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Research article

Linking Climate Change and Regional Economic Growth in Indonesia

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ABSTRACT

Weather factors have become a critical climate change issue at global forums because climate change can impact natural and human life, especially economic activities, as demonstrated by one of the examples of economic growth in a country. As a climate-vulnerable country, Indonesia experiences significant fluctuations in weather patterns, impacting key economic sectors, especially agriculture. Utilizing secondary data from 2014 to 2022, the study applies a panel data regression model to examine the relationship between climate and Gross Regional Domestic Product (GRDP) per capita growth as a proxy of regional economic growth. The findings revealed that rainfall and average air temperature have a negative sign and significantly affect economic growth, particularly in natural-resource-dependent sectors. The population growth rate also has a negative sign and significant influence on GRDP per capita dynamics, underscoring the need for enhanced economic capacity to match demographic changes. These findings provide valuable insights for policymakers to incorporate climate considerations into sustainable economic planning, especially for climate-sensitive sectors.

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1. INTRODUCTION

Economic growth serves as a crucial barometer of a nation's well-being, signaling its ability to improve living standards, alleviate poverty, and foster sustainable development. This growth is shaped by a complex interplay of factors, including the availability of natural resources, shifts in demographics, and prevailing climatic conditions. For Indonesia, a burgeoning economy with a significant reliance on agriculture and natural resources, the influence of climatic variables like rainfall and temperature is particularly profound. These climatic dynamics, combined with rapid population growth, present substantial challenges to achieving sustained economic progress. Therefore, comprehending the intricate interactions among these elements is vital for crafting effective policies that promote long-term economic resilience in the country.

Changes in economic conditions, environmental factors, or policy frameworks can greatly affect the livelihoods of smallholder farmers (Aulia et al., 2020; and Kurniasih et al., 2018). Indonesia's geographical diversity exposes it to significant climate variability and change. Rainfall and temperature fluctuations impact the agricultural sector, which remains a cornerstone of the economy and a primary source of livelihood for much of the population. According to BMKG (2023), Indonesia's average temperature has shown a steady upward trend of approximately 0.03°C per year. Simultaneously, rainfall patterns have become increasingly erratic, leading to adverse outcomes such as droughts, floods, and reduced agricultural yields. These climate changes disrupt agricultural output and broader economic activities, underlining the importance of integrating climate considerations into national development planning.

Global evidence underscores the profound impacts of climate change on economic systems. Globally, the researchers revealed that each additional 1°C of day-to-day temperature fluctuation was associated with a 5% reduction in regional economic growth rate in any given year. Even at the regional level, where yearly rates might vary by 16 percentage points each year, this is a significant shift (Khurshid et al., 2022). Other studies, such as Sequeira et al. (2018); and Arogundade et al. (2024) found that the effect of rising temperatures and extreme climate events has had no relevant economic impact until now, but will have in the future. Global warming affects hot regions more profoundly than cooler regions, significantly negatively affecting Gross Regional Product (GRP) and temperature rises will show an adverse outcome in lower-income countries (Henseler & Schumacher, 2019; Pretis et al., 2018; Sequeira et al., 2018; and Zhang & Masron, 2023). Similarly, in the context of climate change, it is estimated that rainfall intensity will increase, which could have a significant impact on sectors including transportation, agriculture, industry, health, and energy supply (Chamma, 2024; Olanrewaju, 2019; and Adebayo et al., 2021). Projections by BMKG suggest that rising temperatures and changing rainfall patterns will exacerbate these vulnerabilities, with potentially severe implications for food security and rural livelihoods.

Rainfall, as a pivotal climatic factor, wields a dual influence on economic growth: moderate and consistent precipitation fosters agricultural productivity, while extreme variations—either excessive or insufficient—can trigger natural disasters such as floods, droughts, and soil erosion. Studies from other agriculture-dependent economies underscore this sensitivity; for instance, Sangkhaphan & Shu (2020) demonstrated the significant impact of rainfall variability on Thailand's economic performance, particularly within its agricultural sector, and study by Kara & Diken (2020) found a strong correlation between rainfall patterns and agricultural output in Turkey. In Indonesia, the uneven distribution of rainfall across its diverse regions further complicates efforts to manage these economic impacts, especially in provinces with a high reliance on agriculture.

