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Trend analysis of rainfall and temperature (1981–2020) in the Srepok river basin of Vietnam

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Abstract: *Climate change is happening on a global scale, altering the climate patterns in various regions worldwide. Among the most affected climate factors are rainfall and temperature, which are of particular concern due to their direct impact on human activities. The Srepok River basin, a major water source for the Central Highlands of Vietnam, has climate factors that are significantly impacted by climate change. Droughts, a common manifestation in the Central Highlands, severely affect the local economy. Therefore, analyzing and evaluating trends in temperature and rainfall is crucial for policymakers to propose effective measures to address the impacts of climate change within the locale. The study examines changes in temperature and rainfall from 1981 to 2020 using methods such as the Mann-Kendall statistical test, Sen's Slope analysis, and ITA trend analysis. Understanding the trends in rainfall and temperature changes can assist managers in developing policies and strategies for sectors affected by climate change.*

Keywords: *ITA; rainfall; Srepok River Basin; temperature; trend analysis*

1. Introduction

Climate change (CC) has been occurring strongly and impacting climate factors in recent years. CC is happening on a global scale, which has changed the climate factors of different regions around the world. Rainfall and temperature are the two climate factors most affected by CC and are also the most important components due to their direct impact on human activities (IPCC, 2021). Analyzing the trends of changes in rainfall and temperature can assist managers in formulating management policies and development directions for sectors under the influence of CC.

Investigating the trends of temperature and rainfall changes is not a novel topic, yet remains a great interest to scientists both domestically and internationally. Accordingly, different methods have been developed to determine change in rainfall and temperature, such as linear regression, the Mann-Kendall (MK) test, Spearman's rho test, Sen's Slope method, and innovative trend analysis (ITA) method etc. Among these methods, the MK test is the most popular method and is used in many places worldwide. The changes in rainfall as well as streamflow, and evapotranspiration have been studied for the Heihe River basin (Zang and Liu, 2013). Monotonic trends in global rainfall have been assessed using more than 30 years of records from 1900 to 2009 (Westra et al., 2013). The annual and seasonal precipitation trends in the Yangtze River Delta, China, were analyzed by using the MK and ITA methods (Yuefeng Wang et al., 2020), and similar trends were also found in the Yellow River Basin, China (Zengchuan Dong et al., 2020). Non-parametric testing methods were used in the Mann-Kendall and Theil-Sen analyses for Ninh Thuan province, where the research evaluated the changing trends and predicted the trends of temperature, rainfall, potential evapotranspiration, and humidity in the Ninh Thuan region (Tuan and Canh, 2021). A similar study was carried out to evaluate the rainfall varying trends in the Ca River basin based on actual data from 1959 to 2016(Hien and Chien, 2022).

The Serepok River basin is large and provides most of the water for living activities in the Central Highlands region. The Central Highlands is one of the key regions for growing industrial crops and providing raw materials for the manufacturing and processing industry. With the ongoing situation of climate change and its various manifestations, drought, typically in the Central Highlands region, seriously affects the economic life of local people. Therefore, analyzing and evaluating temperature and rainfall trends here creates a premise for managers and policymakers to propose measures and policies applicable

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to localities to cope with the effects of climate change. The goal of the current study is to analyze the changing trend of temperature and precipitation in the period 1981 - 2020 by using a combination of the Mann-Kendall statistical test method, Sen's Slope trend analysis, and ITA trend.

2. Geological background

Serepok is one of the sub-basins of the Mekong River, originating from the Central Highlands and featuring a total range in Vietnam of more than 12,000km^2 (VNMC, 2020). The Serepok River basin is located in the provinces of Lam Dong, Dak Lak, Dak Nong, and Gia Lai in Vietnam and the 3 provinces of Ratanakiri, Mondulkiri, and Stung Treng in Cambodia. In this study, we limited the Srepok River basin locates in the provinces of Lam Dong, Dak Lak, and Dak Nong in Vietnam (Figure 1).

Fig. 1. Research area

The Serepok basin is characterized by large elevation differences and high slopes. The Serepok basin is approximately 330 km long and about 225 km wide. The Serepok River basin is generally flat in the lowlands with some small mountains north of Lumphat running from the east to the border with Vietnam (VNMC, 2020). There are several mountains in the southern part of the Serepok basin, west of Dak Mil. Red soil and gray soil are the main soil types in the Serepok basin. Both types of land have low value for agriculture, but can grow many other crops.

The Serepok river basin originates from two tributaries, Krong Ana and Krong Kno, which are large watersheds in the upstream part of the Serepok basin. The Serepok River joins the Se San River in Cambodia and then merges with the Mekong River in Stung Treng City. The Serepok River basin has the characteristics of a tree-branch system in the upper reaches.

The average rainfall in the Serepok River basin is 1569 - 2800 mm, and the average annual temperature is about 21-23 °C. The total annual hours of sunshine are quite high, up to 2,400 - 2,500 hours/year. The average annual relative humidity in the basin ranges from 80 - 85%.

3. Methodology

3.1. Input data

The series of rain and temperature data measured daily in the period 1981 - 2020 has been used to evaluate the fluctuating trends of rain and temperature (seasonal, annual) in the Serepok river basin. A series of daily rainfall data were measured at 10 stations (statistical details in Table 1 and Figure 1) scattered across the Serepok river basin were used in this study. Rain and temperature are important factors that strongly influence on problems occurring in the river basin. Therefore, the current study only focuses on evaluating the fluctuation trends of rain and temperature without considering other meteorological factors such as evaporation and the number of sunshine hours.

3.1.1. Rainfall

Rainfall data was collected over 40 years (from 1981 to 2020) from 10 rain gauge stations: Ban Don, Buon Ho, Buon Ma Thuot, Cau 14, Dak Nong, Da Lat, Duc Xuyen, Giang Son, Lak, and MDrak.

The collected data are daily measurements at monitoring stations, compiled according to total annual rainfall data and descriptive statistics using RStudio software, which supports many tools for analysis.

Tab. 1. A summary of yearly rainfall data from rain measurement stations during the period (1981-2008)

Table 1 shows the statistical parameters of the rainfall data series. The smallest annual rainfall value was recorded at MDrak station in 1982 with 914.5mm, and the largest annual rainfall value was also recorded at MDrak station in 2008 with 4224.8mm. The average yearly rainfall is between 1572. 35 mm and 2498. 3 mm, with an overall average of 1948. 08 mm for the whole area.

3.1.2. Temperature

Similar to rainfall, temperature data is collected at 5 stations (Buon Ho, Buon Me Thuot, Dak Nong, Lak, and MDrak), which are daily measurements at monitoring stations, aggregated based on the average maximum and minimum temperatures, and then statistically described using RStudio software.

The highest average maximum temperature (Tmax) (Table 2) was recorded at Lak station in 1998 with 31.83°C, and the smallest average Tmax value was recorded at Buon Ho station in 1986 with 24.43°C.

The average maximum temperature ranges from 27.14 to 30.11°C, and the highest average temperature for the whole area is 29.19°C

The highest average minimum temperature (Tmin) (Table 2) was recorded at Lak station in 2016 with 22.23°C, and the smallest at Buon Ho station in 1986 and Dak Nong in 1982 with 17.86°C. The average minimum temperature ranges from 16.56 - 20.99°C, and the average minimum temperature for the entire basin is 20.16°C.

Tab. 2. Descriptive statistics of Tmax and Tmin for the period 1981-2020

3.2. Research Methods

3.2.1. Mann-Kendall non-parametric test

The Mann-Kendall method was proposed by Mann in 1945, then developed by Kendall in 1975. This method is named Mann-Kendall and is widely used to evaluate trends in seasonal data series.

The Mann-Kendall test is used to determine the trend of a time-ordered dataset. Rather than relying on actual values, this method looks at how significant the different parts of the series are compared to each other. This prevents false trends that can occur due to a few extreme values when using the ordinary least squares method to calculate a straight-line trend. In addition, Mann – Kendall test is independent of the underlying data distribution, making it robust for various climate datasets. The fundamental formulas of the test are explained briefly below.

