Spatiotemporal Trends in Temperature and Rainfall in Northwestern Vietnam (2009-2024)

Xuan-Duc Do[*]

Department of Climate Change and Sustainability Science, VNU School of Interdisciplinary Sciences and Arts,
Vietnam National University, Hanoi, Vietnam

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* Corresponding author:
E-mail: ducxd@vnu.edu.vn

ABSTRACT

The present study sought to optimize the data from eleven Regional Hydro-Meteorological Station in the Northwestern Vietnam. The study results indicated that that the average temperature has tended to increase, which is lower than the average global surface temperature. Still, the maximum temperature, and lowest temperature are higher than the global average (values 0.6, 0.3, and 3.0°C, respectively). The rainy season (23.7°C) generally exhibits warmer temperatures than the dry season (16.9°C). There is a positive correlation between temperatures in consecutive months during both the dry and rainy seasons (r values): 0.75 (September, October), 0.53 (October, December), 0.51 (May, June) 0.46 (August, October), 0.45 (November, December), and 0.38 (April, May), respectively. There is negative correlation between the temperatures of months that are in the same season but far apart, R-values -0.61 (February, December), -0.58 (February, November), -0.56 (April, September), -0.31 (April, October), respectively. The total rainfall and total minimum rainfall showed decreasing trend were 127 mm, and 2.8 mm, respectively. By contrast, total rainfall max tends to increase by 230 mm. The highest rainfall was concentrated from May to October (1,219 mm). Higher correlation values for rainfall were observed in winter (January to March, and October to December), at 0.65, 0.78, 0.85, 0.93, 0.94, and 0.99 compared to summer (April to September), with r values of 0.29, 0.36, 0.57, 0.42, and 0.45, respectively. In a year, positive correlations between temperature and rainfall predominate most months of spring (January, February, and March), autumn (July, August, and September), and winter (October, November, and December), R-values: 0.59, 0.36, 0.44, 0.53, respectively, while negative correlations are more common in April, May, and June (summer) with the r values of -0.33, -0.16, and -0.25, respectively. The present study may provide a valuable and future climate, and rainfall projections.

HIGHLIGHTS

- Monitoring data of temperature and rainfall variation were used with the method for standardizing temperature and rainfall numeric data.
- The average temperature has tended to increase, and the total rainfall showed decreasing, and there is a positive correlation between temperatures in consecutive months during both the dry and rainy seasons.
- There is negative correlation between the temperatures of months that are in the same season but far apart.
- Positive correlations between temperature and rainfall predominate most months of spring, autumn while negative correlations are more common in summer.

1. INTRODUCTION

The spatiotemporal analysis of temperature and rainfall is crucial for understanding climate patterns and their impacts on agriculture and water resources. Studies across different regions, including Karnataka, India (Chowhan et al., 2023), and Kashmir Valley Ghana (Abbam et al., 2018) have consistently found significant trends in temperature and rainfall over time, with some regions experiencing increasing temperatures and others showing changes in rainfall patterns. The impacts of these variations are particularly important for agriculture-dependent areas, potentially affecting crop yields and food security (Abbam et al., 2018; Chowhan et al., 2023). The research highlights

the importance of location-specific analyses, as climate patterns can vary significantly across different regions. These findings can inform water resource management strategies and help develop targeted interventions to address the consequences of extreme climate events (Chowhan et al., 2023).

The importance of analyzing spatiotemporal variations in temperature and rainfall lies in their role in agricultural planning and climate change adaptation. Research across Ethiopia, Iran, and other regions reveals significant warming trends, with annual minimum and maximum temperatures increasing by 0.11°C and 0.08°C per decade, respectively (Meseret and Belay, 2019). Rainfall patterns show high variability and irregular distribution, classified as erratic in some areas (Worku et al., 2019). These climatic changes affect agriculture, potentially affecting crop production, disease proliferation, and household resilience (Getnet et al., 2023). To address these challenges, researchers recommend developing context-specific climate change adaptation strategies and implementing climate-smart agriculture technologies, such as small-scale irrigation, improved crop varieties, and efficient fertilizer use (Getnet et al., 2023; Meseret and Belay, 2019).

Analyzed spatial and temporal variations in temperature across different regions. In Ethiopia, annual minimum and maximum temperatures increased significantly by 0.11°C and 0.08°C per decade, respectively, from 1983 to 2014 (Meseret and Belay, 2019). Similarly, the Cauvery River Delta in India showed upward trends in annual and seasonal temperatures from 1960-2018, with warming accelerating after the 1980s (Ganeshkumar et al., 2020). In China's Hengduan Mountains, temperatures increased significantly from 1960-2008, with greater warming at higher altitudes (Zongxing et al., 2012). In China's Qinling- Huaihe demarcation zone, warming trends were observed from 1961 to 2018, particularly pronounced since the 1990s, with minimum temperatures showing the most notable increase (He and Hao, 2024). Within-city temperature variations were also examined in Shenzhen, China, revealing significant spatial heterogeneity and nocturnal and seasonal variability, with temperature differences between locations reaching up to 8.7°C during extreme heat days (Cao et al., 2021). These studies highlight the importance of understanding regional and local temperature variations in the context of global warming.

The spatial and temporal variability of rainfall is crucial for agricultural planning and understanding environmental processes. Studies across different regions have shown significant variations in rainfall patterns. In Bangladesh, moderate inter-annual and high intra-annual rainfall variability was observed, with increasing trends in coastal and northern areas (Shahid, 2009). Similarly, in India's Nagaland state, annual rainfall varied from 859 mm to 2,123 mm, with higher rainfall in the northern part (Kaur et al, 2021). The Parambikulam Aliyar Palar basin in Tamil Nadu exhibited wide rainfall variations, ranging from 445.2 mm to 4,364 mm annually (Balathandayutham et al., 2014). These studies emphasize the importance of analyzing spatial and temporal rainfall variability for effective agricultural and environmental management.

Research indicates a complex relationship between temperature and rainfall, with both positive and negative correlations observed depending on location and season. Studies in Malawi and Sweden found positive correlations between daily rainfall and temperature (Dzupire et al., 2020; Cong et al., 2012). However, in Sweden, negative correlations were observed from April to July and in September (Cong et al., 2012). A study across the contiguous United States found both positive and negative correlations, with most areas showing negative correlations in summer, particularly in the central and southern Great Plains (Zhao and Mak, 1993). The eastern Corn Belt was the only major area with a significant positive correlation in winter. These findings highlight the geographical and seasonal variability in temperature-rainfall relationships.

This study analyses temporal and spatial variations in temperature and rainfall using over 10 years of observational data. Previous studies utilized long-term observational data, ranging from 10 to 50 years, (Meseret and Belay, 2019; Worku et al., 2019). In Vietnam, significant climate changes were revealed. The average temperature rise of 0.26°C per decade since the 1970s is approximately twice the global rate, and decreasing rainfall trendsin northern Vietnam (Nguyen et al., 2018).

All studies employed various statistical techniques, such as trend analysis, correlation analysis, and geostatistical methods. Findings consistently revealed significant spatial and temporal variations in both temperature and rainfall patterns. However, studies on the development of analyzing temporal and spatial variation in temperature and rainfall are lacking. Therefore, it is important to fill this gap in knowledge

regarding the combined temporal and spatial variations of temperature and rainfall.

Northwest Vietnam is highly vulnerable to climate change impacts, particularly natural disasters like droughts, floods, and landslides. In this study, our primary objective was to analyze temporal and spatial variations in temperature and rainfall. We explored three specific objectives in this study: (1) to introduce the temporal and spatial (seasonal) variation of temperature in analyzing the relationship between temperature variables; (2) to combine the analysis of temporal and spatial trend rainfall trends using data monitoring, network, and; (3) to analyze the correlation between temperature and total rainfall each month in every season and over the year in the Northwest Vietnam.