Indonesia experiences significant rainfall fluctuations, with the average annual precipitation between 2014 and 2022 showing considerable variation across regions. While most areas receive at least 2,000 mm of rainfall annually, the extremes range from a high of 4,650.90 mm in South Sulawesi to a low of 879.40 mm in Central Sulawesi, according to the Meteorology, Climatology, and Geophysics Agency (BMKG, 2023). These fluctuations are largely driven by global climate phenomena such as El Niño and La Niña, which directly impact Indonesia's rainfall patterns. For instance, La Niña typically brings increased rainfall, whereas El Niño often leads to drier conditions. Beyond these climatic factors, population growth poses another critical challenge for Indonesia. As the world's fourth most populous country, Indonesia's demographic shifts exert substantial pressure on its resources, infrastructure, and public services. Rapid population expansion escalates the demand for essential needs like food, housing, energy, and employment, underscoring the necessity for robust economic policies to navigate these challenges. While a growing population can expand the workforce, it simultaneously intensifies the need for sustainable resource management and comprehensive economic planning.

The interaction between population growth and climate change further compounds these challenges. Rising temperatures and erratic rainfall patterns threaten agricultural productivity, while population pressures exacerbate resource scarcity and infrastructure demands. Addressing these intertwined issues for Indonesia is critical for achieving inclusive and sustainable economic growth. Economic indicators, such as Gross Regional Domestic Product (GRDP) per capita, provide valuable insights into regional economic performance. GRDP per capita captures the economic output relative to population size, offering a measure of productivity and living standards at the regional level. Climatic factors, such as temperature and rainfall, are hypothesized to influence GRDP per capita directly by affecting agricultural yields, labor productivity, and resource availability. Similarly, population growth influences GRDP per capita by altering the labor market and demand for goods and services.

Previous study provides a strong foundation for examining these relationships. Colacito et al. (2019) demonstrated that higher summer temperatures negatively affected economic growth in the United States, with a 1°F increase reducing growth rates by 0.15% to 0.25%. Jain et al. (2020) highlighted that a 1°C increase in temperature reduced economic growth in India by 2.5%,

underscoring the disproportionate impacts of climate change on developing economies. Henseler & Schumacher (2019) observed climatic conditions affect the factors of production that drive GDP growth, namely TFP, capital stocks, and employment. These studies found evidence that temperature impacts all components of GDP, but does so predominantly only in poor countries. However, Jain et al. (2020); Kara & Diken (2020); and Sequeira et al. (2018) found that rising temperature has no influence on growth in real GDP per capita in the second half of the twentieth century for the world countries. The adverse effect of rising temperatures and the positive effect of rising precipitation come from poor countries. In the Indonesian context, Febriandika & Rahayu (2021) identified negative correlations between rainfall and economic growth, emphasizing the need for adaptive strategies to mitigate climate-related risks. Contrary to that, Adebayo et al. (2021) revealed that the effect of temperature is negative while rainfall is positive on the Gross Regional Domestic Product (GRDP) of Provinces on the island of Java. Febriandika & Rahayu (2021) found that changes in temperature and increased rainfall do not affect GRDP in all provinces in Indonesia.

Despite a growing body of literature on climate change and economic growth, there remains a notable paucity of studies examining the joint impact of climate variables and demographic dynamics on economic performance at the regional level in Indonesia. Existing study often focuses on either climatic or population factors in isolation, or is limited by data that fails to reflect current challenges. This study addresses a significant gap by offering evidence-based recommendations specifically tailored to Indonesia's unique socio-economic and climatic context. Utilizing panel data regression analysis with data from 2014 to 2022, this study quantifies the impact of these variables on regional economic performance. Unlike previous works, it adopts a multidimensional approach, integrating both climatic and demographic factors to comprehensively understand their complex interplay. Accordingly, this study aims to specifically analyze the effects of rainfall, average air temperature, and population growth rate on Gross Regional Domestic Product (GRDP) per capita across Indonesia.

