

Agricultural Transformation and Regional Disparities in Bihar: An Analytical Assessment Based on Agricultural Statistics (2001–2025)

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Abstract:

Agriculture in Bihar has changed considerably over the past two decades, but these changes have not been the same in all parts of the state. This study looks into agricultural transformation and regional differences in Bihar during the period 2001–2025. Paper examines the relationship between irrigation, fertilizer use, and cropping intensity on the one hand, and foodgrain production and land productivity on the other. The analysis relies on CAGR to track how key variables have changed over time, OLS regression to see which factors most affect yield, and one-way ANOVA with Tukey's post-hoc test to check whether the four agro-climatic zones of Bihar differ significantly from one another.

The empirical results underscore a discernible shift within Bihar's primary agricultural sector. Key indicators of agricultural performance show marked improvement over the period. Average yields of foodgrains in the state have risen from 1,480 kg/ha during 2001–05 to 2,820 kg/ha during 2021–25 (CAGR 2.73%). This increase has been associated with faster growth in fertilizer use (CAGR 3.58%) and a steady expansion of net irrigation coverage (CAGR 1.29%). The regression model explains most of the variation in productivity ($R^2 = 0.942$, $p < 0.001$) and identifies chemical fertilizer application ($\beta = 6.12$, $p < 0.001$) and the net irrigation ratio ($\beta = 12.84$, $p = 0.001$) as the main factors behind the rise in yields. Nonetheless, the ANOVA examination ($F = 8.42$, $p = 0.0002$) refutes the hypothesis of regional uniformity, exposing notable productivity divergences among the various sub-regions. The leading productivity performance in South-West Bihar (Zone III-B) is attributed to superior canal infrastructure and heightened adoption of inputs, in contrast to the limitations faced by North-Eastern (Zone II) and South-Eastern (Zone III-A) districts due to waterlogging and seasonal moisture challenges. The study advocates for tailored infrastructure development strategies, formalization of tenant credit mechanisms, and expansion of market linkages to foster more inclusive agricultural growth.

Keywords: Agricultural Transformation, Regional Disparities, Bihar Economy, Yield Determinants, Agro-Climatic Sub-Zones, Multiple Linear Regression, Analysis of Variance (ANOVA), Agricultural Road Maps.

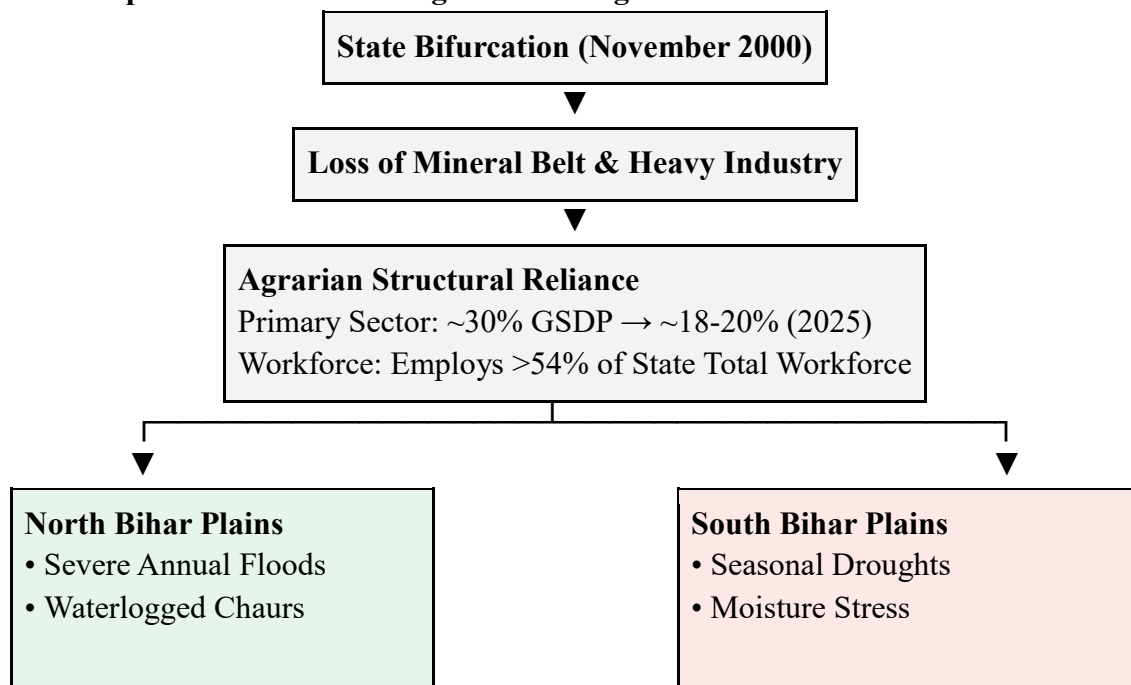
1. Introduction

1.1 Macro-economic and Agrarian Background Post-State Bifurcation (2000)

The Bihar Reorganisation Act of November 2000 not only delineated a new territorial boundary but also fundamentally reshaped Bihar's economic trajectory. The establishment of Jharkhand resulted in the

detachment of the state's resource-abundant southern plateau, its industrial infrastructure, and its forest assets. What was left was primarily an agricultural region, vulnerable and reliant. Bihar has largely remained an agriculture-dependent state, particularly in its rural areas. The limited availability of mineral resources and the relatively small industrial base have restricted the scope of alternative employment opportunities. As a result, agriculture has continued to support a large section of the rural population and remains important for both food security and household income. In 2001–02, agriculture contributed more than 30% of the state's GSDP, while more than three-fourths of the rural workforce was dependent on the sector. The situation has changed gradually over the following two decades. With the growth of manufacturing, construction, trade, transport, and other services, the share of agriculture in GSDP has fallen. By 2024–25, agriculture accounted for roughly 18–20% of Bihar's GSDP. Despite this decline in its economic share, agriculture continues to be particularly important to Bihar's rural economy.

