



## A statistical analysis of inter-state disparities in agricultural development across India

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### ABSTRACT

A comparative analysis of inter-state variations for three years i.e. 2019–20 to 2021–22 in agricultural development across India had been done by using secondary data from the major agricultural states for 28 key development indicators related to agriculture for Triennium Ending (TE) 2022. The composite indices of development based on the optimum combination of indicators related to agriculture had been worked out for four zones and the overall agricultural states of India. The results of Composite Index (CI) showed that Punjab (0.32), West Bengal (0.37), Gujarat (0.52), and Kerala (0.58) ranked highest in the north, east, west, and south zones, respectively. Overall, the state-wise CI ranged from 0.47 in Punjab to 0.83 in Odisha. The states were further ranked and categorised into high (H), high middle (HM), low middle (LM), and low (L) levels of development. Punjab (0.47), Haryana (0.51), Gujarat (0.59), and Madhya Pradesh (0.60) emerged as the most agriculturally developed states. Significant factors, namely gross irrigated area, mechanisation and technical adoption (tube wells), productivity [wheat (*Triticum aestivum* L.), maize (*Zea mays* L.), and vegetables], input usage (chemical fertiliser), and economic dimension of agriculture [sugarcane (*Saccharum officinarum* L.) returns] were identified among the development indicators. Enhancing these factors could improve the socio-economic conditions of Indian farmers. The study suggested that the low-developed states require improvements in various dimensions in most indicators to enhance the overall development of agriculture.

**Keywords:** Agriculture sector, Composite index, Development, Inter-state variation, Regression analysis

Agricultural development is a continuous process of improving crop and livestock production. In India, agriculture employs nearly half of the workforce but contributes only 17.7% to the GDP (Gross domestic product, at current prices in 2015–16) (Deshpande 2017). Technology assimilation in agriculture and industry is considered a primary objective of economic development, alongside the reduction of inequalities in income, social status, and growth potential. Socio-economic development encompasses various dimensions, including agricultural and economic growth, education, health services, housing quality, and access to communication and transportation. Developmental programmes aim to achieve uniform regional development and enhance people's quality of life. However, regional inequalities persist due to differences in resource base distribution. Despite efforts to reallocate resources to less developed regions through subsidies and central assistance, regional inequalities in agricultural development remain relatively high (Ohlan 2013). Realising the need to focus on the attention of policy makers and administrators

for the regional inequalities of socio-economic development in the country, efforts were started in 1982 by organising a seminar jointly by the Planning Commission, Government of India, State Planning Institute and Government of Uttar Pradesh (Narain *et al.* 2007).

A single indicator cannot fully capture the impact of development. Therefore, there was need to construct a Composite index (CI) based on various agricultural indicators across different Indian states. This study aimed to quantify the agricultural development of major agricultural states in India by creating a composite index and providing a comparative scenario of inter-state inequalities in the agricultural sector. By analysing the inter-state disparities, this study had provided valuable insights for policymakers and administrators, helping them to formulate targeted strategies for balanced agricultural development across the country.

### MATERIALS AND METHODS

In the present study, secondary data with respect to 28 development indicators of agriculture corresponding to 22 major agricultural states of India for recently available data of selected variables for three years 2019–20 to 2021–22 were taken from different reliable sources. Data used were

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mean of three years 2019–20 to 2021–22 (Triennium Ending: TE 2022).

These indicators covered many aspects, providing a multifaceted view of the agricultural sector's development. The indicators had been broadly categorised into several key areas of agricultural development. Land use indicators included net sown area (NSA) as a percentage of geographical area and cropping intensity, which measured how intensively the available land was used to measure development in India's agriculture sector. The gross irrigated area represented irrigation as a percentage of the gross cropped area, reflecting water resource utilisation. Input usage was captured through indicators like consumption of chemical fertilisers and pesticides, providing insights into the intensity of agricultural practices. Mechanisation and technological adoption were represented by indicators such as the number of tube wells and tractors/thousand NSA and power consumption in agriculture. These metrics helped to gauge the level of modernisation in farming practices across different states. Infrastructure indicators included warehouse capacity, the area served by regulated markets, and veterinary centers, all of which support agricultural activities and market access. A significant portion of the indicators focused on crop productivity, measuring the average yield of various crops, including rice, wheat, cereals, pulses, cotton, sugarcane, maize, oilseeds, vegetables, and fruits. These yield indicators provided direct measures of agricultural output efficiency across different crop types, allowing for comparisons between states. The economic dimension of agriculture was captured through indicators like Gross Value Added (GVA) and net returns for major crops such as paddy, wheat, maize, cotton, and sugarcane. These financial metrics offered insights into the economic viability and profitability of different agricultural activities across states and zones. Another social development indicator was membership of farmers in co-operative societies. The data for these indicators taken from various reliable sources, ensuring a robust and comprehensive dataset. Sources included were India Stat, Statistical Abstract of Punjab, Agricultural Statistics at a Glance, Directorate of Marketing and Inspection, and government websites like eands.dacnet.nic.in. This diversity of sources helped to provide a well-rounded and accurate picture of agricultural development. The statistical software R was used to analyse data using composite index, stepwise regression, and residual analysis.

