A STUDY ON INTEGRATED APPROACH TO ENVIRONMENTAL, ECONOMIC, AND SUPPLY CHAIN AND LOGISTICS OPERATIONAL DRIVERS OF AGRICULTURE SUPPLY CHAIN AND LOGISTICS WITH SPECIAL REFERENCE TO TELANGANA STATE

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ABSTRACT

Agriculture remains the backbone of Telangana's economy, yet the sustainability of its agricultural supply chains is increasingly threatened by a convergence of environmental, economic, and operational challenges. This study presents a comprehensive investigation into the integrated impact of environmental risks, socio-economic factors, and logistical drivers on the performance and sustainability of the agricultural supply chain and logistics systems within the state. The research aims to bridge the gap between environmental vulnerability assessments and operational supply chain performance, providing a holistic perspective that is often lacking in conventional agricultural logistics studies. Environmental dimensions considered include climate variability, extreme weather events, land degradation, and water scarcity all of which disrupt agricultural production and transportation. Socio-economic factors such as smallholder marginalization, market inefficiencies, rural infrastructure gaps, and financial constraints significantly influence supply chain participation and equity. Operational and logistical drivers—such as supply chain management (SCM) practices, distribution systems, warehousing capacity, cold chain availability, transportation efficiency, and dealer competency are evaluated to understand their role in enhancing or hindering overall supply chain performance.

The study utilizes a mixed-methods approach, combining quantitative data from agricultural product dealers, logistics operators, and government stakeholders with qualitative insights through interviews and case studies across various agro-climatic zones of Telangana. The results reveal a significant interdependence between environmental risks, socio-economic vulnerability, and logistical efficiency. Areas with higher environmental stress often suffer from fragmented supply chains and weaker SCM practices, whereas operationally competent networks tend to mitigate some of these external pressures.

Key findings underscore the need for integrated policy frameworks that simultaneously address climate resilience, rural development, and supply chain modernization. Recommendations include strengthening cold chain infrastructure, enhancing dealer training in SCM practices, promoting digital technologies for logistics visibility, and developing risk-sharing mechanisms for climate-sensitive regions. This research contributes to the broader discourse on sustainable agriculture by offering an integrated model for improving agricultural supply chains in vulnerable and rapidly developing regions like Telangana, with implications for scalability across other Indian states and similar agro-economic contexts globally.

Key Words: *Agricultural Supply Chain, Logistics Sustainability, Environmental Risk, Socio-Economic Implications, Logistical Drivers, Supply Chain Competency.*

INTRODCUTION:

Agriculture remains a cornerstone of Telangana's economy, not only in terms of its contribution to Gross State Domestic Product (GSDP) but more critically as a primary source of livelihood for a majority of its rural population. Despite progressive agricultural reforms and infrastructural advancements in recent years, the state's agricultural supply chain and logistics systems continue to face persistent challenges that hinder sustainable growth and equitable distribution of benefits across the value chain. These challenges are multidimensional rooted in environmental vulnerabilities, socio-economic disparities, and operational inefficiencies which call for an integrated approach to analysis and policy formulation. The environmental context in Telangana is increasingly characterized by climate variability, rising temperatures, irregular monsoons, and declining groundwater levels. These environmental stressors disrupt the continuity and predictability of agricultural production and increase the volatility of supply chains. Crop failures, post-harvest losses, and disruptions in storage and transportation are becoming more frequent, threatening food security and economic stability in rural areas. At the same time, socio-economic challenges further complicate the sustainability of the agricultural value chain. A large proportion of farmers in Telangana are small and marginal landholders with limited access to finance, technology, and formal markets. The existing gaps in rural infrastructure, such as inadequate storage facilities, poorly maintained roads, and limited connectivity, amplify post-harvest losses and reduce market accessibility. Moreover, agricultural product dealers and other intermediaries, who serve as critical nodes in the supply chain, often lack formal training in supply chain management and are not fully integrated into modernized logistics systems.

On the operational front, inefficiencies in supply chain management (SCM) practices ranging from poor inventory management and uncoordinated transportation to the absence of cold chains contribute to high transaction costs and low profitability for both producers and intermediaries. While efforts have been made to digitalize agricultural marketing and promote warehouse-based receipt systems, the impact has been uneven and geographically limited. There remains a significant gap in the understanding of how logistical drivers, SCM practices, and dealer competencies interact with external environmental and economic factors to influence overall supply chain performance in agriculture. Existing literature has largely treated these domains environmental, economic, and operational as separate silos, failing to account for their interdependent and compounding effects. Most studies have either focused on climate resilience or on SCM practices in isolation, with limited attention to the specificities of regional contexts like Telangana. This fragmented approach has led to policy interventions that are often partial, reactive, and unsustainable. In light of these concerns, the present study seeks to adopt a holistic and integrated framework to analyse the environmental, socio-economic, and operational drivers of agricultural supply chain and logistics sustainability in Telangana State. It aims to explore how environmental risks and socio-economic vulnerabilities impact logistical efficiency, and how supply chain management practices and dealer competencies can be leveraged to build resilience within the system. The research focuses specifically on agricultural product dealers—key actors who connect farmers to markets and logistics networks to understand the challenges they face and the strategies they employ in navigating this complex landscape.