2. METHODOLOGY
2.1 Research area

This case study was conducted in Northwestern Vietnam, located in Hoa Binh, Son La, Dien Bien, and Lai Chau provinces, Northwest Vietnam. It covers 38,000 km², accounting for 11.4% of Vietnam's total area. The region is characterized by mountainous terrain, with over 94% of the land classified as sloping (Hoang et al., 2017). The region faces environmental challenges due to agricultural expansion on steep slopes, leading to forest degradation and soil erosion

(Hoang et al., 2017). Figure 1 shows the temperature and rainfall monitoring points. These 11 (coded as S1-S11) points monitored the temperature and rainfall of the region through two parameters: temperature and rainfall. Historical mean values of these parameters for the stations were used for 15 years (2009-2024).

2.2 Data collection

Eleven monitoring stations have been fully operated by the Northwestern Vietnam Regional Hydro-Meteorological Station in the study area since 2009 (Figure 1), including S1 (Tam Duong), S2 (Than Uyen), S3 (Sin Ho), S4 (Muong Lay), S5 (Tuan Giao), S6 (Pha Din), S7 (Phieng Lanh), S8 (Dien Bien), S9 (Song Ma), S10 (Bac Yen), and S11 (Son La). Figure 1 shows that these Meteorological stations S1, S2, S3, S4, S5, S6, S7, S8, S9, S10, and S11 monitored the temperature and rainfall of Northwestern Vietnam. The monitoring frequency is continuous hourly, daily, monthly, and yearly, with temporal variation recorded in all the months from January to December. Monitoring data of temperature and rainfall variation from April to September were used for the rainy season, and data from January, February, March to October, November, and December were used for the dry season. Spatial variation at 11 stations (S1-S11) during 2009-2024 was collected.
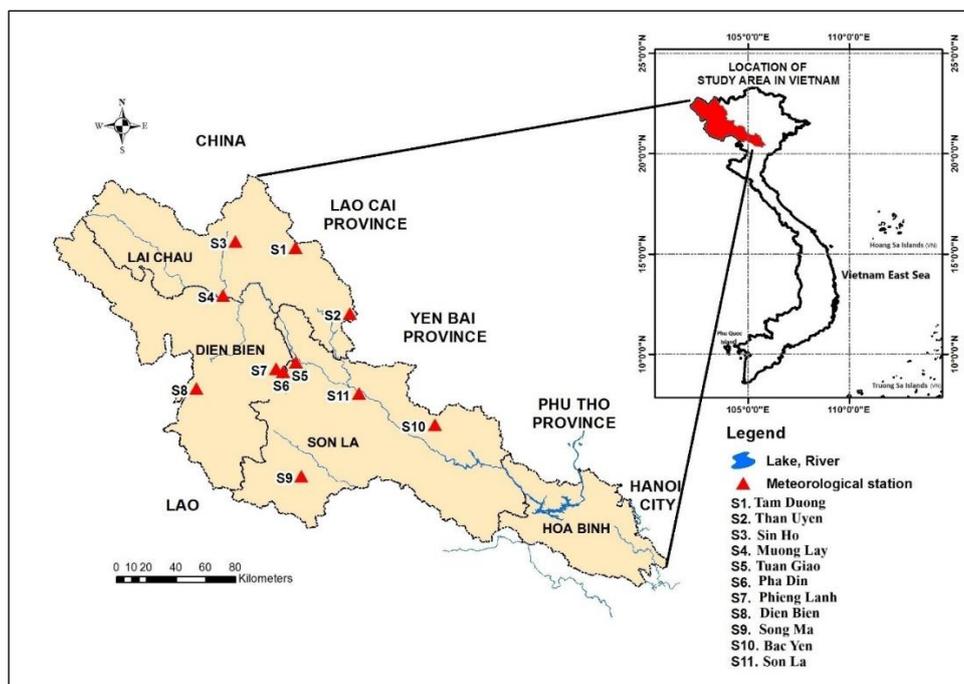
Figure 1. Location of monitoring points temperature and rainfall in Northwestern Vietnam

2.3 Methods

The equation to calculate the mean (algebraic measure) of sample temperature and rainfall is sensitive to outliers (Han and Kamber, 2012). Therefore, a trimmed mean (which removes extreme values) is recommended when analyzing data from the monitoring network over a year, treating variables equally by Equation (1).

$$\bar{x} = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i} \quad (1)$$

According to (Han and Kamber, 2012), the method for standardizing temperature and rainfall numeric data is given by Equation (2).

$$\text{Z-score: } x = \frac{x-\mu}{\sigma} \quad (2)$$

Where; X: raw data, μ: is the mean of the temperature and rainfall, σ: is the standard deviation. The distance between the raw score and the temperature and rainfall mean in units of the standard deviation, <0 when the raw score is below the mean, >0 when above (Han and Kamber, 2012). Along with that an equation to variance and standard deviation (sample: s, population: σ): Standard deviation s (or σ) is the square root of variance by Equations (3), and (4).

$$s^2 = \frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2 = \frac{1}{n}\left[\sum_{i=1}^{n} x_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} x_i\right)^2\right] \quad (3)$$

$$\sigma = \frac{1}{N}\sum_{i=1}^{n}(x_i - \mu)^2 = \frac{1}{n}\sum_{i=1}^{n} x_i^2 - \mu^2 \quad (4)$$

Multivariate correlation analysis method: Pearson (1909), argued that came up with an equation (5) to estimate the correlation coefficient (r), This is a statistical index that measures the correlation between two variables, in this study, between temperature (x) and rainfall (y). The correlation coefficient has values from -1 to 1. The correlation coefficient is equal to 0, or close to 0 means the two variables have no relationship with each other. If the value of the correlation coefficient is negative (r<0) That means when x increases, y decreases and vice versa, when x decreases, y increases; if the correlation coefficient value is positive (r>0) This means that when x increases, y also increases, and when x decreases, y also decreases by Equation (5).

$$r = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2 \sum_{i=1}^{n}(y_i-\bar{y})^2}} \quad (5)$$

Where; (r) is the correlation coefficient Pearson, is the average value of the temperature variable (x) and rainfall (y), and xi, yi is the average value of the variables (x) and (y) at the meteorological station i, n is the number of variables by Equation (5).

2.4 Statistical analysis

Tested for statistical significance and normal distribution, the R-Studio package was used for statistical analysis of the monitoring data. Surface temperature and rainfall data were log-transformed for homogeneity and tested to fit a statistical significance and normal distribution using the Cor. test (Table 1, and Table 2). Significant differences and correlations among variations were determined using one-way analysis to analyze variance (ANOVA) checks whether there are statistically significant differences between more than two variables, and Pearson coefficients (r) with the help of correlation analysis, the linear relationship between variables can be examined, to strength of the correlation is indicated by the correlation coefficient, which ranges from -1 to +1. Significant differences in data between the temperature, rainfall, and between month dry and rainy seasons were analyzed using the Independent-Samples T-Test. Figures were drawn using Origin Pro 2018 v9.5.0 and R-Studio. With probability <0.05, the average data during 2009-2024 (Table 1, and Table 2) of temperature, and rainfall values are considered statistically significant. These values can be used to forecast change trends and quality correlations over temporal and spatial variations. Pearson correlation test in R use the Cor. test function to check the statistical significance of temperature and rainfall monitoring data.

3. RESULTS AND DISCUSSIONS
3.1 Temporal variation in temperature

Figures 2(a), 2(b), and 2(c) show the temperature variation trend in the northwestern of Vietnam in the period from 2009 to 2024, specifically:

The mean temperature (±standard deviation) for each year were as follows, specifically:

2009 (21.1±2.1), 2010 (21.4±2.0), 2011 (21.1±2.3), 2012 (20.6±2.1), 2013 (21.4±2.1), 2014 (21.7±2.3), 2015 (20.6±2.1), 2016 (21.6±2.2), 2017 (21±2.1), 2018 (21.3±2.2), 2019 (21.7±3.4), 2020 (23.0±1.9), 2021 (21.8±2.2), 2022 (20.8±1.9), 2023 (22.1±2.3), 2024 (21.7±2.3).