There is a list of data that is organized by month (xi1, xi2,..., xin), where each xi shows data at time i for a year, starting from year 1 to year n. The Mann-Kendall statistic for month i (Si) is calculated as follows (Ullah et al., 2019):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_j - x_i) \quad (1)$$

$$sign(x_j - x_i)\{1, \quad x_i - x_j > 0\ 0, \quad x_i - x_j = 0\ -1, \quad x_i - x_j < 0$$

If S = 0, it means there is no trend. If S > 0, it means there's an upward trend. If S < 0, it means there's a downward trend.

However, it is important to calculate the probability related to S and n to assess the significance level of the trend.. The variance of S is calculated using this formula:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p-1)(2t_p+5)\right] \quad (2)$$

Where g is the number of groups with the same value, t_p is the number of elements in the pth group.

The standard value Z of S follows the law of normal distribution.

$$Z = \frac{S-1}{[VAR(S)]^{1/2}}, S > 0 \qquad (3)$$

$$Z = 0, S = 0$$

$$Z = \frac{S+1}{[VAR(S)]^{1/2}}, S < 0 \qquad (4)$$

Z is used to test whether the series has a trend or not, with a given level of significance. The value of Z is determined based on the assumption of a normal distribution with a mean value of 0 and a variance of 1. The hypothesis will be accepted or rejected on the basis of the Z value, implying that a trend appears or not.

3.2.2. Estimating Sen's Slope

To determine the magnitude of the Q series trend, we use Sen's estimation method. Q is defined as the median of a sequence of n(n-1)/2 elements (Sen, 1968):

$$Q = medium\left\{\frac{x_j - x_k}{j-k}\right\}, \text{với } k=1,2,\ldots,n-1;\ j>k\}. \quad (5)$$

Q has the same sign as S. Q>0 indicates an increasing trend in the series, and vice versa.

3.2.3. ITA method

The innovative trend analysis (ITA) method, developed by Sen (2012), splits a time series into two parts and then arranges both parts in order from smallest to largest. The first half-series (xi) is on the horizontal axis and the second half-series (yi) is on the vertical axis of the Cartesian coordinate system, as shown in Figure 2. The 1:1 line on the coordinate system is considered a trendless line separating uptrend and downtrend (Sen, 2012 If the scatter points are above the 1:1 line, it shows a basic upward trend over time. If they are below the line, it means a downward trend (Figure 2a).

Fig. 2. ITA method: (a) Monotonic trend and (b) Non-monotonic trend

On the other hand, when the scattered points show non-monotonic trends (indicating that the time series consists of components with different trends), the time series is divided into multiple clusters. As demonstrated in Figure 2(b), meteorological-hydrological data can be categorized into "low," "medium," and "high" groups by dividing the data into three intervals. This classification allows for the identification of the rainfall trends within each cluster, which has important implications: high rainfall can result in floods, while low rainfall can lead to droughts (Öztopal and Sen, 2017). In this study, rainfall intensity and temperature are classified into three categories based on percentiles (Wu, H. and Qian, H., 2017): low rainfall (< 20th percentile), medium (20–80th percentile), and high (> 80th percentile).

S shows how steep the trend is. If S is a positive number, it means the trend is going up. If S is a negative number, it means the trend is going down. The slope of the trend line, shown as ITA, can be estimated using this formula (Sen, 2017).

$$s = \frac{2\left(\overline{y_2} - \overline{y_1}\right)}{n} \quad (6)$$

Where $(\overline{y_2})$ and $(\overline{y_1})$ are the average values of the first and second halves of the data, respectively, and n is the number of data points. In practice, the average of the two halves of the data is referred to as the "midpoint" lying on the data line.

Statistical significance is indicated if the slope of the series falls outside the confidence limits (CL). The confidence limits for the slope (following a Gaussian probability density function with a mean of 0 and standard amount of variation) are stated below:

$$CL_{(1-\alpha)} = 0 \pm s_{cri} \times \sigma_s \quad (7)$$

Where α is the significance level (α = 1% and α = 5% are used to assess the importance of trends in this study), s_{cri} is the CL of a standard normal PDF with a mean of 0 and standard deviation, and σ_s is the standard deviation of the slope coefficient:

$$\sigma_s = \frac{2\sqrt{2}}{n\sqrt{n}}\sigma\sqrt{1 - \rho_{\underline{y_1}\,\underline{y_2}}} \quad (8)$$

Where: $\rho_{\underline{y_1}\,\underline{y_2}}$ The correlation coefficient between two mean values in random processes

$$\rho_{\underline{y_1}\,\underline{y_2}} = \frac{E\left(\underline{y_1}\,\underline{y_2}\right) - E\left(\underline{y_1}\right)E\left(\underline{y_2}\right)}{\sigma_{\underline{y_1}}\sigma_{\underline{y_2}}} \quad (9)$$

The use of time series data, which contains consecutive correlations, limits traditional methods like Mann-Kendall and Sen's slope (Sabzevari et al., 2015). Furthermore, these methods can only represent monotonic trends through purely statistical calculations; Determining trends in different types of values in a single calculation process is not possible.

Furthermore, these methods are limited to representing monotonic trends through purely statistical calculations; identifying trends in different types of values is not possible within a computational process (Wu, H. and Qian, H., 2017). This ITA method is simple and intuitive, can be used regardless of distribution assumptions, and can identify trends in different value types. In Tommaso Caloiero's study (2019), some analyses, that applied the non-parametric MK test method, did not show the trend of data (e.g., years or spring in Canterbury, spring in Nelson Marlborough, summer in Westland), however, the ITA displayed the incline and decline trends because it provides detailed information about the trends of annual and seasonal total rainfall data in evaluating low, medium, and high values. Therefore, this study combined trend analysis, which was calculated by traditional methods (Mann-Kendall, Sen's slope), and analyzed hidden trends at low, medium, and high levels, which were obtained by using the ITA trend analysis method.

4. Results

4.1. Results of the Mann-Kendall method and Sen's slope

4.1.1. Rainfall

The result of the Mann-Kendall method is denoted by S, where S > 0 indicates an incline trend and vice versa for a decline trend, similarly for Sen's slope result. The results of Mann-Kendall and Sen slope are listed in Table 3. Accordingly, the Mann-Kendall and Sen's slope methods show consistent trends. The results indicate clearly that the average annual rainfall at most stations has a decreasing trend, fluctuating from 0.54 to 8.26 mm/year. However, there are three stations with increasing trends: Buon Ho (4.25 mm/year), Da Lat (5.81 mm/year), and MDrak (11.99 mm/year). The station with the most significant decrease in average rainfall is Dak Nong, while Mdrak shows the highest increase, and only Da Lat station reaches a statistically significant level of 95%. Regarding the entire basin, according to the results obtained from the Mann-Kendall method and Sen's slope, the average basin-wide rainfall shows an increasing trend of 0.62 mm/year, with rainfall increasing during the dry season by 1.97 mm/year and decreasing during the wet season by 1.05 mm/year.

Tab. 3. The results of Mann-Kendall and Sen's slope for annual and seasonal rainfall

During the wet season, most stations show a decreasing trend ranging from 1.71 to 9.63 mm/year, while the rainfall at Buon Ho and Da Lat stations shows an increasing trend during the wet season, with rates of 2 mm/year and 2.42 mm/year, respectively. The station with the greatest decrease in rainfall during the wet season is Dak Nong, while Da Lat shows the greatest increase. During the dry season, only three stations, Ban Don, Cau 14, and Duc Xuyen, show decreasing trends of 0.43, 0.17, and 0.98 mm/year, respectively. The remaining seven stations all show increasing trends ranging from 0.28 to 9.35 mm/year. The station with the greatest decrease in rainfall during the dry season is Duc Xuyen, while the greatest increase is observed at MDrak. For the entire basin, rainfall shows a decreasing trend during the wet season (1.05 mm/year) and an increasing trend during the dry season (1.97 mm/year). However, when considering the level of statistical significance, no station shows statistical significance.

4.1.2. Temperature

According to the calculated results in Table 4, the highest maximum temperature (Tmax) averages for most stations show an increasing trend ranging from 0.002°C (Buon Me Thuot station) to 0.17°C/year (MDrak station). However, the station with the highest Tmax temperature, Lak, shows a decreasing trend of 0.03°C/year. During the wet season, except for the Lak station with a decreasing trend in Tmax temperature (0.007°C/year), the remaining stations all show an increasing trend in maximum temperature, with values ranging from 0.023 to 0.032°C/year. During the dry season, besides the Lak station with a decreasing trend (0.043°C/year), there is also the Buon Me Thuot station with a slight decrease (0.007°C/year), and the remaining three stations show increasing trends ranging from 0.012 to 0.031°C/year. Except for the average Tmax temperature during the dry season at the Buon Me Thuot station, the dry season at the MDrak station, and the wet season at the Lak station, all other stations show statistical significance.

