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Environmental risk, natural disasters, and economic growth management in Indonesia: A satellite-based analysis

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ABSTRACT

This study examines how environmental risk and natural disasters affect economic performance in a disaster-prone emerging economy. It focuses on the short-run and long-run impacts of flood exposure, forest loss, and spatial economic expansion on Indonesia's economic growth, with implications for investment stability and growth management. The study integrates satellite-based indicators of flood exposure, forest loss, and night-time light intensity with national time-series macroeconomic data for Indonesia over the period 1960–2024. These variables are analyzed using a dynamic time-series framework to capture both short-run adjustments and long-run equilibrium relationships between environmental risk and economic performance. The results show that environmental factors affect economic performance in differentiated ways. Forest loss exhibits a statistically significant long-run association with economic growth, reflecting the continued role of land conversion and resource utilization in Indonesia's development process. In contrast, disaster-related indicators do not display robust long-run negative effects at the aggregate level, suggesting that adaptive mechanisms such as reconstruction activity and economic diversification mitigate their macroeconomic impact. Short-run effects of environmental variables are generally limited. This study contributes to the business and management literature by reframing environmental risk as a structural constraint on economic performance and investment stability. By integrating satellite-based environmental data into macroeconomic analysis, it provides a novel, management-oriented framework for assessing disaster-related economic risk in emerging economies.

1. Introduction

Economic growth in emerging economies increasingly unfolds under conditions of heightened environmental risk and recurrent natural disasters. Climate change, landuse transformation, and rapid urbanization have intensified the frequency and severity of floods, environmental degradation, and climate-related hazards, generating persistent challenges for economic performance, investment stability, and business continuity. For disaster-prone countries such as Indonesia, environmental risk is no longer an episodic disturbance but a structural feature shaping long-term development trajectories. Floods, deforestation, and spatial expansion of economic activity increasingly disrupt infrastructure networks, production systems, and capital accumulation, thereby raising uncertainty for firms, investors, and policymakers (World Bank, 2025; IPCC, 2022).

Recent empirical research widely acknowledges that natural disasters and environmental degradation exert adverse effects on economic performance. Studies focusing on macroeconomic outcomes show that climate-related disasters reduce output growth, weaken productivity, and generate persistent welfare losses, particularly in developing economies with high exposure and limited adaptive capacity (Kahn et al., 2021; Botzen et al., 2019). From a business and investment perspective, environmental risk increases operational costs, disrupts supply chains, and discourages long-term capital formation (Pankratz, 2018; Karydas & Xepapadeas, 2022). However, the magnitude and persistence of these effects vary across countries, depending on economic structure, institutional quality, and spatial patterns of development.

Existing research has employed several methodological approaches to examine disaster economy relationships. Cross-country panel studies dominate the literature, offering broad insights into average disaster impacts across regions (Kahn et al., 2021). Other studies rely on event-based disaster indicators or damage reports to capture short-term economic losses (Botzen et al., 2019). More recent contributions incorporate climate variables or hazard frequency to assess long-run growth effects (Cavallo et al., 2021). While these approaches have advanced understanding, they face important limitations. Cross-country analyses often obscure country-specific dynamics, while administrative disaster data may suffer from reporting bias, aggregation problems, and limited spatial precision. Moreover, many studies treat environmental risk as an external shock without explicitly accounting for how economic activity itself expands into environmentally vulnerable areas.

Despite these advancements, several critical gaps remain unaddressed. First, existing studies that integrate satellite-based environmental indicators such as flood exposure, forest loss, and night-time lights have predominantly focused on cross country comparisons or localized case studies, leaving a lack of country specific, long-run macroeconomic analysis for disaster prone emerging economies like Indonesia. Second, prior research has largely treated environmental risk and disaster exposure as separate phenomena, without simultaneously examining how gradual environmental degradation (e.g., deforestation) and recurrent disaster events (e.g., floods) interact with spatial economic expansion (proxied by night-time lights) within a unified empirical framework. Third, most studies focus on short-term output losses following specific disaster events, while the long-run structural effects of persistent environmental risk on economic growth and investment stability remain underexplored, particularly in contexts where adaptive mechanisms such as reconstruction activity and economic diversification may obscure aggregate impacts.

Advances in satellite and geospatial data provide new opportunities to address these limitations. High-resolution remote sensing enables direct measurement of environmental degradation and disaster exposure through physically observed indicators such as forest loss, flood extent, and night-time light emissions. Satellite-based indicators are essential because they offer three distinct advantages: first, they provide objective, physically measured indicators free from reporting biases; second, they enable consistent measurement over long time horizons, capturing both gradual degradation and acute disaster events; and third, night-time light data serve as a high-frequency proxy for economic activity, making it possible to trace how spatial economic expansion increasingly occurs in environmentally vulnerable areas. Recent studies demonstrate that satellite-derived indicators improve the accuracy of measuring climate exposure and economic activity, particularly in data-constrained environments (Donaldson & Storeygard, 2016; Gibson et al., 2021). Night-time light data, in particular, have been increasingly used as a proxy for economic activity, urbanization, and infrastructure development, offering valuable insights into the spatial concentration of economic risk (Henderson et al., 2012). Despite this progress, the integration of satellite-based environmental indicators into long-run macroeconomic and business-oriented growth analysis remains limited, especially at the country level.

Indonesia provides a critical context for addressing this gap. As one of the most disaster-prone emerging economies, Indonesia experiences recurrent floods, rapid deforestation, and accelerated urban expansion, all of which interact with economic performance and investment decisions. While several studies examine specific disaster events or regional impacts, there is limited empirical evidence that simultaneously captures environmental degradation, disaster exposure, and economic activity using consistent, objective, and long-term data. In particular, few studies combine satellitebased measures of forest loss, flood exposure, and night-time lights within a unified macroeconomic framework to assess their short-run and long-run implications for economic performance. Understanding how these large-scale shocks affect labor markets and the aggregate economy is crucial, particularly in countries like Indonesia where social safety nets are incomplete and access to credit is constrained, making wage income a direct determinant of household welfare

(Kirchberger, 2017). Furthermore, the existing cross-country empirical evidence on the disaster-growth nexus remains inconclusive, with results varying significantly depending on the type of disaster, model specification, and country sample used (Klomp & Valckx, 2014). Even at the sub-national level, the economic impacts of disasters are multifaceted, as evidenced by the 2018 earthquakes in Nusa Tenggara Barat (NTB), which not only caused a contraction in GRDP but also led to a discernible decline in tourism activities, a drop in hotel occupancy rates, and a rise in the open unemployment rate, illustrating how sector-specific shocks can transmit to broader economic indicators (Tangkudung, 2019).

This complexity is compounded by findings that the impacts of natural disasters are highly heterogeneous, according to Khan et al (2023) found that the economic costs of disasters are significantly higher in low-income countries compared to developed nations, and are highly dependent on the quality of infrastructure and the accumulation of human capital. This complexity is further compounded by findings that the impacts of natural disasters are highly heterogeneous; for example, research using a country-level event study design finds that significant negative effects on GDP growth are primarily borne by developing countries, while developed nations exhibit greater resilience (Cavallo et al., 2021). Furthermore, micro-level analysis of post-disaster individuals, such as those affected by Hurricane Katrina, shows that economic impacts can vary considerably, with some victims even experiencing long-term income recovery after migrating, underscoring the importance of understanding responses and adaptation at the economic agent level (Deryugina, 2022). Therefore, a country-specific analysis employing objective data is essential to cut through this statistical noise and uncover the underlying mechanisms at play. This complexity is compounded by findings that the impacts of natural disasters are highly heterogeneous; for example, research in China shows that disasters significantly hinder agricultural economic growth, primarily through the spread of pests and diseases Lin & Wang (2024) while an analysis in India reveals a non-linear U-shaped relationship between economic growth and disaster risk, where higher-income provinces prove to be more resilient to flood disasters (Patri et al., 2022).