Table 1. Check the statistical significance of temperature monitoring data using the correlation test (Cor. test) for the period 2009-2024

Months of the year	Test statistic value	Probability value
January	t = 2.56	p-value < 0.01
February	t = 6.61	p-value < 0.01
March	t = 2.94	p-value < 0.05
April	t = 2.27	p-value < 0.05
May	t = 2.73	p-value < 0.05
June	t = 2.41	p-value < 0.05
July	t = 2.98	p-value < 0.05
August	t = 2.28	p-value < 0.05
September	t = 2.02	p-value < 0.05
October	t = 2.58	p-value < 0.05
November	t = 3.56	p-value < 0.01
December	t = 2.68	p-value < 0.01

Table 2. Check the statistical significance of rainfall monitoring data using the correlation test (Cor. test) for the period 2009-2024

Months of the year	Test statistic value	Probability value
January	t = 3.19	p-value < 0.01
February	t = 3.62	p-value < 0.01
March	t = 3.94	p-value < 0.01
April	t = 3.79	p-value < 0.01
May	t = 3.68	p-value < 0.05
June	t = 3.87	p-value < 0.05
July	t = 3.73	p-value < 0.05
August	t = 3.04	p-value < 0.05
September	t = 2.29	p-value < 0.05
October	t = 10.2	p-value < 0.01
November	t = 3.27	p-value < 0.05
December	t = 5.79	p-value < 0.01
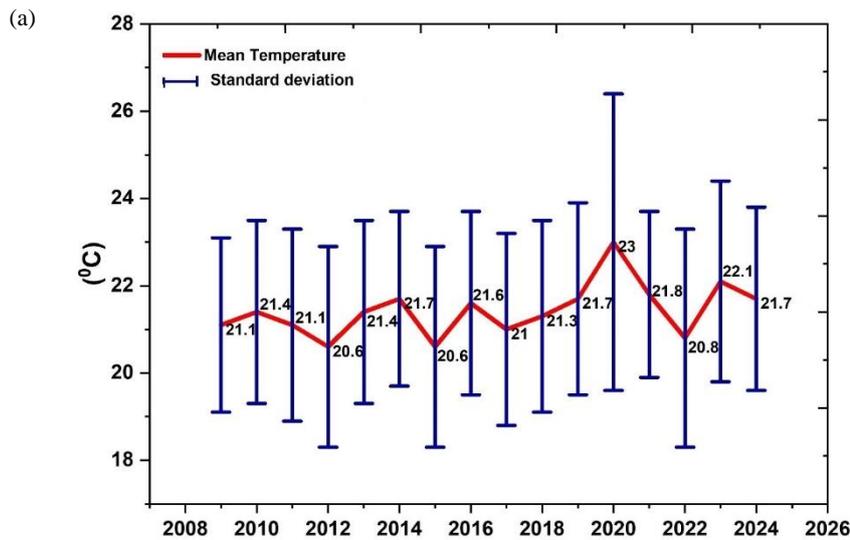
Figure 2. Changes in temperature in the Northwestern of Vietnam during 2009 to 2024

(b)

(c)
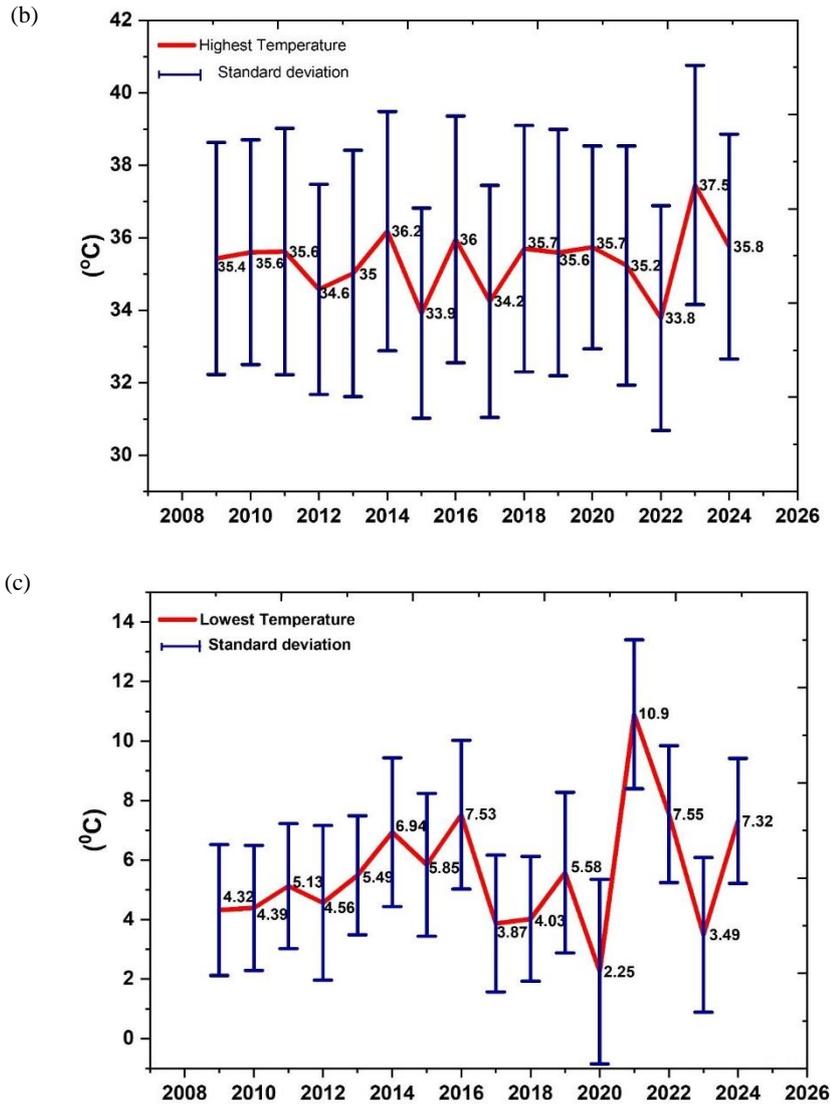
Figure 2. Changes in temperature in the Northwestern of Vietnam during 2009 to 2024 (cont.)

The highest temperatures recorded each year were, specifically: 2009 (35.4±3.2), 2010 (35.6±3.1), 2011 (35.6±3.4), 2012 (34.6±2.9), 2013 (35.0±3.4), 2014 (36.2±3.3), 2015 (33.9±2.9), 2016 (36.0±3.4), 2017 (34.2±3.2), 2018 (35.7±3.4), 2019 (35.6±3.4), 2020 (35.7±2.8), 2021 (35.2±3.3), 2022 (33.8±3.1), 2023 (37.5±3.3), 2024 (35.8±3.1).

The lowest temperatures recorded each year were, specifically: 2009 (4.32±2.2), 2010 (4.39±2.1), 2011 (5.13±2.1), 2012 (4.56±2.6), 2013 (5.49±2.0), 2014 (6.94±2.5), 2015 (5.85±2.4), 2016 (7.53±2.5), 2017 (3.87±2.3), 2018 (4.03±2.1), 2019 (5.58±2.7), 2020 (2.25±3.1), 2021 (10.9±2.5), 2022 (7.55±2.3), 2023 (3.49±2.6), 2024 (7.42±2.1).

An increasing trend in temperature values in the period 2009-2024 was found for the mean temperature (r=0.4, p<0.001). The corresponding temprature increases were 0.6°C for the mean temperature (Figure 2(a)), 0.3°C for the highest temperature (Figure 2(b)), and 3.0°C for the lowest temperature (Figure 2(c)).

3.2 Spatial variation in temperature

Figure 3 shows the monthly mean temperature values, specifically: January (11.8-16.2), February (13.1-19.0°C), March (19.4-21.7°C), April (21.4-24.0°C), May (23.1-24.9°C), June (24.6-25.0°C), July (24.2-24.8°C), August (23.9-24.7°C), September (22.9-24.3°C), October (20.2-23.1°C), November (17.6-20.2°C), December (12.6-16.8°C).

