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Trend and Variability Analysis of CHIRPS-Based Rainfall in Riau, Indonesia

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Abstract

Adequate surface rainfall observation data remains a challenge in Riau Province, both in terms of the number of stations and the length of homogeneous records. This study aims to analyze the trend and variability of rainfall in Riau Province for the period 1990–2024 using CHIRPS (Climate Hazards group InfraRed Precipitation with Stations) satellite data as an alternative climate data source to support water resource planning, agriculture, and hydrometeorological disaster mitigation in the region. Annual and monthly CHIRPS rainfall data were extracted via Google Earth Engine and analyzed using descriptive statistics, linear regression, the non-parametric Mann-Kendall trend test, coefficient of variation (CV), and standard-deviation-based year classification. The results show a mean annual rainfall of 2,811.7 mm with a standard deviation of 325.5 mm and a CV of 11.6%, indicating relatively low interannual variability typical of Sumatra. The linear trend shows a slight increase of 7.4 mm/year but is not statistically significant (p = 0.178; Mann-Kendall p = 0.102), suggesting that rainfall variation is dominated by cyclic interannual factors rather than a long-term trend. The years 1997, 2015, and 2019 were identified as dry years, while 2007, 2008, and 2022 were wet years. The seasonal pattern shows a rainfall peak in October–January and a relatively dry period in June–July. This characterization of the trend, variability, and seasonal pattern of rainfall provides a quantitative basis for planting schedule planning, water resource management, and drought and flood preparedness in Riau Province.

Keywords: *rainfall; CHIRPS; trend; climate variability; Riau Province*

1. Introduction

Rainfall is one of the most important climate parameters for water resource planning, agriculture, and hydrometeorological disaster mitigation in Riau Province. Most agricultural land in Riau, particularly rainfed paddy fields, is highly dependent on regular rainfall patterns, while flooding and drought have long been recurring problems for communities in this region. Accurate information on rainfall trends and variability is an important basis for planning planting schedules, managing water resources, and preparing for hydrometeorological disasters.

Surface rainfall observation data in Riau are relatively limited, both in the number of stations and in the length of homogeneous records, making satellite rainfall products such as CHIRPS (Climate Hazards group InfraRed Precipitation with Stations) a widely used alternative for long-term climate analysis in Indonesia [1]. Several previous studies have evaluated the

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accuracy of CHIRPS data over Sumatra and found good reliability for trend analysis and monthly climatology [2], [3]. However, trend and variability studies based on CHIRPS that specifically focus on Riau Province, with a long time coverage (35 years) and directly linked to water resource and agricultural planning needs, remain scarce. This study analyzes the trend, variability, and seasonal pattern of rainfall in Riau for 1990–2024 using CHIRPS data to produce a data-based classification of dry, normal, and wet years as an empirical basis for water resource planning and disaster mitigation in the region. The contribution of this study is a measurable historical climate characterization of Riau that can serve as a reference for hydrological research and water resource management in Riau Province.

CHIRPS is a quasi-global, high-resolution (0.05°) rainfall dataset combining infrared satellite imagery with station observations, developed to support long-term climate and drought monitoring [1]. Evaluations of CHIRPS against ground observation data in several parts of Sumatra show adequate accuracy for trend analysis and the determination of wet- and dry-season onset [2], [3]. A nationwide study based on 43 years of CHIRPS data also shows that Sumatra and Kalimantan have relatively low interannual rainfall variability (CV < 15%) compared with eastern Indonesia [2], while a non-stationarity analysis of annual rainfall across Indonesia's Maritime Continent identifies a shift point in the rainfall regime during the 1990s [4]. The non-parametric Mann-Kendall trend test and Sen's slope estimator are widely used in hydroclimatological trend analysis because they do not require a normal-distribution assumption and are more robust to outliers than conventional linear regression [7], [8].