*Wroclow Taxonomic method (Composite Index):* The impact of developmental activities is a multidimensional process. Hence, the composite indices of development for different states had been evaluated by applying the Wroclow Taxonomic method developed by Florek *et al.* (1951). States' performance was compared according to ranks assigned to indicators.

Variables for different developmental indicators had different units of measurement, thus, variables were transformed into standardised variables for the combined analysis. Let  $X_{ij}$  be the data matrix giving the values of the variables of the  $i^{\text{th}}$  state and  $j^{\text{th}}$  indicator.

$$[X_{ij}] \text{ is transformed as: } [Z_{ij}] = \frac{X_{ij} - \bar{X}_j}{s_j}$$

Where  $\bar{X}_j$ , Mean of the  $j^{\text{th}}$  indicator;  $S_j$ , Standard deviation of the  $j^{\text{th}}$  indicator;  $[Z_{ij}]$ , Matrix of standardised indicators;  $i, 1, 2, \dots, n$  (number of states);  $j, 1, 2, \dots, k$  (number of indicators). From  $[Z_{ij}]$ , this identified the best value of each indicator. Let it be denoted as  $Z_{0j}$ . The best value can either be maximum or minimum value of the indicator, depending upon the direction of the indicator's impact on the development level. The pattern of development was calculated as:

$$C_i = \left[ \sum_{j=1}^k P_{ij} / (CV)_j \right]^{1/2}$$

Where  $P_{ij} = (Z_{ij} - Z_{0j})^2$ ;  $(CV)_j$ , Coefficient of variation of  $X_{ij}$  for  $j^{\text{th}}$  indicator. A composite index of development is given by:

$$CI = C_i / C$$

Where  $C = \bar{C} + 3SD$ ;  $\bar{C}$ , Mean of  $C_i$ ;  $SD$ , Standard deviation of  $C_i$ . A smaller value of  $D_i$  will indicate a high level of development and a higher value of  $D_i$  will indicate a low level of development. States were categorised into four categories, viz. High [ $<$  (Median - SD)], High Middle [(Median - SD) to Median], Low Middle [Median to (Median + SD)] and Low [ $\geq$  (Median + SD)].

*Stepwise regression analysis:* To identify the most significant indicator variables affecting composite indices, the stepwise regression analysis (Draper and Smith 2003) was applied. This method evaluated independent indicator variables of agriculture for their potential contribution and excluded those variables that were not statistically significant in the multiple regression models ( $p \leq 0.30$ ). Stepwise regression has the advantage of using a small subset of least correlated variables without losing a considerable portion of the explanatory power of the data, thus, minimising the effects of multi-collinearity on the regression model (Huang and Townshend 2003).

$$Y = \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k$$

Where  $Y$ , Composite index;  $X_i$ 's, Independent development indicators of different states.

*Comparison and validation:* Model validation was the most important step in the model-building process. Once a regression model was constructed, it was essential to calculate the goodness of fit statistics of the model and test the residuals. The developed models were compared using goodness of fit statistics, coefficient of determination ( $R^2$ ), adjusted  $R^2$ , and Akaike Information Criterion (AIC). A model with the highest value of  $R^2$  and adjusted  $R^2$  and least value of AIC was considered to be the best model.  $R^2$  and adjusted  $R^2$  measure the proportion of variation in the dependent variables explained by the regression model. AIC measures the quality of the model.  $R^2$  is the variability explained by regression model/ total variability in the dependent variable and ranges from 0 to 1, i.e.  $0 \leq R^2 \leq 1$ .