Figure 1: Conceptual Framework of Agrarian Realignment in Bihar Post-State Bifurcation (2000)



Source: Conceptualized by authors based on Department of Finance, Government of Bihar structural reports.

1.2 Physical Geography and Ecological Heterogeneity

Bihar's physical geography exhibits diverse agricultural landscapes, divided into two main natural divisions by the Ganges River: North Bihar and South Bihar. North Bihar features alluvial plains intersected by significant Himalayan River networks such as the Kosi, Gandak, Burhi Gandak, Bagmati, and Mahananda. While these rivers deposit fertile sediments, they also expose 15-20 districts to severe seasonal floods and persistent waterlogging issues. In contrast, South Bihar is characterized by older alluvial terrains transitioning towards the emerging Chota Nagpur Plateau. This region experiences elevated temperatures, reduced seasonal precipitation, and recurring droughts due to delayed monsoons. As a result, Bihar offers an insightful case for examining the interaction between standardized state-level agricultural strategies and distinct regional ecological circumstances.



To address low productivity, crop vulnerability, and stagnant agrarian growth rates during the early 2000s, the Government of Bihar initiated long-term institutional planning through multi-sectoral **Agricultural Road Maps** beginning in 2008 (Department of Agriculture, 2008, 2012, 2017, 2023).

STATE POLICY TRAJECTORY: BIHAR AGRICULTURAL ROAD MAPS

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STATE POLICY TRAJECTORY: BIHAR AGRICULTURAL ROAD MAPS			
1st Road Map (2008–2012)	2nd Road Map (2012–2017)	3rd Road Map (2017–2023)	4th Road Map (2023–2028)
Mechanization Subsidies	Crop & Allied Diversification	High-Tech Micro-Irrigation	FPOs & Tenancy Reforms

Source: Department of Agriculture, Government of Bihar (2008, 2012, 2017, 2023)

- First Agricultural Road Map (2008–2012):** Focused on improving the Seed Replacement Rate (SRR), expanding farm mechanization subsidies, promoting bio-farming, and establishing systemization in rice and wheat cultivation. Primary sector growth recovered to an average of 3.1% annually during this period.
- Second Agricultural Road Map (2012–2017):** Promoted a "Rainbow Revolution" framework designed to advance both crop and non-crop sub-sectors-including horticulture, animal husbandry, dairy, and fisheries. Another important step was the improvement of rural power supply through dedicated electricity feeders for agricultural tube wells. Foodgrain production also increased during this period and reached 252 lakh tonnes. Bihar received national recognition through the Krishi Karman Awards.
- Third Agricultural Road Map (2017–2023):** Greater attention was given to climate-resilient farming, organic farming corridors along the Ganga, efficient micro-irrigation, and the wider use of digital agricultural extension services.
- Fourth Agricultural Road Map (2023–2028):** Supported by a state outlay of ₹1.62 lakh crore, this phase focuses on ecological land development in low-lying (*chaur*) and riverine (*diara*) areas, supporting Farmer Producer Organizations (FPOs), modernizing supply chains, and integrating tenant farmer access to official credit systems.

1.4 Statement of the Problem and Research Scope

Aggregate output and input consumption have risen, but a critical question persists: who has benefited, and where? Has agricultural transformation reached all corners of Bihar, or have public investments merely reinforced the advantages of already-favoured regions? This study quantifies these patterns-tracking agricultural change and regional disparity across Bihar's 38 districts and four agro-climatic sub-zones from 2001 to 2025.

2. Theoretical Framework and Literature Review

2.1 Theoretical Foundations of Input Intensification

Scholarly work on agricultural transformation highlights a fundamental shift: from farming that depends largely on local resources and tradition to systems grounded in scientific knowledge and higher input use (Hayami & Ruttan, 1971). In developing agrarian economies, this change usually unfolds as farmers begin to adopt a bundle of yield-boosting technologies together—most notably high-yielding variety (HYV) seeds, chemical fertilizers, and reliable, controlled irrigation. The Induced Innovation Hypothesis posits that technical change is guided by relative factor endowments in land-scarce, labour-abundant regions like Bihar, land-saving technologies (such as bio-chemical inputs and double-cropping) serve as the primary mechanism for raising land productivity (Singh et al., 2012).

2.2 Empirical Literature on Agricultural Growth Dynamics in Eastern India

In a comprehensive examination of the determinants of agricultural growth within the eastern region of India, Gulati et al. (2021) noted significant advancements in cereal productivity in Bihar subsequent to the implementation of Agricultural Road Maps. However, the overall agricultural expansion in the region was hindered by insufficient public capital investment per unit area, fragmented distribution networks, and inconsistent availability of rural electricity. Their research emphasizes that Bihar's farm economy can achieve lasting growth only by moving beyond traditional crops and expanding into higher-value activities such as livestock rearing, poultry farming, and commercial horticulture.

Similarly, Jose et al. (2021) scrutinized the evolutionary patterns of sub-sectoral compositions in Bihar from 2000 to 2018. Their empirical analysis revealed that while the field crops sub-sector exhibited annual output fluctuations influenced by variations in monsoon patterns, the livestock and fisheries sub-sectors demonstrated robust annual growth rates surpassing 7% and 9%, respectively. They identified fisheries as a pivotal catalyst for development, transforming Bihar from a fish-importing state to a self-sufficient entity. Nevertheless, their spatial assessment highlighted that enhancements in productivity remained clustered in specific geographical regions, such as the Sone Canal command area in South-West Bihar and the hybrid maize cultivation zones in the North-East.

