Jurnal Presipitasi
Media Komunikasi dan Pengembangan Teknik Lingkungan
e-ISSN: 2550-0023

Vol 23, No 1, 2026,
Article available at homepage presipitasi

Regional Case Study

Long-Term Rainfall and Temperature Trends in East Java Under Climate Change

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Abstract
Climate change is a global issue at present affecting the whole world, including tropical countries like Indonesia. Previous studies have indicated that changes in these conditions have grave impacts on hydrological disasters. Therefore, the pattern of climate change needs to be analyzed for the feasibility of adaptation and mitigation in the future. This present study developed analyses into the trend in temperature variation over East Java both on an annual and daily time scale. Observation data within a long period from 1985 to 2023 was used for comprehensive results. Methods applied include linear regression, the Man-Kendall test, and Sen's Slope test. The new finding that emerged for the temperature variable was that the increase in temperature went over the global and national averages and consistently showed a significant increasing trend across the study area. However, the rainfall variable revealed different results in highlands, where the rainfall intensity decreased-in SDII and R100, inversely proportional to coastal areas. It means that climate change does not occur uniformly everywhere but varies spatially. These findings raise a case for climate change mapping to formulate appropriate adaptation and mitigation strategies.

Keywords: Climate change; Mann-Kendall; rainfall ; temperature

1. Introduction

Climate change that is currently occurring has become a hot topic of conversation both globally and locally in Indonesia. The Intergovernmental Panel on Climate Change (IPCC) highlights that persistent global warming has intensified extreme climate events, posing serious threats to ecosystems and human societies (IPCC, 2022). Global average surface temperature rose by 0.74°C from 1906-2006 (IPCC, 2007), 0.85°C from 1880-2012 (IPCC, 2014) and 0.99°C from 2001-2020 (IPCC, 2021) with stronger projections in northern regions (Vihma et al., 2016). Global climate change is expected to lead to increased frequency and intensity of extreme weather events such of extreme rainfall (Chernet et al., 2014); (Donat et al., 2019), with global land rainfall rising since 1950 and accelerating after the 1980s (IPCC, 2021). Annual-maximum daily precipitation (Rx1day) has increased faster (Asadieh and Krakauer, 2015) occurring at nearly two-thirds of global rainfall stations (Westra, Alexander and Zwiers, 2013; Sun et al., 2021).

Significant increases in rainfall have been observed regional scale such as eastern North and South America, northern Europe, and northern and central Asia (IPCC, 2014) and in the French Mediterranean (Ribes et al., 2019). In Asia, projections show substantial increases in wet days, annual maximum rainfall, and total precipitation by the end of the 21st century (Huang et al., 2024), with rainfall expected to rise by 3–10% in Korea (Kim et al., 2019), 2.56–4.65% in the Yuan River Basin, China (Guo et al., 2019) and 15%-17% in Pakistan's Rawal Dam watersheed ((Hassan et al., 2023).

Indonesia as a country with high levels of rainfall and solar radiation is highly vulnerable to climate change, although impacts vary across regions (Vicuna and Dracup, 2007). According to (Julismin, 2008), climate change in Indonesia is indicated by temperature increases across all regions, with decreasing rainfall in the southern region (Java and Nusa Tenggara), while northern regions (Sumatra and Kalimantan) tend to experience increased rainfall. It is predicted that the rainy season will become shorter but rain will be more intense contributing to the overall risk of flooding and landslides as well as the impact on the agricultural sector (UNDP, 2007). Changes in temperature and precipitation will always be the most important factors in climate change. For example, the average daily maximum and minimum temperatures (0.18 and 0.30 degrees Celsius, respectively) in the last century and daily rainfall intensity increased by 0.21 millimeters per day (Supari et al., 2016).

In Java, climate change is characterized by continuous temperature increments and changes in rainfall. Analyses suggested that during the transitory phase the rainfall is above normal in some areas of the dry season and below normal, in many areas; it is highly erratic and spatially out of balance (Siswanto and Supari, 2015). These same characteristics have been noted in some areas of the Northern coastal Java (Setiawan et al., 2015). In the Java region, phenomena increase the risk of extreme temperatures; variable rainfall is the most major of the factors contributing to the increased risk of hydrometeorological disasters (Hendrawan et al., 2023).

