^{bc}	42.73	56.94^{a}	6.29	47.43^{b}	20.78	49.73	26.68	2.559^{NS}	11.5676
Jharsuguda	1.28^{bc}	32.08	2.41^{a}	32.69	1.42^{b}	55.32	1.71	49.07	8.087*	0.6297
Kalahandi	15.04^{c}	22.34	23.97^{b}	17.06	28.64^{a}	19.18	22.55	31.66	24.599*	4.0415
Kandhamal	2.36^{b}	51.43	1.84^{bc}	20.77	4.0^{a}	55.46	2.73	62.29	5.802*	1.3548
Kendrapara	23.15^{a}	47.9	22.03^{ab}	13.7	11.33^{c}	54.48	18.84	48.12	7.508*	6.9107
Keonjhar	6.12^{ab}	68.6	3.02^{c}	27.44	6.42^{a}	49.8	5.18	64.84	3.734*	2.8297
Khordha	3.52^{b}	63.73	6.41^{a}	42.77	1.87^{c}	46.4	3.93	70.92	11.94*	1.9311
Koraput	0.35^{c}	21.02	1.23^{b}	44.74	3.42^{a}	36.1	1.67	90.79	40.88*	0.7178
Malkangiri	18.56^{c}	68.47	33.11^{a}	41.5	27.55^{ab}	45.96	26.41	52.97	3.169^{NS}	11.9706
Mayurbhanj	4.8^{c}	25.21	10.1^{ab}	34.96	10.38^{a}	45.21	8.43	50.33	8.257*	3.1766
Nabarangapur	1.96^{ab}	48.51	1.91^{abc}	39.01	3.08^{a}	96.36	2.32	80.64	1.28^{NS}	1.6977
Nayagarh	1.49^{ab}	25.59	1.15^{c}	33.09	1.58^{a}	19.75	1.41	28.13	4.093*	0.3301
Nuapada	12.84^{c}	33.85	18.26^{ab}	20.19	19.49^{a}	26.74	16.86	30.9	6.305*	4.0912
Puri	20.05^{bc}	30.62	27.68^{a}	20.16	20.29^{b}	55.68	22.67	37.93	2.878^{NS}	7.4254
Rayagada	0.92^{c}	44.9	1.62^{b}	9.49	2.68^{a}	17.6	1.74	47.01	56.322*	0.3428
Sambalpur	1.18^{bc}	61.1	1.52^{b}	27.14	2.38^{a}	32.01	1.69	47.76	8.904*	0.5973
Subarnapur	3.39^{c}	25.21	5.78^{ab}	50.21	5.86^{a}	26.29	5.01	44.34	5.126*	1.7989
Sundargarh	7.11^{a}	46.36	5.32^{abc}	42.37	5.9^{ab}	19.51	6.11	39.87	1.452^{NS}	2.2009

*CV=Coefficient of Variation (%) CD=Critical Difference at 5% level of significance, *Significant at 5% level of significance*

5. Conclusion

The comprehensive multi-method analysis of Groundnut in Odisha over five decades yields the following major conclusions.

1. Groundnut cultivation in Odisha has undergone a significant structural transformation over the 50-year study period, from an area-expansion dominated growth phase in Period I (1974-83) to a yield-led intensification in Periods IV and V (2004-2023). The highly significant yield trend confirmed by the Mann-Kendall test reflects successful variety adoption and agronomic improvements, even as area under cultivation gradually declined. Groundnut production has maintained a positive trajectory overall, driven entirely by productivity gains.
2. Temporal instability as measured by CV% was most severe during Period I for both crops, reflecting the high-volatility expansion era. The progressive decline in CV% for Groundnut yield from 17.94 per cent in Period I to 4.98 per cent in Period V confirms that yield stabilization has been achieved for Groundnut.
3. District-level growth analysis revealed pronounced spatial heterogeneity in oilseed performance. The southern tribal districts of Koraput, Deogarh, Rayagada, and Boudh have emerged as new frontiers for Groundnut expansion with significant positive trends, while traditionally important northern and coastal districts such as Bargarh, Jajpur, Kendrapara, and Bolangir are experiencing significant decline. This divergence signals a geographic shift in Odisha's Groundnut belt from established areas to newer peripheral zones.

6. Limitations

This study relied on secondary statistics and aggregated annual observations; consequently, data consistency across reporting periods and districts may influence the estimates. The analysis describes statistical associations and trends but does not establish the causes of changes in area, yield or production. District-level data were available for 30 years, compared with 50 years at the state level, limiting direct comparison over identical time frames. The findings should therefore be interpreted as descriptive evidence of growth and variability rather than causal estimates of the effects of specific policies, technologies or climatic factors.

Declaration of AI Use

This manuscript was prepared through the intellectual contributions of the author(s) to the study design, data analysis, interpretation of results, and scholarly content. ChatGPT, Claude and Perplexity were used solely to assist with grammatical refinement and

reference formatting during manuscript revision. The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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