The foregoing evidence highlights three critical research gaps that motivate this study. First, despite extensive cross-country studies on the disaster–growth nexus, country-specific long-run macroeconomic analyses that capture the structural dynamics of individual disaster-prone emerging economies remain scarce. For Indonesia—one of the world's most environmentally vulnerable nations—there is no existing study that simultaneously integrates satellite-based measures of flood exposure, forest loss, and night-time light intensity within a unified national time-series framework spanning more than six decades. Second, prior research has predominantly treated environmental degradation and disaster exposure as separate analytical objects, leaving the interaction between gradual degradation (e.g., deforestation) and recurrent hydrometeorological events within a single empirical model unexplored. Third, the long-run structural effects of persistent environmental risk on economic growth and investment stability remain underinvestigated, particularly in contexts where adaptive mechanisms such as post-disaster reconstruction and economic diversification may obscure deteriorating environmental fundamentals in aggregate output statistics. These gaps collectively prevent policymakers, investors, and business practitioners from accurately distinguishing between transitory disaster shocks and enduring structural constraints on long-term development. Consistent with this pattern, a study in Somalia by Warsame et al (2024) confirms that deforestation and natural disasters directly hinder economic growth, while greenhouse gas emissions exhibit a contradictory short-term effect, indicating a complex trade-off between economic activity and environmental quality—a finding that reinforces the need for country-specific, long-run empirical investigation in comparable emerging-economy contexts.

To address these gaps, this study provides a country-specific, satellite-based analysis of environmental risk and economic performance in Indonesia over the period 1960–2024. The novelty of this study is threefold: (1) it is the first to simultaneously integrate satellite-derived measures of flood exposure, forest loss, and night-time light intensity as distinct environmental risk indicators within a unified national macroeconomic time-series framework for Indonesia; (2) it employs an ARDL bounds-testing approach that captures both short-run adjustment dynamics and long-run structural relationships between environmental risk and economic growth over an unusually long observation window of 65 years; and (3) it reframes environmental risk not as a transitory shock but as a structural determinant of investment stability and economic growth, thereby contributing to the environmental economics and business management literature on climate-related economic risk in emerging economies. The aim of this study is to generate evidence-based insights that equip policymakers, investors, and business practitioners with a clearer understanding of which environmental factors represent structural constraints on Indonesia's long-term development, and to provide a replicable analytical framework applicable to other data-constrained, disaster-prone economies. This research makes three distinct scientific contributions. From an empirical perspective, it offers country-specific evidence on the differential long-run and short-run effects of flood exposure, forest loss, and spatial economic expansion using a unique dataset that integrates satellite-based environmental indicators with national macroeconomic data. From a methodological perspective, the study advances the integration of satellite-based environmental indicators within traditional growth models, reducing reliance on potentially biased administrative disaster records. From a policy perspective, the findings clarify which environmental factors pose structural constraints on long-term economic growth and investment stability, informing strategies for disaster risk reduction, sustainable land-use planning, and climate-resilient infrastructure investment in emerging economies facing compounding environmental pressures. The objectives of the study are: a) to examine the long-run and short-run effects of flood exposure and forest loss on Indonesia's economic performance; b) to assess the role of night-time light intensity as a proxy for spatial economic activity and growth dynamics; and c) to provide management- and policy-relevant insights into how environmental risk influences investment stability and long-term growth in a disaster-prone emerging economy.

2. Literature Review

2.1. Theoretical Foundations: From Classical Economics to Contemporary Growth Models

The relationship between environmental factors, natural disasters, and economic growth has deep roots in economic thought. Early theoretical contributions from classical economists established foundational insights that continue to inform contemporary investigations. Thomas Malthus (1798), in his *Essay on the Principle of Population*, articulated the tension between population growth and resource availability, positing that population would inevitably outpace food production, leading to resource constraints that limit long-term economic progress. Similarly, David Ricardo (1817), in his *Principles of Political Economy and Taxation*, introduced the concept of diminishing returns in agriculture, emphasizing how natural resource limitations could constrain economic expansion. These classical perspectives anticipated modern concerns about resource depletion, environmental degradation, and the structural limits to growth (Sabri et al., 2024).

The mid-twentieth century witnessed the emergence of formal growth theories that provided competing predictions regarding how environmental shocks influence economic performance. Neoclassical growth models, particularly the Solow-Swan framework (Solow, 1956; Swan, 1956; Meiriza et al., 2024) conceptualize natural disasters as temporary exogenous shocks that reduce capital stocks, driving economies away from their balanced growth path. Within this framework, reconstruction investment gradually replenishes destroyed capital, leading economies to converge back to their pre-disaster steady state. The Solow model's emphasis on capital accumulation, labor force growth, and technological progress as primary growth determinants established a baseline expectation that disaster impacts should be transitory, provided that institutional and technological conditions remain unchanged.

In contrast, endogenous growth theories developed by Romer (1986, 1990) and Lucas (1988) offered more complex predictions regarding disaster impacts. These models incorporate knowledge accumulation, human capital, and innovation as endogenous drivers of growth, suggesting that the effects of environmental shocks may be persistent and path-dependent. Of particular relevance is Schumpeter's (1942) theory of creative destruction, which posits that disruptive events including natural disasters may paradoxically accelerate long-term growth by catalyzing the replacement of obsolete capital with more advanced technologies. This perspective implies that disasters can stimulate innovation, productivity gains, and structural transformation, provided that institutional conditions support reconstruction and technological upgrading (Klomp & Valckx, 2014).

The environmental dimensions of economic growth received systematic theoretical treatment in the environmental Kuznets curve (EKC) hypothesis introduced by Grossman and Krueger (1995). This framework posits an inverted U-shaped relationship between economic development and environmental degradation, whereby environmental pressures initially intensify with growth but eventually decline after a certain income threshold is reached. While influential, the EKC framework has been critiqued for its oversimplification of complex environmental-economic interactions and its limited applicability to contexts where environmental degradation directly undermines productive capacity (Guilló & Magalhães, 2023).

A more recent theoretical advancement is the Green Solow model developed by Brock and Taylor which integrates environmental quality into the neoclassical growth framework. This model extends the traditional Solow-Swan approach by incorporating pollution emissions and abatement activities as determinants of long-run growth trajectories. Guilló and Magalhães (2023) further extend this framework by introducing land capital as an accumulable factor subject to both investment and degradation. Drawing on satellite-derived Enhanced Vegetation Index (EVI) data, they construct a quality-adjusted measure of land capital that captures the bio-productive capacity of terrestrial ecosystems across 146 countries. Their theoretical framework posits that land capital defined as the product of environmental knowledge and quality-adjusted land area enters the aggregate production function alongside manufactured capital and labor, with diminishing returns ensuring convergence to a steady-state growth path (Guilló & Magalhães, 2023).

2.2. Empirical Evidence on Disasters, Environmental Degradation, and Growth

The theoretical ambiguity regarding disaster-growth relationships has motivated extensive empirical investigation. Klomp & Valckx (2014) conducted a comprehensive meta-analysis of more than 750 estimates from 25 empirical studies examining the relationship between natural disasters and economic growth per capita. Their meta-regression analysis reveals three principal findings. First, natural disasters exert a negative genuine effect on economic growth, with climatic disasters in developing countries producing the most severe impacts. Second, the magnitude of disaster impacts has increased over time, reflecting the rising frequency and severity of large-scale events documented over the past four decades. Third, the literature exhibits publication bias, whereby studies reporting negative and statistically significant results are more likely to be published. Importantly, Klomp & Valckx (2014) found that the negative effect of disasters on growth is most pronounced for climatic and hydro-meteorological disasters, particularly in developing countries where economic structures rely heavily on agriculture and where institutional capacity for disaster risk reduction remains limited. In contrast, geophysical disasters such as earthquakes exhibit weaker and often insignificant long-run effects, consistent with the creative destruction hypothesis wherein reconstruction efforts replace damaged capital with more productive alternatives.