The impacts of climate change are making East Java province increasingly more fragile. During the last three decades of data collection, certain climatology stations have shown a persistent increasing pattern of annual temperature averages. In the vicinity of the Wlingi Reservoir, a warming trend of >1°C indicates that the area is becoming considerably warmer (Ananta et al., 2024). Across Java Island, and East Java in particular, climate change is spatially distinguished from the background. Mulyanti et al. (2023) found that the northern coastal of Java is more vulnerable than the southern. East java also faces the impacts of climate change on rice production because rising evaporation that makes rice need more water (Amirusholihin et al., 2025). This scenario worsens because East Java is the second most population density province in Indonesia (BPS, 2025) and is a region with substantial agricultural dependency. The area also has a varied topography from coastal to highlands, thta it have possibility differing sensitivities to climate change. Hence, the region warrants the undertaking of scientifically sound assessments of temperature and rainfall for climate change to support the region's climate adaptation initiatives.

2. Methods

2.1. Study Area

This study was conducted in East Java Java Province, Indonesia approximately 7°00′–8°50′S and 112°50′–114°50′E (Figure 1 (a)) using data from 5 rainfall stations located in areas with diverse topographic characteristics, including coastal plains and mountainous zones (Figure 1(b)). The observation period spans from 1985-2023. According to (Aldrian and Dwi Susanto, 2003)), the entire island of Java falls within Climate Region A. By selecting locations within the same region, this study is expected to analyze in more detail the differences in climate characteristics within regional areas.

2.2. Materials

Climate data was obtained from the Indonesian Meteorology, Climatology, and Geophysics Agency (BMKG) covering the period 1985 to 2023. Variables used include surface temperature, rainfall, sunshine duration, relative humidity, wind direction and speed. In the East Java region, there are 12 rainfall stations under the authority of BMKG. Climate change studies require data with a minimum span of 30 years. Based on this, this study only used five rainfall stations. The locations of the rainfall stations used in the analysis also represent a variety of selected topography (Figure 1 and Table 1). This data is expected to produce analysis results that are more representative of regional climate conditions.