Adjusted  $R^2$  is used to compare models with different parameters in the model.

$$\text{Adjusted } R^2 = 1 - [(1 - R^2) (n-1) / (n-p)]$$

$$\text{AIC} = n + n \log(2\pi) + n \log(\text{RSS}/n) + 2p$$

Where  $n$ , Number of observations;  $p$ , Number of parameters in the model; RSS, Residual sum of squares.

*Tests applied to check assumptions of residuals:* Analysis of residuals to check model suitability is required to test regression model  $e_i \sim \text{IN}(0, \sigma^2)$  assumptions. Thus, a Run test was applied for testing the independence of residuals, t-test for testing zero mean, Breusch-Pagan test (Breusch and Pagan 1979) for constant variance, and the Shapiro-Wilk (W) test (Shapiro and Wilk 1965) for normality. Assumptions of residuals were confirmed by plotting of residuals: Linearity assumption by inspecting the residuals vs fitted plot; Homogeneity of variance by examining the scale-location plot, also known as the spread-location plot; Normality by QQ plot of residuals (The normal probability plot should approximately follow a straight line); Influential observations by residuals vs. leverage plot, where x-axis showed the leverage of each point and the y-axis showed the standardised residual of each point.

*Compound Annual Growth Rate (CAGR):* The annual compound growth rate in expenditure on education in India was calculated in percentage using the exponential model.

## RESULTS AND DISCUSSION

*Pattern of development ( $P_{ij}$ ):* The composite index of agricultural development along with ranks for different states and zones were evaluated, however, indicators-wise  $P_{ij}$  was evaluated for different states and zones of India (Table 1 and 2). Minimum value of  $P_{ij}$  and CI implies a better value for the indicator (except for  $P_{ij}$  of fertiliser and pesticide consumption).

Significant variations were noticed among states of the north zone. Punjab and Haryana generally performed well in input-intensive agriculture. They had the highest fertiliser consumption (index value of  $P_{ij}$  is 0.27 and 0.21, respectively) and high net sown area (0.00), indicating intensive cultivation practices. Since the excessive dependence of wheat and rice crop and growing the same crops year after year had led to deterioration in the health of soils, that is why, higher dose of fertilisers had to be applied to achieve the same level of productivity (Krasilnikov *et al.* 2022). In addition to this, Punjab also excelled in irrigation networks (0.00), confirming its well-developed irrigation networks. Due to this, Punjab led in productivity from the mono-cropping system, i.e. paddy and wheat (all 0.00, indicating the highest yield), while Haryana excelled in sugarcane returns (0.00). Himachal Pradesh and Uttarakhand, being mountainous states, showed different patterns. They had low net sown area (0.19 and 0.20, respectively) and least fertiliser and pesticide consumption. Himachal Pradesh excelled in pulses productivity (0.00) and maize returns (0.05). Uttar Pradesh, the largest state in this zone, showed moderate performance across most indicators.

It had the highest member of cooperative societies (0.10).

The west zone showed diverse agricultural patterns. Gujarat stood out with high gross irrigated area (0.04), pulses and oilseeds yield (0.20, 0.03, respectively). Maharashtra showed strong growth in maize returns (0.02) and sugarcane yield (0.04), aligning with its reputation for sugarcane production. Madhya Pradesh performed well in maize yields (0.12), returns from sugarcane (0.08) and cropping intensity (0.01). Despite its arid climate, Rajasthan exhibited and strong performance in cotton yield (0.03).

The south zone states indicated low cropping intensity. Andhra Pradesh led in GSVA (0.15), highest maize returns, fruits and vegetables yield (all 0.00). Karnataka excelled in cotton (0.04) and sugarcane returns (0.02). Kerala expressed unique patterns with high power consumption for agriculture (0.09), tractor numbers (0.22), and fruit productivity (0.16), reflecting its diverse agricultural landscape. Tamil Nadu depicted gross irrigated area (0.04), number of tubewells (0.00), tractors (0.06), storage (0.07), maize (0.00) and oilseeds (0.00) productivity.

The east zone depicted some of the most diverse patterns. West Bengal topped in net sown area (0.02), cropping intensity (0.00), yield of: sugarcane (0.06); wheat (0.06); rice (0.13); maize (0.00) and cereals (0.10). Bihar revealed high tractor numbers (0.02) and strong maize returns (0.01). Odisha led in cotton yield (0.06). Chhattisgarh led in power consumption (0.02) and paddy returns (0.03). The northeastern states like Arunachal Pradesh, Assam, and Jharkhand generally showed lower values for input-intensive indicators and performed moderately in productivity measures.

