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DYNAMICS OF RAINFALL AND TEMPERATURE IN NORTH SUMATRA PROVINCE: COMPREHENSIVE ANALYSIS OF TEMPORAL TRENDS

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ABSTRACT

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This research aims to analyze the temporal trends of rainfall and temperature in North Sumatra Province, focusing on the Medan and Deli Serdang regions. The data used in this study was obtained from the Central Statistics Agency of North Sumatra (BPS Sumut) and spans the period from January 2000 to December 2022. The Mann-Kendall test was applied to identify trends, Sen's Slope Estimator measured the trend slope, and Pearson correlation analysis assessed the relationship between rainfall and temperature. Key findings indicate that Medan has a higher monthly rainfall average than Deli Serdang, with both regions showing a significant increasing trend in rainfall, although the rise is gradual. Additionally, a positive trend in temperature was identified, reflecting broader climate change patterns. However, the correlation between rainfall and temperature was weak, indicating minimal direct interaction between these variables in the study areas. These results contribute valuable insights into climate dynamics and are critical for the development of climate change adaptation strategies in North Sumatra Province.

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1. INTRODUCTION

Climate change has emerged as a pressing concern worldwide, evidenced by alterations in global temperatures, precipitation patterns, and increasing occurrences of extreme weather events such as floods and droughts [1][2]. These changes have been extensively documented and are widely regarded as one of the most critical challenges of our time [3]. Particularly in Indonesia, the fluctuating climate has significantly influenced both rainfall and temperature across various locales, including Medan and Deli Serdang [4][5]. This region, like many others, faces profound impacts on its environmental and socio-economic systems due to these climatic variations [6][7].

Previous studies have highlighted the severe consequences of climate change on rainfall and temperature patterns [8]. For instance, research by Grey et al. demonstrated a significant upward trend in annual temperatures in Australia over the last few decades [9]. Similarly, a study by Diengdoh et al. found that changes in rainfall patterns have led to increased incidences of droughts and floods in tropical regions [10]. These findings underscore the necessity of localized studies to understand better the specific impacts of global climate phenomena.

In North Sumatra, the effects of climate change are particularly pronounced. Changes in rainfall and temperature can lead to significant fluctuations in regional weather patterns, which, in turn, affect crucial sectors such as agriculture [11], the environment [12], and the daily lives of residents [13]. For example, altered rainfall patterns can disrupt the water cycle, affecting water availability for agricultural and domestic use [14]. Soil salinity may increase due to irregular precipitation, adversely impacting crop yields [15]. Furthermore, the sustainability of river ecosystems and forests is at risk, threatening biodiversity and local livelihoods [16][17].

Given these impacts, it is imperative to gain a profound understanding of the trends in climate change and the relationship between rainfall and temperature in Medan and Deli Serdang. This study aims to address this need by employing robust statistical methods to analyze climatic data. The Mann-Kendall method [18][19] will be used to identify trends in rainfall and temperature data over the past several years [20][21]. Additionally, the Sen's Slope Estimator method [22] will be employed to measure the slope of these trends, providing a clearer picture of the rate of change [23]. To further enhance understanding, a correlation analysis will be conducted to explore the relationship between rainfall and temperature [24]. The objectives of this study are to identify trends in changes in rainfall and temperature over the period 2000-2022 in Medan and Deli Serdang, determine the statistical significance of these trends, and analyze factors that may influence these changes and their impacts on the environment.

Despite extensive global research on climate change, there is a lack of localized studies that focus specifically on the interactions between rainfall and temperature trends in tropical regions like North Sumatra. Existing studies often overlook the distinct climate patterns of this region, where unique topographical and environmental factors may influence climate variability differently than in temperate zones. This study addresses this gap by providing a comprehensive analysis of long-term rainfall and temperature trends in North Sumatra, offering insights that contribute to a more nuanced understanding of climate dynamics in tropical contexts. By doing so, it adds valuable data to the limited literature on climate change impacts in Indonesia and similar regions, supporting both local and global adaptation efforts.