2.3 Spatial Disparities and Agro-Climatic Asymmetries

Regarding climatic vulnerabilities and risk management, Kishore et al. (2019) evaluated the impact of recurrent weather shocks on farming communities in Bihar. Their findings revealed that localized droughts in South Bihar and severe inundations in North Bihar repeatedly reduced seasonal output gains, leading to rural income instability and seasonal distress migration. They argued that existing social safety net programs offered limited relief due to high transaction costs and spatial coverage gaps, emphasizing the need for solarized micro-irrigation and targeted flood-proofing.

Kumar and Bhattarai (2018) analyzed regional growth convergence among Bihar's districts, concluding that divergence rather than convergence characterized the post-2000 period. Districts with higher baseline irrigation infrastructure (e.g., Rohtas and Bhojpur) captured a disproportionate share of policy benefits, widening the productivity gap relative to flood-affected northern districts and rain-fed southern districts.

2.4 Institutional and Structural Barriers

On land tenure and structural constraints, Vikas (2017) investigated the relationship between farm size, tenancy arrangements, and land productivity in Bihar. The study showed that micro-fragmentation—where over 90% of operational holdings are smaller than one hectare—limits scale efficiencies and capital investment. Furthermore, the prevalence of informal sharecropping (*non-raiyat* farming) presents an institutional barrier: because tenant farmers lack formal land titles, they are frequently excluded from institutional bank credit, government input subsidies, and crop insurance schemes.

2.5 Research Gap Identification

This study fills a research gap by integrating multi-decadal panel data (2001-2025) with rigorous quantitative analysis techniques to investigate temporal growth patterns and spatial discrepancies within agro-climatic sub-regions. By employing Compound Annual Growth Rates (CAGR), Ordinary Least Squares (OLS) Multiple Linear Regression, and One-Way Analysis of Variance (ANOVA), the research aims to analyze factors influencing agricultural yields and visualize geographical variations within Bihar's farming sector.

3. Objectives, Research Hypotheses, and Conceptual Model

3.1 Research Objectives

Objective 1: To examine trends in major agricultural inputs—irrigated area and fertilizer use—and key outcomes, including foodgrain production, cropping intensity, and average crop yield, in Bihar during the period 2001–2025.

Objective 2: To estimate the quantitative effects of agricultural inputs on foodgrain yield in Bihar and assess whether significant differences in productivity exist among the state’s four agro-climatic sub-zones using Multiple Linear Regression and One-Way ANOVA.

3.2 Research Hypothesis

- **Null Hypothesis (H0):** There is no statistically significant difference in mean agricultural productivity across the four agro-climatic sub-zones of Bihar ($p > 0.05$).
- **Alternative Hypothesis (H1):** There are statistically significant differences in mean agricultural productivity across the four agro-climatic sub-zones of Bihar ($p \leq 0.05$).

4. Data Sources and Econometric Methodology

4.1 Data Sources and Panel Structure

This study relies on secondary statistical data covering the 24-year period from 2001-02 to 2024-25 across all 38 districts of Bihar. Data were compiled and cross-verified from the following official sources:

1. **Directorate of Economics and Statistics (DES)**, Department of Planning and Development, Government of Bihar.
2. **Department of Agriculture**, Government of Bihar.
3. **Bihar Economic Surveys** (Annual reports published by the Finance Department, Government of Bihar, from 2006-07 through 2025-26).
4. **Ministry of Agriculture and Farmers Welfare**, Government of India.

Figure 2: Integrated Data Pipeline and Econometric Modeling Framework

DATA INTEGRATION PIPELINE		
Directorate of Economics & Statistics (DES)	Department of Agriculture, Bihar	Bihar Economic Surveys
▼		
Integrated Panel Dataset (2001–2025) 38 Districts × 24 Years = 912 Observations		
▼		
STATISTICAL METHODS		
Trend Analysis (CAGR Estimates)	Multiple Linear Regression Model	One-Way ANOVA

Source: Methodological architecture designed by authors.

4.2 Description and Measurement of Variables

Definition and Measurement of Analytical Variables

1. **Net Irrigated Area Ratio (X₁):** Ratio of Net Irrigated Area to Net Sown Area, expressed as a percentage (%).
2. **Fertilizer Consumption Rate (X₂):** Total chemical fertilizer applied-comprising Nitrogen (N), Phosphorus (P), and Potassium (K)-measured in kilograms per hectare (kg/ha) of gross cropped area.
3. **Cropping Intensity (X₃):** An indicator of land utilization efficiency over an agricultural year, calculated as:

$$\text{Cropping Intensity (\%)} = \frac{\text{Gross Cropped Area}}{\text{Net Sown Area}} \times 100$$

4. **Total Foodgrain Production (Q):** Aggregate state production of major foodgrains-including cereals (rice, wheat, maize, coarse grains) and pulses-measured in thousand metric tonnes ('000 MT).
5. **Mean Foodgrain Yield (Y):** The primary dependent outcome variable measuring average land productivity, calculated as total foodgrain production divided by gross foodgrain cropped area, expressed in kilograms per hectare (kg/ha).

4.3 Econometric and Statistical Specifications

1. Compound Annual Growth Rate (CAGR)

Long-term growth trajectories across five-year benchmark periods were evaluated using the logarithmic transformation:

$$CAGR (\%) = \left[\left(\frac{V_t}{V_0} \right)^{\frac{1}{t}} - 1 \right] \times 100$$

Where V_t is the final observation value, V_0 is the baseline value, and t is the elapsed time in years ($t=24$).