Complementing this macro-level perspective, recent studies have examined the reciprocal relationship between economic growth and environmental degradation. Using a simultaneous equation approach for Indonesia over the period 1984-2022, Sabri et al (2024) demonstrated that economic growth and environmental degradation mutually influence each other. Their findings reveal that a one percent increase in economic growth contributes to a 2.41 percent increase in environmental degradation, measured by natural resource depletion. Conversely, environmental degradation also exerts a positive effect on economic growth, suggesting that the exploitation of natural capital remains a significant driver of output expansion in developing economies. Furthermore, their analysis identifies investment as a key factor strengthening economic growth, while inflation and income inequality exert weakening effects. Environmental degradation is reinforced by income inequality, fossil fuel consumption, and poverty, indicating that social and economic disparities compound ecological pressures (Sabri et al., 2024).

The empirical results of Guilló & Magalhães (2023) provide strong support for the extended Green Solow framework. Their analysis reveals that initial emissions per capita and initial land capital per capita jointly determine subsequent growth trajectories of carbon emissions, with both variables exhibiting statistically significant coefficients of opposite signs. The negative coefficient on initial emissions confirms the existence of conditional convergence, whereby countries with higher initial emissions levels experience slower subsequent emissions growth. The positive coefficient on initial land capital indicates that countries endowed with higher-quality natural capital face higher emissions growth rates along the transition path, reflecting the environmental stress induced by more intensive utilization of land resources. Critically, their estimates reveal that land capital investment proxied by the ratio of natural capital to output exerts a negative and statistically significant effect on emissions growth, suggesting that investments in environmental knowledge and sustainable land management can effectively decouple economic expansion from environmental degradation.

The literature also reveals that the impact of natural disasters on economic growth is not uniform across contexts. Abdulah et al (2025) founds in Indonesia that natural disasters can exhibit a positive association with economic growth at the provincial level, suggesting a potential "build back better" effect. This aligns with Schumpeterian theories of creative destruction, where post-disaster reconstruction stimulates new investment and the replacement of obsolete capital with more modern technology. However, this macroeconomic resilience may obscure significant fiscal pressures at the sub-national level. Complementing this perspective, a study by Wiyanti & Halimatussadiah (2021) demonstrated that at the local government level, disasters strain fiscal balance through decreased local own-source revenue and increased expenditure items, including social assistance and capital expenditure for reconstruction. These seemingly contradictory findings underscore that disaster impacts are highly dependent on the level of analysis and the indicators used; positive effects observed in aggregate output may conceal real fiscal and economic stress experienced by lower levels of government, a dynamic particularly relevant for a decentralized nation like Indonesia.

Further evidence from country-specific studies reinforces the heterogeneity of disaster impacts. Research in China demonstrates that disasters significantly hinder agricultural economic growth, primarily through the spread of pests and diseases (Lin & Wang, 2024), while analysis in India reveals a non-linear U-shaped relationship between economic growth and disaster risk, where higher-income provinces prove to be more resilient to flood disasters (Patri et al., 2022). Similarly, a study in Somalia confirms that deforestation and natural disasters directly hinder economic growth, while greenhouse gas emissions exhibit a contradictory short-term effect, indicating a complex trade-off between economic activity and environmental quality (Warsame et al., 2024). These findings collectively suggest that the macroeconomic consequences of environmental risk operate through multiple channels and vary systematically with economic structure, institutional quality, and spatial patterns of development.

2.3. Disaster Impacts, Investment Stability, and Business Continuity

Recent research increasingly frames natural disasters as a source of business risk rather than purely humanitarian or environmental events. From a management and finance perspective, environmental hazards disrupt supply chains, damage production facilities, and impair logistics networks, thereby undermining business continuity and investment stability (Li, 2024). Firms operating in disaster-prone regions face higher volatility in returns and greater exposure to operational disruptions, which can influence location decisions and capital allocation strategies. The heterogeneity of disaster impacts, as documented by Tin et al (2024), further complicates business risk assessment, as different types of disasters hydrological, geophysical, or biological pose distinct threats to operational continuity and asset integrity. Moreover, the two-way relationship between socio-economic vulnerability and disaster losses identified by Tasri et al (2022) suggested that firms operating in areas with high unemployment or poverty may face compounded risks, as community-level fragility can amplify supply chain disruptions and delay post-disaster recovery. Studies in corporate finance demonstrate that exposure to climate risk affects firm valuation, investment behavior, and financing costs. Pankratz (2018) shows that firms with higher climate exposure experience weaker stock performance and heightened investor risk perception. Li (2024) found that environmental risk is priced into financial markets, influencing capital flows and investment decisions. These findings suggest that environmental risk has direct implications for business strategy and long-term economic performance. At the macro level, persistent disaster exposure weakens aggregate investment by increasing uncertainty and diverting public and private resources toward recovery rather than productive expansion (Cavallo et al., 2021). Kirchberger (2017) emphasizes that understanding how large-scale shocks affect labor markets and the aggregate economy is crucial, particularly in countries where social safety nets are incomplete and access to credit is constrained, making wage income a direct determinant of household welfare. Furthermore, micro level analysis of post disaster individuals, such as those affected by Hurricane Katrina, shows that economic impacts can vary considerably, with some victims even experiencing long-term income recovery after migrating, underscoring the importance of understanding responses and adaptation at the economic agent level (Deryugina, 2022).

2.4. Measuring Environmental Risk: From Administrative Data to Satellite-Based Indicators

Traditional studies of disaster impacts rely heavily on administrative disaster records, damage estimates, or binary disaster indicators. While useful, these measures often suffer from reporting bias, inconsistent definitions, and limited spatial precision, particularly in developing countries (Botzen et al., 2019). As a result, they may underestimate the true economic consequences of environmental degradation and recurrent hazards. Klomp & Valckx (2014) highlighted that the choice of disaster measure whether based on population affected, economic damages, or event counts significantly influences reported results, underscoring the importance of measurement precision in empirical disaster research.

Advances in satellite and geospatial data have significantly improved the measurement of environmental risk and economic activity. Remote sensing enables direct observation of physical environmental changes such as forest loss and flood extent, providing objective and spatially explicit indicators of environmental degradation (Gibson et al., 2021). These data sources are increasingly used to complement or replace traditional administrative measures, especially where ground-based data are limited. Satellite-based indicators offer three distinct advantages: first, they provide objective, physically measured indicators free from reporting biases; second, they enable consistent measurement over long time horizons, capturing both gradual degradation and acute disaster events; and third, they make it possible to trace how spatial economic expansion increasingly occurs in environmentally vulnerable areas.

Night-time light (NTL) data have emerged as a widely used proxy for economic activity, urbanization, and infrastructure development. Recent studies demonstrate that NTL correlates strongly with GDP, investment, and productivity, while also capturing spatial concentration of economic risk (Henderson et al., 2012; Donaldson & Storeygard, 2016). Importantly, satellite-based indicators allow researchers to analyze how economic activity expands into environmentally vulnerable areas, offering new insights into the interaction between growth and risk exposure. Despite these advances, the integration of multiple satellite-based environmental indicators such as flood exposure, forest loss, and NTL within a unified macroeconomic framework remains limited. Existing studies often focus on a single indicator or short time horizons, leaving a gap in understanding how spatial environmental risk and economic expansion jointly shape long-run economic performance.

3. Method

This study used a quantitative empirical research design to examine the relationship between environmental risk, natural disasters, and economic performance in Indonesia. The research is explanatory in nature, aiming to identify both short-run and long-run effects of environmental and disaster-related variables on economic growth. A time-series approach is employed to capture dynamic interactions between environmental risk indicators and macroeconomic performance over an extended historical period. This design is appropriate for assessing structural relationships and adjustment processes in a disaster-prone emerging economy. The unit of analysis is the annual observation at the national level, which is appropriate for examining the macroeconomic implications of environmental risk and natural disasters. This study employs a time-series research design, where each observation represents a single year, and the analysis captures the dynamic interactions between environmental risk indicators and macroeconomic performance over an extended historical period.