Analysis revealed the diverse agricultural landscape across India. While some states excelled in input-intensive, high-yield agriculture (like Punjab and Haryana), others showed strengths in specific crops or less input-intensive agriculture forms (like the northeastern states). The southern states indicated least cropping intensity but showed good performance across various crops. Western states expressed resilience and specialisation in crops suited to their climates. The eastern states, sometimes lagging in inputs, revealed moderate productivity. These patterns reflected the influence of geographical, climatic, and historical factors on agricultural practices and performance across different regions of India.

*Zone-wise composite index (CI) of agricultural development:* Zone-wise composite indices (Table 3, Fig. 1a) revealed that Punjab (CI: 0.32) and Haryana (CI: 0.35) dominated in north zone due to their extensive irrigation networks, high cropping intensity, and advanced mechanisation (high number of tractors and tube wells). These states are known for their Green Revolution success, with high yields in crops like wheat and rice. Low CI values reflected high agricultural productivity and well-developed infrastructure. Uttar Pradesh (CI: 0.57) ranked third, likely due to its vast agricultural land and significant contribution to India's food grain production, but it lagged behind Punjab and Haryana in terms of mechanisation

Table 1 Indicators-wise ( $P_{ij}$ ) pattern of development among different states of India

States	Zone	Net sown area	Cropping intensity	Gross irrigated area	Fertilizer consumption	Tube wells	Tractors	Power consumption	Storage	Pesticides consumption	GSVA	Market served area (ha)	Vet centre served area	Members of Co.Soc
Punjab	North	0.000	0.000	0.000	0.266	0.015	0.004	0.017	0.000	0.017	0.049	0.159	0.200	0.145
Haryana		0.000	0.007	0.000	0.214	0.056	0.000	0.017	0.023	0.010	0.062	0.156	0.207	0.135
Uttar Pradesh		0.008	0.082	0.006	0.160	0.111	0.021	0.026	0.052	0.084	0.300	0.137	0.115	0.102
Uttarakhand		0.196	0.107	0.053	0.115	0.120	0.020	0.084	0.093	0.000	0.250	0.102	0.102	0.164
Himachal Pradesh		0.191	0.054	0.149	0.019	0.109	0.152	0.091	0.096	0.000	0.149	0.104	0.214	0.165
Gujarat	West	0.035	0.280	0.038	0.076	0.061	0.035	0.041	0.089	0.002	0.132	0.130	0.017	0.067
Madhya Pradesh		0.040	0.012	0.056	0.043	0.091	0.029	0.000	0.009	0.000	0.148	0.124	0.011	0.103
Rajasthan		0.035	0.215	0.077	0.018	0.099	0.057	0.000	0.078	0.003	0.124	0.109	0.131	0.129
Maharashtra		0.031	0.269	0.151	0.075	0.026	0.098	0.014	0.071	0.098	0.216	0.140	0.081	0.000
Tamil Nadu	South	0.082	0.467	0.043	0.134	0.000	0.060	0.040	0.069	0.002	0.175	0.131	0.150	0.135
Andhra Pradesh		0.079	0.499	0.056	0.258	0.037	0.129	0.019	0.076	0.002	0.150	0.130	0.108	0.072
Karnataka		0.022	0.427	0.096	0.085	0.035	0.084	0.002	0.086	0.002	0.184	0.138	0.122	0.111
Kerala		0.035	0.449	0.158	0.022	0.026	0.223	0.087	0.090	0.000	0.270	0.117	0.153	0.143
West Bengal	East	0.017	0.000	0.028	0.115	0.111	0.140	0.081	0.084	0.008	0.217	0.155	0.174	0.122
Bihar		0.031	0.246	0.014	0.273	0.113	0.018	0.076	0.078	0.000	0.363	0.117	0.150	0.114
Jharkhand		0.170	0.306	0.182	0.049	0.143	0.139	0.090	0.093	0.000	0.341	0.134	0.037	0.151
Arunachal Pradesh		0.243	0.327	0.166	0.000	0.148	0.226	0.094	0.096	0.000	0.000	0.000	0.000	0.172
Assam		0.086	0.226	0.185	0.024	0.147	0.158	0.092	0.092	0.000	0.273	0.140	0.080	0.157
Chhattisgarh		0.090	0.511	0.100	0.084	0.094	0.081	0.018	0.078	0.002	0.231	0.110	0.039	0.155
Odisha		0.118	0.642	0.121	0.066	0.136	0.102	0.081	0.085	0.001	0.259	0.142	0.141	0.146

GSVA, Gross state value added.