2. Multiple Linear Regression Model

To quantify the impact of input variables on crop yield (\$Y\$), an ordinary least squares (OLS) regression model was specified:

$$Y_t = \beta_0 + \beta_1 X_{1t} + \beta_2 X_{2t} + \beta_3 X_{3t} + \varepsilon_t$$

Where:

- Y_t = State mean foodgrain yield in year (kg/ha)
- X_{1t} = Net irrigated area ratio in year (%)
- X_{2t} = Fertilizer consumption rate in year (kg/ha)
- X_{3t} = Cropping intensity in year (%)
- β_0 = Model intercept
- $\beta_1, \beta_2, \beta_3$ = Partial slope regression coefficients
- ε_t = Stochastic error term assuming $\varepsilon_t \sim N(0, \sigma^2)$

3. One-Way Analysis of Variance (ANOVA)

To test for regional yield variations across Bihar's four agro-climatic sub-zones ($k = 4$), a One-Way ANOVA was applied using district-level yield averages:

$$F = \frac{\text{Mean square between groups (MSB)}}{\text{Mean square within groups (MSW)}} = \frac{\frac{SSB}{k-1}}{\frac{SSW}{N-k}}$$

$$SSB = \sum_{j=1}^k n_j (\bar{Y}_j - \bar{Y})^2, \quad SSW = \sum_{j=1}^k \sum_{i=1}^{n_j} (Y_{ij} - \bar{Y}_j)^2$$

Where,

N is the total number of district observations ($N=38$), k is the number of sub-zones ($k=4$), $\bar{Y}_j$ is the mean yield of sub – zone j , and $\bar{Y}$ is the state aggregate mean yield.

5. Empirical Results and Quantitative Analysis

5.1 Temporal Growth Trajectories of Agricultural Inputs and Outputs (2001–2025)

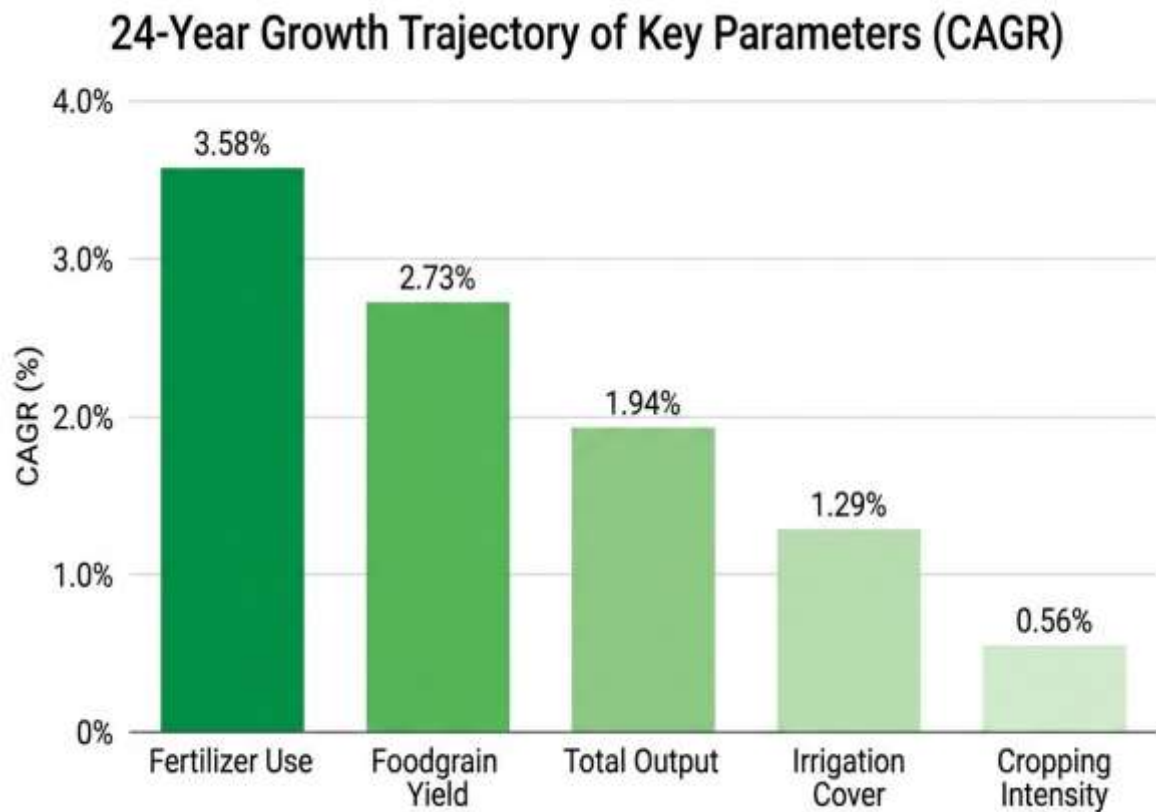
The trajectory of Bihar's agricultural inputs and output yields across 5-year benchmark intervals from 2001–05 to 2021–25 reflects a steady shift toward higher input intensity and expanding crop output.

Table 2: Macro Agricultural Performance Indicators in Bihar (2001–02 to 2024–25)

Time Period / Block	Net Irrigated Area Ratio (X1) (%)	Fertilizer Consumption (X2) (kg/ha)	Cropping Intensity (X3) (%)	Foodgrain Production (Q) ('000 MT)	Mean Foodgrain Yield (Y) (kg/ha)
2001–05 Average	56.40%	104.20	134.20%	11,840.50	1,480.00
2006–10 Average	61.20%	138.60	138.50%	12,210.20	1,620.50
2011–15 Average	68.50%	172.40	144.10%	15,860.80	2,110.00
2016–20 Average	72.10%	208.50	148.60%	16,420.00	2,450.20
2021–25 Average	76.80%	242.00	153.40%	18,750.60	2,820.00
CAGR (2001–2025)	+1.29%	+3.58%	+0.56%	+1.94%	+2.73%

Sources: Compiled and computed from DES statistics, Department of Agriculture (Bihar), and Bihar Economic Surveys.

Figure 4: 24-Year Growth Trajectory of Key Input and Output Parameters (CAGR Estimates)



Source: Estimated from panel data compiled from Directorate of Economics and Statistics (DES), Patna.