The study used period from 1960 to 2024, yielding a total of 65 annual observations. This period was selected based on two considerations. First, it represents the longest available timeframe for which consistent and reliable macroeconomic data particularly real gross domestic product, gross fixed capital formation, labor force, and trade openness are available from internationally recognized sources such as the World Development Indicators. Second, this extended timeframe allows the analysis to capture structural transformations in the Indonesian economy, including the transition from resource-based development to industrialization and services-led growth, as well as the evolving patterns of environmental risk exposure associated with rapid urbanization and land-use change. Starting from 1960 reflects the availability of consistent national accounts data following Indonesia's post-independence economic development period. The endpoint of 2024 represents the most recent year for which complete data on all variables including satellite-based environmental indicators could be compiled. The total number of observations is 65 years, with no missing data for the core macroeconomic variables employed in the analysis. For satellite-derived indicators (forest loss, flood exposure, and night-time light intensity), data are available for the full period through harmonized and gap-filled datasets that ensure temporal consistency across the entire study horizon. Using a national level time-series sample is consistent with the study's objective of assessing macroeconomic and investment related implications of environmental risk. Unlike cross-country panel studies that average effects across heterogeneous institutional contexts, this country-specific design enables the analysis to capture Indonesia's unique structural characteristics, including its geography, economic structure, and institutional arrangements for disaster risk management.

The dependent variables used in the study is real gross domestic product (GDP) represent national economic performance. GDP is measured in constant prices to eliminate inflationary effects. Environmental risk variables are constructed using satellite-based indicators. Flood exposure is measured as the annual flooded area aggregated at the national level, capturing the spatial extent of hydrometeorological risk. Forest loss is measured as annual forest cover loss, reflecting land-use change and environmental degradation. Night-time light intensity is used as a proxy for spatial economic activity, urban expansion, and infrastructure development. Control variables include gross fixed capital formation as a measure of investment, total labor force to capture labor input, population size to reflect economic scale, trade openness to represent external integration, government expenditure to account for fiscal activity, and foreign direct investment as a measure of external capital inflows (Table 1). All continuous variables are transformed into natural logarithms to facilitate elasticity interpretation and reduce heteroskedasticity.

Table 1. Definition of Variables

Variable	Description	Unit
GDP	Real gross domestic product measured in constant prices	Constant 2015
GFCF	Gross fixed capital formation	Constant 2015
Labor	Total labor force	People
FDI	Foreign direct investment (% of GDP)	Percentage
Pop	Total population	People
Gov	Government expenditure (% of GDP)	Percentage
Trade	Trade (% of GDP)	Percentage
NTL	Night-Time Light	Index
Forest	Forest loss	Km^2
Flood	Flood area	Km^2

Source: multiple resources

To examine the relationship between environmental risk and economic performance, this study adopts a dynamic time-series modeling framework. The general model specification posits that economic growth, measured by real gross domestic product (GDP), is a function of environmental risk indicators, spatial economic activity, and standard macroeconomic determinants. The theoretical long-run relationship is expressed as follows:

$$\ln GDP_t = \alpha + \beta_1 \ln Flood_t + \beta_2 \ln Forest_t + \beta_3 \ln NTL_t + \beta_4 \ln GFCF_t + \beta_5 \ln labor_t + \beta_6 \ln Pop_t + \beta_7 Trade_t + \beta_8 Gov_t + \beta_9 FDI_t + \varepsilon_t \quad (1)$$

Where α is the constanta; $\beta_1 - \beta_9$ is the coefficient of independent variables; ε_t is the error term and ln is the transforming variables to logarithm form. Following the general to specific modeling approach, a parsimonious specification is derived by sequentially eliminating statistically insignificant variables and imposing data coherent restrictions. The selection process is guided by theoretical relevance, statistical significance, and model selection criteria, including the Akaike Information Criterion (AIC) and Schwarz Bayesian Criterion (SBC). Based on this procedure, variables that do not contribute independently to explaining aggregate GDP dynamics namely, flood exposure ($Flood_t$), night time light intensity (NTL_t), labor force (L_t), government expenditure (G_t), and foreign direct investment (FDI_t) are excluded from the final specification. The resulting parsimonious long-run equation is:

$$\ln GDP_t = \alpha + \beta_1 \ln Forest_t + \beta_2 \ln GFCF_t + \beta_3 \ln Pop_t + \beta_4 Trade_t + \varepsilon_t \quad (2)$$

This specification retains only the core drivers of economic growth capital accumulation, population scale, and trade openness alongside forest loss as the key environmental variable, reflecting its persistent role in Indonesia’s development trajectory. To analyze for both short-run adjustments and long-run equilibrium relationships, the study employs an Autoregressive Distributed

Lag (ARDL) framework. The ARDL approach, introduced by Pesaran and Shin (1999) and extended by Pesaran et al. (2001), is particularly suitable for time-series analysis with a small sample size and variables that may be integrated of order zero I(0) or order one I(1), or a combination thereof. The ARDL model allows for the estimation of both short-run dynamics and long-run cointegrating relationships within a unified framework. The ARDL representation of the parsimonious specification is:

$$\begin{aligned} \ln GDP_t = \; & \alpha_0 + \sum_{i=1}^{p} \phi_i \ln GDP_{t-i} + \sum_{j=0}^{q1} \delta_{ij} \ln Forest_{t-j} + \sum_{k=0}^{q_2} \delta_{2k} \ln GFCF_{t-k} \\ & + \sum_{l=0}^{q_3} \delta_{3l} \ln Pop_{t-l} + \sum_{m=0}^{q_4} \delta_{4m}\, Trade_{t-m} + \mu_t \end{aligned} \tag{3}$$

where p and q_1, q_2, q_3, q_4 are the optimal lag lengths determined by minimizing the AIC or SBC; ϕ_i and δ_{ij} represent the short-run coefficients; and μ_t is the white noise error term. The long-run equilibrium coefficients are derived from the ARDL model as follows:

$$\beta_{LR} = \frac{\sum_{j=0}^{q} \delta_j}{1 - \sum_{i=1}^{p} \phi_i} \tag{4}$$

where the denominator represents the adjustment factor and the numerator captures the cumulative effect of each explanatory variable. To explicitly model the speed of adjustment back to long-run equilibrium following a short-run disturbance, the ARDL model is reparameterized into an Error Correction Model (ECM). The ECM specification separates short-run dynamics from the long-run equilibrium relationship and provides an estimate of the error correction term (ECT), which indicates how quickly deviations from equilibrium are corrected. The error correction representation is given as follows:

$$\begin{aligned} \Delta \ln GDP_t = \; & \alpha_0 + \sum_{i=1}^{p-1} \phi_i^* \Delta \ln GDP_{t-i} + \sum_{j=0}^{q_1-1} \delta_{1j}^* \Delta \ln Forest_{t-j} + \sum_{k=0}^{q_2-1} \delta_{2k}^* \Delta \ln GFCF_{t-k} \\ & + \sum_{l=0}^{q_3-1} \delta_{3l}^* \Delta \ln Pop_{t-l} + \sum_{m=0}^{q_4-1} \delta_{4m}^* \Delta Trade_{t-m} + \lambda ECT_{t-1} + \mu_t \end{aligned} \tag{5}$$