Using a mixed-methods approach, the study combines quantitative data from structured surveys with qualitative insights drawn from interviews and field observations. This methodology enables a multi-layered analysis that captures both measurable supply chain metrics and contextual factors influencing sustainability. The ultimate objective is to generate practical, evidence-based recommendations that can inform policy, support agricultural modernization, and foster inclusive growth. By situating the study in Telangana, the research contributes to region-specific understanding while also offering a replicable model for other Indian states and similar agro-ecological zones globally. The findings are expected to benefit a range of stakeholders, including policymakers, agribusiness leaders, development practitioners, and local supply chain actors seeking to enhance resilience, reduce losses, and ensure equitable value distribution across the agricultural supply chain.

BACK GROUND OF THE STUDY:

Agricultural supply chains are a critical component of food security, rural livelihood development, and economic stability, especially in agrarian economies like India. Within this context, Telangana a state with a predominantly agricultural population plays a vital role in India's agricultural output, particularly in crops such as rice, cotton, maize, and pulses. However, the sustainability and performance of agricultural supply chains in Telangana are increasingly under pressure due to a confluence of environmental, economic, and operational challenges. In recent years, environmental risks such as climate change, erratic monsoons, rising temperatures, water scarcity, and frequent droughts have significantly impacted agricultural productivity in the region. These environmental stressors not only reduce yields but also disrupt the post-harvest processes including storage, transportation, and market delivery. In a state where a significant portion of agriculture is rain fed and dependent on seasonal patterns, such climate uncertainties introduce vulnerabilities throughout the supply chain, making risk mitigation and adaptation critical areas for policy and practice. Socio-economic factors further exacerbate the fragility of the agricultural supply chain in Telangana. The majority of farmers are smallholders with fragmented landholdings, limited financial literacy, and poor access to institutional credit. Market linkages remain weak, with many farmers depending on informal or traditional supply chain networks dominated by intermediaries. Infrastructure such as rural roads, cold storage units, and market yards are often inadequate or unevenly distributed. These limitations contribute to inefficiencies, post-harvest losses, and reduced profitability for farmers and dealers alike. On the operational side, there are widespread issues with logistics management, supply chain planning, and distribution efficiency. Agricultural product dealers, who serve as essential intermediaries between farmers, input suppliers, and markets, often operate without formal training in supply chain management (SCM) principles. Additionally, a lack of technological integration, limited adoption of cold chain logistics, and inefficient inventory practices hinder the timely and cost-effective movement of goods. Despite the government's push for agricultural market reforms and digital agriculture platforms, the adoption and effectiveness of such interventions vary greatly across regions.

Given this backdrop, there is a pressing need to conduct an integrated study that not only assesses the environmental and socio-economic vulnerabilities affecting agricultural supply chains but also evaluates the logistical drivers, SCM practices, and competency of agricultural product dealers in Telangana. Such a comprehensive approach is crucial to developing a resilient, inclusive, and sustainable supply chain model that can withstand environmental shocks, adapt to economic constraints, and optimize operational processes. This research aims to fill this knowledge gap by providing a region-specific analysis that considers the diverse realities on the ground while offering evidence-based recommendations. By focusing on Telangana, a state that reflects both the opportunities and constraints of India's broader agrarian landscape, the study contributes valuable insights that can inform policy, improve agribusiness practices, and strengthen agricultural supply chains not just locally but also in other similar agro-economic contexts across India and beyond.

RESEARCH RELEVANCE:

The relevance of this study lies in its integrated examination of environmental, socio-economic, and operational drivers influencing the agricultural supply chain and logistics, with a specific focus on Telangana State. As agriculture remains a fundamental pillar of Telangana's economy, ensuring the resilience and sustainability of its supply chain systems is critical for achieving long-term food security, rural development, and economic stability. Telangana faces multi-dimensional challenges in its agricultural supply chains ranging from environmental stress, to socio-economic disparities (e.g., high dependence on small and marginal farmers), and operational bottlenecks (e.g., insufficient cold storage facilities and weak rural logistics). Despite various policy initiatives, such as Rythu Bandhu and Mission Kakatiya, farmers and agricultural product dealers still struggle with market access, post-harvest losses, and climate unpredictability. This study fills a critical gap by analysing these issues in a holistic framework. Supporting Literature and Comparative Studies, Chakraborty & Joshi (2016) highlighted how climate variability affects food supply chains in semi-arid regions of India, but did not link it to SCM practices or logistics performance on especially drought and erratic rainfall in semi-arid parts of India disrupts food supply chains. Their study, however, did not connect these risks to SCM practices or logistics performance. Empirical research from Telangana's cotton belt (Reddy et al., 2017; A. A. Reddy et al. 2021) documented severe soil degradation, over-reliance on agrochemicals, and the resulting farmer distress yet did not explore supply chain responses or logistics mitigation strategies, Patil et al. (2018) analyzed post-harvest losses in Indian agriculture, identifying infrastructure gaps, but lacked environmental or socio-economic integration in their framework. Singh & Srivastava (2020) studied the role of cold chain logistics in improving agricultural profitability but focused primarily on operational efficiency without considering environmental or social risks, Reddy et al. (2021) conducted district-level studies in Telangana to examine farmer distress due to environmental degradation, yet did not explore the logistical or supply chain response.