By conducting this study, we aim to provide a comprehensive understanding of the implications of climate change on weather patterns and their consequential effects on local and global scales, where shifts in rainfall and temperature patterns can disrupt agriculture, water resources, and public health. Understanding these trends is crucial for developing accurate predictive models that can inform sustainable land and water management practices, especially in vulnerable regions like North Sumatra. This knowledge will assist policymakers, institutions, and local communities in crafting effective strategies for adapting to and mitigating the impacts of climate change, ensuring more sustainable management of natural resources. Furthermore, this research contributes to the existing body of knowledge by offering novel insights into the temporal trends of climatic variables in a region that is underrepresented in current climate studies.

In conclusion, understanding the dynamics of rainfall and temperature in North Sumatra is crucial for developing adaptive strategies to combat the adverse effects of climate change. The findings from this study will not only enhance scientific knowledge but also inform practical solutions for sustainable development in the region.

2. RESEARCH METHODS

The Mann-Kendall method, Kendall Tau, Sen's Slope, and Pearson correlation will be used to analyze rainfall and temperature in the North Sumatra region. The data will be obtained from the Central Statistics Agency of North Sumatra (BPS Sumut) specifically from the social and population section that includes climate information, covering the period from January 2000 to December 2022. The Mann-Kendall method [25] will identify significance as well as increases or decreases in the data. Kendall Tau will measure the extent of the relationship between rainfall and temperature over time. The Sen's Slope will calculate the rate of average change in rainfall and temperature. In the final stage, the correlation between temperature and rainfall in each region will be calculated using the Pearson correlation method.

2.1 Mann Kendall

The Mann-Kendall test stands out as a robust statistical method designed to identify trends in time series data [26]. It achieves this through the computation of a specific statistic, known as S. This statistic is derived by systematically evaluating the differences between all possible pairs of data points within the series. The calculation is expressed through the equation::

$$S=\sum_{k=1}^{n-1}\sum_{j=k+1}^{n} sgn\left(x_j-x_k\right) \tag{1}$$

Here, the function sgn plays a critical role. It examines the difference between each pair of data points, x_j and x_k, assigning a value based on its relative magnitude. This results in a comprehensive summation that reflects the overall direction and strength of the trend across the dataset.

The $sgn(\theta)$ value, where N is the number of data points and $x_j - x_k = \theta$, can be observed as follows:

$$sgn=\begin{cases} 1\ if\ \left(x_j-x_k\right)>0 \\ 0\ if\ \left(x_j-x_k\right)=0 \\ -1\ if\ \left(x_j-x_k\right)<0 \end{cases} \tag{2}$$

This test is notably effective when applied to larger data sets (N > 10), and the variance of the S statistic can be accurately computed, providing a robust measure of trend detection in the time series data.

$$Var(S)=\frac{n(n-1)(2n+5)-\sum_{j=1}^{m} t_j\left(t_j-1\right)\left(2t_j+5\right)}{18} \tag{3}$$

In the realm of time series analysis, the presented formula outlines the process for calculating the total number of data points, denoted as n. The variable m stands for the number of groups containing data points that share identical values. These groups are referred to as "tied groups." Each tied group's size is represented by t_j, indicating how many data points belong to the j-th group. For the variance of the S statistic, the formula takes into account the overall data point count n, the number of tied groups m, and the size of each of these groups.

$$Z_{MK}=\begin{cases} \dfrac{S-1}{\sqrt{Var(S)}}\ if\ S>0 \\ 0\ if\ S=0 \\ \dfrac{S+1}{\sqrt{Var(S)}}\ if\ S<0 \end{cases} \tag{4}$$

The Z_{MK} statistic, which follows a standard normal distribution with a mean of zero and a unit variance, is computed based on the value of S. If S is positive, Z_{MK} is calculated using the square root of the variance of S. If S is a zero, then Z_{MK} is zero. For negative S, a similar calculation is conducted but with a different denominator. The hypothesis under investigation is assessed using a confidence interval of 95%. Should the

Z-score be positive, it signifies a rising trend, whereas a negative Z-score suggests a decline. When the P value falls below 0.05, it affirms that the observed trend is statistically significant, meeting the 95% confidence threshold.

