

Agricultural Transformation and Food Security: Challenges, Opportunities and Policy Perspectives

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Abstract—Agriculture remains the backbone of developing economies and is central to ensuring food security, poverty reduction, and sustainable development. With increasing population pressure, climate change, resource degradation, and changing dietary patterns, agricultural transformation has become essential for enhancing productivity and ensuring food security. Agricultural transformation refers to the shift from traditional subsistence farming to modern, technology-driven, market-oriented, and sustainable agricultural systems. This paper examines the relationship between agricultural transformation and food security, highlighting the role of technological innovations, institutional reforms, government interventions, and sustainable farming practices. The study also discusses the major challenges confronting Indian agriculture and suggests policy measures to strengthen agricultural resilience and food systems. The paper concludes that sustainable agricultural transformation is indispensable for achieving long-term food security and inclusive economic development.

Index Terms—Agricultural Transformation, Food Security, Sustainable Agriculture, Climate Change, Digital Agriculture, India

I. Introduction

Agriculture is a fundamental sector of the Indian economy, contributing significantly to employment, food production, and rural livelihoods. Despite the declining share of agriculture in Gross Domestic Product (GDP), it continues to support a large proportion of the population. The demand for food is increasing due to rapid population growth, urbanization, rising incomes, and changing consumption patterns. Simultaneously, agriculture faces numerous challenges, including declining land availability, climate variability, water scarcity, soil degradation, and market uncertainties.

Agricultural transformation is increasingly viewed as the pathway to enhancing agricultural productivity, improving farmers' incomes, and ensuring food security. Food security extends beyond the availability of food to include access, affordability, nutritional adequacy, and stability of food supplies. Therefore, transforming agriculture through technological advancement, institutional reforms, infrastructure development, and sustainable resource management is essential for achieving national and global food security goals.

India's policy framework reflects elements from multiple theories. Procurement and buffer stocks ensure availability, employment programmes enhance purchasing power, nutritional schemes improve utilization,

and legal entitlements strengthen access. However, persistent inequalities, climate risks, and nutritional deficiencies indicate that policy integration remains incomplete. Food security has remained an important component of India's poverty-reduction strategy. The restructuring of the Public Distribution System (PDS) into the Targeted Public Distribution System (TPDS) in 1997 improved the targeting of subsidised food grains towards Below Poverty Line households. The Antyodaya Anna Yojana, introduced in 2000, further strengthened food security by providing highly subsidised food grains to the poorest sections. Subsequently, the National Food Security Act (NFSA), 2013, institutionalised food entitlements for nearly two-thirds of India's population and strengthened protection against hunger and food-price shocks. Programmes such as the Mid-Day Meal Scheme and Poshan Abhiyaan have also contributed to improving nutritional outcomes, particularly among children, women, and vulnerable groups (Keshava & Hanumantharayappa, 2025).

II. Concept of Agricultural Transformation

Agricultural transformation is the process by which agriculture evolves from traditional, labour-intensive, low-productivity farming systems into modern, commercialized, technology-driven, and sustainable agricultural enterprises. It encompasses improvements in productivity, diversification of agricultural activities, mechanization, efficient resource use, market integration, and institutional development.

The transformation process involves:

- Adoption of modern agricultural technologies.
- Increased mechanization.
- Improved irrigation systems.
- Expansion of agricultural markets.
- Diversification into high-value crops.
- Digitalization of farming practices.
- Sustainable natural resource management.

Dimensions of Food Security

According to the Food and Agriculture Organization (FAO), food security exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs for an active and healthy life.

The four dimensions of food security include:

Food Availability

Ensuring adequate production and supply of food through domestic production, imports, and buffer stocks.

Food Accessibility

Providing economic and physical access to food for all sections of society.

Food Utilization

Promoting balanced nutrition, food safety, sanitation, and healthcare.

Food Stability

Maintaining consistent access to food despite seasonal variations, economic shocks, or climatic events.

III. Literature Review

A growing empirical literature has examined the specific mechanisms through which India's agrarian structure constrains food security outcomes, three of which are directly relevant here.

On landholding structure, working-paper evidence compiled by the National Bank for Agriculture and Rural Development shows that the number of marginal holdings (below one hectare) rose from 3.62 crore (51 percent of all holdings) at the time of the first Agricultural Census to 10.0 crore (68.5 percent of all holdings) by the most recent count, even as the average operational holding size fell continuously from 2.28 hectares in 1970–71 to 1.08 hectares in 2015–16 (NABARD, 2025). This body of work argues that continuous subdivision driven by inheritance practices, population growth, and land-market constraints has structurally capped the income small cultivators can generate from land alone, pushing households toward diversified, non-farm income sources.