Tab. 4. Results of the Mann-Kendall (MK) method and Sen's slope for annual and seasonal Tmax, Tmin

The average annual and seasonal Tmin temperatures all show an increasing trend. For the average annual Tmin temperature, stations show an increase ranging from 0.028°C/year (Buon Me Thuot station) to 0.064°C/year (Dak Nong station). During the wet season, the highest increase in the lowest temperature is observed at Dak Nong station (0.05°C/year) and the lowest increase at Buon Me Thuot station (0.026°C/year). In the dry season, the highest increase in the lowest temperature is observed at Dak Nong station (0.08°C/year) and the lowest increase at Lak station (0.021°C/year). The average Tmin temperature and seasons at all stations show statistical significance.

For the entire basin, regarding Tmax and Tmin, the average annual and seasonal trends are all increasing, with average annual Tmax and Tmin being 0.01 and 0.04°C, respectively. For Tmax, the increase during the dry season is very slight, only 0.003°C compared to 0.02°C during the wet season. The Tmin temperature during the wet season is lower than during the dry season, but the differences are not significant. However, only Tmax during the wet season and Tmin reach statistical significance.

4.2. Results of the ITA Trend Analysis Method

4.2.1. Rainfall

Table 5 shows the trend of average yearly rainfall obtained by using the ITA method. The results indicate that the annual rainfall during the period 1981-2020 is in a similar trend to the results obtained by the Mann-Kendall method and Sen's slope. Most stations show a decreasing trend, with the most significant decrease observed at Cau 14 station (10.88 mm/year) and the least decrease at Ban Don station (0.12 mm/year). Rainfall at the Buon Ho, Da Lat, and MDrak stations shows increasing trends of 1.47, 0.29, and 4.04 mm/year, respectively. Most stations reach a statistical significance level of 99%, except for Ban Don and Da Lat stations, which do not reach statistical significance. According to the climate change scenario statistics provided by the Ministry of Natural Resources and Environment in 2020, the rainfall trend in the provinces of the Central Highlands is decreasing. This indicates that the results of the ITA trend analysis are consistent with the findings from the Ministry of Natural Resources and Environment, showing a decrease of 2.8 mm/year.

Tab. 5. The results of the ITA test for annual rainfall from 1981 to 2020

As shown in Figure 3, the trends of the data for average rainfall and the trends of the low, medium, and high clusters are represented by orange, green, and red points, respectively. For the average annual rainfall, the low-intensity rainfall at the Buon Me Thuot, Da Lat, and MDrak stations shows increasing trends of 3.16, 0.90, and 11.31 mm/year, respectively. The remaining stations at low-intensity reveal decreasing trends, with the lowest decrease at 1.48 mm/year (Buon Ho station) and the highest at 14.03 mm/year (Cau 14 station). Regarding average intensity rainfall, two stations, Buon Ho (2.05 mm/year) and Da Lat (0.94 mm/year), show increasing trends, while the remaining stations all show decreasing trends ranging from 0.2 mm/year (MDrak station) to 11.26 mm/year (Dak Nong station). For high-intensity rainfall, three stations, Ban Don, Buon Ho, and MDrak, show increasing trends of 11.95, 1.78, and 6.62 mm/year, respectively, while the remaining stations show the highest decrease at Cau 14 station (26.05 mm/year) and the lowest at Giang Son station (1.78 mm/year). For the entire basin, the highest decrease is observed in high-intensity rainfall at 6.1 mm/year, followed by average intensity rainfall decreasing at 1.15 mm/year, and the lowest decrease is observed in low-intensity rainfall at 1.09 mm/year.

Fig. 3. ITA results of annual rainfall categorized by low, medium, and high intensities (represented by orange, green, and red points, respectively)

The results of the trend analysis for the rainy and dry seasons are presented in Table 6. Rainfall during the rainy season at the Ban Don, Buon Ho, and Da Lat stations shows increasing trends of 2.1, 2.15, and 0.29 mm/year, respectively. The remaining stations show decreasing trends, with the highest decrease in rainfall at the Cau 14 station being 9.32 mm/year and the lowest at the MDrak station being 1.61 mm/year. During the dry season, the Da Lat station remains nearly unchanged, while the rainfall at the other stations shows decreasing trends ranging from 0.71 to 3.38 mm/year, except for the MDrak station, which shows an increasing trend of 5.65 mm/year. For the entire basin, rainfall during both the rainy and dry seasons shows decreasing trends, with a greater decrease observed during the rainy season (2.11 mm/year) compared to the dry season (0.68 mm/year). The rainfall at most stations during the rainy or dry season achieves a statistical significance of 99%, except for the Buon Me Thuot station during the dry season, which achieves a statistical significance of 95%, and the Da Lat station during both seasons, which does not achieve statistical significance.

Tab. 6. Results of the ITA test for seasonal rainfall from 1981 to 2020

Fig. 4. ITA results of wet season rainfall categorized by low, medium, and high intensities (represented by orange, green, and red points, respectively)

During the rainy season, an increasing trend has been found at the BMT, Duc Xuyen, Lak, and MDrak stations, while the other stations are in the opposite tendency (as clearly shown in Figure 4). For the average intensity of rainfall, an increasing trend is found in two stations, Ban Don (which is getting 0.43 mm more rain each year) and Buon Ho (which is getting 2.9 mm more rain each year). In contrast, the other places are less rainy, with decreases ranging from 0.23 mm a year in Da Lat to 9.88 mm a year in Dak Nong. Regarding high-intensity rainfall, five stations, BMT, Cau 14, Duc Xuyen, Lak, and MDrak, show a decreasing trend ranging from 2.26 to 23.75 mm/year, while the remaining stations show an increasing trend, with the highest increase observed at the Ban Don station (12.77 mm/year). For the entire basin, high-intensity rainfall shows the highest decreasing trend of 4.14 mm/year, while the lowest is observed for average-intensity rainfall at 0.96 mm/year.

During the dry season, the intensity of low rainfall at Buon Ho, Cau 14, Duc Xuyen, and Lak stations tends to decrease by 0.16 - 0.41 mm/year, while the remaining stations show an increasing trend, with the highest increase of 3.44 mm/year at the MDrak station. The average intensity of rainfall at four stations shows an increasing trend (BMT, Cau 14, Da Lat, and MDrak), ranging from 0.04 to 2.67 mm/year. The remaining stations exhibit a decreasing trend in rainfall intensity, ranging from 0.45 mm/year (Ban Don) to 2.65 mm/year (Dak Nong). For high-intensity rainfall, except for the MDrak station (increasing by 19.79 mm/year), the remaining stations all show a decreasing trend, with the highest decrease of 9.54 mm/year at the Lak station and the lowest decrease of 2.18 mm/year at Da Lat (as shown clearly in Figure 5). Overall, when comparing rainfall intensity at different seasons, the dry season shows lower levels of increase and decrease compared to the rainy season, and only the MDrak station mostly aligns with the 1:1 line, indicating an increasing trend in rainfall intensity at various levels. In the dry season, the total basin rainfall intensity shows an increasing trend of 1.64 mm/year at low intensity and the highest decrease of 4.01 mm/year at high intensity.

Fig. 5. The ITA results of the dry season rainfall categorized by low, medium, and high intensities (represented by orange, green, and red points, respectively)

4.2.2. Temperature

The trends of annual average Tmax and Tmin applying the ITA method are shown in Table 7. The results indicate that the highest and lowest temperatures annually during the period 1981 - 2020 tend to increase, except for Tmax at the BMT station, which shows no significant trend, while the Lak station exhibits a decreasing trend of 0.035°C per year. The highest temperature shows the highest increasing trend at the Buon Ho station, with 0.036°C per year, and the lowest temperature shows the highest increasing trend at the Dak Nong station, with 0.058°C per year. For the entire basin, both the highest and lowest temperatures show an increasing trend. The increase in the highest Tmax is very low, at 0.0067°C per year, and the increase in the lowest Tmin is 0.039°C per year. All stations have statistical significance at the 99% level.