2.2 Sen's Slope Estimator

The Sen's Slope Estimator is a robust method used to ascertain the rate of change in trends [27], particularly in climate-related datasets such as temperature and rainfall. It computes the slope, β, of a trend line by finding the median of all slopes calculated from the dataset pairs. This is articulated through the formula:

$$\beta = median\left(\frac{x_j - x_k}{j - k}\right) \tag{5}$$

Where x_j and x_k are the measurements at times j and k correspondingly, and $j > k$. This approach ensures a resistant estimate that is less affected by outliers in the data. The calculation of the quantile Q_1 depends on whether the number of observations N is odd or even:

$$Q_i = \begin{cases} T_{\frac{N-1}{2}} & N \text{ is odd} \\ \frac{1}{2} T_{\frac{N}{2} + \frac{N+2}{2}} & N \text{ is even} \end{cases} \tag{6}$$

The sign of Q_1 is indicative of the trend direction, where a positive Q_1 signals a long-term upward trend and a negative Q_1 signals a downward trend. Following the determination of the slope β, it is utilized to construct the trend line equation:

$$Y_t = \beta \cdot t + X_t \tag{7}$$

In this equation, Y_t represents the estimated value predicted by the trend line for time t, and X_t is the intercept, representing the starting point of the trend line on the y-axis. This method provides a systematic approach to understanding and predicting changes in environmental data over time, aiding in decision-making related to climate adaptation and resource management strategies.

2.3 Kendall Tau

Kendall's Tau is a non-parametric statistical measure used to assess the strength and direction of the association between two variables [28], such as rainfall or temperature. This statistic is valuable in identifying how closely these variables move together, indicating either a positive or negative correlation. The calculation of Kendall's Tau is represented by the formula:

$$\tau = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} sgn(x_i - x_j)\ sgn(y_i - y_j)}{n(n-1)} \tag{8}$$

Where sgn is a sign function applied to the differences between the paired data points x_i and x_j, as well as y_i and y_j. This function outputs 1 when the difference is positive, -1 when negative, and 0 when there is no difference,

$$sgn(x_i - x_j) = \begin{cases} 1\ if\ (x_i - x_j) > 0 \\ 0\ if\ (x_i - x_j) = 0 \\ -1\ if\ (x_i - x_j) < 0 \\ sgn(y_i - y_j) \end{cases} \tag{9}$$

$$sgn(y_i - y_j) = \begin{cases} 1\ if\ (y_i - y_j) > 0 \\ 0\ if\ (y_i - y_j) = 0 \\ -1\ if\ (y_i - y_j) < 0 \end{cases}$$

Kendall's Tau effectively captures both concordant and discordant pairs. Concordant pairs occur when both elements in one pair are either larger or smaller than those in the other pair, indicating that the variables change in the same direction. Discordant pairs, where the elements of the pair move in opposite directions, suggest an inverse relationship. The absolute value of Kendall's Tau, ranging from 0 to 1, reflects the strength of the monotonic relationship between the two variables higher values denote stronger correlations. A positive Tau value indicates a direct relationship, while a negative value points to an inverse correlation.

2.4 Pearson Correlation

The Pearson correlation coefficient, symbolized as r_p, is an essential statistical tool that evaluates both the strength and the directional correlation between two variables that have a linear relationship [24], such as rainfall and temperature. This coefficient provides a numerical indicator that ranges from -1 to 1, where each extreme reflects a perfect inverse or direct linear relationship, respectively, and a zero value denotes no linear correlation at all.

The computation of r_p involves a formula that systematically measures how much two variables vary together compared to how much they vary individually:

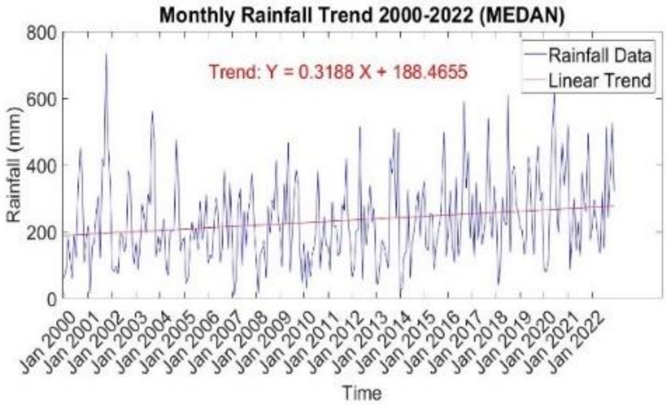
$$r_p = \frac{\sum(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{(\sum(X_i - \bar{X})^2)(\sum(Y_i - \bar{Y})^2)}} \tag{10}$$

In this equation, X_i and Y_i represent the individual observations of variables X and Y, while $\bar{X}$ and $\bar{Y}$ are their respective means. This formula effectively normalizes the product of the deviations of each variable from its mean, providing a scale of correlation that is easy to interpret in terms of statistical significance and real-world relevance. This method is particularly useful in quantifying the linear relationships in data where both variables are assumed to follow a normal distribution and are measured on an interval scale.