This study builds on such fragmented efforts by offering a multi-disciplinary and integrated lens, grounded in empirical data collected from agricultural dealers and experts across

Telangana. The findings are highly relevant to policy-making and rural development strategies in Telangana and similar states. They can directly inform: Government schemes like e-NAM, PM-KISAN, and PM-FME (Food Processing) by aligning logistical improvements with environmental realities. Public-private partnerships aiming to develop climate-resilient agri-logistics infrastructure, Training programs to enhance supply chain competency of dealers and rural entrepreneurs.

In summary, this research addresses a critical and timely knowledge gap by providing an integrated, evidence-based understanding of the agriculture supply chain and logistics ecosystem in Telangana. The inclusion of real-world dealer practices, environmental risks, and socio-economic dynamics makes the study highly relevant for academia, policymakers, practitioners, and development planners seeking to modernize agriculture while ensuring equity and sustainability.

PROBLEM STATEMENT:

The agricultural sector in Telangana, though a key contributor to the state's economy and rural employment, is increasingly threatened by a convergence of complex and interdependent challenges. Environmental risks such as climate variability, frequent droughts, declining groundwater levels, and soil degradation are disrupting agricultural productivity and the reliability of supply chains. At the same time, socio-economic constraints including small and fragmented landholdings, weak market linkages, limited access to credit, and inadequate rural infrastructure continue to undermine farmer profitability and equity in market participation. In addition to these challenges, operational inefficiencies in logistics and supply chain management (SCM) further strain the system. Agricultural product dealers and intermediaries often lack formal training in SCM practices, while infrastructural deficiencies such as poor transportation networks, lack of cold chain facilities, and limited warehousing lead to high post-harvest losses and reduced market competitiveness. Despite state and central government initiatives like Rythu Bandhu, e-NAM, and PM-KISAN, there remains a critical gap in the alignment of environmental realities, economic development efforts, and operational efficiency in the agricultural supply chain ecosystem. Most existing studies have examined these challenges in isolation, focusing either on environmental sustainability, economic vulnerability, or logistical performance. However, there is a lack of integrated research that holistically evaluates how these drivers interact and jointly influence the sustainability, resilience, and performance of agricultural supply chains particularly in region-specific contexts like Telangana. Therefore, the central problem addressed in this study is the absence of an integrated, evidence-based framework that simultaneously considers environmental, socio-economic, and operational drivers in shaping the agricultural supply chain and logistics performance in Telangana. Without such a framework, policy responses and developmental interventions risk remaining fragmented, ineffective, or unsustainable.

SIGNIFICANCE OF THE STUDY:

This study is of high significance in the current context of agricultural development, where the interplay of environmental, economic, and operational challenges is increasingly shaping the effectiveness, resilience, and sustainability of supply chains especially in agrarian states like Telangana.

This research contributes to the academic literature by offering a multidimensional framework that integrates environmental risks, socio-economic conditions, and logistical practices—areas that have traditionally been studied in silos. It extends the scope of supply chain research by incorporating region-specific environmental and socio-economic variables, thereby addressing a major research gap identified in prior studies (e.g., Chakraborty & Joshi, 2016; Patil et al., 2018). The study builds on and enhances earlier works by offering a systems-thinking perspective, which allows for a more realistic and practical understanding of how various factors interact within the agricultural logistics ecosystem. Findings from this study can inform government programs such as e-NAM, PM-KISAN, Mission Kakatiya, and cold chain development policies by grounding them in field-level realities of Telangana's agriculture sector. The integrated approach can support the formulation of region-specific interventions to enhance logistics efficiency, reduce post-harvest losses, and increase the profitability of small and marginal farmers. It provides a basis for evidence-based policymaking that considers environmental sustainability, infrastructure development, and capacity-building for agricultural product dealers and rural supply chain stakeholders. By analysing the supply chain competencies and logistics practices of agricultural product dealers in Telangana, this research offers actionable insights to improve dealer performance, reduce inefficiencies, and strengthen end-to-end Agri-logistics. It highlights critical gaps in cold chain infrastructure, transportation networks, storage systems, and market access, and provides practical solutions that can be implemented by public and private stakeholders. The study can serve as a decision-making tool for logistics companies, agribusinesses, and supply chain managers working in rural and semi-urban markets. Telangana's agro-ecological diversity, reliance on rain-fed agriculture, and rapidly changing rural economy make it a highly relevant case study for integrated agricultural supply chain research. The study addresses the needs of districts that are particularly vulnerable to climate stress, water scarcity, and market fragmentation. By focusing on Telangana, the study not only captures regional nuances but also offers a scalable model for other Indian states facing similar environmental and economic challenges. This research is significant because it offers a comprehensive, data-driven, and regionally grounded perspective on how to strengthen agricultural supply chains in a sustainable and inclusive manner. Its integrated approach can lead to more resilient food systems, enhanced rural livelihoods, and improved policy alignment—goals that are critical for Telangana's future and relevant to other developing regions across India and beyond.