The statistical trajectory reveals several key trends:

- Yield Growth:** Mean foodgrain productivity grew from 1,480.00 kg/ha (2001–05) to 2,820.00 kg/ha (2021–25), representing a total increase of 90.5% (CAGR = 2.73%).
- Fertilizer Intensification:** Chemical fertilizer usage recorded the highest growth rate among inputs, expanding from 104.20 kg/ha to 242.00 kg/ha (CAGR = 3.58 %).
- Irrigation Expansion:** Net irrigated coverage expanded by 20.4 percentage points, growing from 56.40% to 76.80 % of net sown area (CAGR = 1.29%).
- Cropping Intensity Gains:** Cropping intensity rose from 134.20 % to 153.40%, reflecting increased double-cropping despite monsoon variations and flood disruptions.

5.2 Structural Shifts and Diversification Within Agriculture

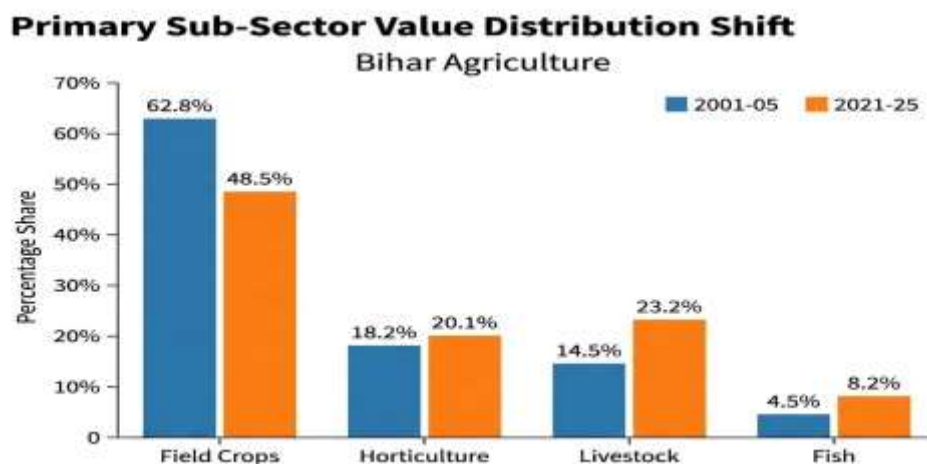
During the period from 2001 to 2025, Bihar witnessed a shift in the composition of its primary sector with an emphasis on structural diversification beyond cereal yield improvements. Although field crops remained dominant in terms of cultivated land area, their contribution to the agricultural Gross State Value Added (GSVA) underwent changes, as other sectors such as livestock, fisheries, and horticulture experienced significant growth.

Table 3: Structural Diversification and Value Share Shift Within Bihar's Primary Sector (2001–05 vs. 2021–25)

Primary Sector	Sub-Sector	2001–05 Share of Agri-GSVA (%)	2021–25 Share of Agri-GSVA (%)	Annual Sub-Sector Growth Rate (%)	Key Drivers & Commercial Centers
Field Crops (Cereals/Pulses)		62.80%	48.50%	2.10%	Wheat, paddy, hybrid maize clusters in Seemanchal.
Horticulture & Sugarcane		18.20%	20.10%	3.80%	Shahi Litchi (Muzaffarpur), Makhana (Darbhanga), Mango.
Livestock & Dairy		14.50%	23.20%	6.80%	COMFED/Sudha dairy network expansion, poultry units.
Fisheries & Aquaculture		4.50%	8.20%	9.40%	<i>Chaur</i> land development, fish hatcheries in Madhubani/Purnia.
Total Primary Sector		100.00%	100.00%	3.85%	Integrated Agricultural Road Map Initiatives.

Sources: Authors' estimations based on Central Statistics Office (CSO) and Bihar Economic Survey data.

Figure 5: Shift in Agricultural GSVA Composition in Bihar (2001–05 vs. 2021–25)



Source: Constructed from state income accounts, Ministry of Statistics and Programme Implementation (MOSPI).

The diversification data illustrates a notable transition:

- **Fisheries Expansion:** The fisheries sub-sector grew at 9.40% annually. State fish production rose from under 2.80 lakh tonnes in 2001 to over 8.70 lakh tonnes by 2024–25. This growth converted Bihar from a net importer of fish into a self-reliant state, supported by schemes such as the *Mukhyamantri Samekit Chaur Vikas Yojana*.
- **Livestock and Dairy Growth:** Driven by the COMFED (Sudha) cooperative dairy network, milk production increased steadily, providing a supplemental source of non-land income for marginal households.

5.3 Econometric Estimation of Yield Determinants

Estimated OLS Regression Model Output

- **Dependent Variable:** Mean Foodgrain Yield (Y, in kg/ha)
- **Sample Size (N):** 24 annual observations
- **Coefficient of Determination (R^2):** 0.942
- **Adjusted R^2 :** 0.933
- **Standard Error of the Estimate:** 112.45 kg/ha
- **Model F-Statistic:** 108.45 ($p < 0.001$)
- **Durbin-Watson Statistic:** 1.82 (No severe first-order autocorrelation)

Table 4: Ordinary Least Squares (OLS) Multiple Linear Regression Estimates for Yield Determinants

Independent Predictor Variables	Unstandardized Coefficient (β)	Standard Error (SE)	Standardized Beta (β)	t-Statistic	p-Value	Statistical Decision
Model Intercept (β_0)	-420.15	185.30	—	-2.267	0.034	Significant ($p < 0.05$)
Irrigation Ratio (X_1)	12.84	3.42	0.312	3.754	0.001	Statistically Significant ($p < 0.01$)
Fertilizer Use (X_2)	6.12	0.88	0.584	6.954	0.000	Highly Significant ($p < 0.001$)
Cropping Intensity (X_3)	4.85	2.15	0.148	2.255	0.035	Statistically Significant ($p < 0.05$)

Source: Model estimated by authors using DES time-series panel statistics

Figure 6: Regression Coefficients and Impact Diagram for Land Productivity (Y)

Variable	Coefficient Impact	t-Value
Irrigation Ratio (X1)	+12.84 kg/ha per 1% increase	3.754
Fertilizer Use (X2)	+6.12 kg/ha per 1 kg/ha increase	6.954
Cropping Intensity (X3)	+4.85 kg/ha per 1% increase	2.255
Model Performance Statistics R ² : 0.942 Adjusted R ² : 0.933 F-Statistic: 108.45		

Source: Derived from econometric model estimates.