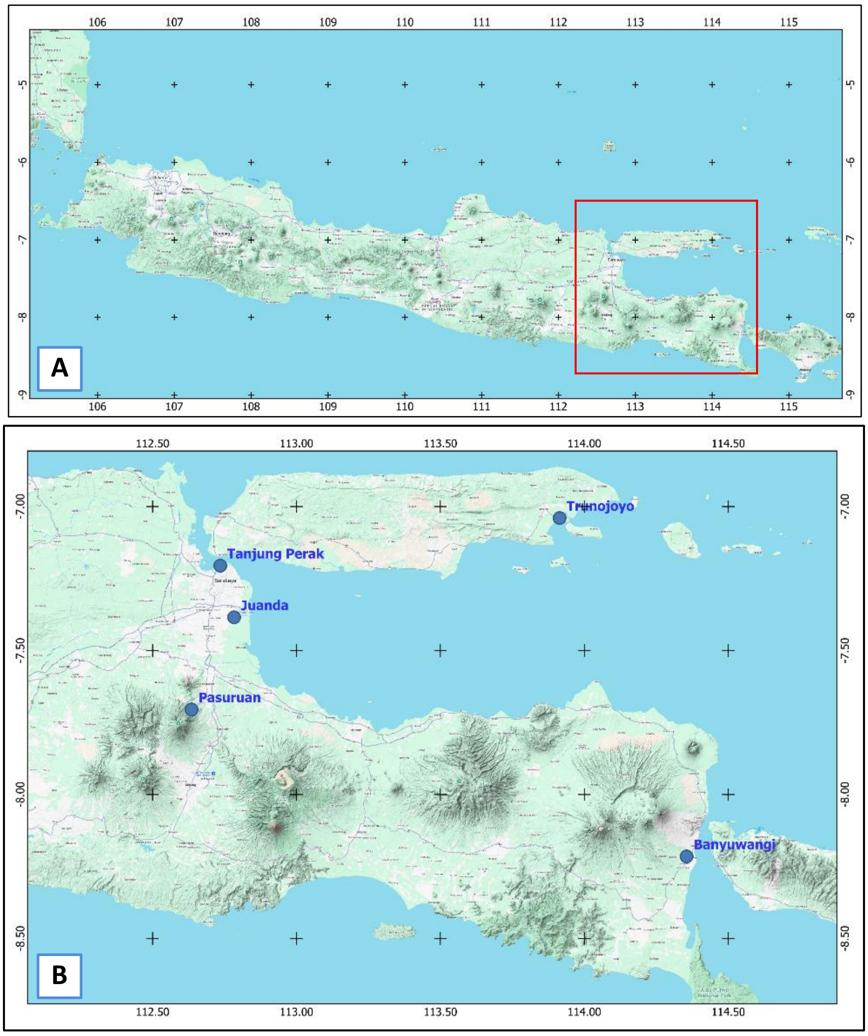


Figure 1. A Study area; B Distribution of rainfall station

Table 1. Rainfall stations

No	Rainfall Station	Latitude	Longitude	Elevation (masl)
1	Stasiun Tanjung Perak	-7.205	112.735	+3
2	Stasiun Banyuwangi	-8.215	114.355	+52
3	Stasiun Juanda	-7.385	112.783	+3
4	Stasiun Trunojoyo	-7.039	113.914	+3
5	Stasiun Pasuruan	-7.705	112.635	+832

2.3. Method

Conducting the analysis requires complete rainfall data. The Normal Ratio method is used to fill in gaps before conducting the analysis (Harto, 1993). After obtaining complete data, a homogeneity test is performed using the SNHT method, assisted by XLSTAT. We have used annual and daily temporal scales to analyze the rainfall and temperature profiles of the research site. This kind of multiscale procedure is useful in obtaining an integrated interpretation of the climate dynamics, including both long-term trends and short-term variability. Both parameters were analyzed using the slope of a linear regression model to determine the direction and magnitude of change over time. The significance of the trend was then tested using the Mann-Kendall method, a non-parametric test used to detect monotonic trends in time series without assuming a normal distribution. A Z-statistic exceeding ±1.96 (at $\alpha = 0.05$)

indicates significance. Its also use Sen's Slope estimator to estimates the median slope of pairwise data combinations to quantify trend magnitude (e.g., °C/year or mm/year). Trend tests were analyzed using add-ins real statistics on Excel software.

Eleven climate indicators were analyzed (see Table 2) by referring to the indices developed by *Expert Team on Climate Change Detection and Indices* (ETCCDI). These indicators were selected based on their relevance in detecting climate variability and change, particularly in tropical regions.

Table 2. Climate indices

Climate Indice	Name	Definition	Unit
Temperature			
Tx	Mean maximum temperature	Annual mean of maximum temperature	°C
Tn	Mean mininimum temperature	Annual mean of minimum temperature	°C
Rainfall/Precipitation			
PRCPTOT	Precipitation Total	Annual total precipitation in wet days (rainfall≥1mm)	mm
RX1day	Maximum Precipitation	Annual maximum precipitation	mm
R1mm	Number of rainy days / wet days	Annual count of days when precipitation ≥1 mm	day
R50mm	Number of rainy days	Annual count of days when precipitation ≥50 mm	day
R100mm	Number of rainy days	Annual count of days when precipitation ≥100 mm	day
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days in the year	mm/day

3. Result and Discussion

3.1. Trend in Annual Temperatur

Based on the linear regression analysis as shown on Figure 2, all stations exhibit an increasing trend in annual maximum temperature. The results of this study demonstrate that global warming is occurring consistently across various topographic levels, from coastal areas to highlands. Pasuruan Station is located in highlands; thus, this region has shown the most increase in temperature. It supports research done by Tanteliniaina et al. (2020), showing that tropical regions with higher elevations experienced the most significant Tmax increase in daily temperatures. Furthermore, the minimum temperature trend shows a comparable pattern, with the most significant decrease also observed at Pasuruan Station.