Table 2 Crop (yield and returns) pattern ( $P_{ij}$ ) of development among different states of India

States	Zone	Yield												Returns				
		Sugarcane	Wheat	Cotton	Rice	Maize	Cereals	Pulses	Oilseeds	Fruits	Vegetable	Paddy	Wheat	Maize	Cotton	Sugarcane		
Punjab	North	0.050	0.000	0.000	0.000	0.081	0.000	0.358	0.081	0.004	0.038	0.000	0.001	0.073	0.000	0.010		
Haryana		0.052	0.001	0.092	0.069	0.123	0.017	0.330	0.022	0.024	0.105	0.000	0.000	0.049	0.045	0.000		
Uttar Pradesh		0.052	0.034	0.201	0.177	0.159	0.105	0.278	0.188	0.002	0.026	0.072	0.045	0.048	0.055	0.089		
Uttarakhand		0.073	0.063	0.122	0.198	0.180	0.208	0.339	0.207	0.193	0.380	0.058	0.086	0.049	0.055	0.069		
Himachal P.		0.413	0.149	0.122	0.438	0.137	0.280	0.000	0.302	0.213	0.152	0.039	0.109	0.046	0.055	0.077		
Gujarat	West	0.076	0.050	0.090	0.298	0.188	0.206	0.202	0.029	0.004	0.052	0.037	0.063	0.084	0.041	0.105		
Madhya Pradesh		0.160	0.060	0.097	0.353	0.115	0.160	0.337	0.204	0.004	0.052	0.047	0.042	0.056	0.141	0.077		
Rajasthan		0.061	0.031	0.028	0.26	0.179	0.303	0.568	0.090	0.039	0.237	0.043	0.043	0.085	0.021	0.077		
Maharashtra		0.043	0.163	0.276	0.368	0.162	0.451	0.428	0.138	0.048	0.127	0.173	0.116	0.015	0.085	0.140		
Tamil Nadu	South	0.005	0.094	0.190	0.031	0.000	0.044	0.589	0.000	0.017	0.017	0.051	0.075	0.050	0.110	0.123		
Andhra Pradesh		0.064	0.276	0.087	0.025	0.005	0.033	0.468	0.228	0.000	0.000	0.021	0.075	0.000	0.069	0.317		
Karnataka		0.026	0.213	0.140	0.105	0.115	0.244	0.618	0.204	0.017	0.105	0.026	0.211	0.046	0.041	0.022		
Kerala		0.000	0.165	0.082	0.110	0.233	0.115	0.340	0.312	0.157	0.026	0.013	0.075	0.049	0.055	0.077		
West Bengal	East	0.057	0.063	0.093	0.127	0.001	0.101	0.419	0.150	0.048	0.105	0.091	0.168	0.049	0.055	0.077		
Bihar		0.099	0.073	0.122	0.350	0.097	0.203	0.427	0.157	0.058	0.105	0.073	0.090	0.014	0.055	0.121		
Jharkhand		0.091	0.126	0.122	0.385	0.178	0.306	0.286	0.266	0.082	0.237	0.090	0.226	0.062	0.055	0.077		
Arunachal Pradesh		0.386	0.135	0.122	0.457	0.209	0.393	0.298	0.182	0.213	0.510	0.043	0.075	0.049	0.055	0.077		
Assam		0.268	0.196	0.582	0.331	0.089	0.265	0.501	0.305	0.039	0.206	0.077	0.075	0.049	0.055	0.077		
Chhattisgarh		0.189	0.193	0.228	0.449	0.129	0.351	0.668	0.306	0.082	0.206	0.026	0.103	0.140	0.055	0.077		
Odisha		0.148	0.167	0.064	0.356	0.130	0.289	0.676	0.260	0.14	0.237	0.068	0.075	0.085	0.097	0.077		

and irrigation coverage. Himachal Pradesh (CI: 0.63) and Uttarakhand (CI: 0.67) had higher CIs, possibly due to their mountainous terrain limiting large-scale agriculture and mechanisation. However, they might had higher returns from high-value horticultural crops. As far as the west zone was concerned, Gujarat (CI: 0.52) topped among all the states, probably due to its well-developed irrigation systems, diverse crop production, and strong agricultural marketing infrastructure. Rajasthan (CI: 0.56) followed closely, possibly due to improvements in drought-resistant farming techniques and irrigation projects despite its arid climate. Madhya Pradesh (CI: 0.73) and Maharashtra (CI: 0.76) had higher CIs, which might seem surprising given their significant agricultural output. This could be due to regional disparities within these large states, with some areas having highly developed agriculture while others lag.

