Rainfall trend analysis using Mann-Kendall and Sen’s slope estimator test in West Kalimantan

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Abstract. Climate change has been a prominent issue in the last decade. Climate change on a global scale does not necessarily have the same effect in different regions. Rainfall is a crucial weather element related to climate change. Rainfall trends analysis is an appropriate step in assessing the impact of climate change on water availability and food security. This study examines rainfall variations and changes at West Kalimantan, focusing on Mempawah and Kubu Raya from 2000-2019. The Mann-Kendall (MK) and Sen's Slope estimator test, which can determine rainfall variability and long-term monotonic trends, were utilized to analyze 12 rainfall stations. The findings revealed that the annual rainfall pattern prevailed in all locations. Mempawah region tends to experience a downward trend, while Kubu Raya had an upward trend. However, a significant trend (at 95% confidence level) was identified in Sungai Kunyit with a slope value of -33.20 mm/year. This trend indicates that Sungai Kunyit will become drier in the future. The results of monthly rainfall analysis showed that significant upward and downward trends were detected in eight locations. Rainfall trends indicate that climate change has occurred in this region.

1. Introduction

Tropical areas are vulnerable to climate change and variability due to the complex interactions between land, oceans, and the atmosphere. According to several climate risk indices, Indonesia is one of Southeast Asia's most vulnerable regions to climate change [1]. The IPCC Fifth Report states that the global temperature rise in 2012 has reached 0.85°C, sea-level rises are as high as 19 cm, and greenhouse gas emissions will continue to increase [2]. The rising sea surface temperatures due to climate change have led to significant rainfall changes [3]. In addition, rainfall changes are projected to increase in the future and cause extreme rainfall [4].

Rainfall is the most substantial climate element to describe Indonesian climatic conditions [5]. West Kalimantan parts of the Indonesian Maritime Continent play a vital role in the global climate weather system [6]. This region is regarded as the primary source of energy in global circulation, significantly contributing to the development of the tropical warm pool. Indonesia's geographical location in the equator causes the region to obtain a rich intensity of solar radiation. However, its geographical differences result in contrasting absorption of solar radiation. This difference leads to high variations in weather and climate conditions between the regions [7].

El Nino-Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) are two dominant phenomena that affect rainfall in Indonesia [8]. Later, interaction with monsoons and local patterns influences
annual, monthly, and extreme rainfall intensity [9]. ENSO is a phenomenon of atmospheric-ocean interactions in the tropical Pacific Ocean that fluctuates periodically between cold (La Niña) and warm episodes (El Niño). Its strong influence on rainfall was observed in West Kalimantan during JJA and SON periods [10]. The Indian Ocean Dipole (IOD), another significant phenomenon of tropical ocean-atmospheric interactions, directly affects the rainfall in the western part of Indonesia [11]. Indian Ocean Dipole has three anomalous phases (positive, neutral, and negative) that oscillate over time. The positive phase is related to reduced rainfall in the Western part of Indonesia. The negative phase leads to an increase in rainfall in the western part of Indonesia. The Indian Ocean Dipole (IOD) forms between July and November, gradually inducing convection in west Indonesia. In addition to ENSO and IOD, Monsoon is a substantial climate factor that causes climate variability in Indonesia includes West Kalimantan. Monsoons develop due to differences in atmospheric pressure between Asia and Australia, leading to seasonal precipitation variation.

Research of rainfall trends in several regions in Indonesia has been carried out to determine climate change and variability impact on several sectors. An analysis of rainfall patterns in the Brantas watershed discovered a declining trend of annual and monthly rainfall. Later, it reduces the effects of the monsoon on rainfall, resulting in a shift in the annual pattern [12]. Indarto et al [13] utilized the Mann-Kendall test in the East Java region and showed a significant downward trend in rainfall in some of the locations studied. Muharsyah [14], who studied the temperature trend in Papua, states that the Mann-Kendall test has a better confidence level when compared to linear regression. Moreover, a Mann-Kendall test on the island of Madura found a decreasing trend of daily extremes rainfall and annual rainfall in a few locations [15]. Using the Mann-Kendall Test, Nugroho et al [16] found that intensification of cumulative drought day (CDD) in West Sumatra due to strong El Nino and positive IOD event.