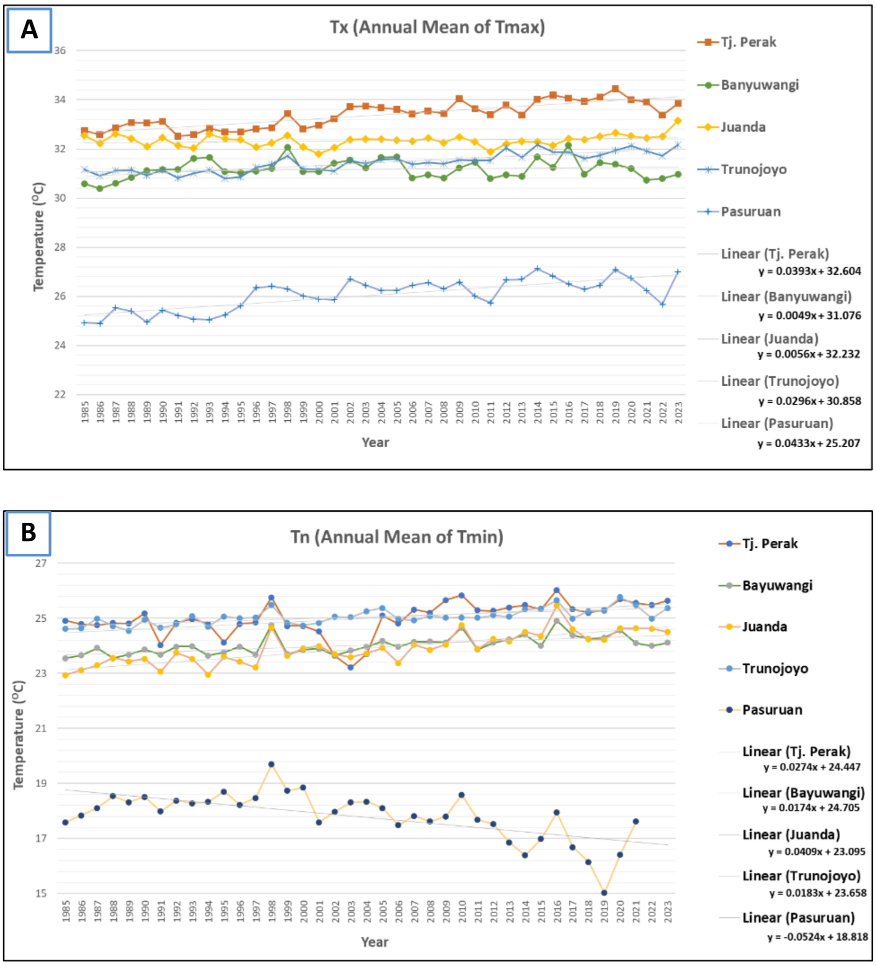


Figure 2. A Linear graph of increase in maximum temperature; B Minimum temperature

Based on the Z-statistic values presented in Table 3, a statistically significant warming temperature trend was identified at Tanjung Perak, Trunojoyo, and Pasuruan stations. According to the Sen's Slope estimates, Tanjung Perak and Trunojoyo reported increases of 0.02-90.04°C per year. These values exceed the global warming trend reported by the IPCC (2021), which is approximately 0.20°C per decade or equivalent to 0.02°C per year. These values also surpass the findings of (Supari et al., 2016) who reported that the increase in daily maximum temperature in Indonesia averages around 0.18°C per decade, or approximately 0.018°C per year. The rising temperature trend is also indicated to be caused by changes in land use in the study area. (Mandala et al., 2024) stated that in East Java, there was a 105% increase in paddy fields, 64% in forest and plantation areas, and a rapid 366% increase in built-up areas between 1970 and 2021.

Table 3. Summary of mann–kendall (MK) test and sen's slope of temperature

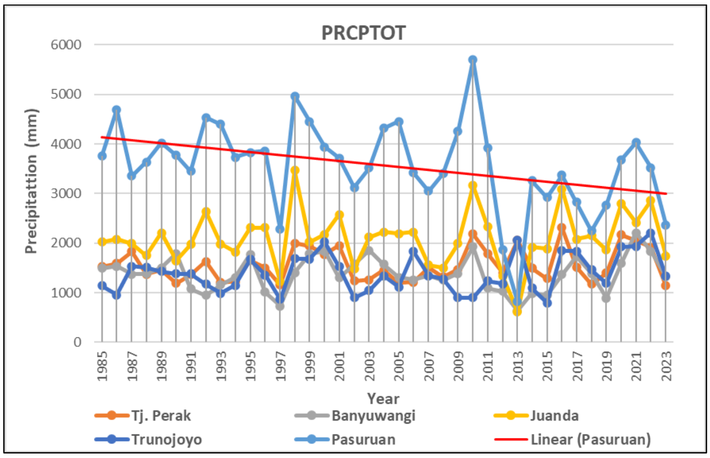
	Tanjung Perak	**Banyuwangi**	**Juanda**	**Trunojoyo**	**Pasuruan**
Tx (Mean Maximum Temperatur)					
Trend	**yes**	no	no	**yes**	**yes**
Sen's Slope	0.041	0.004	0.004	0.029	0.046
Tn (Mean Minimum Temperatur)					
Trend	**yes**	**yes**	**yes**	**yes**	**yes**
Sen's Slope	0.024	0.018	0.039	0.018	-0.044