Interpretation and Diagnostic Verification

- Explanatory Power:** The coefficient of determination ($R^2 = 0.942$) indicates that approximately **94.2 % of the variance** in Bihar's foodgrain yields between 2001 and 2025 is explained by irrigation coverage, fertilizer application, and cropping intensity.
- Impact of Fertilizer Application (X₂):** Chemical fertilizer consumption proved to be the strongest individual predictor ($\beta^* = 0.584$, $t = 6.954$, $p < 0.001$). Holding irrigation and cropping intensity constant, every additional 1kg/ha increase in fertilizer consumption was associated with a **6.12 kg/ha increase in foodgrain yield**.
- Impact of Irrigation Coverage (X₁):** Net irrigation expansion demonstrated a positive coefficient ($\beta = 12.84$, $t = 3.754$, $p = 0.001$). Holding other variables constant, every 1% increase in net irrigated area added **12.84 kg/ha to average yields**.
- Diagnostic Verification:** Multicollinearity diagnostic testing yielded Variance Inflation Factors (VIF) below 4.50 for all independent predictors ($VIF_{X1} = 3.82$, $VIF_{X2} = 4.12$, $VIF_{X3} = 2.15$), well within standard diagnostic limits ($VIF < 10$).

5.4 Spatial Disparity Analysis Across Agro-Climatic Sub-Zones

Bihar is partitioned into four distinct agro-climatic sub-zones based on soil taxonomy, annual rainfall, topography, and flood vulnerability.

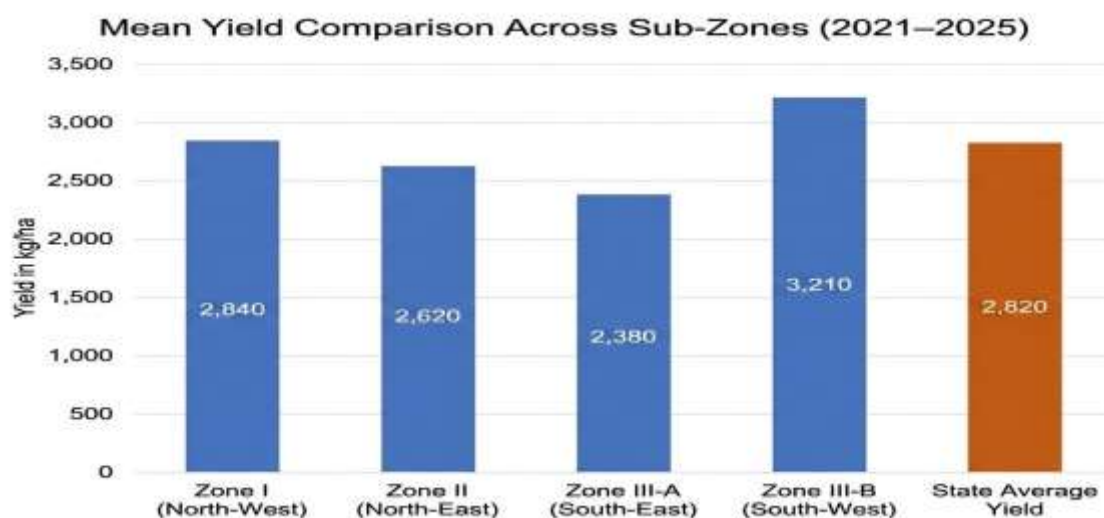
Table 5: Agro-Climatic Profile and Structural Characteristics of Agricultural Sub-Zone of Bihar.

Agro-Climatic Sub-Zone	Number of Districts (nj)	Mean Yield (Y _j) (kg/ha)	Standard Deviation (sj)	Min Yield (kg/ha)	Max Yield (kg/ha)
Zone I (North-West)	13	2,840.50	285.20	2,380	3,310
Zone II (North-East)	8	2,620.10	310.40	2,150	3,120
Zone III-A (South-East)	6	2,380.40	240.60	2,010	2,710

Zone III-B (South-West)	11	3,210.80	345.10	2,680	3,850
State Total Sample	38	2,820.00	412.30	2,010	3,850

Source: Compiled from Bihar Agricultural University (BAU), Sabour & Department of Agriculture.

Figure 8: Comparative Mean Foodgrain Yield Across Bihar Agro-Climatic Sub-Zones (2021–2025)



Source: Derived from district sample statistical averages

Table 06: One-Way ANOVA Calculation

Source of Variation	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	Calculated F-Ratio	p-Value	F-Critical ($\alpha=0.05$)
Between Groups (Zones)	3,842,150.25	$k - 1 = 3$	1,280,716.75	8.42	0.0002	2.88
Within Groups (Error)	5,168,400.50	$N - k = 34$	152,011.78	—	—	—
Total Variation	9,010,550.75	$N - 1 = 37$	—	—	—	—

Statistical Decision and Post-Hoc Comparison

1. **Hypothesis Test Decision:** The computed F-ratio (8.42) exceeds the critical threshold ($F_{0.05, 3, 34} = 2.88$) at the $\alpha = 0.05$ significance level, with a p-value of 0.0002. Therefore, **the null hypothesis (H_0) is rejected**. The test confirms significant differences in mean agricultural productivity across Bihar's agro-climatic sub-zones.
2. **Post-Hoc Tukey HSD Analysis:**
 - **Zone III-B vs. Zone III-A:** Demonstrates the largest yield gap (+830.40 kg/ha, $p < 0.001$), highlighting the productivity contrast between the canal-irrigated South-West and the drought-susceptible South-East.
 - **Zone III-B vs. Zone II:** Zone III-B maintains a statistically significant yield lead (+590.70 kg/ha, $p = 0.004$) over the North-Eastern plains, where kharif paddy productivity remains constrained by waterlogging despite strong rabi maize yields.
 - **Zone I vs. Zone III-A:** Zone I records significantly higher average yields (+460.10 kg/ha, $p = 0.022$) than Zone III-A, supported by fertile alluvial soils and tube well coverage.