On water resources, Jain et al. (2021), using satellite-derived cropping data matched to census records for more than 500,000 villages, found that continued groundwater depletion could reduce winter cropping intensity by up to 20 percent nationally and by as much as 68 percent in the most critically depleted blocks, and that substituting canal irrigation for groundwater would offset only a fraction of this loss. This finding directly challenges the assumption, implicit in much of the government-scheme literature, that irrigation expansion alone can substitute for sustainable groundwater management. A related review in Environmental Science and Pollution Research corroborates this pattern using GRACE satellite gravimetry, confirming a persistent negative trend in groundwater storage across northern India linked to land-use change and cropping intensification (Cao & Sen Roy, 2025).

Keshava (2010) provides a systematic discussion of fundamental economic concepts that are relevant to understanding the broader dimensions of economic development. The study covers key issues including economic growth, national income, inflation, poverty, unemployment, and public finance, thereby providing a conceptual foundation for analysing economic conditions. It also emphasizes the significance of government policies and economic institutions in addressing developmental challenges and promoting

economic stability. The work is therefore useful as a theoretical reference for examining economic issues and understanding their implications within the context of the Indian economy.

Food security should therefore be viewed as an intersection of agriculture, economics, public health, environmental sustainability, and social justice. India has achieved significant progress in food security, transforming from a food-deficit country into a food-surplus country. Agricultural production increased substantially, with food-grain production rising from 46.2 million tonnes in 1950–51 to 296.7 million tonnes in 2020–21. However, challenges related to poverty, malnutrition, and unequal access to food continue to affect food security in India (Keshava, 2022).

On hunger and nutrition outcomes, the Global Hunger Index jointly compiled by Concern Worldwide, Welthungerhilfe, and the Institute for International Law of Peace and Armed Conflict using FAO, UNICEF, and WHO data places India 102nd of 123 ranked countries in 2025, with a score of 25.8, classified as "serious." This reflects an undernourishment rate of 12.0 percent, a child stunting rate of 32.9 percent, and a child wasting rate of 18.7 percent, the second-highest wasting rate recorded in the report (Concern Worldwide et al., 2025; Global Hunger Index, 2025). Taken together, this literature suggests that India's agricultural transformation has been strongest on the production side and weakest on the distributional and resource-sustainability side precisely the gap this revised paper is structured to examine.

IV. Objectives of the Study

1. To examine the concept and significance of agricultural transformation in achieving sustainable food security.
2. To analyse the major challenges affecting agricultural transformation, including climate change, declining land productivity, water scarcity, technological constraints, and market inefficiencies.
3. To identify the opportunities for enhancing agricultural productivity through technological innovation, digital agriculture, sustainable farming practices, and value chain development.
4. To assess the role of government policies and institutional support in promoting agricultural transformation and ensuring food security.
5. To evaluate the impact of agricultural transformation on farmers' income, rural employment, poverty reduction, and nutritional security.

V. Research Methodology

The study adopts a descriptive and analytical research design to examine the relationship between agricultural transformation and food security. The research relies entirely on secondary data collected from reliable national and international sources, including:

- Ministry of Agriculture and Farmers' Welfare, Government of India

- Food and Agriculture Organization (FAO)
- World Bank
- NITI Aayog
- Reserve Bank of India (RBI)
- National Bank for Agriculture and Rural Development (NABARD)
- Economic Survey of India
- Agricultural Statistics at a Glance
- Research articles, books, journals, conference papers, and government reports

This design was adopted because the five objectives of the study — spanning the conceptual, diagnostic, opportunity-identification, policy-evaluation and impact-assessment dimensions of agricultural transformation — are more appropriately addressed through a synthesis of official statistics, institutional reports and empirical literature than through a primary field survey, given the national scope of the enquiry and the time and resource constraints of the study.

Period of the Study: The analysis draws primarily on data, reports and statistics relating to the period from the 1970s (as a benchmark for landholding trends) up to the latest available editions of 2024–2025, so as to capture recent structural shifts in landholding pattern, groundwater use, scheme coverage and nutrition outcomes.

Coverage of the Study: Being a review-based study, no primary sample was drawn. The evidence base instead consists purposively of the major national and international data series cited above — the Agricultural Census/NABARD holding data, satellite-based groundwater assessments, the Global Hunger Index, and the flagship government schemes for agriculture — selected for their direct bearing on the five objectives of the study.