Kerala and Karnataka with a CI of 0.58 led the south zone. Kerala's position might be due to its high-value plantation crops and well-developed agricultural marketing systems. At the same time, Karnataka benefitted from a mix of traditional and commercial crops and improved irrigation systems. Tamil Nadu CI (0.64) followed closely, possibly due to its well-developed irrigation systems and diverse crop production. Andhra Pradesh's higher CI (0.82) was surprising given its reputation for agriculture. This might reflect regional disparities or indicate areas for agricultural infrastructure and practices improvement. These rankings reflected a complex interplay of natural resources, historical development patterns, and current agricultural policies and practices.

In the east zone, West Bengal (CI: 0.37) topped among all the states, probably due to its high cropping intensity, well-developed irrigation systems, and diverse crop production, including rice and vegetables. Bihar (CI: 0.48) followed it, benefitted from fertile lands and improved agricultural practices but might be held back by lower mechanisation and infrastructure development. Assam, Jharkhand, Odisha, and Chhattisgarh had higher CIs (0.63–0.69), possibly reflecting challenges in irrigation

Table 3 Zone-wise composite index (CI) of agricultural development along with rank

Zone	State	CI	Rank
North	Punjab	0.32	1
	Haryana	0.35	2
	Uttar Pradesh	0.57	3
	Himachal Pradesh	0.63	4
	Uttarakhand	0.67	5
West	Gujarat	0.52	1
	Rajasthan	0.56	2
	Madhya Pradesh	0.73	3
	Maharashtra	0.76	4
South	Kerala	0.58	1
	Karnataka	0.58	2
	Tamil Nadu	0.64	3
	Andhra Pradesh	0.82	4
	East	West Bengal	0.37
Bihar		0.48	2
Assam		0.63	3
Jharkhand		0.64	4
Odisha		0.68	5
Chhattisgarh		0.69	6
Arunachal Pradesh		0.74	7

coverage, lower mechanisation, and less development. While Arunachal Pradesh (CI: 0.74) ranked lowest, likely due to its mountainous terrain limiting large-scale agriculture and challenges in infrastructure development.

*State-wise Composite Index (CI) of agricultural development:* The states of India were categorised into four categories, viz. High (H), High Middle (HM), Low Middle (LM), and Low (L) (Table 4, Fig. 1b). The study explained the states within each zone, considering the various indicators taken in the study. Punjab, Haryana, Gujarat, and Madhya Pradesh dominated in the agricultural development.

