Climate Change Spillover Effects on Agricultural Economics: Correlating Rainfall Anomalies (ENSO) and Farmer's Terms of Trade in Indonesia

Leni Sabrina [1], Nurhapsa [2], Elly Jumiati [3] *

[1] Politeknik Negeri Sriwijaya

[2] Universitas Muhammadiyah Parepare

[3] Universitas Borneo Tarakan

* Correspondence: elly_jumiati@borneo.ac.id

ABSTRACT	Article Information

This study investigates the profound socioeconomic implications of precipitation variability on agricultural stability, specifically focusing on how ENSO-induced rainfall anomalies trigger economic spillover effects within the Indonesian agrarian sector. Addressing the critical intersection of climatology and macroeconomics, the research aims to quantify the correlation between meteorological shocks and the Farmer's Terms of Trade (FTT). Utilizing official secondary datasets from the Bureau of Meteorology, Climatology, and Geophysics (BMKG) and Statistics Indonesia (BPS) for the period 2021–2024, the study employs a quantitative approach integrating Pearson correlation analysis and the Vector Error Correction Model (VECM). The results demonstrate a significant positive correlation ($r = .658; p = .003$) between rainfall stability and farmer welfare, revealing a severe "price-squeeze" effect during the 2023 El Niño where escalating production costs outpaced commodity gate prices. Furthermore, the findings highlight that technical irrigation infrastructure acts as a vital moderator, significantly dampening economic volatility in resilient provinces like South Sulawesi compared to rain-fed regions. We conclude that climate-driven economic erosion necessitates a transition toward proactive policy frameworks, such as Weather Index-Based Insurance (WIBI), to safeguard rural purchasing power. This research advances scientific knowledge by empirically decoupling the physical impacts of climate change from its structural economic consequences in tropical agriculture.

Keywords: price indices; rural resilience; meteorological shocks; technical irrigation; weather index-based insurance.

1. **Introduction**

The contemporary agricultural landscape is currently positioned at a critical juncture, navigating the complex tension between urgent global food security imperatives and the profound environmental obligation to mitigate climate change [1]. Within the framework of global ambitions to achieve Net Zero Emissions (NZE), the agricultural sector has been identified as the primary contributor of non-carbon dioxide greenhouse gases (GHG). It is a fundamental correction to note that these gases are produced not merely through physical greenhouses in nurseries, but primarily through biogenic processes, specifically the release of methane (CH_4) and nitrous oxide (N_2O). Anthropogenic global warming has reached a decisive threshold, with agricultural activities accounting for approximately 10–12% of total global anthropogenic GHG emissions [2]. This contribution has reached a global scientific consensus, as established by the IPCC (2023), confirming the sector's significant role in atmospheric degradation.

The significance of this study lies in the necessity of advanced spatial mapping to identify carbon accumulation "hotspots" at the national level, ensuring that agricultural intensification policies do not inadvertently catalyze an exponential expansion of the national carbon footprin [3]. The core importance of this research stems from the requirement to harmonize food production targets with national climate commitments, as outlined in the Enhanced Nationally Determined Contribution (ENDC) published in 2022 [4].

Through enteric fermentation in ruminants, the livestock sector discharges methane, which possesses a global warming potential 28 times greater than CO_2 over a 100-year horizon [5]. Concurrently, the intensive application of NPK (Nitrogen, Phosphorus, and Potassium) fertilizers triggers soil nitrification and denitrification processes, resulting in the liberation of N_2O a gas with a warming potential 265–298 times more potent than CO_2 [6]. Absent precise spatial modeling, mitigation efforts remain overly generic and fail to effectively address high-intensity emission zones.

Current scholarly discourse reflects a global consensus on the adverse atmospheric impacts of agriculture; however, a scientific divergence persists regarding the precision of emission estimations when comparing IPCC Tier 1 and Tier 2 methodologies. Some researchers argue that standardized emission factors (Tier 1) frequently lead to the overestimation or underestimation of actual conditions in tropical latitudes due to variances in livestock feed characteristics and soil moisture level [7].

Conflicting hypotheses also emerge regarding the long-term efficacy of NPK fertilizers; while some posit that intensification is vital to prevent land-use change, others highlight that the emission burden per hectare escalates sharply due to systemic inefficiencies [8]. Furthermore, the implementation of regulations that prevent land conversion, such as Law

No. 41 of 2009 concerning the Protection of Sustainable Food Agricultural Land (SFAL), is crucial to provide a legal shield for productive zones. Such geographical uncertainties underscore the requirement for regionalized modeling based on secondary data to bridge the gap between production-oriented policies and environmental conservation. Developing nations, particularly Indonesia, face a unique paradigm where livestock populations continue to expand in tandem with rising animal protein demand. Previous investigations have largely concentrated on emissions from the waste or energy sectors, yet spatial mapping that integrates real-time livestock data with national fertilizer distribution statistics remains underrepresented in recent literature [9].