Tools of Analysis: The study uses (a) descriptive statistical tools — percentages, averages and growth/decline rates — to examine trends in landholding size, groundwater depletion and nutrition indicators; (b) comparative and trend analysis of scheme coverage and institutional interventions (PM-KISAN, PMFBY, e-NAM, FPOs, and related programmes) to evaluate opportunities and government support; (c) content/document analysis of policy reports, the Economic Survey and NITI Aayog strategy papers to assess institutional and policy dimensions; and (d) qualitative synthesis of the reviewed literature to establish the conceptual and empirical linkages between agricultural transformation and food security.

Limitations of the Methodology: As the study relies entirely on secondary data, it inherits the limitations of the original sources — differences in reference period, definition and data-collection method across

agencies such as NABARD, FAO and the Global Hunger Index partners — and does not capture primary, farm-level or region-specific variation that a field survey would reveal.

VI. Technological Innovations

Technological advancement has significantly improved agricultural productivity through:

- High-yielding seed varieties
- Precision agriculture
- Artificial Intelligence
- Internet of Things (IoT)
- Drone technology
- Satellite-based crop monitoring
- Biotechnology

VII. Institutional Reforms

Institutional reforms have strengthened agricultural development through:

- Land reforms
- Farmer Producer Organizations (FPOs)
- Agricultural marketing reforms
- Contract farming
- Cooperative farming

VIII. Infrastructure Development

Agricultural infrastructure includes:

- Irrigation systems
- Rural roads
- Cold storage facilities
- Warehousing
- Food processing industries
- Agricultural logistics

IX. Agricultural Transformation and Food Security

Agricultural transformation contributes significantly to food security by:

- Increasing crop productivity.
- Reducing production costs.
- Improving farmers' incomes.
- Enhancing market efficiency.
- Minimizing post-harvest losses.
- Promoting nutritional security.
- Increasing climate resilience.

Modern agricultural practices improve resource-use efficiency while ensuring long-term sustainability of food production systems.

X. Government Initiatives in India

The Government of India has introduced several programmes aimed at promoting agricultural transformation and food security. Major initiatives include:

- PM-KISAN
- PM Fasal Bima Yojana
- PM Krishi Sinchayee Yojana
- National Food Security Mission
- Soil Health Card Scheme
- e-NAM
- Agriculture Infrastructure Fund
- National Mission for Sustainable Agriculture
- Digital Agriculture Mission
- Formation and Promotion of Farmer Producer Organizations (FPOs)

These programmes aim to improve agricultural productivity, reduce farmers' risks, strengthen markets, and promote sustainable farming.

XI. Challenges to Agricultural Transformation

Climate Change

Increasing frequency of droughts, floods, and temperature fluctuations adversely affect crop production.

Small and Fragmented Land Holdings

Small farms limit mechanization and reduce economies of scale.

Water Scarcity

Groundwater depletion threatens irrigation sustainability.

Soil Degradation

Excessive fertilizer use, erosion, and declining organic matter reduce soil fertility.

Market Volatility

Price fluctuations discourage investment and increase farmers' income uncertainty.

Post-Harvest Losses

Poor storage, transportation, and processing infrastructure lead to significant losses.

Limited Access to Credit

Small farmers often face financial constraints due to inadequate institutional credit.

XII. Sustainable Agricultural Practices

Sustainable agriculture integrates economic viability, environmental conservation, and social equity.

Major practices include:

- Organic farming
- Natural farming
- Crop diversification
- Integrated farming systems
- Agroforestry
- Precision irrigation
- Climate-smart agriculture
- Conservation agriculture

XIII. Data Analysis

Secondary data compiled from official Government of India sources, NABARD, the Central Ground Water Board and the Global Hunger Index consortium were tabulated and analysed against the five objectives of the study. Table 1 summarises the key indicators used in this analysis, with sources cited in APA format.

Table 1: Key Secondary Data Indicators on Agricultural Transformation and Food Security in India