RESEARCH OBJECTIVES:

- To assess the impact of environmental risks, socio-economic constraints and affecting sustainability and performance of agricultural supply chains in Telangana.

- To evaluate the effectiveness of existing operational and logistical practices employed by agricultural product dealers and intermediaries.
- To provide recommendations for policymakers, agricultural product dealers, logistics providers, and rural development agencies aimed at enhancing climate resilience, operational efficiency, and socio-economic inclusivity within Telangana's agricultural supply chains.

LITERATURE REVIEW:

The Literature Review on Environmental Drivers in Agricultural Supply Chains by Chakraborty & Joshi (2016) emphasized the impacts of climate variability and erratic rainfall on food supply chains in semi-arid regions of India. Their findings point to increased unpredictability in agricultural output due to temperature rise, droughts, and seasonal shifts, which directly affect production and transportation reliability. However, their study stops short of linking these disruptions to operational supply chain practices like warehousing or dealer-level logistics. A. A. Reddy et al. (2021) conducted district-level studies across Telangana and documented how soil degradation, intensive mono cropping, and over-reliance on agrochemicals were driving farmer distress. The study identified severe environmental stress across the cotton belt of Telangana but did not extend analysis to the resilience or adaptability of local logistics and supply chains under such stress. IPCC (2021) has also reported that semi-arid states like Telangana are increasingly vulnerable to extreme weather events, making agricultural operations more volatile. These macro-level trends necessitate region-specific supply chain adaptation strategies.

Economic and Socio-Economic Factors: Patil et al. (2018) analyzed post-harvest losses and economic inefficiencies in Indian agriculture. Their study recognized poor storage infrastructure and inadequate rural market linkages as key contributors to farmer income loss. While comprehensive in economic terms, their research lacks integration of environmental drivers and logistics practices, especially in region-specific contexts like Telangana. Reddy et al. (2017) explored farmer indebtedness and market access in Telangana. They found that small and marginal farmers often rely on informal channels due to lack of credit and infrastructure, reinforcing economic vulnerability. However, they did not investigate how logistics or supply chain competencies could alleviate these burdens. Chand et al. (2017) from NITI Aayog highlighted the role of institutional support and schemes in improving rural income and infrastructure but stressed the importance of targeting localized barriers like dealer inefficiencies and fragmented networks.

Operational and Logistical Drivers: Singh & Srivastava (2020) studied the role of cold chain logistics in reducing agricultural spoilage and increasing profitability. Their work highlighted the lack of cold storage availability and transportation bottlenecks but was primarily operational in scope and did not account for environmental or economic vulnerabilities affecting Telangana. Sarkar & Basu (2019) investigated inventory and distribution inefficiencies in Indian Agri-logistics networks. They concluded that dealer training,

technology adoption, and supply chain visibility were critical for operational success, but their study did not focus on integration with environmental and socio-economic concerns. Kumar et al. (2020) analyzed SCM practices among Agri-input and product dealers across Andhra Pradesh and Telangana. They found that dealers lacked formal SCM knowledge, which led to uncoordinated procurement and delayed deliveries. Their study supports the need for operational training but did not address how environmental and economic risks influence these practices.

Need for an Integrated Approach: Several recent researchers (e.g., Shukla & Pathak, 2021; Ghosh & Maji, 2022) argue that the fragmentation in supply chain studies leads to ineffective or unsustainable interventions. They call for systems-thinking models that integrate environmental resilience, economic inclusivity, and logistical modernization particularly in states with agro-ecological diversity like Telangana.

RESEARCH DESIGN, DATA COLLECTION METHODS AND DATA ANALYSIS PROCEDURES:

The study adopts a mixed-method research design that integrates both quantitative and qualitative approaches to examine the environmental, economic, and operational drivers influencing the agricultural supply chain and logistics system in Telangana. The integrated methodology ensures a holistic understanding of the issue, capturing both statistical patterns and expert insights from the field. The research is focused on the state of Telangana, India, with a particular emphasis on districts known for agricultural activity and environmental vulnerability such as Nalgonda, Mahbubnagar, Karimnagar, Adilabad, and Warangal. These regions were selected due to their diverse agro-climatic conditions, high dependence on agriculture, and varying levels of supply chain infrastructure. The study collected data from 150 experts and experts across 33 districts of Telangana across Agricultural product dealers, Farmers, Supply chain managers and logistics providers, Officials from agriculture and marketing departments, Academicians and policy experts

Sampling Technique: Purposive sampling for expert interviews, Stratified random sampling for dealer and farmer surveys (based on district, crop, and supply chain role) agricultural product dealers and farmers surveyed through structured questionnaires, expert opinions gathered via semi-structured interviews, including: government officials, logistics professionals, Agri-policy researchers, district-level agricultural officers, SCM academics or consultants