Rainfall variability in Sumatra is influenced by the interaction of several regional climate phenomena, particularly the El Niño–Southern Oscillation (ENSO). A study of the effect of ENSO on forest and land fires in Kalimantan, South Sumatra, and Riau found that the impact of ENSO intensity on dry-season length varies across regions; unlike Kalimantan and South Sumatra, which are sensitive to moderate-to-strong ENSO, Riau shows no clear relationship between ENSO strength and the number of dry days, indicating that local factors also play an important role in shaping the dry-season pattern in Riau [5]. The Oldeman climate classification based on monthly rainfall has been applied spatially across Riau Province and shows that most of the region is dominated by moist and wet months, with dry months occurring mainly in February, June, July, and August [6]. Meanwhile, a water-balance analysis based on long-term rainfall data for irrigation planning of rainfed paddy fields in Riau underscores the importance of characterizing local rainfall variability as a basis for water availability planning [9]. These findings motivate this study to examine not only the linear trend but also the interannual variability and seasonal rainfall pattern more comprehensively.

2. Methodology

This study is descriptive-quantitative, using secondary CHIRPS satellite rainfall data for Riau Province for 1990–2024. Annual rainfall data (35 data points) and monthly rainfall data (420 data points) were extracted through the Google Earth Engine platform and checked for completeness before analysis; no missing data were found for the entire study period. The analysis consisted of: (1) descriptive statistics (mean, standard deviation, and coefficient of variation/CV) to quantify the magnitude and spread of annual rainfall; (2) trend analysis using linear regression and the non-parametric Mann-Kendall test to test trend significance at α = 0.05 [7]; (3) classification of dry, normal, and wet years based on a one-standard-deviation deviation from the long-term mean; and (4) monthly climatology analysis to identify the seasonal rainfall pattern. All data processing was performed in Python (pandas, numpy, and scipy libraries).

2.1. Analytical Formulas

The descriptive and trend-analysis methods used in this study are summarized by the following equations. Let x_1, x_2, …, x_n denote the n = 35 annual rainfall values (mm/year) for 1990–2024. The mean annual rainfall ($\bar{x}$) is calculated as:

$$\bar{x} = (1/n)\ \Sigma\ x_i \quad (1)$$

where x_i is the annual rainfall in year i. The standard deviation (s), which measures the spread of annual rainfall around the mean, is calculated as:

$$s = [\ (1/(n-1))\ \Sigma\ (x_i - \bar{x})^2\ ]^{1/2} \quad (2)$$

The coefficient of variation (CV), used to express interannual variability relative to the mean, is:

$$CV = (s / \bar{x}) \times 100\% \quad (3)$$

The linear trend of annual rainfall over time (t, in years) is estimated using ordinary least-squares regression:

$$\hat{y}_t = a + b \cdot t \quad (4)$$

where $\hat{y}_t$ is the predicted rainfall at year t, a is the intercept, and b is the regression slope (mm/year), whose significance is tested against the null hypothesis b = 0 at $\alpha = 0.05$. Because rainfall series often contain outliers and do not necessarily follow a normal distribution, trend significance is cross-checked using the non-parametric Mann-Kendall test [7], whose test statistic S is:

$$S = \Sigma_{i=1}^{n-1}\ \Sigma_{j=i+1}^{n}\ \mathrm{sgn}(x_j - x_i) \quad (5)$$

where sgn(·) equals +1, 0, or −1 depending on whether its argument is positive, zero, or negative. For $n > 10$, S is approximately normally distributed and is standardized to a Z statistic; a positive Z indicates an increasing trend and a negative Z indicates a decreasing trend, with the trend considered statistically significant when |Z| exceeds the critical value at the chosen α. The magnitude of the monotonic trend is estimated using Sen's slope estimator [8]:

$$\beta = \mathrm{median}[\ (x_j - x_i) / (j - i)\ ], \text{ for all } i < j \quad (6)$$

Finally, each year is classified as dry, normal, or wet based on its deviation from the long-term mean relative to one standard deviation:

$$\text{Dry: } x_i < \bar{x} - s;\ \text{Normal: } \bar{x} - s \le x_i \le \bar{x} + s;\ \text{Wet: } x_i > \bar{x} + s \quad (7)$$

This threshold-based classification follows standard practice in regional climate characterization and provides an objective, data-driven alternative to arbitrary percentage-based scenario definitions.