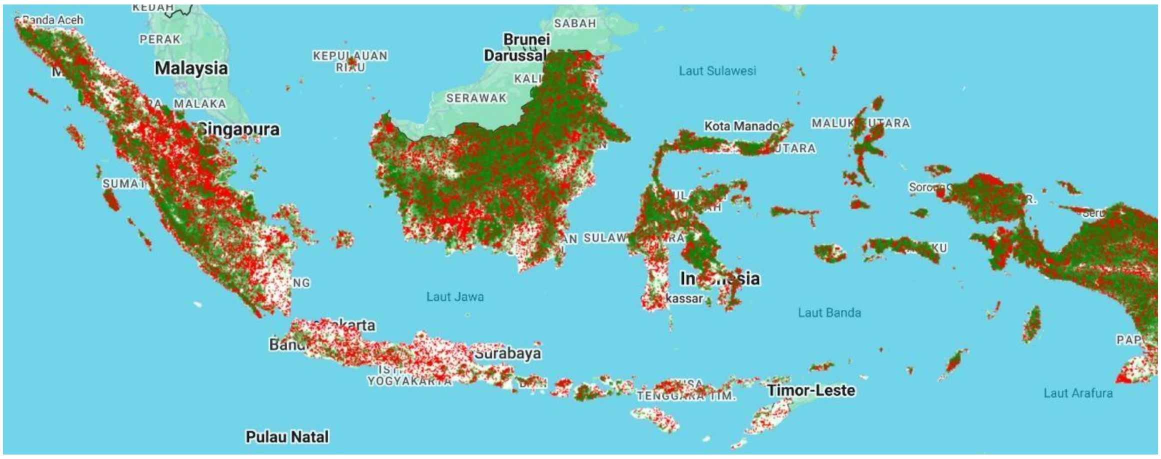
Where Δ is the first difference operator; ϕ_i^*, δ_{ij}^* are short-run dynamic coefficients; $ECT_{t-1} = \ln GDP_{t-1} - (\hat{\alpha} + \hat{\beta} \ln Forest_{t-1} + \hat{\gamma}_1 \ln GFCF_{t-1} + \hat{\gamma}_2 \ln Pop_{t-1} + \hat{\gamma}_3 Trade_{t-1})$ is the lagged error correction term representing the deviation from long-run equilibrium in the previous period; λ is the error correction coefficient, measuring the speed of adjustment back to equilibrium. A negative, statistically significant λ (with $-1 < \lambda < 0$) confirms the presence of cointegration and indicates that approximately $\lambda \times 100$ percent of the deviation from equilibrium is corrected within one period. This ECM formulation ensures that the model captures both the immediate short-run effects of environmental and economic variables, as well as the gradual process of adjustment toward the long-run equilibrium path.

The ARDL model is estimated using ordinary least squares (OLS) with appropriate lag lengths selected based on the AIC, which balances goodness-of-fit against model parsimony. Given the time-series nature of the data, the analysis employs the bounds testing procedure developed by Pesaran et al. (2001) to test for the existence of a long-run cointegrating relationship among the variables. The bounds test evaluates the joint significance of the lagged level variables in the conditional ECM using an F-test. The null hypothesis of no cointegration ($H_0: \beta = \gamma_1 = \gamma_2 = \gamma_3 = 0$) is tested against the alternative of cointegration ($H_1: \beta \neq 0, \gamma_1 \neq 0, \gamma_2 \neq 0, \gamma_3 \neq 0$). The computed F-statistic is compared against critical value bounds provided by Pesaran et al. (2001). If the F-statistic exceeds the upper critical bound, the null hypothesis of no cointegration is rejected, confirming the existence of a long-run relationship.

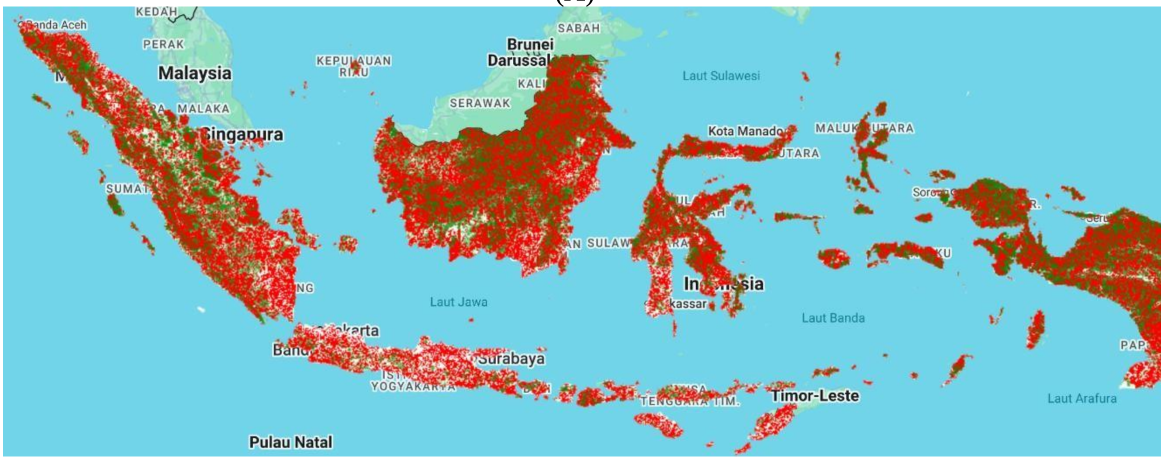
4. Results and Discussion

4.1. Descriptive Analysis of Environmental Risk and Economic Performance

Descriptive analysis reveals a clear upward trend in real GDP, reflecting long-term economic growth alongside structural transformation. However, this growth trajectory coincides with increasing environmental pressure, particularly in the form of rising flood exposure and cumulative forest loss. Flood-affected areas expand notably after the 1990s, corresponding with rapid urbanization and land-use change, while forest loss accelerates during periods of economic expansion and infrastructure development.



(A)



(B)

Source: Hansen Global Forest Change dataset (UMD, Google Earth Engine) (2025)

Figure 1. Forest Loss in Indonesia 1990-2010 (A) and 2011-2020 (B)

Figure 1, 2 and 3 illustrates the spatial evolution of forest loss, flood-prone areas, and night-time light (NTL) intensity across Indonesia over two distinct development periods: 1990–2010 and 2010–2020. The comparison reveals profound structural shifts in land use, disaster exposure, and economic agglomeration, highlighting the accelerating environmental degradation and economic expansion.

(A)

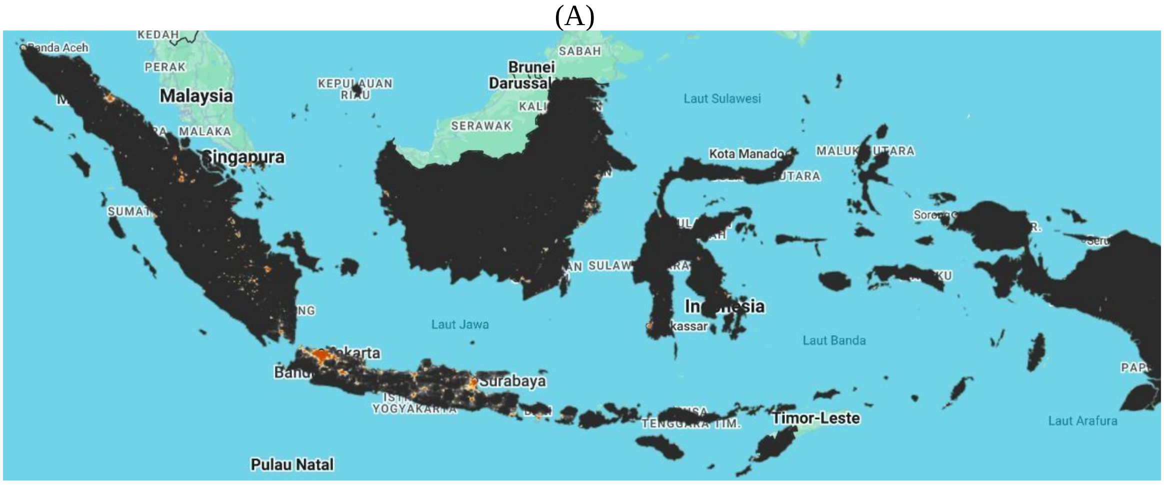
(B)

Source: JRC Global Surface Water Monthly History dataset (European Commission) (2025)

Figure 2. Flood Exposure in Indonesia 1990-2010 (A) and 2011-2020 (B)

Figure 1 shows during the 1990–2010 period, forest loss is highly concentrated in Sumatra and Kalimantan, reflecting the early phase of large-scale land conversion driven by logging, plantation expansion, and resource-based growth. At this stage, deforestation remains spatially clustered and largely confined to frontier regions.