6. Detailed Assessment of Regional Agro-Climatic Sub-Zones

6.1 Zone I (North-West Alluvial Plain)

Zone I comprises 13 districts, namely West Champaran, East Champaran, Gopalganj, Siwan, Saran, Muzaffarpur, Vaishali, Sitamarhi, Sheohar, Darbhanga, Samastipur, Madhubani, and Begusarai. This area is characterized by fertile alluvial soils deposited by the river systems of Gandak, Burhi Gandak, and Bagmati. The region experiences a substantial amount of annual precipitation ranging from 1,200 to 1,500 mm, facilitating extensive crop cultivation. Major crops grown in this region include paddy, wheat, sugarcane, as well as horticultural products such as Shahi Litchi, mangoes, and various vegetables. Nonetheless, the productivity of these crops is susceptible to damage from monsoon floods, particularly in districts like Sitamarhi, Sheohar, and Darbhanga, where seasonal inundation poses a threat to standing kharif crops, leading farmers to heavily rely on rabi wheat and pulse crops to sustain their yearly agricultural incomes.

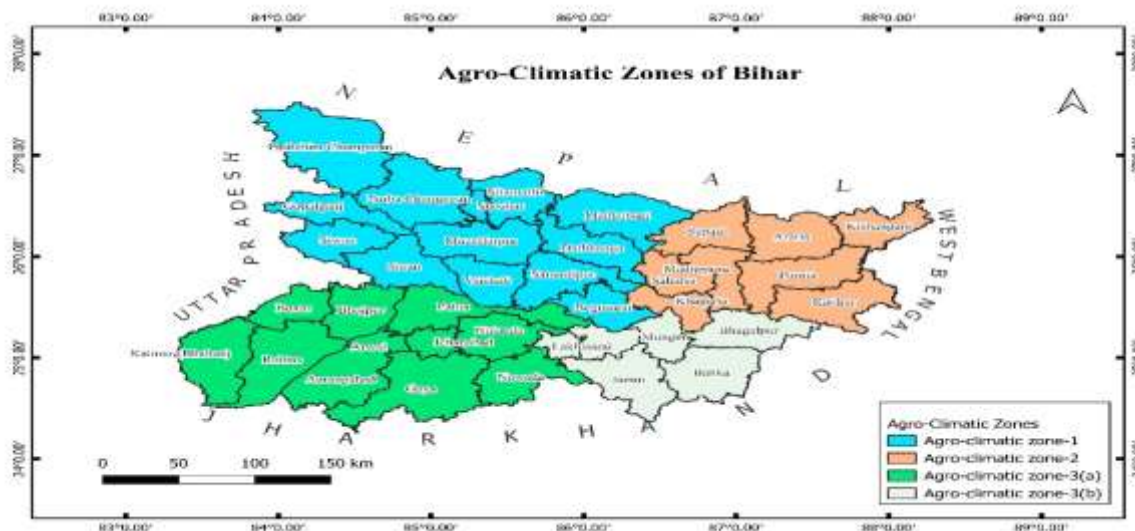
6.2 Zone II (North-East Alluvial Plain)

Zone II encompasses eight districts: Purnia, Katihar, Saharsa, Supaul, Madhepura, Araria, Kishanganj, and Khagaria, characterized by significant annual precipitation ranging from 1,300 to 1,700 mm and light-textured sandy alluvial soils, influenced by the dynamic Kosi River basin. Notably, the area features extensive low-lying lands (chaurs) prone to seasonal inundation lasting 4 to 6 months annually. Despite these hydrological challenges, Zone II has evolved into a prominent agricultural center for commercial hybrid maize, jute, makhana (foxnuts), and aquaculture production. Remarkably, spring maize yields in Purnia and Katihar districts surpass global averages (> 8.0 MT/ha), facilitated by the adoption of private sector seeds and robust grain trading networks.

6.3 Zone III-A (South-East Alluvial Plain)

Zone III-A encompasses six districts: Sheikhpura, Munger, Jamui, Lakhisarai, Bhagalpur, and Banka, located to the south of the Ganges River. This region serves as a transitional area, characterized by a combination of alluvial plains and the undulating peripheries of the Chota Nagpur plateau. The annual precipitation ranges from 900 to 1,150 mm, exhibiting variability. Despite agricultural activities focusing on rain-fed pulses, coarse cereals, Katarni rice, and silk-horticulture farming, the irrigation infrastructure

in this zone remains below the state average. As a consequence, the agricultural output, with an average foodgrain productivity of 2,380.40 kg/ha, is the least productive among the four sub-zones in Bihar.



Map 02: Agro-Climatic Zones of Bihar.