The findings of this study are poised to offer valuable insights for policymakers and stakeholders by elucidating the critical role of climatic and demographic factors in shaping economic outcomes. This study underscores the imperative of integrating these considerations into national and regional development plans, with implications extending beyond academia to inform practical policymaking. As Indonesia endeavors to achieve its sustainable development goals, comprehending the intricate relationships between climate, population, and economic growth becomes increasingly vital. Specifically, this study aims to identify key drivers of regional economic performance and provide actionable insights for enhancing economic resilience in the face of ongoing climate change and demographic pressures. By addressing these critical issues, this work contributes to the broader discourse on sustainable development, emphasizing the inherent interconnectedness of environmental, social, and economic systems. Ultimately, the findings are expected to guide the formulation of policies that promote equitable and sustainable growth, thereby ensuring Indonesia's economic progress is robust and resilient against future climatic and demographic challenges. The subsequent sections of this article detail the methodology, present the empirical results and discussion, and conclude with policy implications.

2. RESEARCH METHODS

2.1. Data

This study utilized secondary data from authoritative sources spanning 2014–2022. The dataset includes dependent variable is GRDP per capita growth, and three independent variables—rainfall, average air temperature, and population growth rate, data sourced from Indonesian Meteorological, Climatological, and Geophysical (BMKG), and Statistics Indonesia (BPS). Each variable's details and sources are provided in Table 1 as follows:

Table 1. Description of Variables and Sources

Variables	Explanation	Source
GRDP per capita growth ($GRDP$)	This variable reflects regional economic output divided by the population size, providing a measure of economic performance adjusted for population (% per year).	BPS
Rainfall amount ($Rainfall$)	The data were aggregated at the provincial level and represent annual trends for each region (mm per year).	BMKG
Average air temperature ($Temperature$)	This variable captures the annual average temperature trends at the provincial level (°C per year).	BMKG
Population growth rate ($PopGrowth$)	This variable reflects the annual increase in the population of each region (% per year).	BPS

2.2. Model Specifications

The study employed a quantitative descriptive approach, focus on panel data regression analysis. Panel data combines cross-sectional data (observations across 34 provinces) with time-series data (from 2014 to 2022), so that the total observation is 306 samples. The panel data approach offers significant advantages compared to using cross-sectional data alone. These advantages arise not only from the nature of the data—which varies across both time and space—but also from the approach's ability to control for many unobserved variables (Deschenes & Greenstone, as cited in Kolstad & Moore, 2020). In panel data, observations are made on multiple subjects and analyzed over time. Thus, the panel data equation, which combines cross-sectional and time series data, can be written as follows.

$$Y_{i,t} = \beta_0 + \beta_1 X_{i,t} + \varepsilon_{it} \quad (1)$$

Consistent with the specification in Equation (1), the model examines how changes in climatic variables and population growth influence GRDP per capita growth across Indonesia's provinces over time. Following study by Febriandika & Rahayu (2021); and Sangkhaphan & Shu (2020), in this analysis, feasible generalized least squares (FGLS) with a fixed effects approach is used to estimate panel data. The empirical model is expressed as the following Equation (2):

$$\Delta GRDP_{i,t} = \beta_0 + \beta_1 Rainfall_{i,t} + \beta_2 Temperature_{i,t} + \beta_3 PopGrowth_{i,t} + \alpha_i + \alpha_t + \varepsilon_{it} \quad (2)$$

where, $\Delta Y_{i,t}$ is growth in GRDP per capita for region *i* at time *t*; $Rainfall_{i,t}$ is annual average rainfall for region *i* at time *t*; $Temperature_{i,t}$ is annual average air temperature for region i at time t; $PopGrowth_{i,t}$ is population growth rate for region i at time t; β_0 is intercept, $\beta_1, \beta_2, \beta_3$ is the regression coefficient for each independent variable; α_i is region-specific fixed effect to control for time-invariant regional differences; α_t represent time time-specific fixed effect to account for macroeconomic shocks affecting all regions; and ε_{it} is the error term.