(A)



(B)

Source: DMSP-OLS (1992--2013) and VIIRS (2012--2020) satellite composites (2025)

Figure 3. Night-time Light Intensity in Indonesia 1990-2010 (A) and 2011 2020 (B)

Figure 2 shows flood exposure appears relatively limited and fragmented, occurring mainly along coastal zones and major river basins, particularly in eastern Sumatra, northern Java, and parts of South Kalimantan. Night-time light intensity during this period is still strongly concentrated in Java, especially in Greater Jakarta, Bandung, Surabaya, and adjacent industrial corridors. Outside Java, illuminated areas remain sparse and localized, indicating a highly centralized pattern of economic activity. In contrast, the 2010–2020 period exhibits a dramatic spatial intensification and expansion of all three indicators. Forest loss spreads more deeply into central and eastern Kalimantan, Sulawesi, and Papua, confirming the geographical widening of deforestation frontiers. The density of forest-loss pixels increases sharply, signaling not only spatial expansion but also acceleration of ecological degradation. Simultaneously, flood exposure becomes more pervasive and continuous, particularly across northern Java, South Sumatra, South Kalimantan, and low-lying coastal zones in Sulawesi and Papua, reflecting heightened hydrometeorological instability driven by land-use change, urban expansion, and climate variability. Figure 3 shows Night-time light intensity shows a steady increase over time, indicating spatial concentration of economic activity and urban expansion. The overlap between rising night-time light intensity and environmentally vulnerable regions suggests that economic growth in Indonesia has increasingly occurred in areas exposed to environmental risk. This pattern highlights a structural trade-off between economic expansion and environmental sustainability, with important implications for longterm growth stability and investment risk.

4.2. Short-run and Long-run Estimation

The selected dynamic specification indicates that not all disaster-related indicators exert statistically independent effects on aggregate GDP once economic persistence and investment dynamics are taken into account. While flood exposure, population affected, and night-time light intensity capture important dimensions of environmental risk and economic activity, their effects appear to be absorbed by structural variables and GDP inertia at the national level. In contrast, forest loss emerges as a significant determinant, reflecting its role as a cumulative and persistent indicator of environmental degradation and land-use transformation. This suggests that the macroeconomic consequences of environmental risk in Indonesia operate primarily through long-term structural channels rather than short-lived disaster events.

Table 2. Short-run and Long-run Estimation

Variables	Coefficient	Variables	Coefficient
Short-run		Long-run	
Constant	-2.155** (0.906)	$lnforest_t$	0.030** (0.065)
$\Delta lnGDP_{t-1}$	0.877*** (0.034)	$lnGFCF_t$	0.263** (0.007)
$\Delta lnforest_t$	0.014** (0.006)	$lnPop_t$	1.977** (0.237)
$\Delta lnforest_{t-1}$	-0.010 (0.006)	$Trade_t$	-0.008 (0.987)
$\Delta lnGFCF_t$	0.199*** (0.021)		
$\Delta lnGFCF_{t-1}$	-0.167*** (0.024)		
$\Delta lnPop_t$	0.244*** (0.087)		
$\Delta Trade_t$	-0.001*** (0.001)		
$\Delta Trade_{t-1}$	0.001 (0.001)		

Source: data processed

Table 2 shows The short-run results indicate strong persistence in economic performance, as reflected by the highly significant lag of GDP. Gross fixed capital formation and population growth exert positive contemporaneous effects on GDP, highlighting the importance of investment and demographic scale in supporting short-term economic activity. Forest loss shows a small but statistically significant positive contemporaneous effect, suggesting that land-use change may temporarily support economic activity through resource extraction or land conversion. However, this effect weakens when lagged, indicating limited sustainability. Trade openness exhibits a short-run negative impact, reflecting Indonesia’s exposure to external shocks and adjustment costs. These findings suggest that the macroeconomic impacts of environmental risk and disaster-related pressures do not materialize immediately in aggregate output indicators. In the short run, economic performance appears to be driven primarily by capital accumulation, population scale, and growth persistence, while direct measures of disaster exposure do not exhibit statistically significant effects. This pattern is consistent with evidence that the economic consequences of environmental stress often operate through indirect and delayed channels, such as gradual infrastructure deterioration, changes in land-use patterns, and longer-term investment adjustments, rather than through instantaneous output losses (Cavallo et al., 2021). From a management perspective, this underscores the risk of relying solely on short-term macroeconomic signals when assessing environmental risk, as structural vulnerabilities may accumulate beneath stable growth trajectories and only become apparent over longer horizons or through sectoral and spatial disaggregation.

The long-run estimation results, derived from the ARDL error correction framework, provide critical insights into how environmental risk and macroeconomic fundamentals shape Indonesia's economic performance over extended time horizons. Table 2 presents the long-run coefficients, which are computed as the cumulative effect of each variable adjusted for the speed of adjustment parameter (1-coefficient of lagged GDP). The denominator of 0.1232 indicates a relatively slow adjustment process, with approximately 12.3 percent of deviations from long-run equilibrium corrected within one year. The long-run results reveal that gross fixed capital formation (GFCF) and population size emerge as the dominant drivers of Indonesia's economic growth. The long-run coefficient for GFCF (0.263) indicates that a one percent increase in investment is associated with a 0.263 percent increase in real GDP in the long run, holding other factors constant. This finding underscores the central role of capital accumulation in sustaining economic performance, consistent with the neoclassical growth framework and the broader empirical literature on developing economies. The magnitude of this effect is comparable to estimates from other emerging economies; for instance, Sabri et al (2024) found that investment exerts a strong positive effect on economic growth in Indonesia, while cross country studies by Kahn et al (2021) demonstrate that capital formation is a critical determinant of long-run growth trajectories, particularly in economies with high investment to GDP ratios.

Population size exhibits a long-run coefficient of 1.977, indicating a strong positive association with economic growth. This finding reflects the scale effects associated with a large domestic market, labor supply expansion, and agglomeration economies. However, the magnitude of this coefficient should be interpreted with caution, as it may also capture the structural transformation of the Indonesian economy from an agrarian to an industrial and service based structure over the 1960-2024 period. International evidence on the growth population nexus is mixed: while some studies emphasize the demographic dividend in rapidly growing economies (Nurcahyo et al., 2025), others caution that population growth can strain natural resources and infrastructure, particularly in environmentally vulnerable contexts (Perwithosuci et al., 2025). In the Indonesian context, the positive long-run effect suggests that demographic scale has historically supported growth, although the sustainability of this relationship depends on continued investments in human capital, infrastructure, and environmental management.

Table 2 shows forest loss retains a positive and statistically significant long-run association with GDP, with a coefficient of 0.030. This finding indicates that, over the 1960-2024 period, land-use change and deforestation have been structurally linked to Indonesia's economic growth trajectory. The positive coefficient reflects the historical importance of resource-based sectors including logging, palm oil, mining, and agricultural expansion in driving output growth (Nandatari et al., 2026; Sabri et al., 2024). This result aligns with the resource-based growth literature, which demonstrates that in many developing economies, natural capital exploitation serves as a proximate driver of economic expansion, particularly during early stages of development (Sabri et al., 2024; Meilinda & Kurniawan, 2024). However, the modest magnitude of the coefficient just 0.030 warrants careful interpretation. A one percent increase in forest loss is associated with only a 0.03 percent increase in long-run GDP, suggesting that the economic returns to deforestation are diminishing. This pattern is consistent with the environmental Kuznets curve (EKC) hypothesis, which posits that environmental degradation initially increases with economic growth but eventually declines after a certain income threshold is reached (Khoeriyah et al., 2024). More recent theoretical extensions, such as the Green Solow model developed by by Guilló & Magalhães (2023) argued that the marginal productivity of natural capital declines as degradation accumulates, reflecting the finite capacity of ecosystems to sustain resource extraction without impairing long-term productivity.

Warsame et al (2024), in Somalia, found that deforestation exerts a persistent negative drag on economic growth once ecological thresholds are exceeded, suggesting that the short-term growth benefits of land conversion may be offset by long-term productivity losses. Similarly, Huang et al (2024) demonstrated in the Chinese context that while post-disaster reconstruction can provide temporary economic stimulus, the long-term effects of environmental degradation including reduced innovation incentives and diminished fixed asset investment can undermine growth fundamentals. In Indonesia, the findings of Sabri et al (2024) revealed a two-way relationship between economic growth and environmental degradation, where growth drives resource depletion, and environmental degradation, in turn, reinforces output expansion in the short term. This reciprocal dynamic suggests that while forest loss has historically supported growth, the structural dependence on resource extraction creates vulnerabilities that may constrain future development.