Table 1. Summary of the rainfall data source and coverage used in this study

No.	Description	Value
1	Data source	CHIRPS v2.0 (Climate Hazards group InfraRed Precipitation with Stations) [1]
2	Spatial resolution	0.05° (≈ 5 km)
3	Period and data coverage	1990–2024 (35 annual data points; 420 monthly data points, no missing data)

Source: Climate Hazards Center (UCSB), accessed via Google Earth Engine

3. Results and Discussion

This section presents the results of descriptive statistical analysis, trend analysis, year classification, and the seasonal rainfall pattern of CHIRPS data in Riau for 1990–2024, and discusses their implications for water resource planning and hydrometeorological disaster mitigation in Riau Province.

3.1. Annual Rainfall Trend and Variability

Annual rainfall in Riau for 1990–2024 shows a mean of 2,811.7 mm/year with a standard deviation of 325.5 mm and a coefficient of variation (CV) of 11.6%, indicating relatively low interannual variability. This CV value is consistent with a nationwide study showing that Sumatra has an annual rainfall CV below 15% [2]. Linear regression shows a slight increasing tendency of 7.4 mm/year ($R^2 = 0.054$), but significance tests through both regression ($p = 0.178$) and the non-parametric Mann-Kendall test ($\tau = 0.193$; $p = 0.102$) show that the trend is

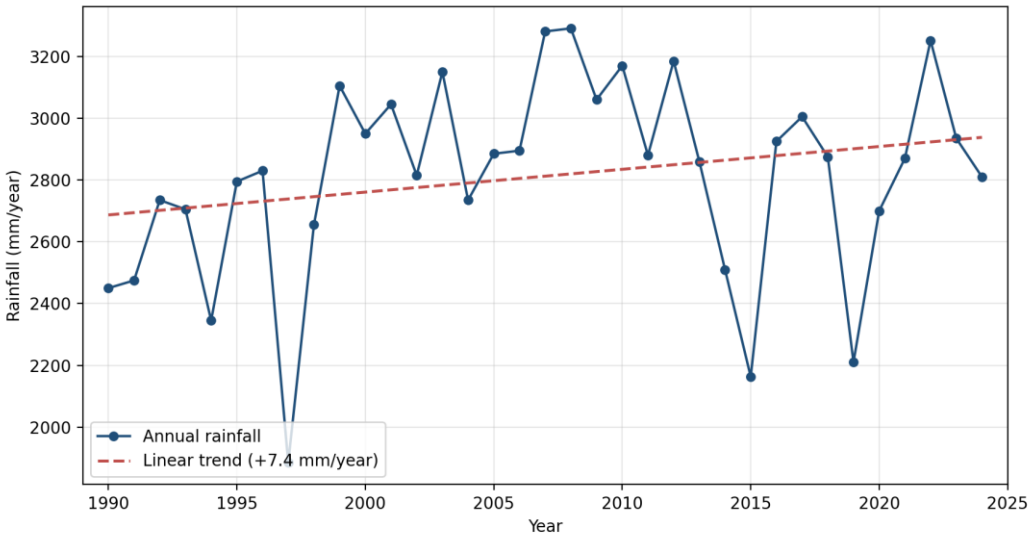
not statistically significant at the 5% level. This is consistent with the general rainfall pattern in Sumatra, which tends not to show a long-term monotonic trend but is instead dominated by cyclic interannual variation [4].

Based on a one-standard-deviation classification from the mean, 6 dry years, 23 normal years, and 6 wet years were identified over the 35 years of observation. 1997 was recorded as the driest year (1,884.6 mm), followed by 2015 (2,163.0 mm) and 2019 (2,210.2 mm), while 2008 was recorded as the wettest year (3,290.9 mm), followed by 2007 (3,280.8 mm) and 2022 (3,251.6 mm). The three dry years coincided with strong regional El Niño events; however, a study of ENSO's influence on drought in Riau shows that the relationship between ENSO strength and dry-season intensity in Riau is not as strong as in Kalimantan or South Sumatra [5], so local factors also contributed to these dry years and warrant further study that explicitly incorporates ENSO/IOD indices.