The study employed a fixed effects model (FEM)**,** which accounts for unobserved heterogeneity across provinces by allowing each region to have its unique intercept. Diagnostic tests guided model selection, such as Chow test, to determine whether a fixed effect model (FEM) is more appropriate than a common effect model (CEM). Chow test calculation obtained a Chi-Square significance value <0.05 so that Ho is rejected, then the FEM is used. Hausman test to determine whether fixed effect (FEM) and random effect models (REM). The Hausman test confirmed the suitability of FEM for this analysis. The Hausman test calculation obtained a Chi-Square significance value <0.05, so Ho was rejected, and the fixed effect model was used. In this paper, we propose residual diagnostic tests for the detection of multicollinearity and heteroscedasticity between the explanatory variables.

3. RESULTS AND DISCUSSION

3.1. Result

The study analyzed the effects of rainfall, average air temperature, and population growth rate on GRDP per capita in Indonesia for 2014–2022. Using panel data regression analysis, the study

provides insights into the relationship between these variables and regional economic performance. This section describes all the study variables used based on existing statistical data. The average GRDP per capita growth for the sampled period is around 5.14%, with a maximum value of 11.32% and a minimum of -2.06%, respectively. Indonesia experiences annual rainfall and average air temperature of around 2.67 mm per year and 27.60 °C. The maximum value of rainfall is 4,650.9 mm per year, while the minimum value of this variable is 879.4 mm per year. Similarly, the maximum (29.41 °C) and minimum (24.99 °C) values of air temperature are recorded, respectively. Finally, the population growth in Indonesia is 1.25% on average, while the maximum is 3.84% and the minimum is -0.12%.

Table 2. The Result of Descriptive Statistics

Variables	Mean	Min	Max
GRDP	5.14	-2.06	11.32
Rainfall	2.67	879.4	4,650.9
Temperature	27.60	24.99	29.41
PopGrowth	1.25	-0.12	3.84

Table 3 presents the correlation matrix result. Based on Table 3, it is known that the correlation coefficients of all independent variables have a value of less then 0.80, so it can be concluded that the variables are free from multicollinearity.

Table 3. The Result of Correlation Matrix

Correlation	Rainfall	Temperature	PopGrowth
Rainfall	1.000	-0.073	-0.034
Temperature	-0.073	1.000	-0.026
PopGrowth	-0.034	0.026	1.000

Prior to estimating the panel data regression, the selection of the most appropriate model is a crucial preliminary step. Several panel data regression models can be considered, including the common effect model, fixed effect, and random effect model. After selecting the appropriate model, classical assumption tests and parameter estimation procedures are typically conducted. Tabel 3 reports the Chow and Hausman test results both indicate that the fixed effect model (FEM) is the most appropriate model, with significant Chi-square values at the 1% level. Furthermore, the classical assumption test is carried out. The classical assumption test includes a normality test, a multicollinearity test, and a heteroscedasticity test. The normality test in this study was not used. This is following what was suggested by Alita et al. (2011) that the normality test is only carried out if the study has several observations <30 to determine whether the error term is close to normally distributed data.