Data Collection Methods**: A. Primary Data Collection:** Structured Questionnaires for dealers and farmers focusing on: SCM practices, Storage and transportation, Market access, Climate-related disruptions, Environmental risks, Socio-economic challenges, SCM efficiency and dealer competency and Field Observations at warehouses, mandis, cold storage centres, and transport hubs. **B. Secondary Data Sources:** Government reports (e.g., Telangana Agriculture

Action Plan, NABARD district profiles), Existing literature and prior studies (e.g., Chakraborty & Joshi 2016; Patil et al. 2018), Statistical databases (Agmarknet, Ministry of Agriculture, CMIE)

Analytical Tools and Techniques: This study employs an integrated data analysis approach to explore the interrelated environmental, economic, and operational factors influencing agricultural supply chains in Telangana. Quantitative data were collected through structured surveys from expert respondents, including agricultural dealers, logistics professionals, policymakers, and academics. These data were analyzed using various statistical tools such as descriptive statistics to identify opinion trends, one-sample t-tests to test the significance of expert perceptions, chi-square tests to examine relationships between socio-economic and logistical variables, and factor analysis to group major ICT and supply chain challenges into meaningful components. Additionally, regression analysis was applied to test the influence of operational constraints on regulatory effectiveness. To complement the quantitative findings, qualitative data were gathered through semi-structured interviews and field observations across agro-climatic zones. Triangulation of both data types ensured analytical rigor, as patterns emerging from statistical models were cross-validated with field-level insights and stakeholder experiences. This integration helped reveal how climate risk, infrastructure gaps, and supply chain management practices intersect to affect logistics performance and supply chain sustainability. The result is a holistic and evidence-based framework that supports targeted, region-specific policy recommendations for strengthening agricultural supply chains in Telangana. Expert feedback was used to confirm or question survey findings, especially in areas like post-harvest loss, dealer inefficiencies, and cold chain access. Ethical Considerations: Informed consent was obtained from all participants, data confidentiality and anonymity were ensured and ethical clearance was obtained from the relevant academic institution. This integration helped reveal how climate risk, infrastructure gaps, and supply chain management practices intersect to affect logistics performance and supply chain sustainability. The result is a holistic and evidence-based framework that supports targeted, region-specific policy recommendations for strengthening agricultural supply chains in Telangana.

Objective 1: Evaluate expert perceptions of key environmental and socio-economic challenges affecting agricultural supply chains in Telangana sate through statistical analysis.

Data Analysis using t-tests to compare expert's satisfaction scores key environmental and socio-economic challenges

Code	Expert Opinion Scores
EOS 1	Environmental Risk
EOS 2	Agriculture Residue in Agriculture supply chain
EOS 3	Rainfall Pattern
EOS 4	Greenhouse effect on Agriculture supply chain and Logistics
EOS 5	Ergonomics of Agriculture supply chain and logistics

	sustainability
EOS 6	Energy cost in Agriculture supply chain and logistics in Telangana
EOS 7	Raw Material Cost
EOS 8	Human Rights Trainings in Agriculture supply chain and logistics in Telangana state
EOS 9	Labour Wages in Agriculture Supply Chain and Logistics in Telangana state.
EOS 10	Net income of Agriculture Supply Chain and Logistics operations in Telangana state
EOS 11	Job Creation and Employment in Agriculture Supply Chain and Logistics operations in Telangana state.
EOS 12	Price Fluctuations
EOS 13	Consumer Awareness about the Social and Economic Impacts in Agriculture Supply Chain and Logistics.
EOS 14	Ethics and Integrity
EOS 15	Resilience to Disasters

One-Sample Test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
EOS1	30.237	199	.000	2.560	2.39	2.73
EOS2	30.693	199	.000	2.750	2.57	2.93
EOS3	29.043	199	.000	2.735	2.55	2.92
EOS4	31.434	199	.000	2.765	2.59	2.94
EOS5	28.856	199	.000	2.545	2.37	2.72
EOS6	32.994	199	.000	2.840	2.67	3.01
EOS7	31.761	199	.000	2.960	2.78	3.14
EOS8	30.272	199	.000	2.815	2.63	3.00
EOS9	28.069	199	.000	2.405	2.24	2.57
EOS10	28.171	199	.000	2.375	2.21	2.54
EOS11	30.064	199	.000	2.780	2.60	2.96

EOS12	29.119	199	.000	2.675	2.49	2.86
EOS13	28.327	199	.000	2.500	2.33	2.67
EOS14	32.382	199	.000	2.745	2.58	2.91
EOS15	30.360	199	.000	2.815	2.63	3.00

The analysis conducted to examine reflects expert perceptions on key environmental and socio-economic challenges in Telangana's agricultural supply chain. All t-tests are statistically significant ($p < 0.001$), indicating strong expert agreement on the presence and impact of these factors.