A significant trend of increasing minimum temperatures was observed at the four rainfall stations analyzed, while a decrease was observed only at Pasuruan Station. This is because Pasuruan Station is topographically different from the other stations. This difference in results is likely due to local topographic characteristics. The results of this study contradict previous research, which generally showed an increasing trend in minimum temperatures. Therefore, further research is needed with an approach that is more detailed, for instance, seasonal analysis, for an improved interpretation of the dynamics of minimum temperature changes in this region.

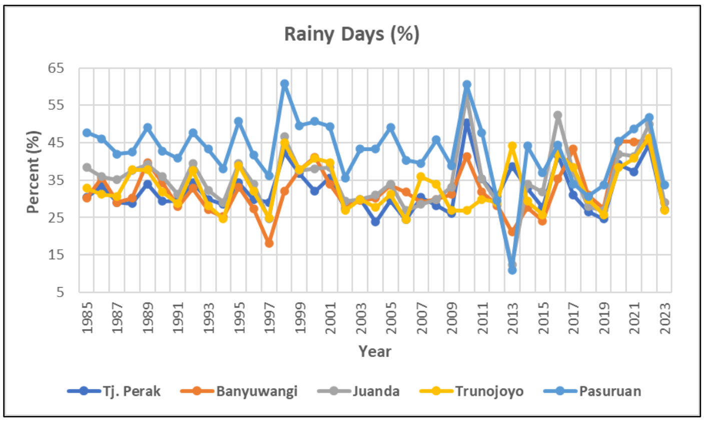
The results of this study show how global warming cannot be characterized geographically in one single area and how different global warming topographies distributed from the coast to the mountains. East Java's temperature rise is above the averages at both the global and national levels which mean that East Java is very vurnerable to climate change, indications of the need for local adaptation strategies as it relates to climate change, specifically for stakeholders on agriculture, agriculture resource management, and disaster risk reduction strategies.

3.2. Trend in Annual Rainfall

The analysis of the trends in annual rainfall in this study uses total annual accumulated rainfall and the number of rainy days. This approach is justified because the identification of the long-term trend in rainfall would consider the total volume and frequency of the events of rainfall over time. The analysis in Figure 3 showed that the highest annual rainfall and rainy days were recorded at a station located in the highlands, Pasuruan Station (+832 masl). (Siswanto and Supari, 2015) also found that this region tends to become drier. This finding is consistent with a phenomenon known as orographic precipitation, where rainfall tends to be higher in areas with higher elevations, particularly in tropical regions.



(a)



(b)

Figure 3. (a) Trend of annual rainfall total; (b) percentage of rainy days

There is no clear trend is observed in either parameter, except at the Pasuruan Station, which shows an increasing trend in total annual rainfall as presented in Table 4.

Table 4. Summary of mann–kendall (MK) test and sen's slope of annual rainfall and wet days

	Tanjung Perak	Banyuwangi	Juanda	Trunojoyo	Pasuruan
Annual Rainfall					
Trend	no	no	no	no	**yes**
Sen's Slope	4.81	-1.03	3.95	7.69	-26.71
Wet Days					
Trend	no	no	no	no	no
Sen's Slope	0.19	0.23	-0.32	0.00	-0.64

Although no statistically significant trends were found, the Sen's Slope values can still be interpreted as indicators of trend direction at each station. For annual rainfall, the slope values appear to correlate with topography. Positive rainfall trends, meaning that the rainfall increased, were recorded at stations located in coastal areas, whereas negative values, which mean a decrease in rainfall, were seen at more elevated stations. A similar pattern was also seen in the IKN region, where annual rainfall tends to increase in coastal areas and decreases as one moves away from the coastline (Ramadhan et al., 2022).