Tab. 7**.** Results of the ITA test for annual Tmax, Tmin from 1981 to 2020

The highest and lowest annual temperatures are divided into 3 intensity levels: low, medium, and high, as shown in Figure 6. Most of the Tmax and Tmin averages at the stations lie along the 1:1 line, indicating an increasing trend in temperature intensity. However, except for Tmax at the Lak station, which lies below the 1:1 line, indicating a decreasing trend. The high-intensity Tmax at the Buon Ho and MDrak stations also shows a slight decreasing trend (data displayed in Figure 6). The highest and lowest average temperatures for the entire basin at all intensity levels show an increasing trend, except for the low-intensity Tmax, which shows a slightly decreasing trend of 0.001°C per year, while the lowest temperature trend is higher than that of the highest temperature.

Fig. 6. The ITA results of annual Tmax, and Tmin are categorized by low, medium, and high intensities (represented by orange, green, and red points, respectively)

The highest and lowest temperatures during the rainy season show an increasing trend, with the highest increase at the Buon Ho station, 0.044°C per year for Tmax, and the Dak Nong station, 0.051°C per year for Tmin. However, Tmax at the Lak station shows a decreasing trend of 0.021°C per year. During the dry season, except for the BMT station (decreasing by 0.009°C per year) and Lak station (decreasing by 0.048°C per year) for Tmax, the remaining Tmax and Tmin stations show an increasing trend (Table 8). Most Tmax and Tmin stations have a statistical significance of 99%, except for the Lak station Tmax during the rainy season, which achieves a statistical significance of 95%, and the MDrak station Tmax during the dry season, which lacks statistical significance. Temperature trends during the rainy and dry seasons for the entire basin show an increasing trend, at 0.037 and 0.04°C per year for Tmin, and an increase of 0.014°C per year during the rainy season and a decrease of 0.001°C per year during the dry season for Tmax.

Tab. 8. Results of the ITA test for seasonal Tmax, Tmin from 1981 to 2020

Fig. 7. ITA results of Tmax, Tmin in the wet season are categorized by low, medium, and high intensities (represented by orange, green, and red points, respectively)

Figure 7 illustrates the trends of Tmax and Tmin during the rainy season, divided into 3 intensity levels: low, medium, and high. Most of the data points lie along the 1:1 line, indicating an increasing trend in both Tmax and Tmin intensities during the rainy season. Specifically, the high-intensity Tmax at the Dak Nong station shows a slight decreasing trend of 0.004°C per year, while the Lak station exhibits decreasing trends in both medium and high Tmax intensities, at 0.0035 and 0.0043°C per year, respectively. Moreover, it can be observed that Tmin tends to increase more than Tmax, and only 2 intensity levels (low and medium) are observed for Tmin at the stations due to the small temperature differences over the years.

Fig. 8. ITA results of Tmax, Tmin in the dry season are categorized by low, medium, and high intensities (represented by orange, green, and red points, respectively)

Figure 8 displays the trends of Tmax and Tmin during the dry season, divided into 3 intensity levels. For Tmin, all data points lie along the 1:1 line, indicating an increasing trend in Tmin intensities during the dry season, and the increase is higher than that of Tmax. Regarding Tmax, the Dak Nong and Buon Ho stations show increasing trends, while the BMT and Lak stations lie below the 1:1 line, indicating decreasing trends. At the MDrak station, low and high-intensity Tmax show decreasing trends of 0.01°C per year, while medium-intensity Tmax shows an increasing trend of 0.02°C per year. For the entire basin, low and high-intensity Tmax show decreasing trends of 0.02 and 0.003°C per year, respectively, while medium-intensity Tmax shows an increasing trend of 0.005°C per year.

In general, concerning the highest and lowest temperatures, the trends from 1981 to 2020 display increases or decreases of no more than 0.1°C per year, with the majority of trends showing an increasing tendency.

Fig. 9. Maps illustrate the distribution trend of ITA for rainfall and temperature during the period 1981-2020

5. Conclusion

In summary, the average annual rainfall ranges from 1572.35 to 2498.3mm, with a basin-wide average of 1948.08mm. The Serepok River basin experiences uneven distribution of rainfall, with over 70% of the rainfall concentrated during the rainy season. Results from Sen's slope, Mann-Kendall, and ITA analyses all indicate that three stations exhibit an increasing trend, with MDrak station showing the highest increase of 11.99 mm/year according to Sen's slope and 4.04 mm/year according to ITA. However, when considering the entire basin, results from Sen's slope and Mann-Kendall suggest a trend of rainfall increase by 0.62 mm/year, whereas results from ITA suggest a decrease by 2.8 mm/year. Figure 9 illustrates the spatial distribution of stations on the map and, combined with the results from Tables 4 and 5, it can be observed that stations in the western part of the basin tend to experience decreasing rainfall, while stations in the central basin exhibit a decreasing trend, and areas in the northeast and southeast of the basin show an increasing trend in rainfall.

For Tmax, results from the three methods indicate that only one station, Lak, exhibits a decreasing trend, while the remaining stations show an increasing trend. The highest increase is observed at Buon Ho station with 0.031°C/year according to Sen’s slope and 0.036°C/year according to ITA. For Tmin, all stations show an increasing trend, with Dak Nong station exhibiting the highest increase of 0.064°C/year according to Sen’s slope and 0.058°C/year according to ITA. Based on the data from Tables 6, 7, and Figure 9, Tmax shows a decreasing trend at stations in the central basin and an increasing trend towards the periphery. Tmin at all stations exhibits an increasing trend, with the highest increase observed at stations in the central basin and the southern part of the basin. The temperature for both Tmax and Tmin across the entire basin shows an increasing trend according to all three calculation methods, with ITA results having significant statistical significance at the 99% level, while results from Sen’s slope and Mann-Kendall do not reach statistical significance.

Tables and figures

Tab. 1. A summary of yearly rainfall data from rain measurement stations during the period (1981-2008)

Station	Max (mm)	Min (mm)	Mean (mm)	SD	Skew	SE	Kurtosis
Ban Don	2787.8	930.4	1592.08	313.59	1.24	49.58	3.81
Buon Me Thuot	2598	1347.1	1865.78	296.32	0.39	46.28	-0.44
Buon ho	1970.1	1158.3	1572.35	220.33	-0.3	34.84	-0.97
Cau 14	3697.6	1117.4	1721.25	412.12	2.68	65.16	10.69
Dak Nong	3772	1777.3	2498.23	429.32	0.77	69.65	0.53
Da Lat	2378.7	1355.1	1840.8	208.26	0.1	32.93	0.01
Duc Xuyen	2402	1289	1869.71	288.05	-0.07	45.55	-0.7
Giang Son	2468.1	1245.4	1878.76	311.22	-0.1	49.21	-0.9
Lak	2880.7	1277.9	1960.51	396.16	0.32	67.94	-0.47
MDrak	4224.8	914.5	2095.06	690.51	0.99	109.18	0.62
Basin	2273.76	1388.88	1848.08	239.42	0.09	37.68	-0.92

Tab. 2. Descriptive statistics of Tmax and Tmin for the period 1981-2020

	Station	Max	Min	Mean	SD	Skew	SE	Kurtosis
Tmax	**Buon Me Thuot**	30.87	28.82	29.69	0.44	0.55	0.07	0.24
	Buon Ho	28.55	24.43	27.14	0.73	-0.88	0.12	2.84
	Dak Nong	30.37	27.92	29.24	0.54	0.09	0.09	-0.14
	Lak	31.83	27.43	30.11	0.77	-1.02	0.13	2.42
	MDrak	30.34	27.79	28.9	0.56	0.27	0.09	-0.23
	Basin	30.41	28.46	29.19	0.45	0.71	0.07	0.32
Tmin	**Buon Me Thuot**	21.5	19.79	20.53	0.43	0.53	0.07	-0.52
	Buon Ho	20.4	17.68	16.56	0.7	-1.03	0.11	2.79
	Dak Nong	20.31	17.68	19	0.75	-0.21	0.13	-1.19
	Lak	22.23	20.31	20.9	0.49	0.98	0.26	0.08
	MDrak	22	20.17	20.99	0.51	0.19	0.08	-1.1
	Basin	21.26	19.32	20.16	0.5	0.21	0.08	-0.78