The variation in average monthly temperature between the years 2009-2024 was recorded with mean values highest from April to September each year corresponding to 22.7°C (April, p<0.05), 24.2°C (May, p<0.05), 24.7°C (June, p<0.05), 24.4°C (July, p<0.05), 24.2°C (August, p<0.05), and 23.8°C

(September, p<0.05) during the rainy season. The dry season lasts from January to March. From October to December each year the average monthly temperature is lower than in the rainy season, with corresponding values of 14.9°C (January, p<0.01) 15.5°C (February,

p<0.01), 20.1°C (March, p<0.05), 21.6°C (October, p<0.05), 19.1°C (November, p<0.01), and 15.1°C (December, p<0.01), respectively (Figure 3, and Figure 4).
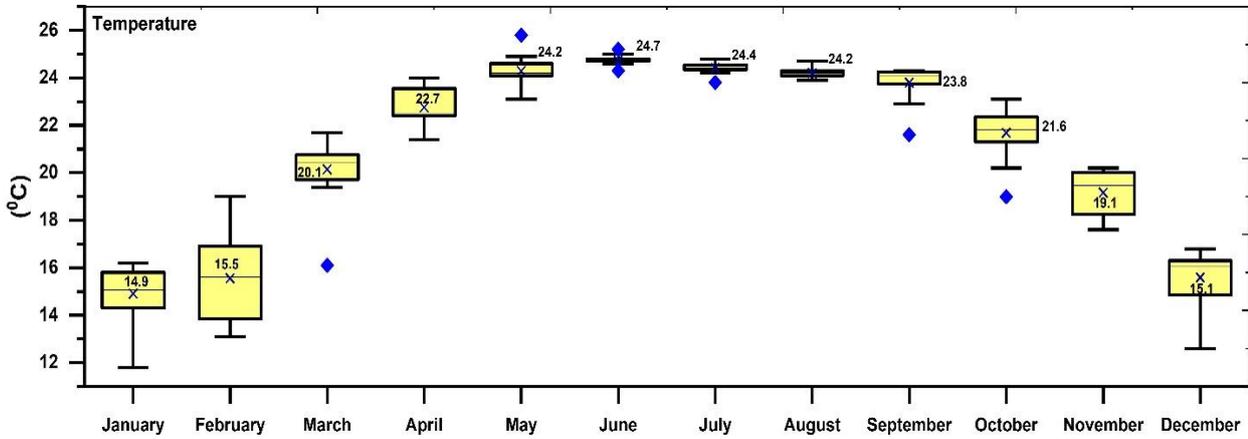

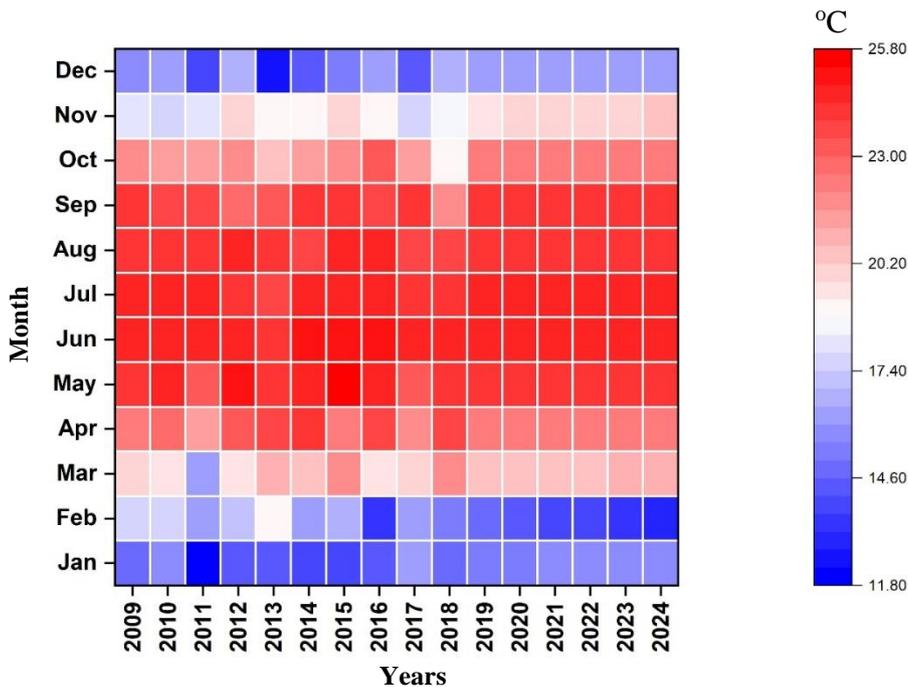**Figure 3.** Change temperature in months from 2009 to 2024

Figure 4. The monthly temperature concentration levels temperatures

Figure 5 shows the correlation (r) between the average temperatures of each month over the period from 2009 to 2024. A strong and moderate positive correlation was found between January and March, as well as between January and December (r=0.60, p<0.01; r=0.44, p<0.01). The between March and April, May, and November (r=0.45, p<0.05; r=0.49, p<0.01; r=0.45, p<0.05). The between April and May (r=0.38, p<0.05). The between May and June, August,

November, and December (r=0.51, p<0.05; r=0.43, p<0.05; r=0.37, p<0.05; r=0.41, p<0.05). The between August and October (r=0.46, p<0.01), between September and October (r=0.75, p<0.01), and between October and November, as well as between October and December (r=0.53, p<0.01; r=0.41, p<0.01; r=0.45, p<0.01). Figure 4 also shows a strong negative correlation between the temperatures of February and October, November, and December (r=-0.58, p<0.01;

r=-0.61, p<0.01). The and between April and September (r=-0.56, p<0.05). Figure 4 indicates a relatively clear correlation between the average temperatures of some months in the dry season and certain months in the rainy season. Additionally, it shows a weak and unclear positive or negative correlation between the months of the dry and rainy seasons. Monthly temperature correlations are influenced by various factors.
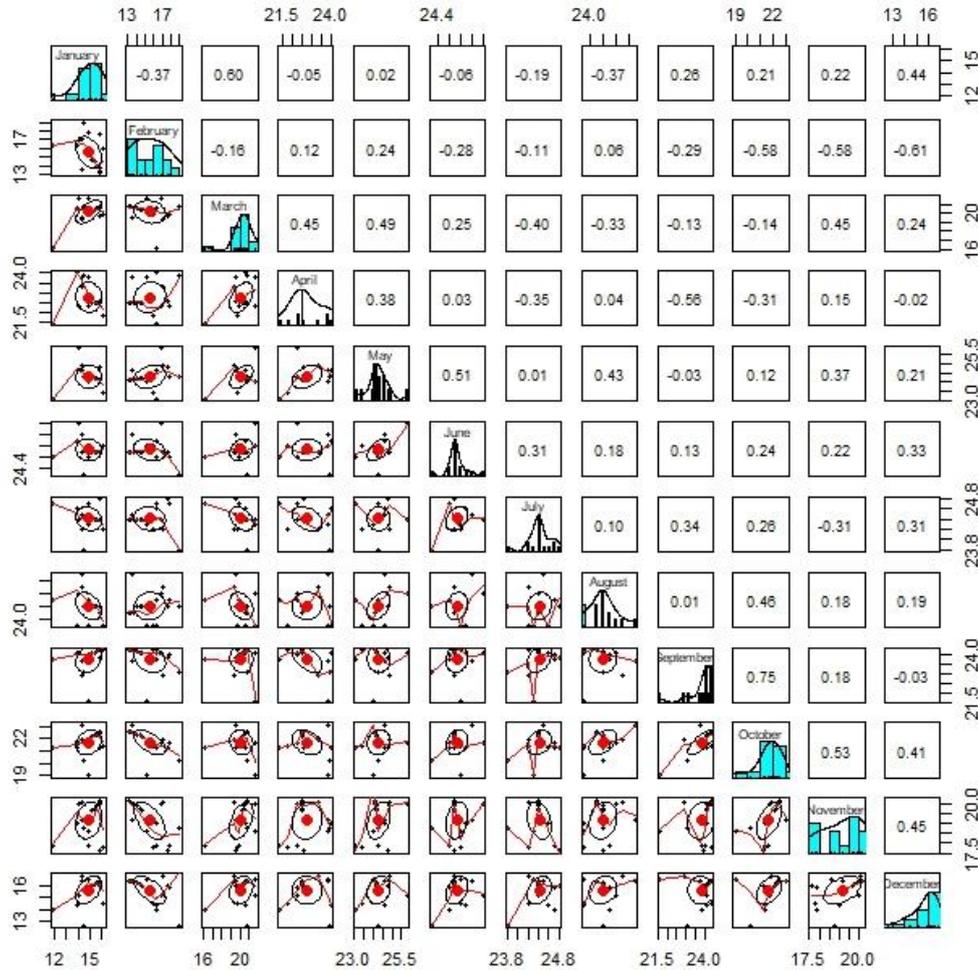