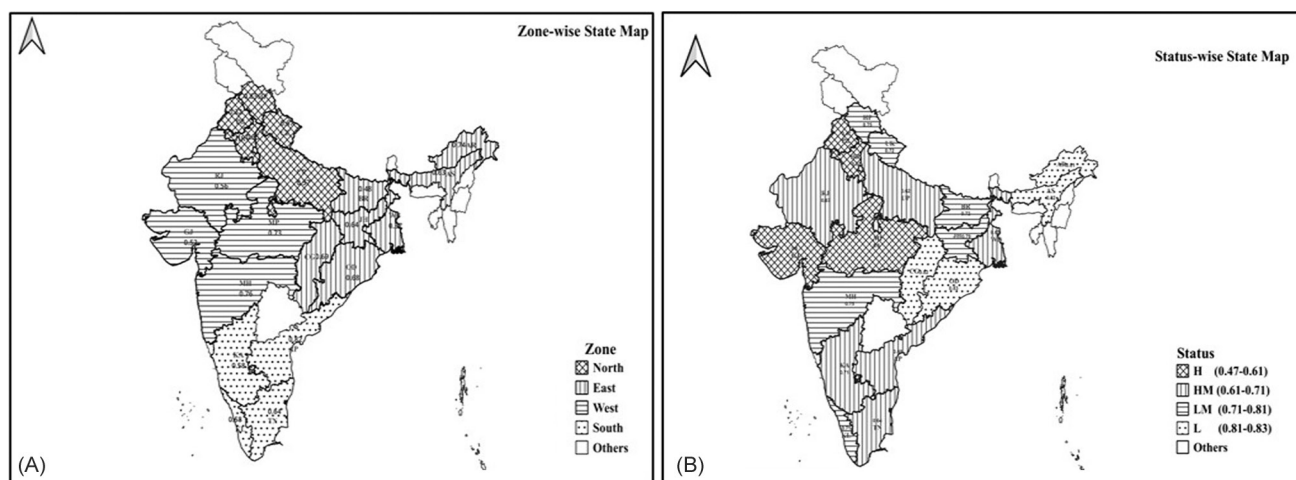


Fig. 1 Zone-wise and state-wise map of composite index. H, High; HM, High middle; LM, Low middle; L, Low.

These states excelled in most of the indicators mentioned. They probably had high percentages of net sown area, good cropping intensity, and extensive irrigation coverage. Their input usage (fertilisers, pesticides) had been high, as was their level of mechanisation (tube wells, tractors, power consumption). These states had robust agricultural infrastructure and high crop yields across various crops. Their GVA and net returns for major crops were probably the highest in the country. Uttar Pradesh, West Bengal, Tamil Nadu, Rajasthan, Andhra Pradesh, and Karnataka followed closely. These states performed well in many indicators but might not be as consistent across all factors as the top tier. They might have varying strengths, for example, some excelled in irrigation while others led in crop diversity or mechanisation. Their crop yields and economic returns were likely above the national average but showed more variation across different crops. Kerala, Bihar, Uttarakhand, Maharashtra, Himachal Pradesh, and Jharkhand fell in the low middle category. These states showed a mix of strengths and areas for improvement across the various indicators. Some might have geographical constraints affecting their net sown area or irrigation potential. They might have moderate levels of mechanisation and input usage. Their crop yields and economic returns likely varied significantly across different crops and regions within the state. Arunachal Pradesh, Assam, Chhattisgarh, and Odisha had the lowest CI scores. These states likely faced more challenges across multiple indicators. They had lower percentages of net sown area, less irrigation coverage, and lower levels of mechanisation. Their input usage and agricultural infrastructure might be less developed than in other states. Crop yields and economic returns were below the national average for most crops. However, it was important to note that these states might have unique agricultural practices or crops suited to their specific geographical and climatic conditions, which might need to be fully captured in the standardised indicators (Nath and Nath 2023).

This analysis provided a broad overview based on the composite index. It's important to remember that each state had its unique agricultural profile, strengths, and challenges, which might need to be fully reflected in a single composite score.

*Factors responsible for development indicators:* The model demonstrated a robust explanatory power, accounting for 98.02% of the variability in the composite index (Table 5). This high level of explanatory capability was achieved by incorporating variables such as gross irrigated area (GIA), number of tube wells, wheat yield, vegetable yield, chemical fertilisers consumption, maize yield, and sugarcane returns. Although the test was calculated at 5% level of significance, GIA was included in the model owing to its critical role in agricultural development. Additionally, multi-collinearity was tested by using Variance Inflation Factor (Table 5) and the results represented that there was no multi-collinearity among the variables.

Most of the indicator variables exhibited a negative coefficient in the regression model, indicating that an

Table 4 State-wise composite index (CI) of agricultural development along

Zone	State	Geo-graphical area (%)	Population (%)	CI	Rank	Status
North	Punjab	1.64	2.26	0.47	1	H
North	Haryana	1.42	2.19	0.51	2	H
West	Gujarat	6.20	4.93	0.59	3	H
West	Madhya Pradesh	9.99	6.21	0.60	4	H
North	Uttar Pradesh	7.85	17.55	0.62	5	HM
East	West Bengal	2.82	7.26	0.63	6	HM
South	Tamil Nadu	4.23	5.27	0.64	7	HM
West	Rajasthan	11.14	5.80	0.67	8	HM
South	Andhra Pradesh	5.29	6.82	0.68	9	HM
South	Karnataka	6.19	4.83	0.70	10	HM
South	Kerala	1.26	2.72	0.71	11	LM
East	Bihar	3.04	8.17	0.72	12	LM
North	Uttarakhand	1.95	0.84	0.72	13	LM
West	Maharashtra	9.99	9.49	0.75	14	LM
North	Himachal Pradesh	1.49	0.55	0.75	15	LM
East	Jharkhand	2.59	2.66	0.79	16	LM
East	Arunachal Pradesh	2.33	0.10	0.81	17	L
East	Assam	2.55	2.55	0.82	18	L
East	Chhattisgarh	4.48	2.04	0.82	19	L
East	Odisha	5.01	3.28	0.83	20	L