The novelty of this research lies in the systematic synthesis of these multidimensional datasets into a spatial modeling framework to establish a comprehensive agricultural carbon footprint index. The primary objective of this study is to develop a spatial model of the agricultural carbon footprint by quantifying GHG emissions derived from livestock populations and national NPK fertilizer consumption. Through this methodology, the research seeks to identify spatial correlations between livestock density and methane burdens, while geographically assessing the impact of NPK distribution on nitrous oxide emissions. These findings will serve as the evidentiary basis for more precise, localized, and data-driven "Climate-Smart Agriculture" strategies. By conducting a rigorous analysis, this article provides an evidence-based narrative regarding the environmental costs associated with every unit of fertilizer distributed and every head of livestock maintained within the national production system [10, 11].

2. Materials and Method

The methodological framework used in this study is designed to integrate biophysical climatological variables with macroeconomic parameters using a descriptive, quantitative, and econometric approach. The central focus lies on the analysis of longitudinal time-series data sourced from the public repositories of Indonesian governmental authorities to ensure empirical validity and data transparency. By synthesizing hydrometeorological anomalies with agricultural economic indicators, this research provides a robust empirical basis for identifying climate-driven economic spillover effects.

2.1. Data Acquisition and Accessibility

All datasets employed in this investigation constitute open-access secondary data. Meteorological parameters were extracted from the Bureau of Meteorology, Climatology, and Geophysics (BMKG) via the BMKG Database Center Online Portal. Concurrently, agricultural economic indicators were retrieved from Statistics Indonesia (BPS) through

monthly Socio-Economic Reports and Farmer's Terms of Trade Statistics. The data spans a comprehensive timeframe designed to capture extreme climate anomaly cycles, specifically targeting significant El Niño and La Niña events.

2.2. Research Population and Sampling

The research population encompasses all administrative regions serving as primary food production hubs in Indonesia. Purposive sampling was applied to identify regions with substantial contributions to the regional gross domestic product (RGDP) of the agricultural sector, namely:

- East Java and Central Java Provinces: Serving as representative centers for food crops (rice and secondary crops).
- South Sulawesi Province: Functioning as the primary rice production hub for Eastern Indonesia.
- South Sumatra Province: Representing regions with high vulnerability to rainfall anomalies concerning tidal and swamp lands.

The unit of analysis consists of aggregated monthly data at both national and provincial levels from 2021 through late 2024. This resulted in a total of 48 temporal observation points per variable, providing sufficient degrees of freedom for robust regression analysis.

2.3. Operational Definition of Variables

This study involves two primary clusters of variables: independent variables (climatology) and dependent variables (agricultural economics).

1. Independent Variables (Climatology)

- Rainfall Anomaly (RR_{anom}): The deviation of monthly precipitation from the 30-year climatological mean (1991–2020), measured in millimeters (mm).
- Oceanic Niño Index (ONI): Secondary data obtained from NOAA and cross-validated with local BMKG records to classify the intensity of ENSO phenomena.

2. Dependent Variables (Agricultural Economics)

- Farmer's Terms of Trade (FTT/NTP): The ratio between the Index of Prices Received by Farmers (I_t) and the Index of Prices Paid by Farmers (I_b).
- Producer Price Index (PPI/IHP): An index reflecting price volatility at the farm-gate level for agricultural commodities.

2.4. Data Analytical Procedures

- To detect economic spillover effects, the analytical protocol followed several stages: Stationarity Testing (Augmented Dickey-Fuller Test): Conducted to ensure that time-series data do not possess a unit root, thereby preventing spurious regressions.
- Pearson Correlation Analysis: Utilized to determine the strength and direction of the relationship between precipitation intensity and FTT fluctuations.
- Vector Error Correction Model (VECM): Employed to evaluate both short-term and long-term equilibriums, as well as the speed of agricultural economic adjustment following climatic shocks.
- Granger Causality Test: Applied to confirm whether rainfall anomalies statistically "cause" shifts in food price indices or whether other transmission factors are more dominant.

2.5. Data Integrity and Ethics

Given that this research relies entirely on publicly available secondary data from government agencies (BPS and BMKG), specific ethical clearance for human or animal subjects was not required. Data integrity is maintained through cross-validation processes between BPS annual reports and sectoral databases from relevant ministries. All data processing codes (R/Stata) remain available for replication purposes in alignment with open science principles.

3. Result

3.1. Analysis of Rainfall Deviations and ENSO Cycles

Based on formal secondary data released by BMKG, the interval from 2021 to 2024 was defined by extreme fluctuations in atmospheric indices. The years 2021 and 2022 were characterized by a persistent La Niña phenomenon, whereas 2023 saw the emergence of a moderate-to-strong El Niño, with the Niño 3.4 index climbing to +2.0 units by the final quarter [11]. These meteorological shifts directly correspond to significant precipitation deficits in primary rice-producing provinces such as East Java and South Sumatra [11], where rainfall dropped below 50 mm per month during the 2023 dry season peak.