The study spans over two separate 20 year periods, and found that no statistically significant trends are observable, however, year on year trends are particularly visible as illustrated in Figure 4. This would suggest that the rate of increase in total annual rainfall has been higher than in previous years in the past two decades, and could be an early indication that the study area is indeed experiencing a shift in rainfall patterns. This strengthens evidence that climate change is accelerating rainfall intensity in the tropics. As reported by Sukhatme and Venugopal (2015), there has been a significant increase in the incidence of annual extreme rainfall in the tropics since 1998 compared to the previous period.

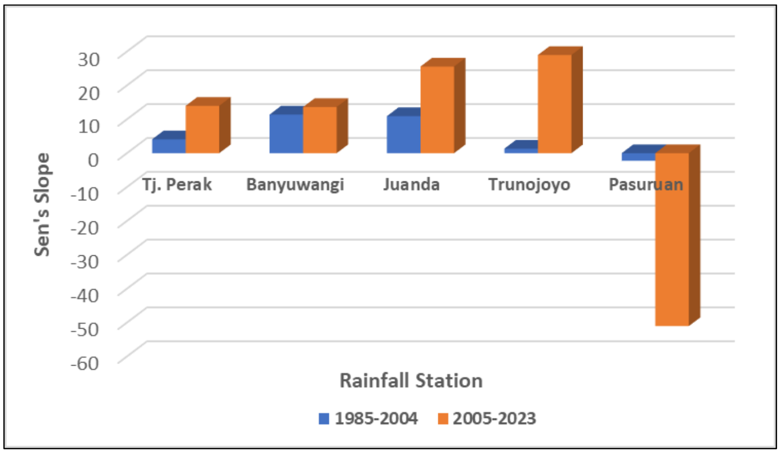


Figure 4. Annual rainfall increasing trend in the last 2 decades

3.3. Maximum Precipitation

In hydrological studies, annual maximum rainfall is a crucial parameter because it serves as a reference in determining design rainfall, which directly influences flood discharge estimates. Figure 5 shows an increasing trend in annual maximum rainfall at Tanjung Perak and Banyuwangi stations. Conversely, the other three stations showed a decreasing trend throughout the observation period.

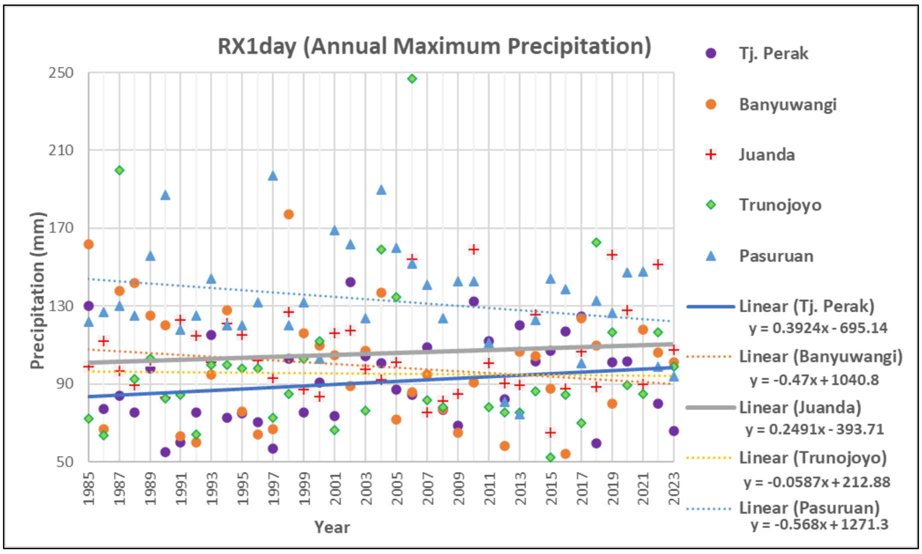


Figure 5. Linear increase in annual maximum rainfall trend

Based on Table 5, the Z-statistic values for all stations are above the critical threshold, indicating that the increasing or decreasing trends in annual maximum rainfall at the five stations are not statistically significant. However, several stations namely Tanjung Perak, Juanda, and Trunojoyo show positive Z-statistic values. According to Gocic and Trajkovic (2013), a positive Z-statistic value indicates an increasing trend, while a negative value indicates a decreasing trend. The highest annual rate of change with a positive slope was observed at Tanjung Perak station, at 0.457 mm/year, while the most significant negative slope was recorded at Banyuwangi station.