H, High (0.47–0.61); HM, High Middle (0.61–0.71); LM, Low Middle (0.71–0.81); L, Low (0.81–0.83).

increase in these variables had been associated with a decrease in the composite index. This reduction had been interpreted as a sign of growth in the agricultural sector. For instance, an increase in gross irrigated area might imply more extensive irrigation efforts, which, initially reduced the composite index, ultimately contributed to better agricultural productivity and growth. Similarly, the proliferation of tube-wells, although initially led to a drop in the composite index, supported enhanced irrigation and water management, fostering agricultural development. The negative and highly significant coefficients of wheat and vegetable yields on the composite index could be understood in the context of agricultural efficiency and market dynamics. Higher yields often reflect improved agricultural practices, better crop varieties, and effective resource utilisation, all of which were indicative of sectoral growth despite their initial negative (Ahvo *et al.* 2022).

Further, the study was confirmed by testing the assumptions of residuals to check model suitability at the 5% level of significance. Residuals of the composite index on different indicators using a step-wise regression model followed all the assumptions (Supplementary Table 1). The independence of residuals assumption was tested using the run test of randomness ( $p=0.64$ ), the zero mean of residuals

Table 5 Stepwise regression analysis of composite index on different indicators

Indicators	Coefficient	SE	t-value	p-value	VIF
Intercept	1.029e+00**	3.055e-02	33.67	0.00**	-
Tube wells	-1.803e-04*	6.769e-05	-2.66	0.02*	3.60
Wheat yield	-5.715e-05**	8.571e-06	-6.67	0.00**	6.44
Vegetable yield	-7.704e-03**	1.475e-03	-5.22	0.00**	3.34
Fertiliser consumption	5.896e-04**	1.523e-04	3.87	0.00**	5.56
Maize yield	-2.066e-05**	5.057e-06	-4.09	0.02**	3.66
Returns from sugarcane	-3.804e-07*	1.388e-07	-2.74	0.02*	5.05
Gross irrigated area	-6.751e-04	5.952e-04	-1.13	0.28	3.06

R<sup>2</sup> = 0.98\*\*, Adj R<sup>2</sup> = 0.97\*\* and AIC = -152.58

\* and \*\* indicate significance at the 5% and 1% levels, respectively (-1.803e-04, = -0.0001803). SE, Standard error; VIF, Variance inflation factor; AIC, Akaike Information Criterion.

by t-test ( $p=1$ ), variance homogeneity by the Bseuch-Pagan test ( $p=0.68$ ), and normality by the Shapiro-Wilk test ( $p=0.73$ ).

States like Punjab, Haryana, Gujarat, and Madhya Pradesh emerged as leaders with very high agricultural development levels, extensive irrigation networks, high cropping intensity, advanced mechanisation, and strong agricultural infrastructure. These states likely benefitted from historical investments, favourable geographical conditions, and effective agricultural policies. However, the states like Arunachal Pradesh, Assam, Chhattisgarh, and Odisha showed lower levels of agricultural development, suggesting challenges in areas such as irrigation coverage, mechanisation, and agricultural infrastructure. This highlighted the need for targeted interventions and investments in these regions to bridge the development gap. The regression analysis identified key factors contributing to agricultural development, including number of tube wells, crop yields (particularly wheat, vegetables, and maize), chemical fertiliser consumption, and returns from sugarcane. The negative coefficients of these variables in relation to the composite index suggested that improvements in these areas were associated with overall agricultural growth and development.

Interestingly, some states with reputations for strong agricultural output, such as Maharashtra and Andhra Pradesh showed middling composite index scores. This could indicate regional disparities within these large states or suggest areas for potential improvement in certain aspects of their agricultural sectors. Overall, the study underscored India's complex, multifaceted nature of agricultural development. It highlighted the importance of a holistic approach to agricultural policy, addressing factors such as irrigation, mechanisation, crop diversification, and agricultural infrastructure. The findings could guide policymakers in formulating targeted strategies to promote more balanced agricultural development across all regions of India.

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