3. RESULTS AND DISCUSSION

3.1 Rainfall Trend

In this study, a monthly rainfall trend analysis was conducted for the Medan and Deli Serdang regions using the Mann-Kendall, Kendall Tau, and Sen's Slope methods. The results of the analysis indicate an increase in rainfall during the period from 2000 to 2022.



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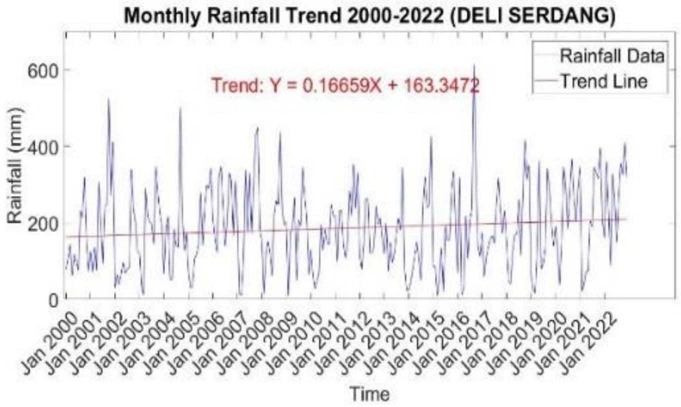

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Figure 1. Rainfall Trend Analysis using Mann-Kendall (a) Medan (b) Deli Serdang

Figure 1 **(a)** illustrates the monthly rainfall trend in Medan from 2000 to 2022, characterized by the linear equation $y = 0.3188x + 188.4655$. This equation indicates a monthly increase in rainfall of 0.3188 mm. The data shows notable fluctuations, yet visually reveals recurring patterns, predominantly trending upwards over time. **Figure 1** **(b)** depicts the monthly rainfall trend in Deli Serdang during the same period, represented by the equation $y = 0.16659x + 163.3472$, indicating a monthly increase in rainfall of 0.16659 mm. Both figures illustrate fluctuating rainfall data with observable recurring patterns, ultimately demonstrating a rising trend as represented by the linear models.

Table 1. MK Test Results for Values, Mean, Median, and Change Points of Rainfall Data for the Study Area.

Area	Mean	Median	Mann Kendall Test		Tau Value	Slope Value
			Z-Value	P-Value		
Medan	232.62	206	3.5125	0.00044397	0.14187	0.95345
Deli Serdang	186.41	175.5	2.1415	0.03223	0.086509	0.87273

***Data source**: The Data Was Processed Using Matlab*

Based on the data analyzed using the Mann-Kendall test, the results presented in **Table 1** show a Z value of 3.5125 for Medan with a P value of 0.00044397, and a Z value of 2.1415 for Deli Serdang with a P value of 0.03223. These results indicate that the increasing trend in rainfall in both regions is statistically significant, with a low probability that these results occurred by chance. The trend in Medan is stronger compared to Deli Serdang, as reflected by the higher Z value. This is supported by research conducted by Nyikadzino**[18]**, which showed a similar phenomenon related to the significance of rainfall trends.

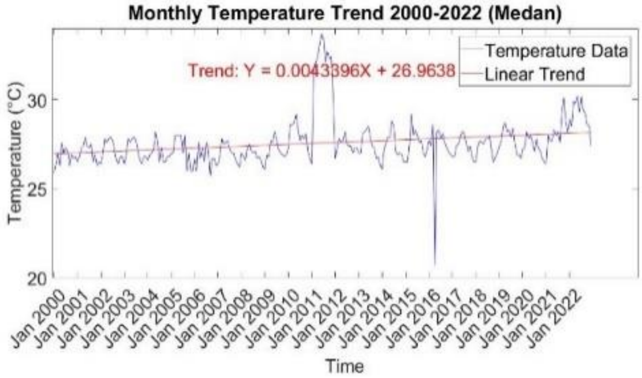
Kendall Tau, which measures the strength of the correlation between time and rainfall, shows a value of 0.14187 for Medan and 0.086509 for Deli Serdang. Although this correlation is not very strong, the higher Tau value in Medan suggests a closer relationship between increasing rainfall and time compared to Deli Serdang. This positive correlation indicates that rainfall tends to increase over time in both regions.