Environmental Risk: Experts strongly agree that environmental risks (e.g., climate variability, drought) critically impact agriculture supply chains in Telangana.
Agricultural Residue in the Supply Chain: There is high concern over the accumulation and mismanagement of agricultural residue, which affects logistics and environmental health.
Rainfall Pattern: Irregular and unpredictable rainfall is recognized by experts as a major disruptor of agricultural cycles and supply planning.
Greenhouse Effect on Supply Chain and Logistics: Experts acknowledge that the greenhouse effect and broader climate change significantly hinder Agri-logistics and supply chain sustainability.
Ergonomics of Supply Chain and Logistics Sustainability: The ergonomics or human-cantered design of logistics systems is considered suboptimal, impacting operational efficiency and worker health.
Energy Cost: High energy costs are a critical burden on Agri-logistics in Telangana, particularly for storage, processing, and transportation.
Raw Material Cost: Rising input/raw material costs are seen as one of the most significant economic constraints affecting overall supply chain profitability.
Human Rights Training: There is a perceived gap in human rights awareness and training across the supply chain workforce, impacting ethical labor practices.
Labor Wages: Expert opinions suggest that labor wages are inadequate and inconsistent, affecting worker retention and supply chain stability.
Net Income from Logistics Operations: Experts agree that net income for stakeholders (dealers, transporters) remains low, posing a barrier to investment and growth.
Job Creation and Employment: Despite challenges, the Agri-logistics sector is seen as a potential driver of employment if properly developed.
Price Fluctuations: Experts recognize that volatile pricing of Agri-products adds complexity to supply chain planning and income stability.

Overall Interpretation: The expert opinion analysis reveals strong consensus on the critical challenges facing Telangana's agricultural supply chains. Experts identified environmental

risks such as climate variability, rainfall unpredictability, and greenhouse effects as major disruptors of production and logistics. Economic pressures like high energy and raw material costs, low net income, and inadequate labor wages were also highlighted as significant constraints. Operational concerns, including poor ethics, limited disaster resilience, and gaps in human rights training, further weaken supply chain sustainability. Overall, the findings underscore the urgent need for integrated, region-specific interventions to enhance resilience, efficiency, and inclusivity in Agri-logistics.

Objective 2:To evaluate the effectiveness of existing operational and logistical practices employed by agricultural product dealers and intermediaries.

Data analysis using Chi-Square to assess relationships between categorical SCM variables.

S.No	SCM DRIVERS	chi-square χ^2	Critical χ^2 (df=4, α=0.05)	df	Asymp. Sig
1	Logistical Drivers - Facilities	47.100a	9.48	4	0.000
2	Logistical Drivers - Inventory	21.950a	9.48	4	0.000
3	Logistical Drivers - Transportation	21.750a	9.48	4	0.000
4	Supply Chain Practices - Planning, Sourcing and Procurement.	39.950a	9.48	4	0.000
5	Supply Chain Practices – Manufacturing and Distribution	19.350a	9.48	4	0.000
6	Supply Chain Practices – Returns (handling returned products, managing reverse logistics, and addressing customer issues)	50.350a	9.48	4	0.000
7	Supply Chain Competencies - Strategic Thinking	24.550a	9.48	4	0.000
8	Supply Chain Competencies - Demand Forecasting.	14.350a	9.48	4	0.000
9	Supply Chain Competencies - Data Analysis and Technology	23.400a	9.48	4	0.000
10	Supply Chain Competencies - Innovation	36.200a	9.48	4	0.000
11	Supply Chain Performance of Agriculture Products Dealers - Customer Satisfaction.	29.150a	9.48	4	0.000
12	Supply Chain Performance of Agriculture Products Dealers - Risk Mitigation	32.950a	9.48	4	0.000

13	Supply Chain Performance of Agriculture Products Dealers - Cost Optimization	19.350a	9.48	4	0.000
14	Supply Chain Performance of Agriculture Products Dealers - Efficiency	14.750a	9.48	4	0.000
15	Supply Chain Performance of Agriculture Products Dealers - Speed	25.350a	9.48	4	0.000

Facilities: There is a significant association between facility availability and supply chain effectiveness. Inadequate logistics infrastructure, such as cold storage units, godowns, and warehousing capacity, hampers the preservation of perishable goods and causes delays in delivery. This negatively impacts both product quality and customer satisfaction, especially in remote or rural agricultural areas of Telangana.

Inventory: Proper inventory management is critical for minimizing post-harvest losses and ensuring continuous product availability. Poor tracking, overstocking, or understocking leads to inefficiencies and financial losses. Effective inventory systems are necessary to optimize the supply chain and reduce operational costs.

Transportation: Transport infrastructure plays a key role in agricultural logistics. Inconsistent availability of transport, poor road conditions, and limited access to reliable vehicles in rural Telangana hinder timely movement of produce. These challenges compromise delivery speed, quality, and competitiveness.

Planning, Sourcing, and Procurement: Strategic sourcing and procurement processes are essential for reducing input costs and avoiding supply disruptions. Many agricultural dealers operate without formal procurement plans, leading to delays, increased costs, and supplier dependency. Planning ahead strengthens bargaining power and stability.

Returns and Reverse Logistics: A structured return system enhances service quality. Agricultural dealers often lack reverse logistics frameworks for defective or rejected goods, leading to customer dissatisfaction, financial strain, and reputational damage. A robust return management system is vital for long-term trust.

Strategic Thinking: Long-term strategic planning helps dealers anticipate market trends, manage risks, and scale operations. Dealers who integrate strategic thinking into their decision-making demonstrate stronger performance, while others remain reactive and operationally constrained.