3.2. Quantitative Correlation: Rainfall and Farmer's Welfare

The intersection between precipitation consistency and agrarian prosperity is quantified through the Farmer's Terms of Trade (FTT) [10]. Regression models demonstrate that economic shocks on the production input side, triggered by prolonged drought, frequently precede any favorable price adjustments for producers.

Table 1. Impact Analysis of Rainfall Anomalies on National Food Crop Farmer's Terms of Trade (Processed from BPS and BMKG official data, 2021-2024)

Year	Rainfall Anomaly (%)	Avg. FTT (NTP)	Production Cost Index (I_b)
2021	+24.15	102.45	110.12
2022	+18.30	103.18	111.45
2023	-35.20	100.42	120.55
2024	-04.10	101.85	118.20
Total	Mean = .08	Mean = 101.97	Mean = 115.08

Note: 2023 FTT data reflects a sharp decline between August and October, aligning with El Niño intensification (BPS, 2023).

Statistical verification using Pearson's correlation coefficient resulted in $r = .658; p = .003$. This confirms a statistically significant positive relationship between rainfall stability and farmer welfare indices. Hypothesis testing via F-test yielded $F(1,46) = 11.892; p < .01;$ with a partial eta squared (η_p^2) of .20. This suggests that precipitation anomalies account for 20% of the variance observed in Indonesian farmer welfare.

3.3. Regional Spillover Effects

Economic spillover effects are evident in the divergent regional responses to climate shocks. Provinces equipped with established technical irrigation systems demonstrate lower FTT volatility, even when subjected to similar precipitation deficits as other regions.

Table 2. Regional Comparison of Climatic Anomaly Impacts on FTT (Secondary Data Processed from Provincial BPS Offices, 2023)

Province	Rainfall Deficit (%)	FTT Point Change	Significance (p)
East Java	-42.00	-2.10	.002
South Sulawesi	-25.00	-0.38	.075
South Sumatra	-48.00	-2.95	.001
National Avg	-38.33	-1.81	< .01

A t-test comparing regions with high water infrastructure resilience (South Sulawesi) against those with lower resilience (South Sumatra) revealed a stark contrast, $t(46) = 4.125; p < .001;$ with a Cohen's d effect size of .88. These findings validate the hypothesis that

physical infrastructure acts as a critical moderating variable in dampening the economic spillovers of weather irregularities.

3.4. Producer Price Volatility

The Producer Price Index (PPI) indicates that while unhusked rice prices at the farm-gate rose by 14.20% during the 2023 El Niño, these gains were largely neutralized. The Index of Prices Paid by Farmers (I_b) for both production inputs and daily living expenses surged by 12.80% during the same window. This economic squeeze explains why FTT remains stagnant or improves only marginally despite soaring retail food prices.

4. Discussion

4.1. The Climate-Economy Nexus: Validating the Impact of Rainfall Anomaly

The empirical evidence synthesized in this research confirms the working hypothesis that precipitation anomalies serve as a primary destabilizer of agricultural economic equilibrium. The observed correlation ($r = .658$) between hydrological stability and the Farmer's Terms of Trade (FTT) indicates that the "climate-economy nexus" in the Indonesian context is an empirically measurable phenomenon rather than a mere theoretical abstraction. These findings align with the broader framework of the Ricardian model in agricultural economics, which suggests that exogenous environmental factors are foundational determinants of net economic productivity [13].

4.2. Vertical Spillover: How Drought Triggers a Price-Squeeze Effect

A nuanced interpretation of the 2023 El Niño outcomes reveals a significant "price-squeeze" mechanism affecting upstream producers. While the results indicated a nominal rise in farm-gate prices, the simultaneous escalation of the Index of Prices Paid by Farmers (I_b) suggests that inflation within the agrarian sector during climate anomalies is predominantly driven by cost-push factors rather than demand-pull dynamics [13]. This observation mirrors earlier scholarship indicating that extreme weather events disproportionately inflate operational costs for smallholders who lack access to capital-intensive, high-efficiency irrigation systems. Consequently, the spillover effect identified in this study is not merely a horizontal transmission across geographic regions but also a vertical one, where the socio-economic burden of climate adaptation is disproportionately shifted toward primary producers [13].

4.3. Infrastructure as a Resilience Buffer: Analyzing the Adaptation Gap

The regional discrepancies documented in the results emphasize the role of physical and institutional infrastructure as a critical moderating variable. The economic resilience demonstrated by regions such as South Sulawesi, despite experiencing substantial rainfall deficits, provides empirical support for the argument that infrastructure-led adaptation can successfully decouple agricultural welfare from direct meteorological shocks. Conversely, the high sensitivity recorded in provinces like South Sumatra highlights a persistent "adaptation gap," leaving rural economies susceptible to systemic poverty traps during prolonged periods of water scarcity [12].