Table 2. Annual rainfall statistics for Riau Province (1990–2024)

No.	Description	Value
1	Mean annual rainfall	2,811.7 mm/year
2	Standard deviation	325.5 mm
3	Coefficient of variation (CV)	11.6%
4	Wettest year	2008 (3,290.9 mm)
5	Driest year	1997 (1,884.6 mm)
6	Dry years (< 2,486.2 mm; n = 6)	1990, 1991, 1994, 1997, 2015, 2019
7	Wet years (> 3,137.2 mm; n = 6)	2003, 2007, 2008, 2010, 2012, 2022

Source: Processed CHIRPS data, 2025



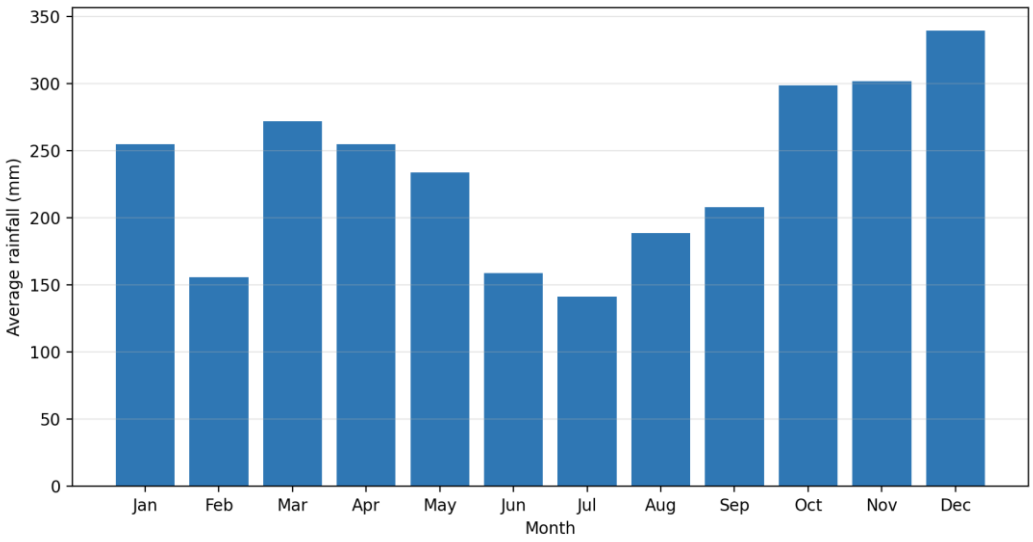
Source: Processed CHIRPS data, 2025

Figure 1. Annual rainfall trend in Riau, 1990–2024

3.2. Seasonal Pattern and Monthly Climatology

Monthly climatology analysis shows a clear seasonal pattern, with the highest rainfall occurring in December (339.8 mm) and the lowest in July (141.4 mm). Seasonally, the October–January period (SON–DJF) is the peak rainy season, averaging 250–270 mm/month, while June–August (JJA) is the relatively dry season, averaging around 163 mm/month. This bimodal pattern is consistent with the equatorial climate characteristics of Sumatra, which are

influenced by the movement of the Inter-Tropical Convergence Zone (ITCZ) and the Asian–Australian monsoon [3]. This seasonal pattern information is important as a basis for planning rice planting schedules, irrigation management, and preparedness for dry periods in Riau Province.



Source: Processed CHIRPS data, 2025

Figure 2. Monthly rainfall climatology in Riau (1990–2024 average)

3.3. Implications for Water Resource Planning, Agriculture, and Disaster Mitigation

The dry, normal, and wet year classification and the seasonal rainfall pattern identified in this study provide a practical, data-driven basis for several planning needs in Riau Province. For rainfed paddy agriculture, which depends heavily on the timing of rainfall onset and cessation, the identification of the October–January wet period and the June–July dry period can inform the design of planting calendars that reduce the risk of both waterlogging during land preparation and moisture stress during the growing season. This complements the spatial Oldeman climate classification previously applied across Riau Province [6], which characterizes wet and dry months based on long-term monthly averages; the interannual dry/normal/wet classification developed here adds a complementary year-to-year perspective that the monthly Oldeman classification alone does not capture. Similarly, the water-balance approach used for irrigation planning of rainfed paddy fields in Riau [9] can be strengthened by incorporating this study's year-type classification to distinguish years that require supplementary irrigation or water-saving measures from years with adequate natural water supply.