Tab. 3. The results of Mann-Kendall and Sen's slope for annual and seasonal rainfall

Site	Annual			Rainy season			Dry season		
	Sen’s slope	MK (S)	p	Sen’s slope	MK (S)	p	Sen’s slope	MK (S)	p
Ban Don	-1.99	-78	0.37	-1.71	-52	0.55	-0.43	-29	0.74

Buon Me Thuot	-1.83	-44	0.62	-2.9	-60	-0.49	**1.39**	84	0.33
Buon ho	**4.25**	106	0.22	**2.00**	70	0.42	**0.28**	17	0.85
Cau 14	-4.52	-79	0.36	-4.6	-103	0.23	-0.17	-12	0.90
Dak Nong	-8.26	-107	0.18	-9.63	-131	0.10	**0.4**	7	0.94
Da Lat	**5.81***	186	0.03	**2.42**	68	0.34	**3.18**	134	0.12
Duc Xuyen	-3.57	-78	0.37	-1.9	-60	0.49	-0.98	-42	0.63
Giang Son	-0.54	-8	0.93	-2.07	-54	0.54	**2.4**	72	0.41
Lak	-2.71	-35	0.61	-2.66	-17	0.81	**1.16**	25	0.72
MDrak	**11.99**	116	0.18	-2.57	-66	0.45	**9.35**	132	0.13
Basin	**0.62**	8	0.93	-1.05	-56	0.52	**1.97**	88	0.31

* is at the 95% confidence level.

(The unit of Sen's slope is mm/year)

Tab. 4. Results of the Mann-Kendall (MK) method and Sen's slope for annual and seasonal Tmax, Tmin

	Site	**Annual**			**Rainy season**			**Dry season**		
		Sen's slope	**MK (S)**	**p**	**Sen's slope**	**MK (S)**	**p**	**Sen's slope**	**MK (S)**	**p**
Tmax	**Buon Me Thuot**	0.002	26	0.77	0.023	292	0.0007	-0.007	-78	0.37
	Buon Ho	**0.031**	333	0.0001	0.032	361	$2.73x10^{-5}$	0.031	295	0.0006
	Dak Nong	0.021	196	0.008	0.024	238	0.001	0.021	188	0.01
	Lak	**-0.03**	-177	0.009	-0.007	-47	0.49	-0.043	-237	0.0005
	MDrak	0.017	180	0.037	0.023	276	0.001	0.012	98	0.26
	Basin	0.01	137	0.087	0.02	225	0.005	0.003	45	0.58
Tmin	**Buon Me Thuot**	0.028	496	$8.06x10^{-9}$	0.026	448	$1.91x10^{-7}$	0.035	462	$7.82x10^{-8}$
	Buon Ho	0.042	491	$1.13x10^{-8}$	0.042	525	$1.02x10^{-9}$	0.04	405	$2.51x10^{-6}$
	Dak Nong	**0.064**	422	$9.77x10^{-9}$	0.05	462	$3.4x10^{-10}$	0.08	358	$1.16x10^{-6}$
	Lak	0.031	279	$3.77x10^{-5}$	0.044	383	$1.49x10^{-8}$	0.021	135	0.047
	MDrak	0.039	562	$6.31x10^{-11}$	0.038	504	$4.62x10^{-9}$	0.039	480	$2.39x10^{-8}$
	Basin	0.04	501	0.00	0.036	459	0.00	0.043	421	0.00

(The unit of Sen's slope is °C/year)

Tab. 5. The results of the ITA test for annual rainfall from 1981 to 2020

Site	Slope S (mm/year)	Correlation	Slope standard deviation	Sig. level 95%	Sig. level 99%
Ban Don	-0.12	0.97	0.57	±1.12	±1.48
Buon Me Thuot	-4.1	0.96	0.63	±1.24	±1.62
Buon ho	**1.47**	0.96	0.52	±1.01	±1.33
Cau 14	-10.88	0.79	2.11	±4.14	±5.45
Dak Nong	-9.62	0.94	1.31	±2.56	±3.37
Da Lat	**0.29**	0.94	0.56	±1.1	±1.44
Duc Xuyen	-7.62	0.98	0.46	±0.9	±1.18
Giang Son	-3.04	0.97	0.59	±1.16	±1.53
Lak	-8.11	0.97	0.94	±1.85	±2.43
MDrak	**4.04**	0.94	1.92	±3.75	±4.94
Basin	**-2.8**	0.96	0.52	±1.02	±1.34

Tab. 6. Results of the ITA test for seasonal rainfall from 1981 to 2020

*, ** is at the 95% and 99% confidence level

Site	Rainy season	Dry season
Ban Don	**2.1****	-2.22**
Buon Me Thuot	-3.39**	-0.71*
Buon ho	**2.15****	-1.23**
Cau 14	-9.32**	-1.57**
Dak Nong	-7.36**	-2.26**
Da Lat	**0.29****	**0.00**
Duc Xuyen	-4.35**	-3.28**
Giang Son	-2.08**	-0.96**
Lak	-4.72**	-3.38**
MDrak	-1.61***	**5.65****
Basin	-2.11**	-0.68**

Tab. 7. Results of the ITA test for annual Tmax, Tmin from 1981 to 2020

	Site	Slope S	Correlation	Slope standard deviation	Sig. level 95%	Sig. level 99%
Tmax	**Buon Me Thuot**	0.000	0.94	0.0012	±0.0024	±0.0031
	Buon Ho	**0.036**	0.85	0.0031	±0.0061	±0.0081
	Dak Nong	0.025	0.95	0.0015	±0.003	±0.0039
	Lak	-0.035	0.90	0.035	±0.0068	±0.009

	M'Drak	0.011	0.92	0.0018	±0.0035	±0.0046
	Basin	0.0067	0.94	0.0013	±0.0027	±0.0036
Tmin	**Buon Me Thuot**	0.028	0.89	0.0016	±0.0031	±0.0041
	Buon Ho	0.043	0.86	0.0029	±0.0057	±0.0075
	Dak Nong	**0.058**	0.97	0.0017	±0.0033	±0.0044
	Lak	0.034	0.93	0.0018	±0.0035	±0.0046
	M'Drak	0.043	0.98	0.00072	±0.0014	±0.0019
	Basin	0.039	0.96	0.001	±0.0023	±0.003

Tab. 8. Results of the ITA test for seasonal Tmax, Tmin from 1981 to 2020

	Stations	Rainy season	Dry season
Tmax	**Buon Me Thuot**	0.018**	-0.009**
	Buon Ho	**0.044****	**0.032****
	Dak Nong	0.023**	0.028**
	Lak	-0.021*	-0.048**
	M'Drak	0.018**	0.004
	Basin	0.014**	-0.001
Tmin	**Buon Me Thuot**	0.029**	0.031**
	Buon Ho	0.05**	0.037**
	Dak Nong	**0.051****	**0.065****
	Lak	0.044**	0.023**
	M'Drak	0.044**	0.041**
	Basin	0.037**	0.04**

*, ** is at the 95% and 99% confidence level

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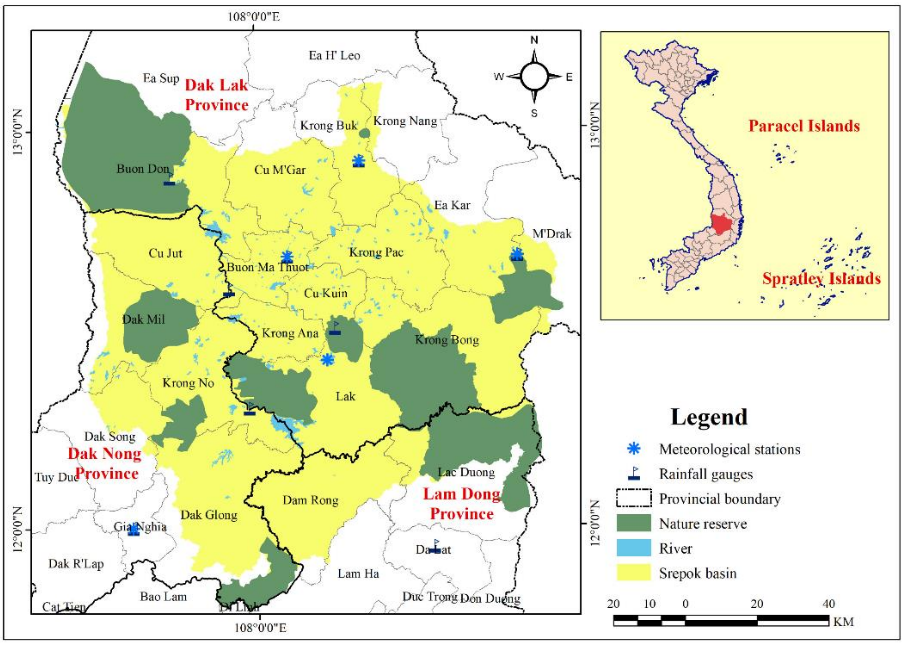