Sen's Slope is used to measure the rate of change in rainfall over time. The analysis results show that Medan has a Sen's Slope of 0.95345, while Deli Serdang has a Sen's Slope of 0.87273. This means that the monthly rainfall in Medan increases by 0.95345 mm each month, while in Deli Serdang, it increases by 0.87273 mm each month. Although both regions show an increasing trend, the rate of change in Medan is slightly higher compared to Deli Serdang. This difference can be attributed to local climate fluctuations or other environmental factors affecting rainfall patterns. Despite having different increase values compared to the regression model, both approaches indicate an increase in rainfall over the past twenty years. This reflects that Sen's Slope captures more subtle and dynamic changes in rainfall compared to the linear regression model, which might be more influenced by extreme data fluctuations. Sen's Slope provides a more robust estimate of the rate of change in rainfall that is more consistent over time. Overall, both the linear regression model and Sen's Slope indicate an increasing trend in rainfall, but Sen's Slope offers a more accurate view of the actual rate of change in rainfall.

The average monthly rainfall for Medan is recorded at 232.6 mm, with a median of 206 mm. Meanwhile, the average monthly rainfall for Deli Serdang is 186.41 mm, with a median of 175.5 mm. The higher average and median values in Medan indicate that this region receives more overall rainfall compared to Deli Serdang. This difference can provide insights into the more varied distribution of rainfall in Medan, which can impact water resource planning and flood risk management in the region.

3.2 Temperature Trend

This research conducted a monthly temperature trend analysis for the Medan and Deli Serdang regions using the Mann-Kendall, Kendall Tau, and Sen's Slope methods. The analysis results show an increase in temperature during the period from 2000 to 2022.



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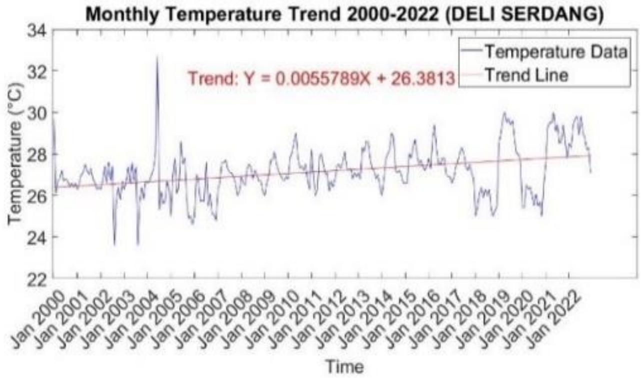


(b)

Figure 2. Temperature Trend Analysis Using Mann-Kendall (a) Medan (b) Deli Serdang

Based on the analyzed data, **Figure 2 (a)** illustrates the monthly temperature trend in Medan from 2000 to 2022, represented by the linear equation $y = 0.0043396x + 26.9638$. This equation indicates a monthly temperature increase of 0.0043396°C. Despite significant fluctuations, the data visually show a recurring and generally rising pattern over time, indicating a trend of increasing temperatures in Medan over the past two decades. **Figure 2 (b)** shows the monthly temperature trend in Deli Serdang during the same period, represented by the equation $y = 0.0055789x + 26.3813$. This equation indicates a monthly temperature increase of 0.0055789°C. The data in this figure also show significant fluctuations but overall present a recurring and generally rising pattern over time. This indicates a trend of increasing temperatures in Deli Serdang.

Table 2. MK Test Results for Values, Mean, Median, and Change Points of Temperature for the Study Area

Area	Mean	Median	Mann Kendall Test		Tau Value	Slope Value
			Z-Value	P-Value		
Medan	27.56	27.3	6.638	$3.1798e^{-11}$	0.26809	0.0054545
Deli Serdang	27.15	27.05	6.5819	$4.6454e^{-11}$	0.26582	-0.0094545

***Data source**: The Data Was Processed Using Matlab*

The results of the Mann-Kendall test analysis, as presented in **Table 2**, show a Z value of 6.638 for Medan with a P value of $3.1798e^{-11}$. This indicates that the temperature increase trend is highly statistically significant, with a low probability that this result occurred by chance. In Deli Serdang, a Z value of 6.5819 with a P value of $4.6454e^{-11}$ also indicates a significant trend, confirming the presence of a significant temperature increase trend in both regions during the study period.