Comparing the classified extreme years with the historical record of El Niño–Southern Oscillation (ENSO) phases, as reported by NOAA's Oceanic Niño Index, shows a broadly consistent pattern: all three dry years identified in this study (1997, 2015, 2019) coincided with recorded El Niño episodes, while all three wet years (2007, 2008, 2022) coincided with recorded La Niña episodes (Table 3). This is consistent with the discussion in Section 1, which notes that ENSO influences dry-season intensity in Riau, although the relationship is weaker and less consistent than in Kalimantan or South Sumatra [5]. This correspondence suggests that seasonal ENSO forecasts could be used alongside the historical year-type classification developed here as an early indicator for drought and flood preparedness, water rationing decisions, and agricultural risk management in Riau Province, while acknowledging that local factors beyond ENSO also contribute to year-to-year rainfall variability.

Table 3. Classified extreme years compared with recorded ENSO phases

No.	Year	Rainfall category	Recorded ENSO phase
1	1997	Dry (1,884.6 mm)	Strong El Niño
2	2015	Dry (2,163.0 mm)	Strong El Niño
3	2019	Dry (2,210.2 mm)	Weak El Niño
4	2007	Wet (3,280.8 mm)	Moderate–strong La Niña
5	2008	Wet (3,290.9 mm)	Moderate–strong La Niña
6	2022	Wet (3,251.6 mm)	Weak–moderate La Niña (2020–2023 triple-dip)

Source: Rainfall classification from this study; ENSO phase from NOAA Oceanic Niño Index historical record

3.4. Limitations of the Study

This study has several limitations that should be considered when applying its results. First, CHIRPS is a satellite-and-station blended rainfall product and, despite generally good performance over Sumatra [2], [3], still carries estimation uncertainty, particularly for short-duration and highly localized convective rainfall events that are not fully captured at its 0.05° spatial resolution. Second, this study uses a single, spatially averaged rainfall series representative of Riau Province as a whole; it therefore does not resolve sub-regional heterogeneity between coastal, peatland, and inland areas that may experience different rainfall regimes. Third, the dry/normal/wet classification is based on annual totals and does not capture within-season extremes, such as short-duration heavy rainfall events relevant to flash flooding. Future research should therefore consider station- or grid-based sub-regional analysis, incorporate daily rainfall extreme indices, and validate CHIRPS estimates against available ground-based rain gauge records within Riau Province to strengthen confidence in the data for operational water resource and disaster-mitigation planning.

4. Conclusion

This study analyzed the trend and variability of rainfall in Riau Province for 1990–2024 using CHIRPS data as an empirical basis for water resource planning and hydrometeorological disaster mitigation. The 35-year CHIRPS record used here contains no missing data (35 annual and 420 monthly values) and exceeds the 30-year period commonly used for climatological normals, providing a robust basis for confidence in the trend and variability results. Mean annual rainfall was recorded at 2,811.7 mm with a CV of 11.6%, indicating relatively low interannual variability and no statistically significant long-term trend (regression $p = 0.178$; Mann-Kendall $p = 0.102$). The years 1997, 2015, and 2019 were identified as dry years, while 2007, 2008, and 2022 were wet years, with a seasonal pattern showing a rainfall peak in October–January and a dry period in June–July. This characterization of rainfall trend, variability, and seasonal pattern provides a quantitative basis that can be used for planting schedule planning, water resource management, and preparedness for drought and flooding in Riau Province. Further research is recommended to explicitly link this dry/wet year classification to historical ENSO and IOD indices, and to validate CHIRPS data against available ground station data in Riau Province to strengthen the reliability of data for water resource planning.

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