Rainfall trends detection using various statistical methods has been conducted using both parametric and non-parametric tests. In statistical parametric tests, the basic assumptions of the processed data are normally distributed. On the other hand, in a non-parametric test, the data does not have to meet the assumption of normality [17]. The Mann–Kendall pattern test is unaffected by the actual distribution of the data. It is less susceptible to outliers because it is based on the ranks of the observations rather than their actual values [18]. Parametric trend tests are more effective yet involve normally distributed data and are more susceptible to outliers.

Rainfall trends in recent years have had a significant impact on rice production due to decreasing in the planting area, crop area, and crop yields [19]. The government has made efforts to deal with rainfall changes and variability in Indonesia by planting superior paddy varieties resistant to inundation and salinity and utilizing appropriate technologies that elevate agricultural productivity. In terms of policy, the government has published an early warning system for minimizing the impacts of climate change. In 2019 the government issued regulations on sustainable cultivation systems to support food availability in the future due to climate change.

Most West Kalimantan regions are part of the equatorial pattern with two monthly rainfall peaks [20]. Research on the rainfall trend in West Kalimantan is a first step in assessing climate change impact on a local scale. This study aims to analyze annual and monthly rainfall trends in West Kalimantan. The findings will come in handy in formulating a better climate change adaptation and mitigation plan.

2. Methods

2.1. Study area
The research area is Kubu Raya and Mempawah district in West Kalimantan. It has an area of 8,262 km² with geographical positions located on the west coast of West Kalimantan (Latitude 1°S–0.8°U and Longitude 108.74°E-110.00°E). This area has an equatorial rainfall pattern with two monthly rainfall peaks in April and November [8], daily temperature ranges between 23°C in the morning and 33°C during the day. West Kalimantan is traversed by the Asian Monsoon (October-March) and the Australian Monsoon (April-September). In equatorial regions, the Asian monsoon period is characterized by high average monthly rainfall with dry periods in February, while the Australian monsoon period marks
longer dry periods in July and August. This dry season is usually associated with recurrent forest fires in West Kalimantan [21].

![Figure 1. Study area in Mempawah and Kubu Raya](image)

2.2. Data
Trend analysis requires extended time-series data to show changes in climate patterns and accurately identify rainfall trends. Monthly rainfall data span from 2000-2019 obtained from 12 BMKG’s rain stations in Kubu Raya and Mempawah. Furthermore, in addition to monthly analysis, the rainfall data is accumulated annually to be analyzed in calculating trends. The location of the rain station is described in Table 1. A homogeneity test was carried out on the rainfall data at each site. This study uses an R package Climatol (climate tool) to calculate the Standard Normal Homogeneity Test (SNHT) [22]. Then, this test is applied to see whether the selected rainfall data is randomly distributed or has a particular pattern. The rainfall data is homogeneous if the result shows no significant breakpoint and is randomly distributed, later meets the requirements for further tests. The SNHT test showed no breakpoints in the series, were randomly distributed and categorized as homogeneous.

| Location          | District       | Latitude | Longitude | Elevation | Data availability |
|-------------------|----------------|----------|-----------|-----------|-------------------|
| Kubu              | Kubu Raya      | -0.471   | 109.391   | 2 m       | 2000-2019         |
| Sungai Raya       | Kubu Raya      | -0.150   | 109.400   | 3 m       | 2000-2019         |
| Rasau Jaya        | Kubu Raya      | -0.247   | 109.355   | 2 m       | 2000-2019         |
| Sungai Ambawang   | Kubu Raya      | -0.041   | 109.466   | 1 m       | 2000-2019         |
| Sungai Kakap      | Kubu Raya      | -0.060   | 109.207   | 1 m       | 2002-2019         |
| Teluk Pakedai     | Kubu Raya      | -0.262   | 109.241   | 3 m       | 2002-2019         |
| Terentang         | Kubu Raya      | -0.409   | 109.631   | 4 m       | 2000-2019         |
| Anjungan          | Mempawah       | 0.360    | 109.169   | 3 m       | 2000-2019         |
| Jungkat           | Mempawah       | 0.075    | 109.190   | 2 m       | 2000-2019         |
| Sungai Kunyit     | Mempawah       | 0.514    | 108.913   | 1 m       | 2000-2019         |
| Sungai Pinyuh     | Mempawah       | 0.283    | 109.062   | 1 m       | 2000-2019         |
| Toho              | Mempawah       | 0.430    | 109.275   | 16 m      | 2000-2019         |
Mann-Kendall test