Indicator	Value / Trend	Reference Year	Source (APA)
Total foodgrain production (India)	332.22 million tonnes (record)	2023–24	Government of India, Ministry of Agriculture and Farmers Welfare, 2024a
Share of agriculture & allied sector in GVA	17.7% (FY24); $\approx$ 16% of GDP (FY24 PE)	FY24	Government of India, Ministry of Finance, 2024, 2025
Average annual growth rate of agriculture sector	5% per annum	FY17–FY23	Government of India, Ministry of Finance, 2025
Average monthly income of agricultural/rural households	₹12,698 (up from ₹8,059 in 2016–17; CAGR 9.5%)	2021–22	National Bank for Agriculture and Rural Development, 2024
Average operational landholding size (NAFIS)	0.74 hectare (down from 1.08 hectare in 2016–17)	2021–22	National Bank for Agriculture and Rural Development, 2024
Groundwater assessment units – Over-exploited category	11.13% (down from 17.24% in 2017); concentrated in Punjab, Haryana, Delhi, Rajasthan, Tamil Nadu, Karnataka, Telangana & Gujarat	2024	Government of India, Ministry of Jal Shakti, 2025
PM-KISAN beneficiaries / cumulative disbursement	9.44 crore farmers (23rd instalment); ₹4.46 lakh crore disbursed since 2019	2026	Government of India, Ministry of Agriculture and Farmers Welfare, 2026
PMFBY farmer applications / claims paid	13.48 crore applications; 22.67 crore farmers received claims totalling ₹1.83 lakh crore (cumulative)	2024–25	Government of India, Ministry of Agriculture and Farmers Welfare, 2025a
Farmer Producer Organisations (FPOs) registered	10,000 FPOs formed (target achieved); $\approx$ 30 lakh farmers connected	Feb. 2025	Government of India, Ministry of Agriculture and Farmers Welfare, 2025b

e-NAM integration	1,522 mandis integrated; 1.79 crore farmers & 2.67 lakh traders registered; cumulative trade ₹4.39 lakh crore	June 2025	Indian Cooperative, 2025
Marginal holdings (below 1 hectare)	68.5% of all operational holdings; average holding size 1.08 hectare (Agricultural Census series)	2015–16	National Bank for Agriculture and Rural Development, 2025
Undernourishment / child stunting / child wasting (Global Hunger Index)	12.0% / 32.9% / 18.7%; India ranked 102nd of 123 countries, “serious” category	2025	Global Hunger Index, 2025

On the conceptual and production dimension, official estimates place total foodgrain production at a record 332.22 million tonnes in 2023–24 (Government of India, Ministry of Agriculture and Farmers Welfare, 2024a), while the agriculture and allied sector grew at an average of 5 percent per annum between FY17 and FY23, contributing 17.7 percent of gross value added in FY24 (Government of India, Ministry of Finance, 2024, 2025). These figures indicate that the technological and market-oriented transformation described in the concept section has translated into measurable production and output gains.

On the challenges dimension, NABARD’s NAFIS 2021–22 survey records that the average operational landholding size held by surveyed households had fallen to 0.74 hectare by 2021–22, compared with 1.08 hectare in 2016–17 (National Bank for Agriculture and Rural Development, 2024), corroborating the longer Agricultural Census trend in which marginal holdings below one hectare account for 68.5 percent of all operational holdings (National Bank for Agriculture and Rural Development, 2025). On groundwater, however, the latest Dynamic Ground Water Resource Assessment shows the share of ‘over-exploited’ assessment units falling from 17.24 percent in 2017 to 11.13 percent in 2024, with stress remaining concentrated in Punjab, Haryana, Delhi, Rajasthan, Tamil Nadu, Karnataka, Telangana and Gujarat (Government of India, Ministry of Jal Shakti, 2025). This most recent official data qualifies the more alarming national-level projections in the literature (e.g., Jain et al., 2021): at the aggregate level, groundwater over-exploitation has been receding, even though the challenge remains acute and geographically concentrated precisely in states with the smallest average holdings and the most intensive cropping.

On the opportunities dimension, e-NAM had integrated 1,522 mandis and registered 1.79 crore farmers and 2.67 lakh traders by June 2025, facilitating a cumulative trade value of ₹4.39 lakh crore (Indian

Cooperative, 2025), while the Central Sector Scheme for Formation and Promotion of FPOs reached its target of 10,000 registered FPOs by February 2025, connecting nearly 30 lakh farmers (Government of India, Ministry of Agriculture and Farmers Welfare, 2025b). These figures show that digital-market and collective-institution opportunities have scaled rapidly in absolute terms, though their per-farmer reach remains modest set against India's total operational holdings of roughly 14 crore.

On the institutional and policy dimension, PM-KISAN had disbursed ₹4.46 lakh crore to 9.44 crore farmers since 2019 as of its 23rd instalment (Government of India, Ministry of Agriculture and Farmers Welfare, 2026), and PMFBY recorded 13.48 crore farmer applications with cumulative claims of ₹1.83 lakh crore paid to 22.67 crore farmer-applicants (Government of India, Ministry of Agriculture and Farmers Welfare, 2025a). The scale of these transfers confirms wide institutional reach; read alongside the landholding and groundwater data above, however, it also shows that direct income-support and insurance transfers have grown faster than the resource-management interventions needed to make that support durable.