The Kendall Tau values, which measure the strength of the correlation between time and temperature, show a value of 0.26809 for Medan and 0.26582 for Deli Serdang. These values indicate a moderate positive correlation, suggesting that temperatures tend to increase over time in both regions. The slightly higher Tau value in Medan suggests a somewhat stronger relationship between temperature increase and time compared to Deli Serdang.

Sen's Slope is used to measure the rate of temperature change over time. The analysis results show that Medan has a Sen's Slope value of 0.0054545, meaning that monthly temperatures in Medan increased by 0.0054545°C each month. Conversely, Deli Serdang shows a negative slope value of -0.0094545, indicating a slight decrease in monthly temperatures during the study period. This difference in slope values highlights regional variations in temperature trends, which may be influenced by local climate factors or other environmental conditions.

The average monthly temperature for Medan is recorded at 27.56°C, with a median of 27.3°C. Meanwhile, the average monthly temperature for Deli Serdang is 27.15°C, with a median of 27.05°C. The higher average and median temperatures in Medan indicate that this region generally has a warmer climate compared to Deli Serdang. The relatively close average and median values suggest a symmetric distribution of temperature data in both regions.

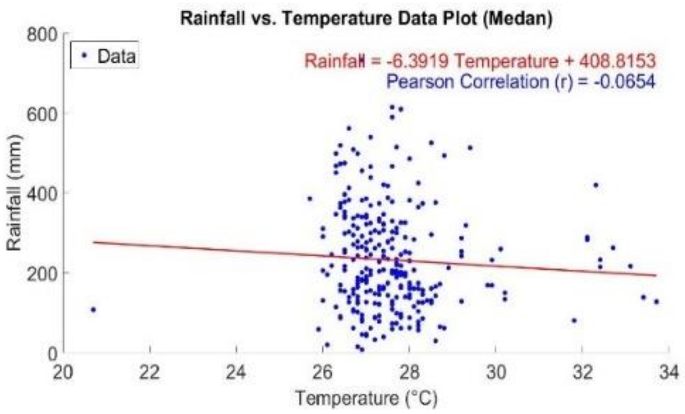
The linear regression models for both regions show an increase in monthly temperatures over the study period. However, these values differ from Sen's Slope, which reflects different aspects of temperature trends. While linear regression captures the overall trend influenced by extreme fluctuations, Sen's Slope provides a more detailed view of consistent changes over time. The difference between the slope in the linear regression trend and Sen's Slope value highlights the importance of using various analytical methods to obtain a more comprehensive picture of climate change.

These results are consistent with the findings of Nath [28], where an upward temperature trend was also identified, reflecting a similar pattern of temperature increases in other regions. Nath's findings confirm that climate change-driven temperature rises are widespread, including in tropical areas like Sumatra, aligning with the trends observed in this study.

The observed temperature increase has significant implications for climate adaptation and planning at the regional level. The stronger trend in Medan compared to Deli Serdang may require stricter measures to manage heat-related impacts on public health, agriculture, and infrastructure. Understanding these trends is crucial for developing strategies to mitigate negative impacts and enhance resilience to climate change in these regions.

3.3 Correlation of Rainfall with Temperature

This research conducted a monthly rainfall and temperature relationship analysis for the Medan and Deli Serdang regions using the Pearson correlation method. The analysis results show a weak negative relationship between rainfall and temperature in both regions during the analyzed period.