Fig. 1. Research area

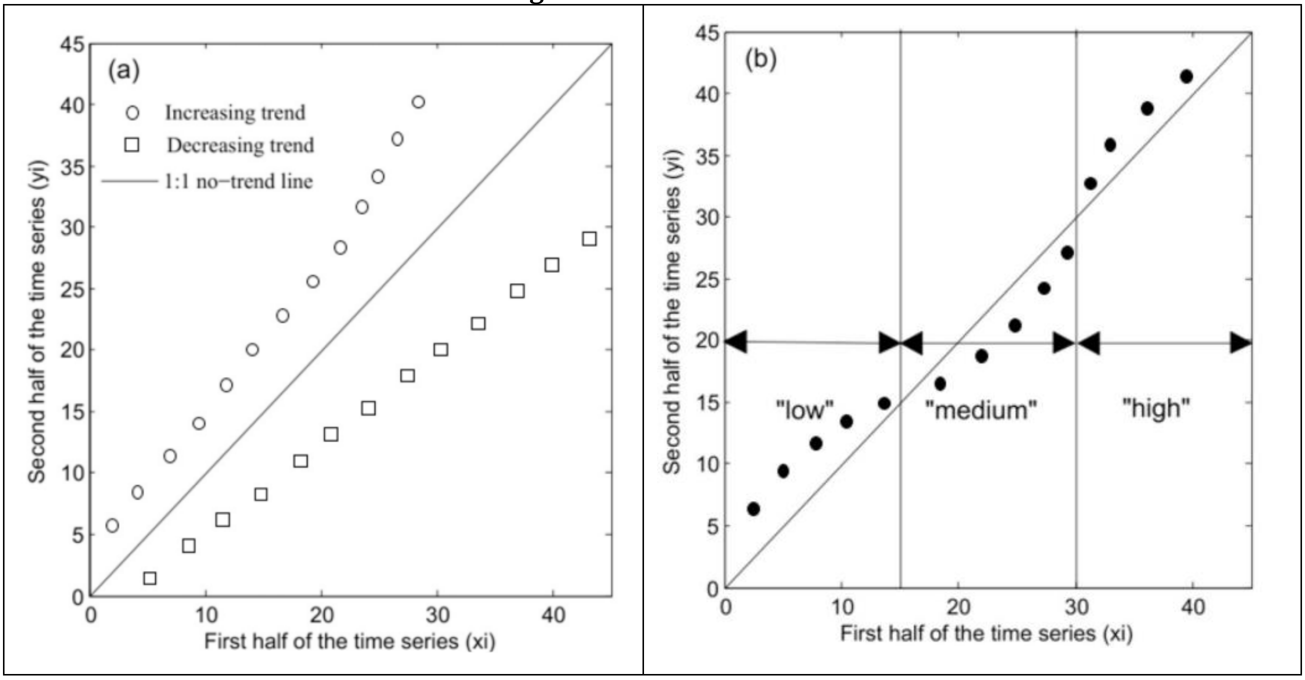

Fig. 2. ITA method: (a) Monotonic trend and (b) Non-monotonic trend

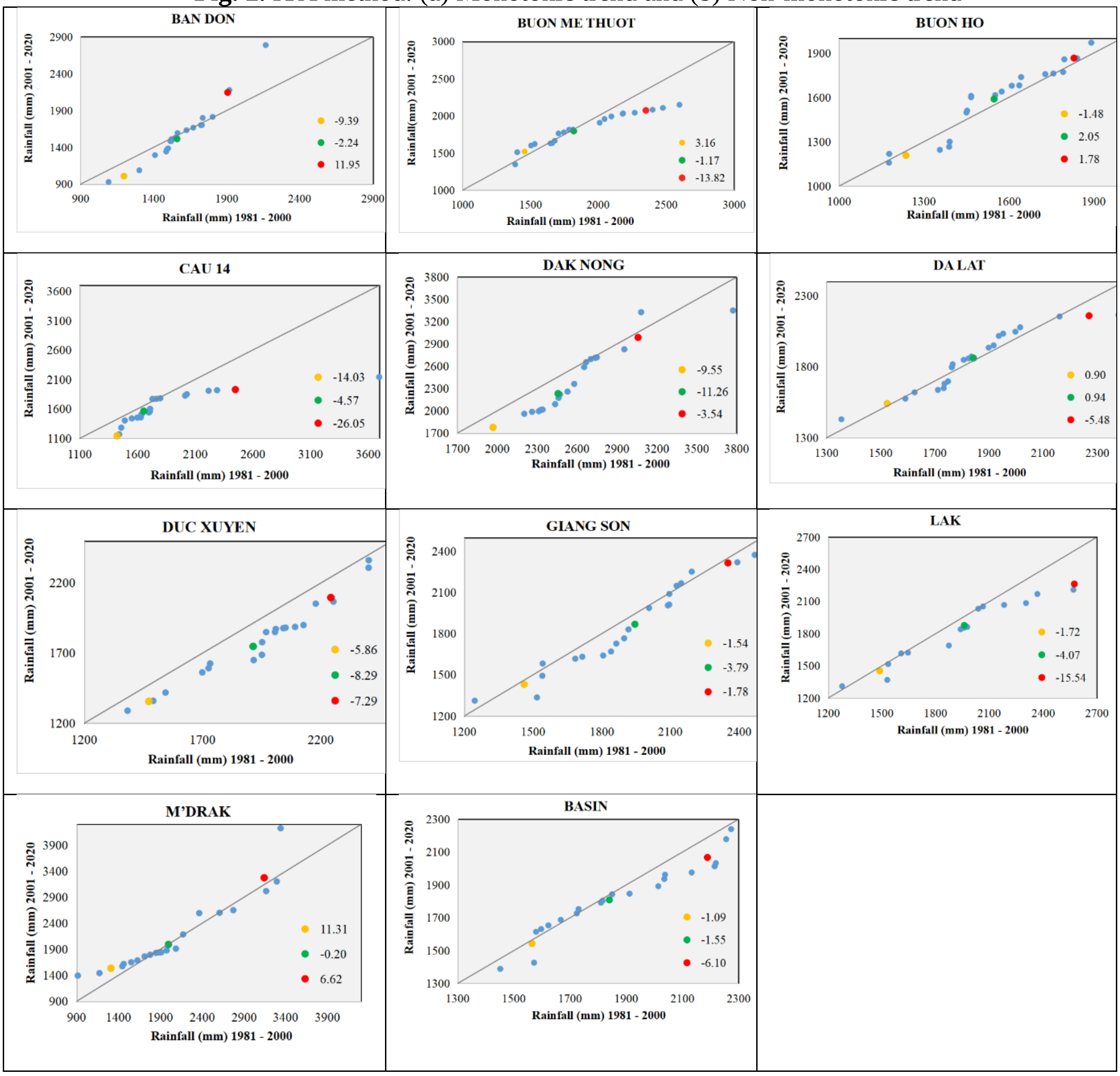

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Fig. 3. The ITA results of annual rainfall categorized by low, medium, and high intensities (represented by orange, green, and red points, respectively)