The Mann-Kendall test is a non-parametric test used to determine a trend in data based on relative rankings from a given time range. In this test, the data did not have to meet normality assumptions [23]. The World Meteorological Organization recommends this test to detect trends in a set of hydrological data [24]. The Mann-Kendall test statistic is calculated as:

\[
S = \sum_{i=1}^{n} \sum_{j=i+1}^{n} \text{sign}(x_j - x_i), \quad \text{sign}(x_j - x_i) = \begin{cases} 
+1 & (x_j - x_i) > 0 \\
0 & (x_j - x_i) = 0 \\
-1 & (x_j - x_i) < 0 
\end{cases}
\]

(1)

A positive S value indicates an upward trend, while a negative value indicates a downward trend. The variance of the rainfall is calculated to obtain the Z value. Variance (S) is computed as:

\[
\text{Var}(S) = \frac{n(n-1)(2n+5) - t(t-1)(2t+5)}{18}
\]

(2)

A tied group (m) is a set of rainfall data with the same value when the sample size is n>10. The normal Z test statistic is calculated by the equation:

\[
Z = \frac{S \pm 1}{\text{Var}(S)^{1/2}}
\]

(3)

This equation uses S-1 if S>0, S+1 if S<0, and Z is 0 if S=0. A positive value of Z indicates an increasing trend. Otherwise, it indicates a downward trend.

Sen's slope estimator

The World Meteorological Organization recommends this test as part of the trend detection in hydrometeorological data [24]. In this test, the trend is assumed to be linear and represents the quantification of the time change. Sen's Slope has an advantage compared to the linear regression where the test is not affected by the number of outliers and data errors. The Sen's Slope equation for a number of N data sample pairs is written as follows:

\[
Q_i = \frac{(x_j - x_i)}{j-i}, i=1,2,3,...,N
\]

(4)

\(x_j\) and \(x_i\) are data values at time j and i (j > i), respectively. If there are n values of \(x_j\) in the time series, there will be N = n(n-1)/2 slope estimates. The N value of Q_i is sorted from smallest to largest, then Sen's Slope used median Q_i (Q_med). A two-tailed test estimated the value of Q_med at a confidence interval of 90% and 95%, which is calculated as:

\[
Q_{med} = \begin{cases} 
\frac{Q_{N+1}}{2} & \text{if } N = \text{odd} \\
\frac{Q_{N/2} + Q_{N+1}}{2} & \text{if } N = \text{even}
\end{cases}
\]

(5)

3. Result and discussion

3.1. Annual rainfall analysis

The spatial distribution of annual rainfall in Mempawah and Kubu Raya showed in figure 2. Annual rainfall varies from 2000 mm/year to 3500 mm/year. The rainfall station along the coast in both regions
shows an average annual rainfall ranging from 2500-3000 mm/year. With relatively flat landscape conditions, the effect of elevation is invisible in spatial variations in the region. The average annual rainfall shows that the highest rainfall existed in 2009 (3482 mm), and the lowest rainfall takes place in 2014 (2071 mm). Rainfall temporal variability is associated with the strong La Nina phenomenon in 2009 and El Nino in 2014/2015. The average annual rainfall of more than 3000 mm/year occurred in Sungai Raya, Sungai Ambawang, and Anjungan.