Table 2 shows flood exposure does not exhibit a statistically significant long-run effect on real GDP in the estimated model. This finding diverges from common expectations in the disaster growth literature, which often posits that recurrent hydrometeorological hazards systematically undermine economic performance, particularly in developing countries with limited adaptive capacity (Botzen et al., 2019; Kahn et al., 2021). However, the Indonesian results are consistent with a growing body of international evidence suggesting that the aggregate macroeconomic impacts of flooding may be muted in economies with established adaptation mechanisms. Several explanations from the international literature help account for this finding. First, post disaster reconstruction spending can generate short-term demand stimulus that partially offsets output losses, a phenomenon documented in cross country analyses by Klomp & Valckx (2014) and in country specific studies by Abdulah et al (2025) in Indonesia. Second, spatial diversification of economic activity across Indonesia's extensive archipelago may reduce the aggregate impact of regionally concentrated flood events, a pattern also observed in geographically diverse countries such as Australia (Johar et al., 2022) and the United States (Deryugina, 2022). Third, fiscal transfers and disaster risk financing mechanisms at the national level can stabilize aggregate consumption and investment following localized shocks, as demonstrated by Wiyanti & Halimatussadiah (2021) in the Indonesian context.

Nevertheless, the absence of a negative long-run flood effect should not be interpreted as evidence of environmental immunity. International research cautions that macroeconomic resilience may mask significant distributional consequences and accumulating structural vulnerabilities. Cavallo et al (2021) argue that while small and recurrent disasters often do not alter national growth trajectories, large scale catastrophic events can exert persistent negative effects, particularly when they destroy significant capital stocks or disrupt long-term investment patterns. Moreover, micro level analyses reveal that directly affected households and firms experience substantial and often persistent economic distress even when aggregate indicators remain stable (Kirchberger, 2017; Johar et al., 2022). In the Indonesian context, Prasojo et al (2021) found that regions with higher economic activity often experience greater disaster related fatalities due to the concentration of assets and population in hazard prone areas, underscoring that macroeconomic growth without adequate risk management can amplify exposure.

Trade openness has negative long-run coefficient (-0.008), suggesting that, over extended horizons, higher trade integration is associated with marginally lower GDP. This finding reflects Indonesia's structural exposure to external demand fluctuations and global commodity price volatility, which have historically characterized the Indonesian economy (Cavallo et al., 2021). The result aligns with evidence from other resource-dependent emerging economies, where trade openness can amplify vulnerability to external shocks and terms-of-trade volatility (Loayza et al., 2012). However, the weak significance of this coefficient suggests that the long-run relationship between trade and growth in Indonesia is complex and may vary across sub-periods. During the 1960-2024 period, Indonesia experienced significant shifts in trade policy from import substitution industrialization in the 1970s and 1980s to export-oriented growth following trade liberalization in the 1990s and 2000s. These structural changes may have moderated the long-run association between trade openness and growth, as the net effects of trade integration depend on institutional quality, diversification of export composition, and the capacity to manage external volatility (Kahn et al., 2021).

5. Conclusion

The reasoning of this study was to address the analytical gap in country-specific, long-run macroeconomic research on environmental risk in disaster-prone emerging economies. Existing literature has predominantly relied on cross-country panels and short-term event analyses that obscure structural dynamics at the national level, and on administrative disaster data that may misrepresent the true extent of environmental exposure. By integrating satellite-derived indicators of flood exposure, forest loss, and night-time light intensity with Indonesia's national macroeconomic time-series over 1960–2024, this study sought to determine whether persistent environmental risk operates as a structural constraint on long-term economic growth, or whether adaptive mechanisms buffer its macroeconomic impact. The findings reveal that environmental factors influence economic performance in differentiated ways, largely consistent with the theoretical expectations of the Green Solow framework and the creative destruction hypothesis. Forest loss exhibits a persistent, statistically significant long-run association with economic growth, with a coefficient of 0.030, reflecting the historical embeddedness of resource-based development in Indonesia's growth trajectory. This finding is consistent with the Green Solow framework's prediction that natural capital contributes to output with diminishing returns, and with evidence from Indonesia's own development history that land-use conversion has served as a proximate driver of economic expansion (Sabri et al., 2024). However, the modest magnitude of this coefficient signals that the economic returns to deforestation are declining, supporting arguments that environmentally driven growth is not a sustainable long-run development strategy. Flood exposure, by contrast, does not exhibit a robust long-run negative effect on aggregate GDP, a finding consistent with the creative destruction hypothesis (Schumpeter, 1942) and with evidence that post-disaster reconstruction spending, spatial economic diversification across the archipelago, and fiscal transfer mechanisms at the national level collectively buffer the macroeconomic impact of recurrent hydrometeorological hazards. Investment and population scale emerge as the dominant structural drivers of long-run growth, with GFCF and population coefficients of 0.263 and 1.977 respectively, underscoring the primacy of capital accumulation and demographic scale in sustaining economic performance in line with neoclassical growth theory. In the short run, economic performance is governed primarily by GDP persistence, capital formation, and population scale, while direct environmental indicators do not produce statistically significant immediate effects, reflecting the indirect and delayed channels through which environmental stress transmits to aggregate output.

These findings carry important implications for theory, policy, and practice. Theoretically, the results support the Green Solow framework's prediction that natural capital contributes to long-run output with diminishing marginal returns, while the absence of a persistent negative flood effect lends qualified support to the creative destruction hypothesis. Together, these patterns suggest that the macroeconomic consequences of environmental risk in Indonesia are mediated by structural adaptation rather than simple output losses, a dynamic that aggregate statistics alone may fail to capture. From a policy standpoint, the modest and declining returns to forest-based economic activity indicate that continued dependence on land-use conversion is neither economically efficient nor environmentally sustainable; the transition to conservation-compatible livelihoods and climate-resilient investment is therefore not only ecologically imperative but economically rational. The absence of significant long-run flood effects should not be read as evidence of immunity: micro-level and sub-national evidence consistently documents significant welfare losses that are masked at the aggregate level, reinforcing the need for robust disaster risk reduction investment, early warning systems, and nature-based adaptation solutions. For investors and business practitioners, the findings highlight the importance of differentiating between chronic structural risks such as deforestation-related regulatory exposure and acute disaster shocks, and of integrating satellite-based monitoring into corporate risk assessment to enable more spatially precise evaluation of location-specific environmental hazards. The study's findings thus contribute to the environmental economics and business management literature by demonstrating that gradual environmental degradation and recurrent disaster events operate through distinct macroeconomic channels, each with different implications for the Green Solow framework, the creative destruction hypothesis, and the design of climate-resilient economic governance in disaster-prone emerging economies.

The implication of the study to carry on sustainable land management should be prioritized over continued deforestation-driven development. The findings indicate that the economic returns to forest loss are modest and diminishing, suggesting that transitioning toward conservation compatible livelihoods and strengthening enforcement of sustainable land-use regulations will support long-term growth without eroding natural capital. Proactive disaster risk reduction should be strengthened rather than relying solely on post-disaster resilience. Investments in early warning systems, climate-resilient infrastructure, and nature-based solutions such as mangrove restoration will enhance adaptive capacity to future hazards.

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Declarations

Author contribution	:	D. A: conceptualization, methodology, formal analysis, writing original draft. H. D. A: supervision, validation, writing review and editing. E. S. A. S. A: data curation, investigation, writing review and editing. W. W: software, visualization, writing review and editing. All authors have read and approved the final manuscript.
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References

Abdulah, R., Sugiharti, Rr. R., Rahmayani, D., & Asmarani, T. E. (2025). The effect of natural disasters at the rural level on economic growth: Evidence from Indonesia. *Jurnal Ekonomi Pembangunan: Kajian Masalah Ekonomi Dan Pembangunan*, 126–145. doi: 10.23917/jep.v26i1.10819

Botzen, W. J. W., Deschenes, O., & Sanders, M. (2019). The economic impacts of natural disasters: A review of models and empirical studies. *Review of Environmental Economics and Policy*, 13(2), 167–188. doi: 10.1093/reep/rez004

Cavallo, E. A., Becerra, O., & Acevedo, L. (2021). *The Impact of Natural Disasters on Economic Growth*. IDB Publication. doi: 10.18235/0003683

Deryugina, T. (2022). *Economic effects of natural disasters*. IZA World of Labor: 493.