Figure 5. The correlation coefficient (r) between monthly temperatures

3.3 Temporal variation in rainfall

The total rainfall values recorded at the eleven monitoring stations are shown in Figure 6. The annual rainfall (in mm) across the years is as follows: 2009 (1,810±465), 2010 (1,449±440), 2011 (1,787±453), 2012 (2,315±528), 2013 (1,580±426), 2014 (1,628±481), 2015 (1,462±417), 2016 (1,968±501), 2017 (1,997±462), 2018 (1,830±505), 2019 (2,029±405), 2020 (1,609±350), 2021 (2,083±636), 2022 (1,979±571), 2023 (1,540±589), 2024 (1,683±587).

The decreasing trend of total rainfall and total rainfall min (in mm) was observed during 2009-2024, respectively: 127 mm (r=-0.71, p<0.05), 2.8 mm (r=-0.83, p<0.01). By contrast, the total rainfall max (in

mm) tends to increase during 2009-2024, was 230 mm (r=0.82, p<0.01). The values of rainfall in the years were different amongst the total rainfall, total rainfall max, and total rainfall min (in mm). The rainfall trend in Northwestern, Vietnam, highlights the regional variability in rainfall trends and the importance of local-scale analysis for climate adaptation strategies.

3.4 Spatial variation in rainfall

The comparative data on the values of rainfall (in mm) in month during 2009-2024 were, specifically: January (134-706 mm), February (41-299 mm), March (347-549 mm), April (471-843 mm), May (624-1,931 mm), June (464-2,055 mm), July (336-2,068 mm), August (928-2,275 mm), September (883-2,106 mm), October (273-1,964 mm), November (114-379 mm),

December (81-390 mm), (Figure 7). The mean month values of rainfall were, specifically: with January (374±346), February (175±247), March (437±456), April (600±910), May (1,141±1,399), June (1,082±1,316), July (1,161±1,232), August (1,543±1,864), September (1,442±1,688), October (945±1,277), November (245±233), December (221±247) (Figure 7).
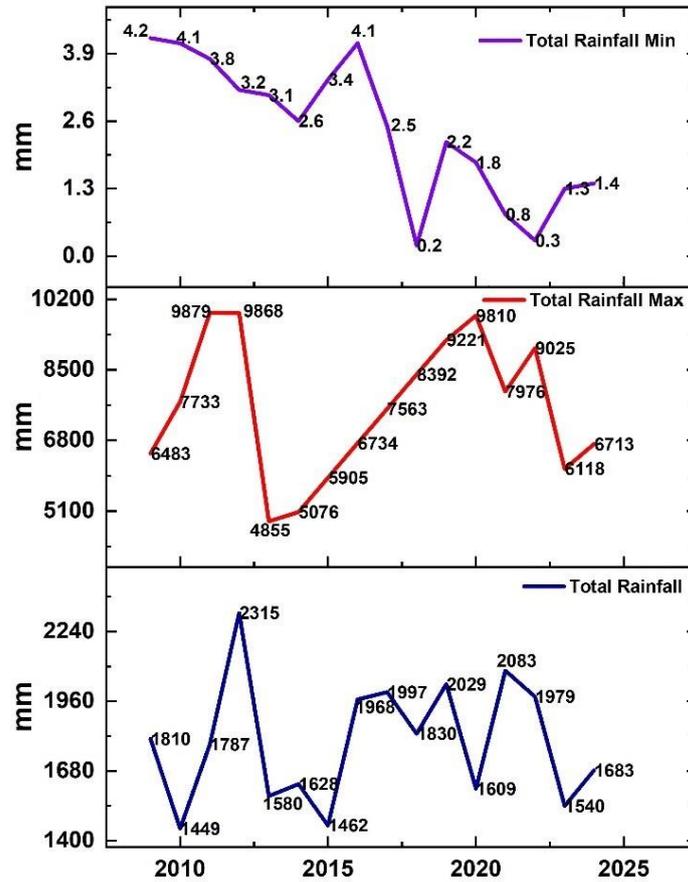

Figure 6. The rainfall in Northwestern, Vietnam during 2009-2024
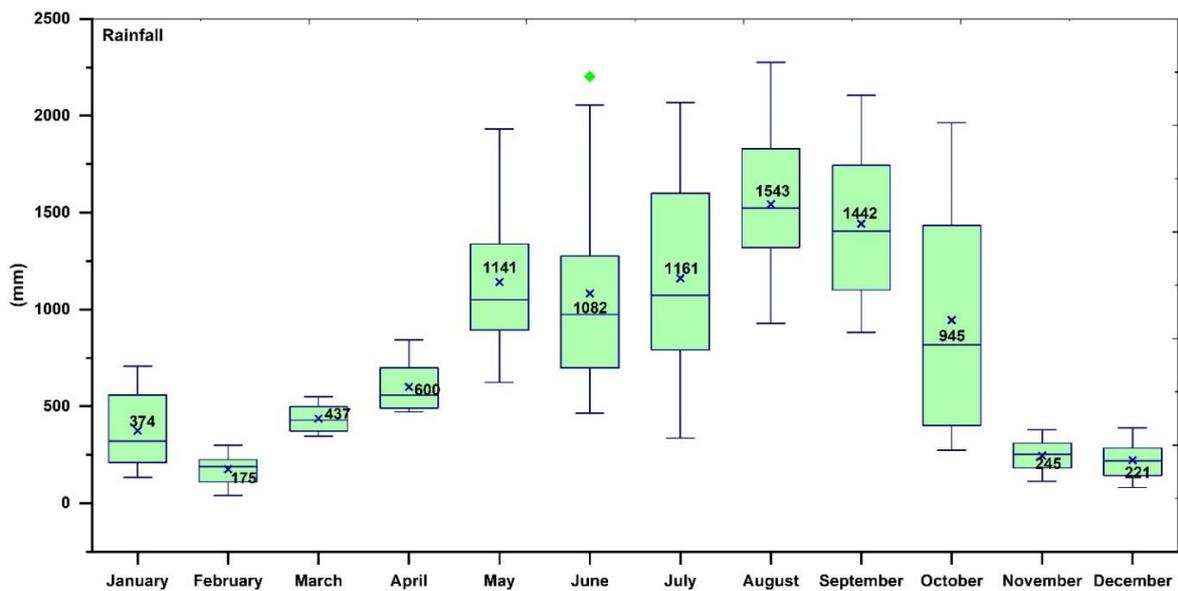

Figure 7. Change of rainfall in months from 2009 to 2024

Figures 8 and 9 show Northwestern Vietnam experiences alternating wet and dry and dry seasons. The highest total rainfall is consistently concentrated in the rainy season, which lasts from May to October. The dry season, occurring in January, February, March, April, November, and December, has a lower average total rainfall. Thus, the intensity and distribution of rainfall vary between seasons, with the dry season generally having lower total rainfall. These seasonal rainfall patterns strongly affect hydrology, vegetation, and sediment transport, particularly in mountainous Northwestern, Vietnam.