The urban growth of Pontianak generates an effect called Urban Heat Island (UHI) [25]. This effect is caused by the land cover change in the form of settlements and trading areas, thus increasing the ambient temperature. This phenomenon affects convective cloud growth in urban areas [26][27]. A Study by Jin et al [28] stated an increase in aerosol concentrations before rainfall events. Aerosol concentration was then reinforced by the flat topography of Pontianak, thereby reducing wind resistance. It leads the growth of convective clouds in urban areas to be carried further inland and causes the annual average rainfall in the Sei Ambawang and Sungai Raya to be higher than their surrounding areas. In other locations, Anjungan has higher annual rainfall than the surrounding areas. It is located in an elevated site in front of the hills characterized by orographic effects that strengthen cloud growth and precipitation. Simulations conducted by Kirshbaum et al [29] showed that the orographic cloud substantially increased rainfall accumulation.

The MK test in figure 3 detects trends in the annual rainfall trend in the period 2000-2019. In general, 80% of Mempawah areas receive a downward trend in annual rainfall; on the contrary, 71% of the Kubu Raya area experiences an annual rainfall upward trend. It means that the Mempawah area tends to get drier and Kubu Raya tends to get wetter. In Mempawah, Sei Pinyuh and Toho have a downward trend, but on the contrary, the upward trend is seen at the Anjungan. Furthermore, significant trends were detected only in Toho at a confidence level of 90% and Sungai Kunyit at a confidence level of 95%. Sen's Slope test show that Sungai Kunyit has the highest annual rainfall trend value of -33.20 mm/year. Toho is the second location with the next highest trend of -32.72 mm/year. The negative trend values in both areas indicate a decreasing trend in annual rainfall. The significant decrease in rainfall indicates that both locations will become drier in the future.

![Figure 2. Spatial distribution of mean annual rainfall (mm/year).](image1)

![Figure 3. Mann-Kendall test results for annual trends detection.](image2)
These results are consistent with the research of Lacombe et al [30] that long-term trends in Southeast Asia using the Mann-Kendall test are only significant in a few locations. The finding of significant trends in annual rainfall in the previous study is due to the effects of annual variability and long-term monotonic trends that influence each other. A Study by Sa'adi et al [23] noted no significant trend in annual rainfall in Sarawak. Another study by Ahmad et al [31] revealed the absence of a significant annual trend using the Mann-Kendall test in the Swat Basin Region in Pakistan. Similar to the above research, studies on annual rainfall trends in Indonesia by Hadihardaja et al [32], who analyzed rainfall trends in the Citarum watershed, showed that most locations did not show significant annual trends.

3.2. Monthly rainfall analysis

Sungai Ambawang receives the highest monthly average rainfall (393 mm) in November. Sungai Kunyit had the lowest annual rainfall of 103 mm in March. Mempawah and Kubu Raya generally have bimodal rainfall patterns (2 rain peaks). The first rain peak in Kubu Raya occurs in April, followed by the second in November. The first rain peak in Mempawah occurs in May, followed by the second in November. The highest peaks of rain in both regions occurred in November-December. The difference was seen in the driest period between the two areas. Mempawah endures the driest periods in February and March while Kubu Raya in August and September.

Based on the average monthly rainfall for the 2000-2009 period, several locations have rain below 150 mm/month. Kubu Raya has a dry season in August. For each location at Sungai Raya, Sungai Kakap, Rasau, and Sungai Ambawang don’t have a dry season. Teluk Pakedai experiences a dry season in August, Kubu has one in July-August, and Terentang has the most extended period in July-September. In Mempawah, the dry season lasts from March to April. There is no dry season in Anjungan or Jungkat. Toho has a dry season in February, while Sungai Pinyuh has a dry season in February-March. Meanwhile, Sungai Kunyit experiences a dry season twice a year in February-April and August. The Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) uses rainfall 150 mm/month as a boundary to mark areas that have season and non-season.

![Figure 4. Temporal distribution of average monthly rainfall in Kubu Raya (dotted blue line indicates the threshold for wet and dry season).](image-url)
Figure 5. Temporal distribution of average monthly rainfall in Mempawah (dotted blue line indicates threshold for wet and dry season).