Table 4. The Result of Panel Data Regression using Fixed Effect

Dependent variable = $GRDP$				
Variables	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
Constant	33.504***	7.688	4.357	0.000
Rainfall	-0.001***	0.000	-3.212	0.001
Temperature	-0.727***	0.274	-2.647	0.008
PopGrowth	-4.566***	0.714	-6.390	0.000
Chow test	84.830***			
Hausman test	17.082***			
R^2	0.3374			
Adj R^2	0.2488			
DW stat	1.7810			
Heteroscedasticity	0.2720			

Note: ***, **, and * indicate significance level at 1%, 5%, and 10%

For the heteroskedasticity results, it can be seen in Table 4 that the probability value of each independent variable is greater then 0.05 or 5%, so that all independent variables are free from heteroscedasticity problems. As a result of the presence of the fixed effect model, we proceed to the panel data multiplier linear regression for the effects of rainfall, average air temperature, and population growth rate on GRDP per capita in Indonesia.

Table 4, it can be seen that the adjusted R-squared value is 0.2488 or 24.8%. The coefficient value shows that the independent variables, consisting of the amount of rainfall, average air temperature, and population growth rate, can explain the GDP per capita growth variable in Indonesia by 24.8%. In comparison, the remaining 75.2% is explained by other variables not included in this study. The low Adjusted R-squared value in panel data is often caused by heterogeneity between units and unobserved variables that are difficult to measure (Greene, 1990).

Table 4 reports that the results obtained indicate that all explanatory variable coefficients in the GRDP per capita model have a probability value of less than 5%. Thus, it can be said that these variables have a statistically significant relationship. Specifically, the findings presented in Table 4 indicate that the level of rainfall has a negative sign and a significant influence on GRDP growth per capita, this implies that a 1% increase in rainfall will weaken economic growth by -0.001%. Similarly, air temperature has a negative sign and a significant influence on GRDP growth per capita, this indicates that a 1% increase in air temperature will also slow growth by -0.727%. Likewise, population growth has a negative sign and a significant impact on GRDP growth per capita, this implies that a 1% increase in population will slow economic growth by -4.566%. In other words, GRDP per capita between regencies/cities in Indonesia is influenced by the level of rainfall, air temperature, and population growth.

3.2. Discussion

Our findings reveal that rainfall is negatively correlated with per capita GRDP growth. In this study, the relationship between rainfall and per capita GRDP growth is significant. This suggests that higher rainfall in Indonesia leads to lower GRDP per capita growth. This supports evidence from several developing countries, such as Indonesia, where irrigation systems for the agricultural sector are considered suboptimal. Approximately 60% of rice fields in Indonesia are rainfed, while only 40% are irrigated. Most of this irrigation relies on 215 dams, supporting 811,000 hectares of agricultural land, while groundwater irrigation plays a minimal role, covering only 3,678 hectares (Gatti et al., 2021). This limited irrigation infrastructure makes agricultural productivity highly sensitive to weather patterns, potentially leading to reduced economic output during periods of excessive or erratic rainfall. Thus, if rainfall conditions deviate from normal limits, where earlier rainfall usually affects agricultural and plantation production, which affects community income (Tampubolon & Sihombing, 2017 in Febriandika & Rahayu, 2021). These findings align with research by Osman et al. (2025); Meyghani et al. (2023); Olanrewaju (2019); and Sangkhaphan & Shu (2020) which showed that rainfall has a significant negative impact on GDP growth at the national level, and the agricultural and service sectors were shown to be most vulnerable to rainfall. This is in line with a study by Febriandika & Rahayu (2021) which stated that rainfall variables have a negative impact on the regional economy. If the agricultural sector is disrupted by increasingly unpredictable climate conditions, the ripple effects can be severe. In Indonesia, agriculture is economically interconnected with other sectors through various channels; therefore, any disruption in agriculture can impact not only the local economy but also significantly affect the broader national or regional economic structure (Chamma, 2024; and Saban et al., 2024). This study is inconsistent with the research of Kara & Diken (2020); Adebayo et al. (2021); and Uddin et al. (2024), which states that there is a positive correlation between rainfall and agricultural sector growth or economic growth. This means that rainfall does not cause losses to agricultural productivity and GRDP.