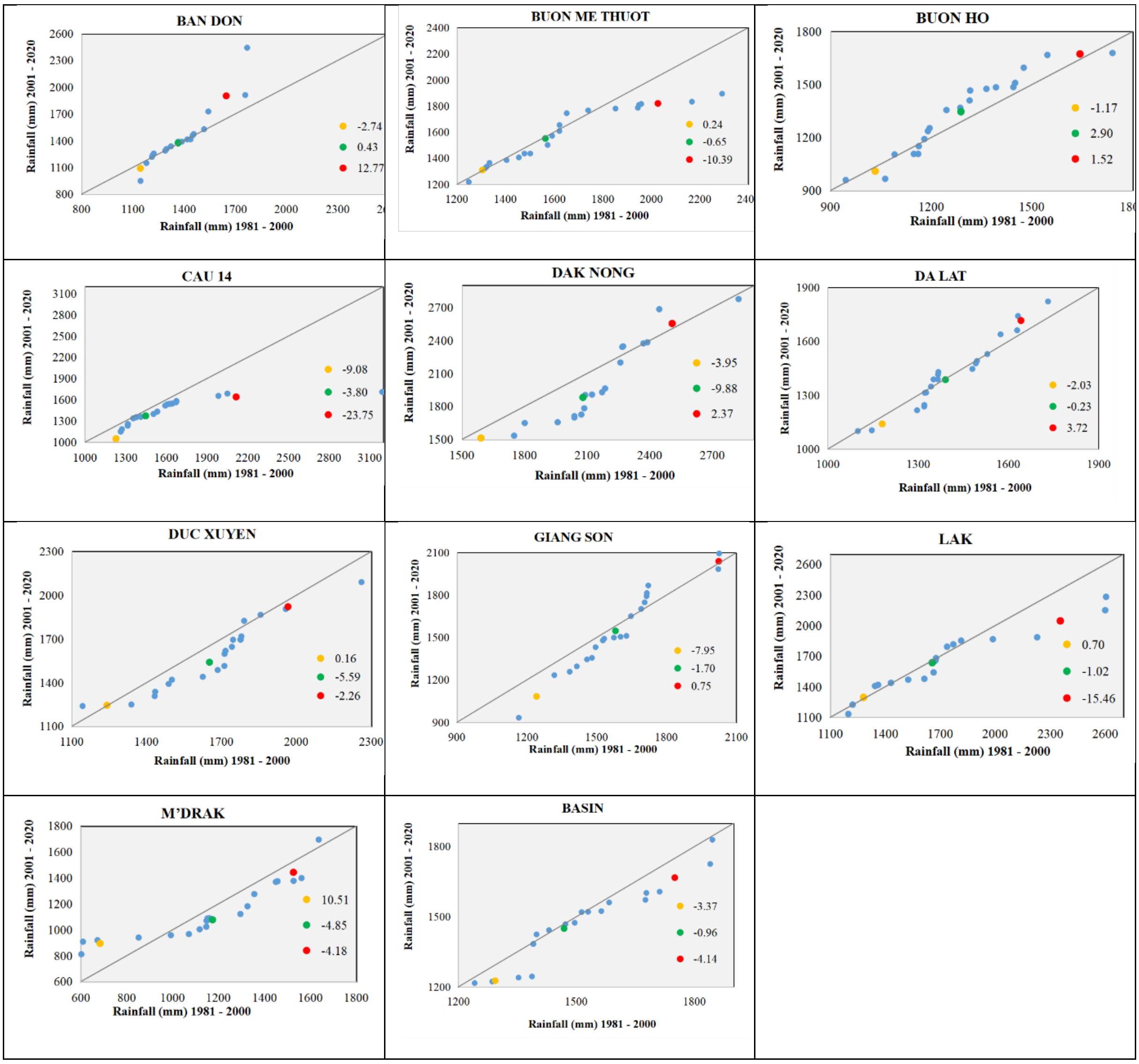
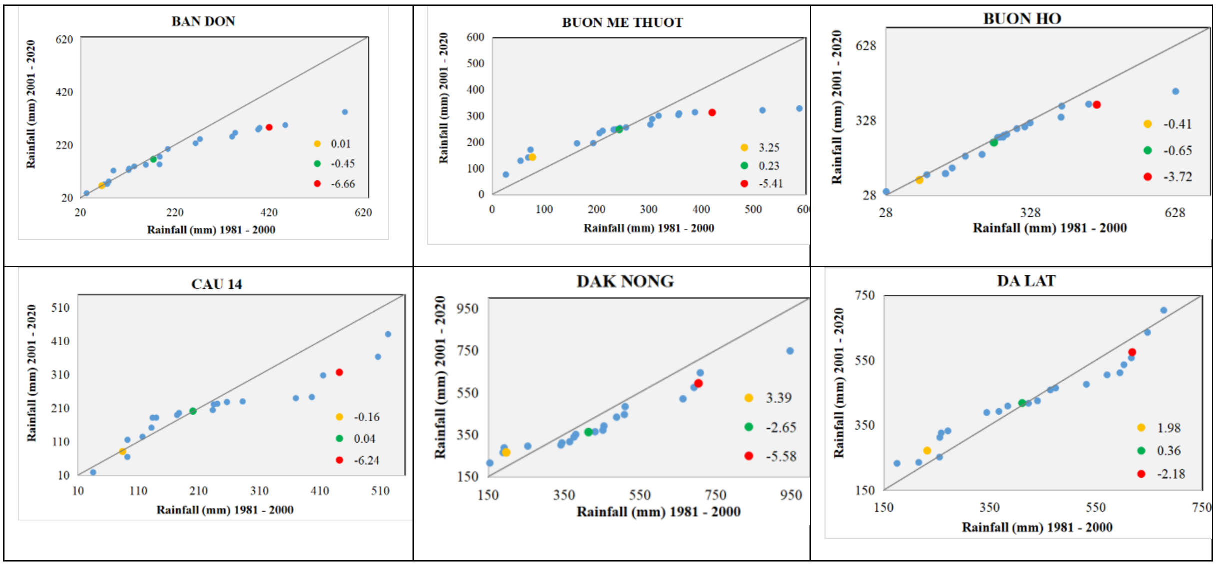


Fig. 4. The ITA results of the wet season rainfall are categorized by low, medium, and high intensities (represented by orange, green, and red points, respectively)



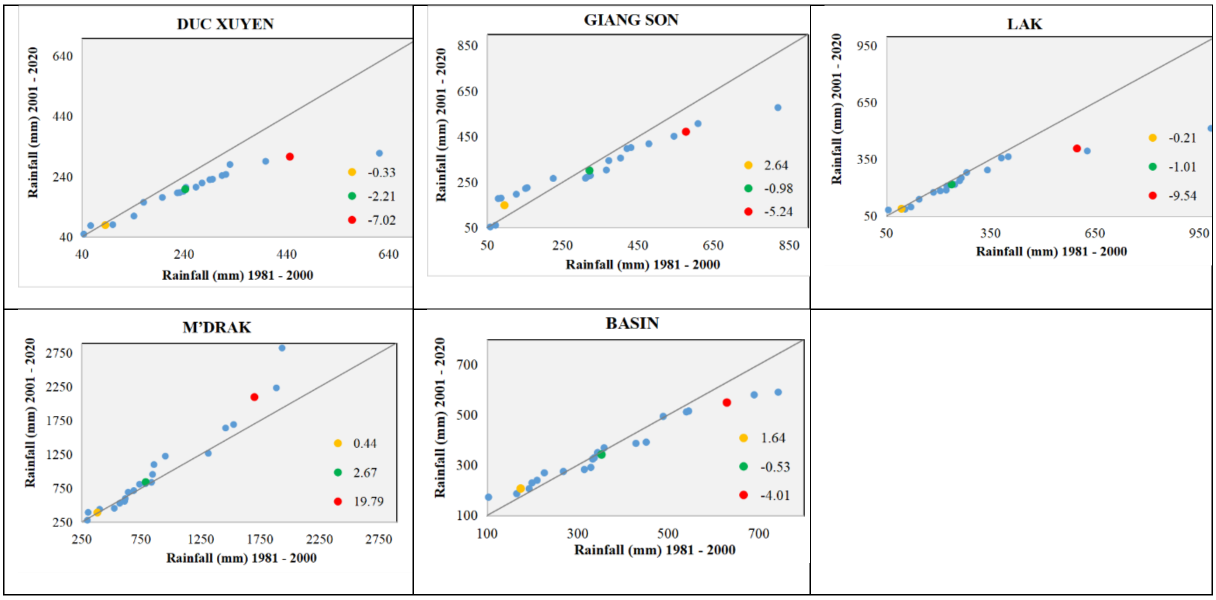


Fig. 5. The ITA results of dry season rainfall are categorized by low, medium, and high intensities (represented by orange, green, and red points, respectively)