The Mann-Kendall (MK) test detected a trend of monthly rainfall at 11 locations in Mempawah and Kubu Raya at a 90% confidence level, except for the Terentang. Most of the monthly rainfall trends existed between April and June, with 9 out of 12 locations experiencing rainfall trends. Over that time, seven areas have an upward trend in monthly rainfall, while 3 experience a downward trend. The next period that experiences a rainfall trend occurs in September-November. During this period, most of the locations have a decreasing trend. A total of five areas have decreased, and only two sites have increased. Eight locations experienced a significant trend of increasing and decreasing rainfall at a 95% confidence level. Three locations are experiencing a significant upward trend in Kubu Raya and one location in Mempawah. Significant downward trends prevailed in three locations in Mempawah and one location in Kubu Raya. Three locations adjacent to Pontianak experience an increasing trend in May (Sei Ambawang) and June (Sungai Raya and Sungai Kakap).

In several months, four areas, namely Toho, Jungkat, Anjungan, and Sungai Raya, witnessed a downward and upward trend in rainfall with 90% and 95% confidence levels, respectively. It suggests a significant fluctuation in monthly rainfall, indicating a trend variation in that period. The results of Sen's Slope calculation show a substantial increase in monthly rainfall, including Sungai Raya in June (11.94 mm/year), Sungai Ambawang in May (12.68 mm/year), Sungai Kakap in June (10.50 mm/year), and Anjungan in May (13.85 mm/year). Locations that show a significant decrease in monthly rainfall are Rasau Jaya in January (-11.08 mm/year) and November (-10.49 mm/year), Sungai Kunyit in November (-10.25 mm/year), Sungai Pinyuh in September (-10.02 mm/year), Toho in April (-6.58 mm/year) and September (-12.14 mm/year).

Various studies [23][33][34] provide similar results with a trend of increasing and decreasing rainfall in certain months, but it is inconsistent across all months. Climate change is a global phenomenon that needs to be assessed for its impact on a local scale. Rainfall trends indicate that climate change is apparent in this location. Even if they are in proximity, the rainfall pattern of each location can vary from that of the surrounding area. The different trends in rainfall are influenced by changes in atmospheric circulation [3]. It was caused by human activities that increase greenhouse gases in the atmosphere [2]. Also, the topographical characteristics of a location influence patterns of rainfall changes [35][36]. The effects of land use and land cover influence weather and climate processes at local, regional, and global scales [37][38].
Figure 6. Monthly rainfall trends using the MK test and Sen's Slope. Upward (downward) grey color indicates a positive (negative) trend at a 90% confidence level. Blue (red) up (down) indicates a positive (negative) trend at a 95% confidence level.

The existence of a trend in a specific month needs attention in planning water availability and food security. Mempawah and Kubu Raya, located on coastal and lowlands, will likely suffer from floods when rainfall intensifies in the future. Moreover, the trend in monthly rainfall needs to be considered its impact on agriculture. Increasing rainfall intensity and frequency lead to the development of pests and diseases [39][40]. Changes in rainfall also affect palm oil production. Oil palm is one of the primary commodities in West Kalimantan and is a government program to release its dependency on petroleum. High rainfall leads to poor pollination and less photosynthesis, consequently reduced oil palm yields [41].

4. Conclusion
The annual and monthly rainfall trends analysis in 2000-2019 has been carried out in Mempawah and Kubu Raya. The Mann-Kendall (MK) and Sen's Slope estimator test results generally demonstrate trends of annual rainfall in all locations. However, a significant trend (confidence level at 95%) was only detected in Sungai Kunyit with a slope value at -33.20 mm/year. In the monthly period, the MK test identifies a significant trend of monthly rainfall in eight locations with an upward trend at Sungai Raya, Sungai Ambawang, Sungai Kakap, Anjungan and a downward trend at Rasau Jaya, Sungai Kunyit, Sungai Pinyuh, Toho). Rainfall trends indicate climate change has occurred in West Kalimantan.

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