Table 5. Summary of mann–kendall (MK) test and sen's slope of annual maximum precipitation

Rainfall Station	Z Statistic	Trend	Sen's Slope
Tanjung Perak	1.258	no	0.457
Banyuwangi	-0.956	no	-0.438
Juanda	0.157	no	0.050
Trunojoyo	0.266	no	0.073
Pasuruan	-0.932	no	-0.391

These findings indicate upward and downward variations in the trend of annual maximum rainfall. Available statistical evidence cannot establish a continuous long-term trend. Evaluation and projection of potential future trends thus call for further in-depth analysis. This is particularly the case given that global climate models are projecting significant increases in future rainfall, whereas the historical record so far has not shown a statistically significant trend. Similar trends have been reported to be in existence in the continental US (Sharif et al., 2025), parts of East Africa (Rowell et al., 2015), and Jakarta, Indonesia (Rowell et al., 2015).

3.4. Extreme Precipitation

Rainfall intensity above 50 mm R50 and 100 mm R100 was considered extreme rainfall in this study. According to the BMKG, these values fall into the category of moderate and heavy rainfall. This index is especially important in determining the start of the rainy season.

Table 6. Summary of mann–kendall (MK) test and sen's slope of R50 and R100

	Tanjung Perak	**Banyuwangi**	**Juanda**	**Trunojoyo**	**Pasuruan**
R50mm					
Trend	no	no	no	no	no
Sen's Slope	0.00	0.00	0.03	0.00	-0.12
R100mm					
Trend	no	no	no	no	**yes**
Sen's Slope	0.00	0.00	0.00	0.00	-0.06

The R50 indicator analysis in Table 6 does not show a significant trend at any station. This indicates that the frequency of heavy rainfall (>50 mm) naturally fluctuates and does not yet show a statistically consistent pattern. This corroborates the analysis of annual rainfall and the number of rainy days, where the majority of stations also show no significant upward or downward trend. The significant upward trend observed at most stations makes the R50 indicator's stagnant trend peculiar. Similar studies have documented trend discordances in Indonesia in mapping the studies (Supari et al., 2016). High temperatures, from a theoretical point of view, would enhance the potential for evaporation and the atmosphere's capacity to hold water vapor, which could raise extreme rainfall. The increased frequency of such events, combined with the dominating influence of large-scale phenomena such as the El Niño-Southern Oscillation (ENSO), results in high variability and makes the identification of long-term trends in heavy precipitation events difficult. Additional studies should analyze that considers of other factors affecting land cover and the configuration of the regional topography.

Based on the R100 trend, only Pasuruan station, located in the highlands at +873 meters above sea level, shows a negative trend, although it is not statistically significant. This is in line with the most prominent downward trends at the same station, namely annual maximum rainfall and minimum temperature. This relationship indicates that highland areas like Pasuruan are experiencing a decrease in extreme rainfall intensity due to the decreasing conventional energy used to produce heavy rain. Furthermore, Tanjung Perak and Juanda stations, located on the coast, show an increasing temperature trend, making them highly susceptible to increasing annual maximum rainfall, although the R100 indicators at these stations are not statistically significant. Although the direction of the trend is not significant, it is certainly important to observe as an early sign of changing extreme rainfall patterns.

3.5. Simple Daily Intensity Index (SDII)

The SDII index is employed for mapping the change in rainfall intensity. The value of SDII will be able to indicate whether the trends in rainfall are getting heavier and more intense, even though there has been no significant change in the annual rainfall total index. As shown by the analysis in Table 7, the trend at Pasuruan Station is significantly downward. This indicates a downward trend in average daily rainfall intensity on rainy days. This result is consistent with the decreasing trend in extreme rainfall (R100) and annual maximum rainfall recorded at the same station. The decreasing trend is also in line with the decreasing minimum temperature in Pasuruan, which has the potential to reduce atmospheric convection energy and reduce the likelihood of high-intensity rainfall. Conversely, stations in coastal areas such as Tanjung Perak and Juanda, although not showing a significant SDII trend, tend to experience increasing temperatures and an increasing trend in annual maximum rainfall.