On the impact dimension, NABARD's NAFIS data show that average monthly household income rose from ₹8,059 in 2016–17 to ₹12,698 in 2021–22, a compound annual growth rate of 9.5 percent (National Bank for Agriculture and Rural Development, 2024), even as landholding size continued to shrink over the same period. Read against the Global Hunger Index 2025 finding that India records an undernourishment rate of 12.0 percent, a child stunting rate of 32.9 percent and a child wasting rate of 18.7 percent, ranking 102nd of 123 countries in the “serious” category (Global Hunger Index, 2025), the data indicate that rising household income and institutional coverage have not yet been matched by proportionate gains in child nutrition outcomes the clearest quantitative evidence in this study that agricultural transformation has advanced production, income and institutional-coverage objectives faster than the nutritional-security objective.

XIV. Findings

On the basis of the data analysis presented in Table 1 and the discussion above, the following findings emerge, considered jointly across the five objectives of the study:

- India's record foodgrain output (332.22 million tonnes, 2023–24) and sustained agricultural growth (5% p.a., FY17–FY23) confirm that the production-oriented objective of agricultural transformation is substantially being met (Government of India, Ministry of Agriculture and Farmers Welfare, 2024a; Government of India, Ministry of Finance, 2025).
- Landholding fragmentation is accelerating rather than stabilising: NAFIS data show the average operational holding falling to 0.74 hectare by 2021–22 from 1.08 hectare in 2016–17, a faster rate of decline than the longer Agricultural Census trend (National Bank for Agriculture and Rural Development, 2024, 2025).

- Groundwater over-exploitation has declined nationally (17.24% of units in 2017 to 11.13% in 2024) but remains sharply concentrated in a handful of states, indicating that national averages mask a persistent, regionally concentrated resource constraint (Government of India, Ministry of Jal Shakti, 2025).
- Digital and institutional opportunities (e-NAM, FPOs) have scaled rapidly in absolute numbers but still cover a modest share of India's roughly 14 crore operational holdings, suggesting the opportunity dimension is real but not yet saturating (Indian Cooperative, 2025; Government of India, Ministry of Agriculture and Farmers Welfare, 2025b).
- Direct-transfer and insurance schemes (PM-KISAN, PMFBY) show the widest reach of all interventions studied, measured in crores of beneficiaries and lakh-crore rupee disbursements, confirming strong institutional and policy support for farmers' income (Government of India, Ministry of Agriculture and Farmers Welfare, 2025a, 2026).
- Despite rising household income (CAGR 9.5%, NAFIS 2021–22) and wide scheme coverage, India's child stunting (32.9%) and wasting (18.7%) rates remain in the "serious" category nationally, showing that income and coverage gains have not yet produced proportionate nutritional-security outcomes (National Bank for Agriculture and Rural Development, 2024; Global Hunger Index, 2025).
- Taken together, the data show agricultural transformation in India advancing unevenly across the five objectives: strongest on production, growth and scheme coverage; weakest on landholding consolidation, regionally concentrated resource sustainability, and nutritional impact.

XV. Suggestions

To strengthen agricultural transformation and food security, the following measures are recommended:

- Increase investment in agricultural research and innovation.
- Expand irrigation coverage and promote micro-irrigation.
- Strengthen agricultural extension services.
- Promote digital agriculture and precision farming.
- Improve rural infrastructure and cold chain networks.
- Encourage crop diversification.
- Strengthen Farmer Producer Organizations.
- Improve access to institutional credit.
- Enhance crop insurance coverage.
- Promote climate-resilient agricultural practices.

- Pursue land-pooling, cooperative and leasing reforms to counter continuous landholding fragmentation and enable mechanization.
- Introduce binding groundwater-use regulation alongside irrigation investment, so that scheme outlays do not continue to coexist with groundwater decline.
- Shift scheme monitoring from enrolment/coverage metrics to outcome metrics (income, nutrition, resource sustainability) so that institutional reach translates into impact.

XVI. Conclusion

Agricultural transformation is essential for attaining sustainable food security and fostering inclusive economic growth. Although India has significantly boosted food production via technological advancements and policy measures, persistent structural and environmental obstacles still exist. Tackling these issues demands a holistic strategy that includes technological progress, institutional reforms, sustainable resource management, and policies centered on farmers. Enhancing agricultural resilience will boost food security and also support poverty alleviation, rural growth, and progress toward the Sustainable Development Goals (SDGs). Future agricultural policies must prioritize sustainability, climate resilience, digital transformation, and inclusive.

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