The total rainfall correlation levels by month are determined and shown in Figure 8 Strong correlations were observed, such as January with April (r=0.99, p<0.01) and January with March (r=0.94, p<0.01); April with October (r=0.90, p<0.01), October with December (r=0.93, p<0.01) as most important month correlation in Northwestern Vietnam (in 12 monitored month). The correlation of month total rainfall variables in the rainy is determined and shown in Figure 9. The total rainfall correlation between July and August, June and July, and May and August is the most important month correlation in the rain of Northwestern Vietnam. The correlation of the month were r=0.45 (p<0.05), r=0.42 (p<0.05), r=0.35 (p<0.05), r=0.22 (p<0.05), respectively. The relationship between dry and rainy season rainfall should be considered carefully to improve monitoring and understanding of total rainfall trends.
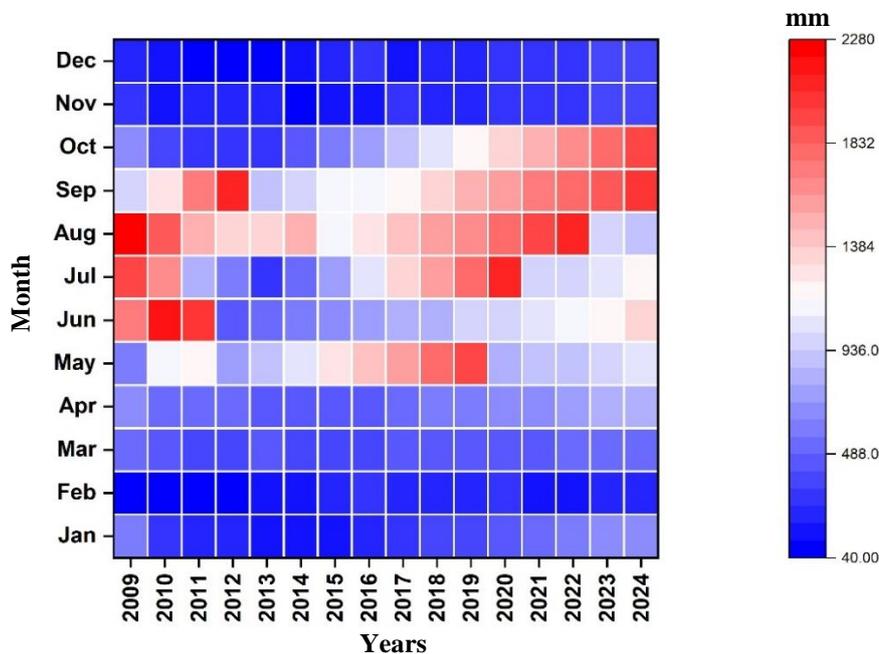

Figure 8. The monthly rainfall concentration levels

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3.5 The correlation between temperature and total rainfall

Figure 10 shows the correlation between temperature and total monthly rainfall in the Northwest region of Vietnam during the period 2009-2024. January and December are identified as the two months of the dry season with the strongest positive correlation among the 12 months of the year. The correlation coefficients between temperature and total rainfall in January and December were (r=0.59, p<0.01; r=0.53, p<0.05), respectively. In addition,

during the dry season, a moderate positive correlation between temperature and total rainfall is observed in March, October, and November. The correlation coefficients between temperature and total rainfall for March, October, and November were (r=0.36, p<0.05; r=0.44, p<0.05; r=0.36, p<0.05), respectively. However, a strong negative correlation between temperature and total precipitation is found in February (dry season), with a correlation coefficient were (r=-0.65). Thus, the positive correlation between temperature and total rainfall is generally observed during the dry season (in with winter), except for February.
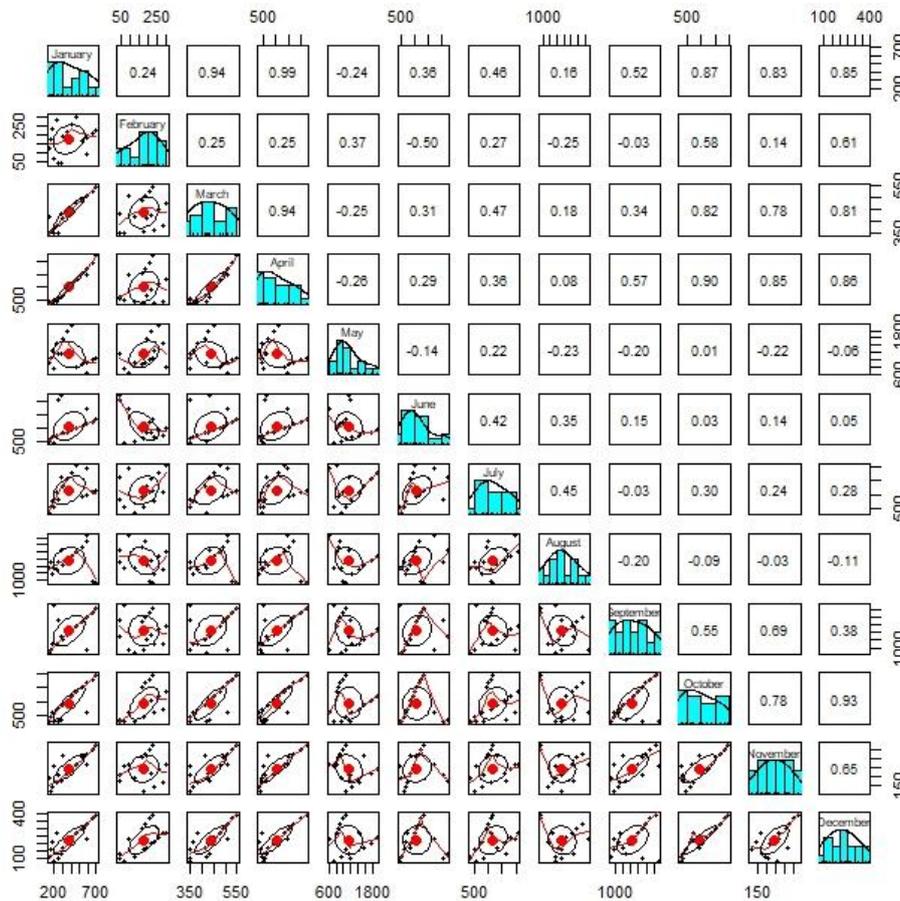
Figure 9. The correlation coefficient (r) between monthly rainfall

Figure 10 shows the correlation between temperature and rainfall during the summer (corresponding to the rainy season) with contrasting results in the Northwest region of Vietnam. Rainfall and summer temperature typically have a low negative average correlation (4 out of 6 summer months). The correlation coefficients between temperature and rainfall for April, May, June, and August are (r=-0.33, p<0.05; r=-0.16, p<0.05; r=-0.25, p<0.05; r=-0.07, p<0.05), respectively. However, for July and September, a low positive correlation between temperature and rainfall was identified, with coefficients of (r=0.39, p<0.05; r=0.10, p<0.05), respectively. These varied findings suggest that the relationship between temperature and rainfall is complex and region-specific.

4. DISCUSSIONS
4.1 The increasing trend of temperature and temporal and spatial

Over the past 15 years (2009-2024), the average temperature in the Northwest region of Vietnam increased by 0.6°C. This is lower than the global average surface temperature increase of 1.09°C recorded between 2010 and 2020 (Shukla et al., 2022). According to the IPCC's Sixth Assessment Report (AR6), the decade from 2011 to 2020 was approximately 1.09°C warmer than pre-industrial levels (Zhou, 2021). The maximum temperature increase in the Northwest of Vietnam during the period 2010-2020 was 0.3°C, which is higher than the global average maximum temperature increase. Analysis of the highest temperature of the year reveals