Another finding concerns the air temperature variable, which also has a negative sign and significantly impacts per capita GRDP growth. This implies that the higher the average air temperature in Indonesia, the greater the impact on declining production activities, including agriculture, a crucial sector of the Indonesian economy. Temperature itself is a measure of the degree of coldness or heat of a body or environment (Uddin et al., 2024). Although the rate of

temperature change is slow, even small adjustments can have significant global impacts. Earth's temperature is currently increasing annually, and the rate of increase, initially very small, is accelerating, making it easier to identify signs of global warming. Increasing temperature or heat levels will have a global impact, causing numerous changes to the Earth's surface, such as increased extreme weather, decreased productivity, changes in water demand, faster water extraction rates, and decreased crop quality (Febriandika & Rahayu, 2021). The relationship between GDP per capita and air temperature can be illustrated by the "Lafer curve" (an inverted U-shaped curve), where economic growth increases for temperatures below 24.9°C but decreases for temperatures above that value (Adam & Drakos, 2022; Zhao & Liu, 2023). Based on BMKG data (BMKG, 2023), the average air temperature in Indonesia varies across provinces. The highest average temperature is in East Nusa Tenggara at 29.35°C, while the lowest temperature is in East Java at 24.99°C. The average temperature between provinces is 28°C. This indicates that there are significant temperature differences between provinces that affect GRDP per capita. This is in line with research by Osman et al. (2025); Meyghani et al. (2023); Adebayo et al. (2021); and Sequeira et al. (2018) which state that there is a negative impact of high temperatures on economic growth. In developing countries, a 1°C increase in temperature can reduce economic growth by around 1.3%, consistent with research by Colacito et al. (2019) that found that warmer temperatures significantly impact the US economy, both aggregately and across economic sectors. Previous studies, such as Kalkuhl & Wenz (2020) and Khurshid et al. (2022), have shown a positive relationship between precipitation and economic growth, primarily driven by the agricultural sector in cooler regions.

Finally, we also found that the population growth rate variable is also negative and has a significant effect on GRDP per capita growth. This implies that the higher the population growth rate in Indonesia, the weaker the GRDP per capita growth will be. This is because the increasing population growth rate will impact the increasing demand for natural resources, food, and energy. If economic growth is not in line with population growth, it will reduce the quality of life and hamper the growth of GRDP per capita. This is in line with Malthus's theory, which states that population growth that is not balanced by an increase in economic resources will put pressure on resources, reduce the quality of life, and limit economic growth (Adeosun & Popogbe, 2021). Our findings are inconsistent with Khurshid et al. (2022) who found that population size has a significant beneficial impact on economic growth due to the large available workforce and the division of labor.

4. CONCLUSIONS

The conclusions of this study indicate that the impact of rainfall, average air temperature, and population growth rate will significantly hamper the growth of Indonesia's per capita GRDP. Climate variability can reduce regional GRDP growth in Indonesia, representing the cumulative impact of climate change on environmental degradation. The impacts of rising temperatures and rainfall are also likely to worsen in the future if policymakers do not take appropriate mitigation measures. The practical implications of these findings offer several policy recommendations. First, improving irrigation infrastructure and drainage systems is necessary to optimally accommodate and distribute water. This also includes increasing water retention capacity during the rainy season and optimizing its use during the dry season. Second, the government needs to develop and disseminate adaptive agricultural techniques, such as the use of heat-tolerant crop varieties or improving more environmentally friendly and energy-efficient agricultural technologies. Finally, controlling population growth, including controlling urbanization and educating about family planning, is crucial for maintaining a balance between population and resource policies. Future studies could incorporate other climate variables that may influence per capita GRDP growth, including humidity, climate hazards, seasonal changes, air quality, variability in growing seasons, changes in wind patterns, and so on, to investigate sensitivity variances across annual or monthly data, as well as explore potential short- and long-term effects associated with various fluctuations. Detailed sector-specific studies could be considered.

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