Table 7. Summary of mann–kendall (MK) test and sen's slope of simple daily intensity index (SDII)

Rainfall Station	Trend	Sen's Slope
Tanjung Perak	no	0.028
Banyuwangi	no	-0.046
Juanda	no	0.030

Rainfall Station	Trend	Sen's Slope
Trunojoyo	no	0.056
Pasuruan	**yes**	-0.090

3.6. Climate Trend Impact

Increased maximum and minimum temperatures observed at all rainfall stations in the study area showed a regular trend of warming. This rise in temperature will eventually enhance the rate of evapotranspiration, increasing crop water requirements. Although total annual rainfall did not show a statistically significant trend, the decrease in the number of rainy days and the trend toward higher but less frequent rainfall, as evidenced by the increase in SDII values, could trigger a shift in the growing season and increase the risk of crop damage from extreme rainfall. These different changes have highly affected land productivity, particularly in the rain-fed agricultural system, which is highly susceptible to climate change.

Volume and distribution of rainfall greatly affect the availability of both surface and groundwater resources. Insufficient significant positive annual rainfall increase and a reduced number of days with rainfall have a substantial consequence on long-term water availability. Evidence of increased rainfall along the coasts, which is inconsistent with decreasing trends in the highlands, simply shows climate variability. Equitable availability of water within the region will be affected by this quite substantially. Besides, shorter periods of rainfall with greater intensity will further reduce the effectiveness of infiltration, thereby limiting recharge and increasing surface runoff. This again limits the availability of water during the dry season. Areas dependent upon shallow aquifers or rain-fed reservoirs will be particularly affected.

Observations show that the trend of annual maximum rainfall is not statistically significant, the slope value and trend in the graph indicate positive growth. This still indicates increased rainfall events, especially in the Tanjung Perak and Banyuwangi station areas. This is in agreement with previous research showing that tropical regions exhibit an increase in extreme rainfall and greater risks of flooding, particularly in urban and lowland areas. Moreover, the decrease in rainy days without an increase in total annual rainfall indicates the occurrence of dry seasons and droughts. These threatened flood and drought risks underlined the importance of comprehensive and sustainable climate adaptation planning.

Seasonal analysis is thus required to gain a deep understanding of the dynamics of climate change and to correlate the pattern of rainfall and temperature with global climate phenomena such as ENSO and the IOD. The seasonal approach presents the possibility to define El Niño in terms of decreased rainfall and the positive contribution of the IOD in terms of increased extreme rainfall in East Java. These findings give the scientific rationale for formulating adaptation strategies in the agricultural sector, water resources management, and mitigation of hydrometeorological disasters at the regional scale.

4. Conclusions

This study is one of the rare assessments of the long-term climate trends in East Java, using ground station observations from 1984 to 2023, with the focus on the trend analysis of temperature and rainfall at varying geographical locations. The results showed that most of the stations had a significant increase in maximum temperature. This was indicative of a warming trend above national and global averages. This therefore means East Java is getting increasingly vulnerable to the effects of global warming.

The rainfall trend parameters indicate significant spatial and temporal variability: there is no consistent change in annual rainfall and the number of rainy days, but some indicators, such as total annual rainfall, rainfall intensity (SDII), and extreme rainfall events (R100), showed a decreasing trend at Pasuruan station, which was located in highlands, but an increase in various coastal areas. This variability indicates large disparities in the distribution and strength of rain, increasing the risk of droughts and flooding.

The overall outcome of the study examines the manifestations of climate change at the local level, with a focus on suitable adaptation and mitigation. The differential increase of temperature and rainfall will have direct consequences on various aspects of the agricultural sector, availability of water resources, and disaster mitigation. Thus, the socio-economic and ecosystem integration expected from the stakeholders of East Java is of paramount importance.

Acknowledgement

The researcher is very grateful and thankful for being given the opportunity to receive the Indonesian Education Scholarship, the Center for Funding and Assessment of Higher Education, the Ministry of Research, Technology and Higher Education and the Education Endowment Fund, the Ministry of Finance and BMKG which provided full support.

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