a global increase of 0.19-0.25°C per decade in the last 30 years (Papalexiou et al., 2018). The lowest temperature in the Northwest region of Vietnam has increased by an average of 3°C, which is higher than the lowest temperature increase globally. The findings indicate a positive correlation between temperature and precipitation during most months of spring, autumn, and winter (Vose et al., 2005). The consistent increase in minimum temperatures, particularly evident after 2010, aligns with global trends and serves as an indicator of the global warming trend with a notable rise in the rate of warming observed in recent decades.
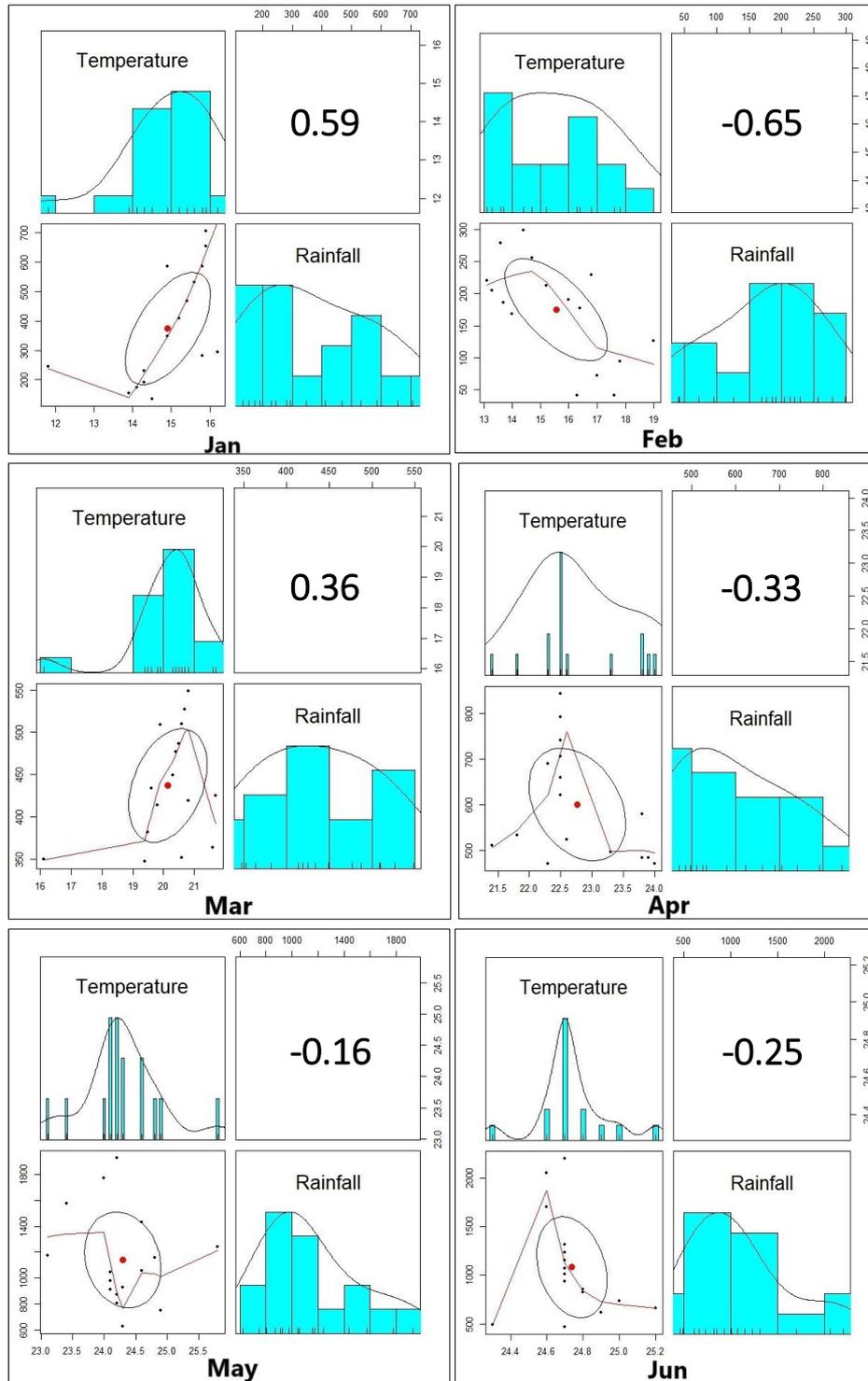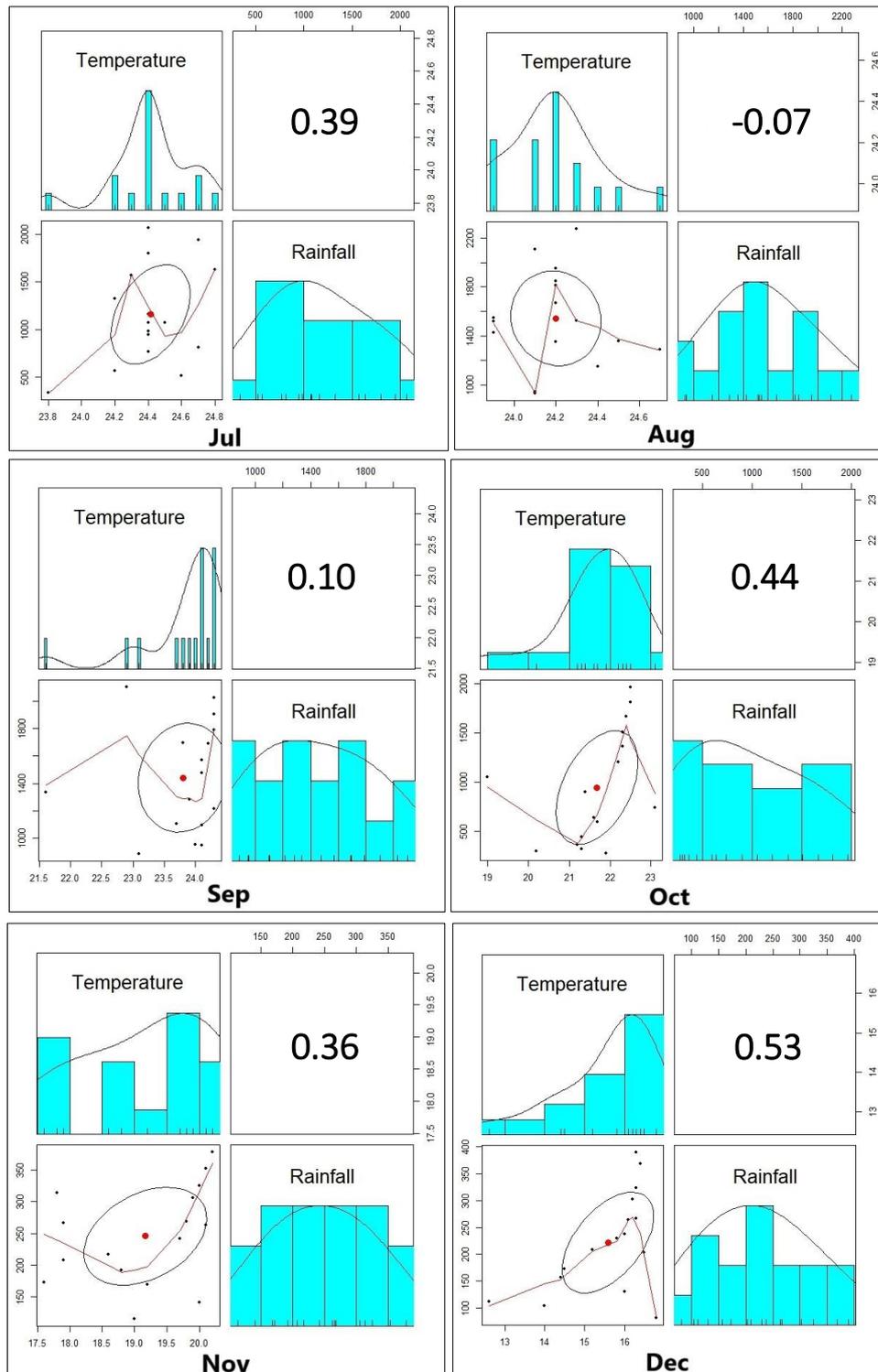

Figure 10. The correlation between temperature and total rainfall by month

Figure 10. The correlation between temperature and total rainfall by month (cont.)

The research results show that the summer in the Northwest of Vietnam, corresponding to the rainy season from April to September each year, has the temperature average highest in the year. The research findings are consistent with other following studies. Research indicates that the rainy season generally exhibits warmer temperatures than the dry season in tropical regions. Similarly, East Java, Indonesia has experienced temperature increases of more than 1°C over 34 years, with the rainy season exhibiting warmer temperatures than the dry season (Natayu et al., 2021). This phenomenon could be attributed to the increased cloud cover and reduced solar radiation during the rainy season, leading to a greenhouse effect that traps

heat and results in higher temperatures. Research has shown significant positive correlations between temperatures of successive months seasons. In Iceland, extremely high correlations (r>0.8) were observed, especially in areas during summer (Degenhardt et al., 2019).