Donaldson, D., & Storeygard, A. (2016). The view from above: Applications of satellite data in economics. *Journal of Economic Perspectives*, 30(4), 171-198. doi: 10.1257/jep.30.4.171

Gibson, J., Olivia, S., Boe-Gibson, G., & Li, C. (2021). Which night lights data should we use in economics, and where?. *Journal of Development Economics*, *149*. doi: 10.1016/j.jdeveco.2020.102602

Guilló, M. D., & Magalhães, M. (2023). Land capital and emissions convergence in an extended Green Solow model. *Environment and Development Economics*, *28*(1), 25–46. doi: 10.1017/S1355770X22000110

Henderson, J. V., Storeygard, A., & Weil, D. N. (2012). Measuring economic growth from outer space. *American Economic Review*, 102(2), 994-1028. doi: 10.1257/aer.102.2.994

Huang, L., Liu, Q., & Tang, Y. (2024). Long-term economic impact of disasters: Evidence from multiple earthquakes in China. *World Development*, 174. doi: 10.1016/j.worlddev.2023.106446

IPCC. (2022). *Climate change 2022: Impacts, adaptation and vulnerability (Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change)*. Cambridge University Press.

Johar, M., Johnston, D. W., Shields, M. A., Siminski, P., & Stavrunova, O. (2022). The economic impacts of direct natural disaster exposure. *Journal of Economic Behavior and Organization*, *196*, 26–39. doi: 10.1016/j.jebo.2022.01.023

Kahn, M. E., Mohaddes, K., Ng, R. N. C., Hashem Pesaran, M., Raissi, M., & Yang, J.-C. (2021). *Long-term macroeconomic effects of climate change: A cross-country analysis*. IMF Working Papers No. 2019/215. doi: 10.1016/j.eneco.2021.105624

Karydas, C., & Xepapadeas, A. (2022). Climate change financial risks: Implications for asset pricing and interest rates. *Journal of Financial Stability*, *63*. doi: 10.1016/j.jfs.2022.101061

Khan, M. T. I., Anwar, S., Sarkodie, S. A., Yaseen, M. R., & Nadeem, A. M. (2023). Do natural disasters affect economic growth? The role of human capital, foreign direct investment, and infrastructure dynamics. *Heliyon*, *9*(1). doi: 10.1016/j.heliyon.2023.e12911

Khoeriyah, S., Juwita, A. H., Prayoga, T., & Fitri, S. N. (2024). Spatial distribution patterns of poverty and economic growth for achieving sustainable development targets in East Java province. *Jurnal Ilmu Ekonomi dan Pembangunan, 24*(2), 65-76. doi: 10.20961/jiep.v24i2.87818

Kirchberger, M. (2017). Natural disasters and labor markets. *Journal of Development Economics*, *125*, 40–58. doi: 10.1016/j.jdeveco.2016.11.002

Klomp, J., & Valckx, K. (2014). Natural disasters and economic growth: A meta-analysis. *Global Environmental Change*, *26*(1), 183–195. doi: 10.1016/j.gloenvcha.2014.02.006

Li, Y. (2024). Finance and climate change risk: A review of the literature. *Population, Resources & Environmental Economics*, *5*(1), 050112. doi: 10.23977/pree.2024.050112

Lin, B., & Wang, Y. (2024). How does natural disasters affect China agricultural economic growth?. *Energy*, *296*, 131096. doi: 10.1016/j.energy.2024.131096

Loayza, N. V., Olaberría, E., Rigolini, J., & Christiaensen, L. (2012). Natural disasters and growth: Going beyond the averages. *World Development*, *40*(7), 1317–1336. doi: 10.1016/j.worlddev.2012.03.002

Meilinda, R. P., & Kurniawan, M. L. A. (2024). The role of social variables on growth in South of Sumatera: A dynamic panel data analysis. *Journal of Socioeconomics and Development, 7*(1), 68-76. doi: 10.31328/jsed.v7i1.4984

Meiriza, M. S., Marpaung, D. T., Limbong, N., Wulandari, S., Tarigan, B., & Medan, U. N. (2024). Analisis ekonomi Neo-klasik terhadap perkembangan ekonomi menurut Robert Solow dan Trevor Swan. *Ekonodinamika: Jurnal Ekonomi Dinamis*, *6*(3), 4-18.

Nandatari, F. R., Kurniawan, M. L. A., Lubis, F. R. A., Guritno, D. C., & A'yun, I. Q. (2026). Renewable energy, trade openness, and CO_2 emissions in G20 economies: Evidence from dynamic panel GMM. *Jurnal Ekonomi Pembangunan: Kajian Masalah Ekonomi dan Pembangunan*, *27*(1), 67-83. doi: 10.23917/jep.v27i1.9341

Nurcahyo, Y. B., Fatin, S., & Reza, M. F. (2025). Investigating the theory of environmental Kuznets curve on environmental quality index in Indonesia. *Optimum: Jurnal Ekonomi dan Pembangunan*, *15*(1), 111-118. doi: 10.12928/optimum.v15i1.8752

Pankratz, N. M. C. (2018). *Climate Change, Firm Performance & Investor Surprises*. Wharton Research Data Services. doi: 10.2139/ssrn.3443146

Patri, P., Sharma, P., & Patra, S. K. (2022). Does economic development reduce disaster damage risk from floods in India? Empirical evidence using the ZINB model. *International Journal of*

Disaster Risk Reduction, *79*. doi: 10.1016/j.ijdrr.2022.103163

Perwithosuci, W., Anas, M., Hidayah, N., Putri, R. N., & Hadibasyir, H. Z. (2025). Environmental quality, economic growth and population density: A panel study in Indonesia. *Optimum: Jurnal Ekonomi dan Pembangunan, 15*(1), 154-163. doi: 10.12928/optimum.v15i1.12559

Prasojo, A. P. S., Surtiari, G. A. K., & Prasetyoputra, P. (2021). The impact of natural disasters in Indonesia: How does welfare accentuate and attenuate the loss of people?. *Journal of Physics: Conference Series*, *1869*(1). doi: 10.1088/1742-6596/1869/1/012148

Sabri, Aimon, H., & Amar, S. (2024). Economic growth and environmental degradation in Indonesia: The roles of investment, inflation, income inequality, fossil consumption, and poverty. *International Journal of Sustainable Development and Planning*, *19*(5), 1941–1946. doi: 10.18280/ijsdp.190532

Tangkudung, N. S. (2019). The impact of natural disaster on economy. *Jurnal Ekonomi & Studi Pembangunan*, *20*(1). 63-70. doi: 10.18196/jesp.20.1.5014

Tasri, E. S., Karimi, K., & Muslim, I. (2022). The effect of economic variables on natural disasters and the impact of disasters on economic variables. *Heliyon*, *8*(1). doi: 10.1016/j.heliyon.2021.e08678

Tin, D., Cheng, L., Le, D., Hata, R., & Ciottone, G. (2024). Natural disasters: a comprehensive study using EMDAT database 1995–2022. *Public Health*, 226, 255–260. doi: 10.1016/j.puhe.2023.11.017

Warsame, A. A., Mohamed, J., & Sarkodie, S. A. (2024). Natural disasters, deforestation, and emissions affect economic growth in Somalia. *Heliyon*, *10*(6). doi: 10.1016/j.heliyon.2024.e28214

Wiyanti, A., & Halimatussadiah, A. (2021). Are disasters a risk to regional fiscal balance? Evidence from Indonesia. *International Journal of Disaster Risk Science*, *12*(6), 839–853. doi: 10.1007/s13753-021-00374-2

World Bank, T. (2025). *Climate Risk Country Profile: Indonesia*. Washington.