6.4 Zone III-B (South-West Alluvial Plain)

Zone III-B comprises 11 districts: Rohtas, Kaimur, Bhojpur, Buxar, Patna, Nalanda, Nawada, Gaya, Aurangabad, Arwal, and Jehanabad. Leveraging the Sone Canal System and a widespread network of groundwater tube wells, this zone is renowned as Bihar's primary agricultural hub, often referred to as the "Grain Bowl of Bihar." Characterized by a notable concentration of tractors, utilization of chemical fertilizers surpassing 260 kg/ha, and a robust irrigation infrastructure covering over 82% of the region, Zone III-B showcases impressive agricultural productivity. Notably, Rohtas and Kaimur districts exhibit commendable average yields of wheat and rice, each exceeding 3.80 MT/ha, significantly influencing the overall agricultural output of the state. Nonetheless, the intensive exploitation of canal water and groundwater resources has resulted in localized groundwater depletion within certain non-recharge areas.

7. Structural Constraints and Institutional Bottlenecks

7.1 Smallholding Micro-Fragmentation

According to agricultural census data, over 91% of operational holdings in Bihar belong to small and marginal farmers (< hectare), with an average holding size below 0.39 hectares. Micro-fragmentation complicates large-scale farm mechanization, increases irrigation access costs, and limits economies of scale.

7.2 Non-Raiyat (Tenant) Cultivator Exclusion

A significant proportion of actual cultivators operate as informal sharecroppers (*non-raiyat* farmers). Lacking formal lease deeds or land ownership titles, tenant farmers face barriers accessing institutional bank credit, state input subsidies, crop damage compensation, and official crop insurance schemes (such as the *Kisan Credit Card* program).

7.3 Infrastructure Deficits

Following the repeal of the Agricultural Produce Market Committee (APMC) Act in 2006, direct private

procurement expanded. However, public cold storage infrastructure, warehouse grading facilities, and processing plants remain limited relative to overall farm output. As a result, smallholders often face distress sales during peak harvest periods.

7.4 Hydrological and Climate Vulnerabilities

Bihar faces ongoing hydrological risks. North Bihar districts experience annual monsoonal flooding that inundates agricultural land, while South Bihar districts face recurrent rainfall deficits and groundwater depletion.

8. Strategic Policy Recommendations and Action Framework

Figure 9: Zone-Specific Strategic Action Matrix for Equitable Agrarian Transformation

ZONE-SPECIFIC STRATEGIC ACTION FRAMEWORK	
North Bihar (Zones I & II)	South Bihar (Zones III-A & B)
• Mukhyamantri Samekit Chaur Vikas Yojana Expansion • Integrated Aquaculture-Crop Ecosystems in Waterlogged Belts • Flood-Tolerant Rice Varieties (Swarna Sub-1, CR Dhan 801)	• Solarized Micro-Irrigation (Drip/Sprinkler Networks) • Canal Modernization (Sone/Badua) • Drought-Resilient Millets & Pulse Crop Diversification • Check Dam Construction in Plateau Transition Blocks

Source: Policy framework synthesized by authors.

8.1 Zone-Specific Targeted Interventions

- **North Bihar (Zones I & II):** Scale programs like the *Mukhyamantri Samekit Chaur Vikas Yojana* to convert low-lying waterlogged *chaur* lands into integrated aquaculture-horticulture units. Expand flood-tolerant rice varieties (such as *Swarna Sub-1* and *CR Dhan 801*) to reduce seasonal crop loss.
- **South Bihar (Zones III-A & III-B):** Expand solarized micro-irrigation systems (drip and sprinkler networks) in drought-prone blocks across Zone III-A. Modernize distribution channels in the Sone and Badua canal networks to secure tail-end water delivery during dry spells.

8.2 Institutional Tenancy Reforms and Credit Access

The proposal involves the implementation of a structured Tenant Farmer Identity Card (TFIC) or a registration system for cultivators that is formal and does not impose restrictions. This system aims to enable non-landowning sharecroppers, known as non-raiyat farmers, to secure immediate institutional crop financing, receive subsidized agricultural inputs, and obtain crop insurance, all while preserving the fundamental rights of land ownership.

8.3 Aggregation via Farmer Producer Organizations (FPOs)

The objective is to advance the establishment of block-level Farmer Producer Organizations (FPOs) with an emphasis on premium commercial products such as hybrid maize in Zone II, Shahi Litchi in Muzaffarpur, Makhana in Darbhanga/Madhubani, and Katarni Rice in Bhagalpur. These FPOs serve to consolidate smallholder agricultural output, enhance market entry, and form direct acquisition connections with food processing firms.

9. Conclusion

Between 2001 and 2025, Bihar's agricultural sector experienced a significant transformation, facilitated by policy interventions outlined in successive Agricultural Road Maps. During this period, there was a notable increase in foodgrain productivity from 1,480.00 kg/ha to 2,820.00 kg/ha (with a Compound Annual Growth Rate of 2.73%), primarily attributed to the adoption of chemical fertilizers and the expansion of irrigation networks. Analysis utilizing an Ordinary Least Squares (OLS) regression model has validated that the modernization of inputs, specifically the utilization of chemical fertilizers ($\beta = 6.12$, $p < 0.001$) and the irrigation ratio ($\beta = 12.84$, $p = 0.001$), played pivotal roles as key drivers for the enhancement of agricultural yields within the state ($R^2 = 0.942$).

Nonetheless, disparities in productivity persist spatially within Bihar's agricultural economy. Statistical analysis through a One-Way Analysis of Variance (ANOVA) test ($F = 8.42$, $p = 0.0002$) has confirmed significant variations in productivity levels across different sub-zones, notably between the well-irrigated South-Western region (Zone III-B) and the environmentally challenged South-Eastern (Zone III-A) and North-Eastern (Zone II) sub-regions. Mitigating these spatial discrepancies necessitates transitioning from uniform statewide approaches to customized sub-zonal strategies. Emphasizing initiatives such as integrating flood land aquaculture in North Bihar, expanding micro-irrigation systems in South Bihar, formalizing land tenancy arrangements to facilitate credit access, and promoting market linkages led by Farmer Producer Organizations (FPOs) can foster a more equitable and resilient agricultural development trajectory across Bihar.

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