4.4. Policy Implications: Integrating Climate Intelligence and Social Safety Nets

The implications of these findings should be considered within the broadest possible context of national food security and social stability. Traditional policy frameworks that focus exclusively on yield stabilization are insufficient if the economic incentives for farmers are eroded by climate-induced cost spikes. There is a manifest necessity for integrating real-time climate intelligence from BMKG into the economic monitoring systems of BPS to develop proactive social safety nets. Specifically, the adoption of Weather Index-Based Insurance (WIBI) is proposed as a vital tool to safeguard the Farmer's Terms of Trade (FTT) by providing immediate liquidity when specific rainfall thresholds are breached, thereby preventing the distress liquidation of productive assets during climatic crises.

Previous studies emphasize that climate-indexed insurance instruments can significantly reduce the vulnerability of agricultural households to hydroclimatic shocks while improving financial resilience in rural economies [8]. Furthermore, empirical research on climate-related economic shocks demonstrates that climate variability disproportionately affects low-income agricultural communities, reinforcing the importance of policy mechanisms that combine climate intelligence with economic protection systems [12].

4.5. Future Research Directions: Beyond Reactive Management

Future research directions should aim to investigate the granular impacts of rainfall anomalies on high-value horticultural value chains as compared to cereal staples. Such sector-specific analyses may reveal differentiated vulnerability patterns across agricultural commodities and production systems. Additionally, longitudinal analyses are required to ascertain whether the recurring "Triple-Dip" La Niña episodes and rapid transitions toward El Niño represent a structural shift or a temporary fluctuation in tropical climatological regimes.

Understanding these long-term climatic dynamics is essential for refining economic impact models of weather variability and improving risk management frameworks within the agricultural sector. Previous studies highlight that climate variability can generate persistent macroeconomic consequences for agricultural productivity and rural welfare, particularly in developing economies with high climate sensitivity [9,12]. Consequently, future research should expand toward integrated climate–economy modeling approaches that incorporate agrarian financial systems, adaptive infrastructure, and digital climate information services. The ultimate objective remains the transition from reactive crisis management toward a structurally resilient agricultural economy capable of navigating the increasingly volatile global hydrological cycle.

5. Conclusions

5.1. Research Synthesis and Contribution

This investigation provides rigorous empirical validation that precipitation anomalies, driven by ENSO cycles, are a fundamental determinant of agricultural economic instability in Indonesia. The primary findings indicate that spillover effects from climatic disruptions extend beyond physical yield reductions, significantly distorting producers' economic welfare, as evidenced by fluctuations in the Farmer's Terms of Trade (FTT). By analyzing official secondary datasets from BMKG and Statistics Indonesia (BPS) for the 2021–2024 period, this study confirms the presence of a "price-squeeze" phenomenon. During this window, particularly during the intense 2023 El Niño, adaptation costs and production input prices escalated at a rate far exceeding the appreciation of commodity gate prices.

This research advances the existing body of scientific knowledge by identifying technical irrigation infrastructure as a pivotal moderating variable capable of decoupling the negative correlation between climatic anomalies and rural impoverishment. However, the generalization of these findings necessitates caution due to heterogeneous topographical conditions, market accessibility, and varying climate sensitivities across Indonesia's diverse agricultural landscape. A notable limitation of this study is its reliance on monthly aggregate data, which may fail to capture high-frequency price shocks or micro-climatic variances at the sub-district level. Ultimately, this work underscores that national food security is inextricably linked to the protection of farmers' purchasing power from hydrometeorological volatility.

5.2. Recommendations for Policy and Future Inquiry

Based on the socio-economic implications identified in this research, several strategic recommendations are proposed for stakeholders and the scientific community:

- For Government and Policymakers: There is a manifest need to transition agricultural social safety nets toward Weather Index-Based Insurance (WIBI) frameworks integrated with BMKG's real-time meteorological data. Such a system would facilitate rapid financial compensation, preserving farmer liquidity before the economic consequences of rainfall anomalies reach a catastrophic threshold.

- Infrastructural Reinforcement: Public investment should prioritize the rehabilitation and expansion of irrigation networks in regions exhibiting high "adaptation gaps," specifically targeting rain-fed and tidal swamplands in Sumatra and Eastern Indonesia.

- Directions for Future Research: Prospective studies should employ household-level panel data to capture the micro-economic adaptation strategies utilized by individual farmers. Furthermore, exploring the role of digital agriculture (agritech) in mitigating information asymmetries between meteorological agencies and smallholders is essential to deepen understanding of sectoral resilience.

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