The research results indicate that there is a positive correlation between the temperatures of consecutive months in both the dry and rainy seasons and a negative correlation between the temperatures of months that are in the same season but far apart, particularly in northern Japan between April and August since 1998 (Kanno, 2013), Similar observed across North America and Europe, especially during summers (Madden and Williams, 1978).

The research results indicate a positive correlation between the temperatures of consecutive months during both the dry and rainy seasons. For example, there is a positive correlation between January, February, and March (dry season, and a positive correlation between April, May, June, July, August, and September (rainy season). The study identified a positive correlation between the temperatures of consecutive months within both the dry (e.g., January to March) and rainy seasons (e.g., April to September). This result is consistent with previous studies when research on temperature correlations across seasons reveals complex patterns. Studies indicate positive correlations between temperatures of consecutive months within both dry and rainy seasons (Emekwuru et al., 2023). However, negative correlations are observed between temperatures of months in the same season but a long (Madden and Williams, 1978). These findings highlight the intricate relationships between temperature and seasonal variations in different geographical contexts. Northern Vietnam has seen a substantial increase in hot days and a decrease in cold days, with the Northwest region showing a decline of 3.5 to 4.5 cold days per decade (Ngo and Bui, 2023). These temperature changes have implications for public health.

4.2 The rainfall tends to decrease and temporal and spatial variation

The average total rainfall in the study area tends to decrease after 15 years, corresponding to 127 mm may be influenced by deforestation with larger deforested areas associated with decreased rainfall, and changes and topography, climate models predict that continued deforestation could lead to further

decreases in precipitation (Bonini et al., 2014; Ramos da Silva et al., 2008).This finding is consistent with long-term trends observed in other regions, such as the Yarra River catchment in Australia, which has experienced significant declines in monthly and annual precipitation over the past 50 years (Barua et al., 2013), and Punjab, India, where both total rainfall and the number of rainy days declined from 2001-2015 compared to 1986-2000 (Kaur et al., 2021). The Kathmandu Valley in Nepal experienced a significant reduction in rainfall after 2000, with mountain stations showing decreasing trends in all seasons (Prajapati et al., 2021). While no significant temporal trends were found in basin-scale precipitation in southeast Arizona, spatial variability of cumulative precipitation decreased exponentially over time, becoming uniform after 20 years. These findings suggest a consistent reduction in rainfall across different regions, which may have important implications for water resource management and ecosystem dynamics. These changes necessitate adaptive water resource management strategies, including supply-demand adaptations, capacity building, public participation, and regional cooperation.

The total average rainfall value in the study area shows a clear seasonal variation, with the highest rainfall concentrated from May to October (summer), while during the winter season (from October to December and until April of the following year), the rainfall is significantly lower compared to summer. This result is consistent with recent studies that collectively highlight significant seasonal variations in rainfall patterns across different regions. For example, in Costa Rica's Reventazón River basin, two distinct seasonal periods were identified: December-April with predominantly orographic rain, and May-November with convective showers (Chacón et al., 1985). In monsoon systems, summer typically brings higher rainfall due to thermal contrasts between land and ocean, causing low-level moist air convergence over land. These findings highlight the complex interactions between various climatic factors in determining precipitation regimes.

This result is the correlation of rainfall in Northwestern, Vietnam in have highlighted significant patterns in rainfall trends and their correlations with global climate phenomena. A general downward trend in rainfall in in South Africa's, region of Africa, Australia to global warming (Nenwiini et al., 2013). The correlation coefficient (r) between the rainfall amounts of the months in winter is higher than in

summer, with the highest r values between winter months ranging from (r=0.65 to r=0.99), whereas the highest correlation coefficient for summer months ranges from (r=0.55 to r=0.95). This result is consistent with recent studies shows the spatial variability of rainfall differs between seasons, with higher correlations observed in winter compared to summer (Chacón et al., 1985). The winter rainfall is more strongly correlated with the rainfall than in the summer, possibly due to the high latitude of Northwestern Vietnam. Research in California revealed positive precipitation correlation trends in winter with strong correlations to ENSO (The alternation of warm El Nino and cold La Nina conditions, referred to as the El Nino-Southern Oscillation (ENSO, AAO (The Antarctic Oscillation), and NAO (North Atlantic Oscillation) (González et al., 2022). In High Mountain Asia, winter precipitation showed positive correlations with various global modes of variability, while summer precipitation exhibited negative correlations, particularly with the Eurasian teleconnection (Massoud et al., 2024).

These findings collectively suggest that seasonal rainfall patterns are dynamic and closely linked to large-scale climate oscillations. These studies highlight the complex and regionally-specific nature of seasonal rainfall correlations, emphasizing the importance of considering local climate patterns in rainfall predictions, forecasting landslides and debris flows in mountainous regions, and understanding rainfall patterns for effective disaster prevention in mountainous areas, and reduce impacting crop yields and farming strategies. Besides understanding rainfall distribution is essential for addressing environmental to mitigate these challenges, can adopted various management strategies.

4.3 Temperature and rainfall trend fluctuate seasonally

The research results show there is a positive correlation between temperature and rainfall in most months of spring, autumn, and winter. However, in summer, a negative correlation between temperature and rainfall predominates in Northwestern, Vietnam. Correlation between the variables studied indicates a significant relationship between the two factors. Research worldwide shows similar results in regions on a global scale, For example, In Europe, specifically Scania, Sweden, negative correlations between rainfall and temperature were found from April to July (Cong et al., 2012). Similarly in Europe, positive

correlations between temperature and rainfall predominate in walinter, while negative correlations are more common in summer (Lhotka et al., 2022; Rodrigo, 2022). In summer, a negative correlation between temperature and rainfall predominates in most areas, particularly in the central and southern Great Plains of the United States (Zhao and Mak, 1993; Madden and Williams, 1978). In Southern South America, the correlation between temperature and precipitation varies by season and region, with some areas showing positive correlations in winter and negative correlations in summer (Rusticucci and Penalba, 2000). These studies highlight the importance of understanding regional variations in temperature-precipitation relationships and their connection to large-scale atmospheric circulation for better water management and future climate projections.

Climate projections for Vietnam indicate significant warming trends, with average temperatures expected to rise by 1.3-4.3°C by the end of the 21st century, the Northwestern region is projected to experience the most substantial temperature increase (Nguyen et al., 2018).

5. CONCLUSION

The study, we analyzed the temporal and spatial variations and the relationship between temperature and precipitation, using data from 11 monitoring stations over a 15 years. The case study is in the Northwest Vietnam revealed that:

- The average temperature increase in the Northwest of Vietnam is lower than the global average, but,increases in both maximum and minimum temperatures exceeding the global average.

- The highest average temperature in the year is concentrated in the rainy season corresponding to summer, there is a positive correlation between consecutive months within the same season, and a negative correlation is observed between months in the same season that are far apart.

- There is a significant decreasing trend in both annual and monthly precipitation over the past 15 years in the study area. The highest precipitation is concentrated in the summer months, and significantly lower precipitation in winter.

- The value of the strong positive correlation coefficient of rainfall is higher during winter months and lower duringsummer months, indicating that the spatial variation of rainfall differs between seasons.

- Something like, temperature and rainfall during spring, autumn, and winter months exhibit a common positive correlation; however, a dominant negative correlation is observed in summer.

The findings suggest the need for improved water conservation strategies and climate-resilient agricultural practices in Northwestern Vietnam. Adaptive water resources management can address climate change-induced droughts, and reservoir expansion can serve as a critical infrastructural intervention to augment water storage capacity, thereby enhancing the resilience of local communities to hydrological variability.

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AUTHOR CONTRIBUTIONS

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DECLARATION OF CONFLICT OF INTEREST

The author declare no conflict of interest could have appeared to influence the work reported in this paper.

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