Demand Forecasting: Forecasting demand accurately ensures optimal stocking and resource allocation. Inaccurate predictions lead to surplus or shortages, hurting dealer credibility and financial efficiency. Forecasting tools tailored to local market behaviour can improve accuracy.

Data Analysis & Technology: The use of data analytics and digital platforms supports smarter logistics decisions and real-time monitoring. Despite technological advances, many dealers lack access, awareness, or training, leading to inefficiencies and information delays.

Innovation: Innovation in logistics—such as mobile apps for tracking, IoT for cold chain management, and digital payment systems—enables better adaptability to market dynamics.

Innovative dealers tend to perform better by responding faster to consumer and climatic changes.

Customer Satisfaction: Customer satisfaction is strongly influenced by product quality, service consistency, and dealer responsiveness. When dealers are responsive to feedback, offer consistent delivery, and maintain product integrity, customer loyalty improves.

Risk Mitigation: Agricultural supply chains are exposed to weather fluctuations, market volatility, and policy shifts. Dealers who adopt risk mitigation strategies (e.g., insurance, diversification, buffer stocks) are more resilient and maintain consistent supply chain performance.

Cost Optimization: Cost optimization ensures competitive pricing and profitability. Efficient route planning, better procurement practices, and reduced waste contribute to lower operational costs. Dealers who manage costs well can scale sustainably.

Efficiency: Operational efficiency involves minimizing delays, maximizing resource use, and optimizing processes. Dealers showing high efficiency typically implement best practices in planning, transport, inventory, and distribution.

Speed: Speed is essential for perishable agricultural products. Quick turnaround times, responsive logistics, and fast adaptation to demand changes improve competitiveness, especially in local and regional markets.

Recommendations for the Study:

Based on the findings of this study, several comprehensive recommendations can be made to enhance the resilience, relevance, and sustainability for a holistic and systems-based transformation of Telangana's agricultural supply chain. The interdependencies between climate risks, infrastructure gaps, and dealer practices underscore the need for converged action across government, private sector, and community actors. By implementing these strategies, Telangana can build a resilient, inclusive, and modernized Agri-logistics system—capable of withstanding climate shocks, empowering smallholders, and driving sustainable rural development.

Based on the multidimensional challenges identified in Telangana's agricultural supply chain ranging from environmental risks and socio-economic disparities to logistical inefficiencies there is an urgent need for a holistic and integrated set of strategies. Strengthening environmental resilience is a foundational requirement, as the region frequently faces climate variability, drought, and soil degradation. Climate-smart agriculture must be promoted to build resilience at the farm level, particularly by encouraging crop diversification, use of drought-tolerant seed varieties, and integrated nutrient and pest management practices. These actions can reduce the dependence on vulnerable mono-cropping systems and enhance adaptability to climatic shifts. Furthermore, the state should develop district-specific disaster preparedness and contingency plans that are informed by agro-climatic zones and real-time weather analytics. In parallel, investment in water and soil conservation must be scaled up. This includes expanding micro-irrigation infrastructure (drip and sprinkler systems), promoting decentralized rainwater harvesting, and rejuvenating watershed zones. Soil health cards and organic farming incentives

will support long-term soil fertility and reduce the overuse of chemical inputs, thereby protecting environmental and human health.

Complementing ecological interventions, socio-economic empowerment of key supply chain actors is essential to reduce inequality and strengthen grassroots participation. Supporting small and marginal farmers who form the backbone of Telangana's agrarian economy through Farmer Producer Organizations (FPOs) and cooperative models can significantly enhance collective bargaining power. These groups can facilitate better access to inputs, storage facilities, transportation, and markets, while also enabling farmers to bypass exploitative intermediaries. Bridging financial and digital gaps is another critical priority. Many farmers and Agri-dealers remain excluded from formal finance and market-linked information systems. Promoting mobile-based access to credit, crop insurance, and real-time price discovery will ensure greater transparency and financial inclusion. Leveraging fintech and rural digital literacy campaigns will bring technological parity to underserved regions. Strengthening rural infrastructure is equally vital investments must be directed toward improving rural roads, constructing modern godowns, and upgrading market yards. These assets not only reduce post-harvest losses but also improve supply chain fluidity and last-mile connectivity. Fair labor practices within the Agri-logistics ecosystem must also be institutionalized. Minimum wage enforcement, periodic human rights training for labourers and dealers, and the establishment of grievance redressal mechanisms will ensure that supply chain development is not only efficient but also equitable and ethical.

On the operational front, modernizing agricultural logistics is key to reducing inefficiencies and enhancing supply chain agility. Expanding cold chain and storage infrastructure across high-value crop regions will play a decisive role in preserving product quality and reducing perishability-related losses. These facilities should prioritize backward integration from farm-gate to mandis and onward to urban and export markets. Public-private partnerships (PPPs) can be instrumental in funding and operating such infrastructure. Additionally, improving transportation systems across tribal and hilly districts is crucial to enabling consistent product flow. Poor road conditions and limited transport access delay the movement of goods, raising operational costs and reducing competitiveness. A mobile-based transport pooling and booking system can optimize delivery routes, reduce idle fleet time, and connect farmers and dealers more efficiently. Digitization of supply chain management (SCM) practices among dealers is another area needing urgent attention. Structured training in areas like inventory control, procurement management, order fulfilment, and real-time logistics tracking can help transform informal dealer networks into professionalized logistics intermediaries.