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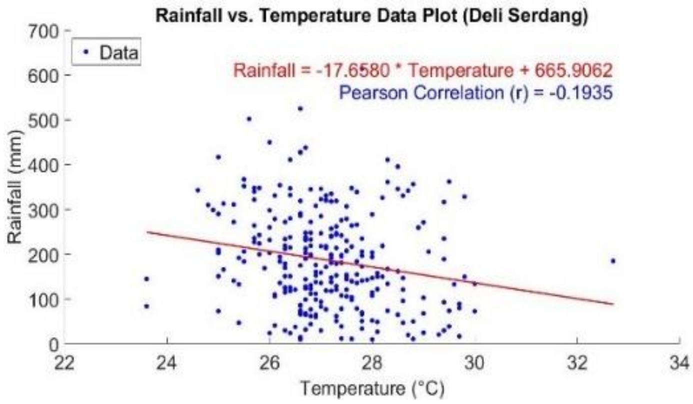

(b)

Figure 3. Correlation Analysis Between Rainfall and Temperature (a) Medan (b) Deli Serdang

Table 3. Pearson Correlation Results

Area	Pearson Correlation (r)
Medan	-0.0654
Deli Serdang	-0.1935

***Data source**: The Data Was Processed Using Matlab*

Using **Equation (10)**, the results of the Pearson correlation analysis between rainfall and temperature in the Medan region show that the correlation coefficient (r) is approximately -0.0654, as seen in **Table 3**. This indicates a weak and negative relationship between monthly rainfall and temperature in the Medan region. In other words, when rainfall increases, the temperature tends to slightly decrease, and vice versa. Although this correlation is negative, its value is very close to zero, indicating that there is no significant relationship between these two variables in this region.

Meanwhile, the results of the Pearson correlation for Deli Serdang indicate a value of -0.1935. This suggests a slightly stronger negative correlation between monthly rainfall and temperature in the Deli Serdang region. Although this correlation is also negative, its value still falls within the weak range, indicating that changes in rainfall only slightly affect temperature changes in this region.

Based on **Figure 3**, temperature does not significantly influence the rainfall pattern in Medan, at least for the dataset used in this analysis. This can be observed from the very low correlation coefficient and the relatively wide distribution of data in the graph.

The results of the Pearson correlation analysis between rainfall and temperature in these two regions show a weak and negative relationship. In Medan, the regression equation obtained is $Rainfall = -6.3919\, Temperature + 408.8153$ with a Pearson correlation value (r) of -0.0654. This shows that an increase in temperature is slightly related to a decrease in rainfall, but this relationship is very weak. In Deli Serdang, the regression equation obtained is $Rainfall = -17.6580\, Temperature + 665.9062$ with a Pearson correlation value (r) of -0.1935. This correlation is also negative, indicating that an increase in temperature in Deli Serdang is also related to a decrease in rainfall, but the relationship is still weak, although stronger than in Medan.

Statistically, the low correlation values in both regions indicate that temperature is not the main factor determining rainfall in Medan and Deli Serdang. The large variability in rainfall data that cannot be fully explained by temperature changes suggests that other factors may be more influential, such as humidity, wind, and other climatic phenomena. Additionally, these weak negative correlation values may not be statistically significant, necessitating further significance tests to ensure whether the observed relationships are statistically meaningful. This weak correlation aligns with the findings of Nath, who also observed a similarly low correlation between rainfall and temperature. Nath's results indicate that rainfall and temperature do not exhibit a strong direct relationship in other tropical regions as well **[28]**.

4. CONCLUSIONS

Based on the analysis of rainfall and temperature data in North Sumatra Province, particularly in the Medan and Deli Serdang regions, several important findings have been identified.

1. There is a trend of increasing monthly rainfall in both regions, although the increase is not very steep. Medan experiences higher monthly rainfall compared to Deli Serdang. This trend indicates that there have been significant changes in rainfall patterns in these regions over the study period from 2000 to 2022.
2. Second, there is a positive relationship between monthly rainfall and temperature in both regions, although the relationship is not very strong. Correlation analysis shows that when rainfall increases, temperature also tends to increase. This relationship, although weak, indicates an interaction between these two climate variables.
3. Third, there is a significant increasing trend in temperature in both regions, although the rate of increase is very small. This increase in temperature is consistent with global climate change patterns, where temperatures tend to gradually increase over the study period.

These findings address critical gaps in localized climate studies by providing insights into specific climate trends in North Sumatra, an underrepresented region in climate research. They highlight the need for government, research institutions, and communities to develop targeted adaptation and mitigation strategies to manage the potential impacts of climate change in the future. This study contributes to a comprehensive understanding of the dynamics of rainfall and temperature in Medan and Deli Serdang, offering valuable information to support climate-resilient policy and planning in the region.

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