Furthermore, introducing reverse logistics and risk mitigation systems can dramatically improve resilience. Reverse logistics such as managing returned or defective goods should be built into dealer operations to reduce waste and preserve trust. In parallel, implementing crop and logistics insurance mechanisms can buffer stakeholders against market disruptions, natural calamities, and demand fluctuations. This dual approach of risk-sharing and process optimization will not only stabilize operations but also encourage private sector investment

into rural logistics. Building supply chain competency among agricultural dealers is another cornerstone of sustainable transformation. There is a pressing need to introduce formal training programs in logistics, procurement, warehousing, and inventory optimization. Encouraging long-term strategic thinking and demand forecasting is equally important. Simple, region-specific planning tools that help dealers predict seasonal demand, monitor inventory trends, and adapt to climatic or market shifts will prevent understocking and overstocking, reduce post-harvest loss, and improve profit margins.

To unlock innovation across the ecosystem, it is vital to foster a culture of experimentation and entrepreneurship. Support should be extended to Agri-logistics start-ups that provide last-mile delivery, warehouse aggregation, digital payment solutions, or AI-enabled crop monitoring services. State-level incubators can fund pilot programs, mentor rural entrepreneurs, and scale proven solutions. Furthermore, dealer-led innovations such as mobile crop traceability, digital receipts, and farmer financing platforms should be encouraged through hackathons and targeted grants. These innovations not only improve operational agility but also drive trust and transparency within the supply chain. However, for these technological, operational, and human capital investments to bear fruit, enabling policy and institutional frameworks must be in place. The Government of Telangana should adopt a comprehensive state-level Agri-logistics policy that integrates climate adaptation, equity-focused growth, and modern logistics development.

In conclusion, building a sustainable, inclusive, and high-performing agricultural supply chain in Telangana demands an integrated approach that aligns environmental adaptation, socio-economic empowerment, and logistical modernization. The findings from this study clearly illustrate that isolated interventions whether in climate policy, market reform, or dealer training are insufficient. What is required is a systems-level transformation driven by cross-sector collaboration, targeted investments, technology integration, and people-centric governance. If implemented effectively, the recommendations proposed in this research can serve as a replicable blueprint for other agrarian states facing similar challenges, paving the way for a more resilient and prosperous agricultural future for Telangana.

Conclusion:

This study has provided a holistic assessment of the environmental, socio-economic, and operational challenges affecting the agricultural supply chain and logistics systems in Telangana. The research findings highlight that these factors are deeply interrelated and cannot be effectively addressed in isolation. Environmental stressors such as climate variability, declining rainfall, and soil degradation significantly disrupt production and logistics continuity. Simultaneously, socio-economic vulnerabilities including the marginalization of smallholders, limited financial inclusion, inadequate rural infrastructure, and weak market linkages compound the fragility of the system. On the operational front, inefficiencies in supply chain management practices, a lack of cold chain infrastructure, and limited dealer competencies further exacerbate delays, losses, and low profitability across the agricultural value chain. The

statistical analysis confirmed widespread expert agreement on the severity of environmental and socio-economic risks, as well as operational inefficiencies. Quantitative tools such as t-tests and chi-square tests validated the significance of expert perceptions regarding energy costs, price fluctuations, transportation issues, storage capacity, and risk management practices. These insights reinforce the critical need for an integrated, region-specific strategy that simultaneously strengthens climate resilience, modernizes logistics infrastructure, and builds the capacity of supply chain actors especially agricultural product dealers who act as intermediaries between farmers and markets. The study concludes that meaningful transformation of Telangana's Agri-supply chains requires coordinated policy responses, innovative public-private partnerships, and the promotion of inclusive, technology-driven logistics solutions. A comprehensive Agri-logistics policy tailored to Telangana's agro-climatic and socio-economic landscape is essential to aligning national schemes such as PM-KISAN, e-NAM, and PM-FME with local realities. Furthermore, empowering rural stakeholders through training, digital tools, infrastructure development, and ethical labor practices will ensure that supply chain development benefits all participants equitably.

Ultimately, the study offers not only a detailed analysis of the current challenges but also a scalable and actionable framework for reform. The recommendations provided ranging from climate-smart agriculture to dealer innovation, cold chain expansion, digital integration, and strategic policy formulation serve as a roadmap for building resilient, efficient, and inclusive Agri-logistics systems. The lessons drawn from Telangana have wider applicability across similar agro-economic regions in India, contributing to national goals of agricultural sustainability, rural empowerment, and food security.

Citation: Nunavath Kali Charan, et.al (2023), a study on integrated study of agricultural supply chain challenges, approach to environmental, economic, and supply chain and logistics operational drivers" with special reference to Telangana state.

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