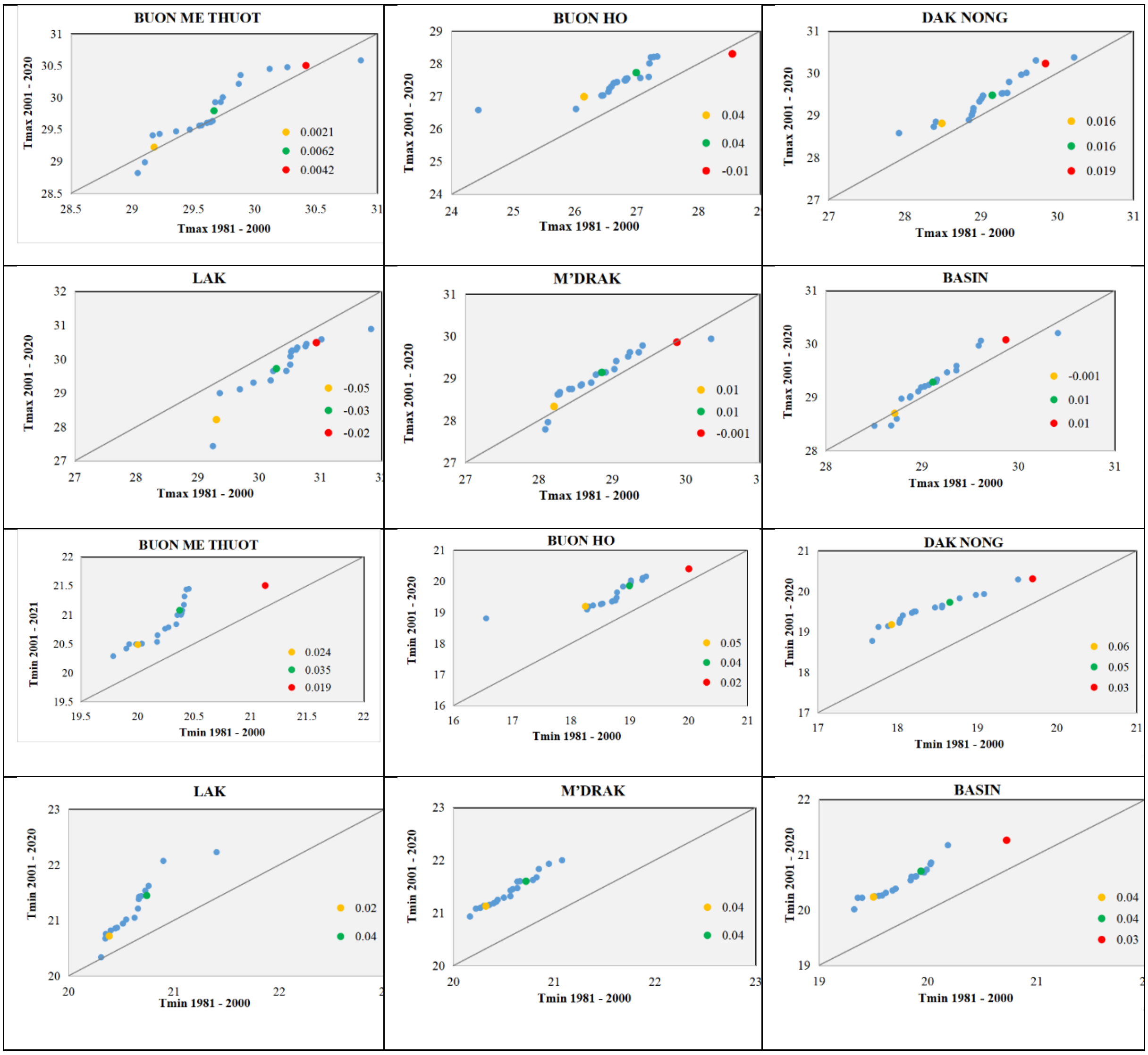


Fig. 6. The ITA results of annual Tmax, and Tmin are categorized by low, medium, and high intensities (represented by orange, green, and red points, respectively)

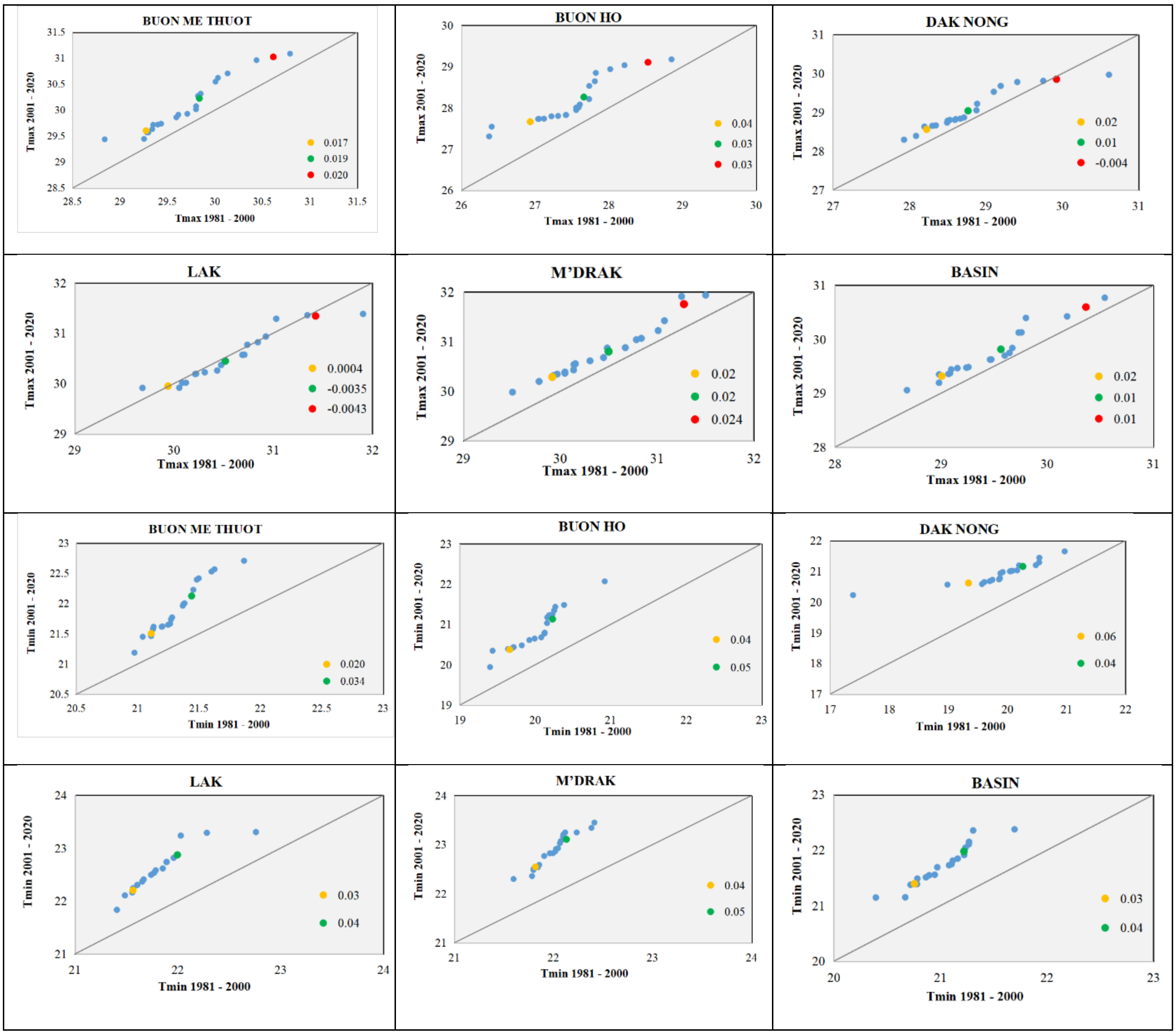
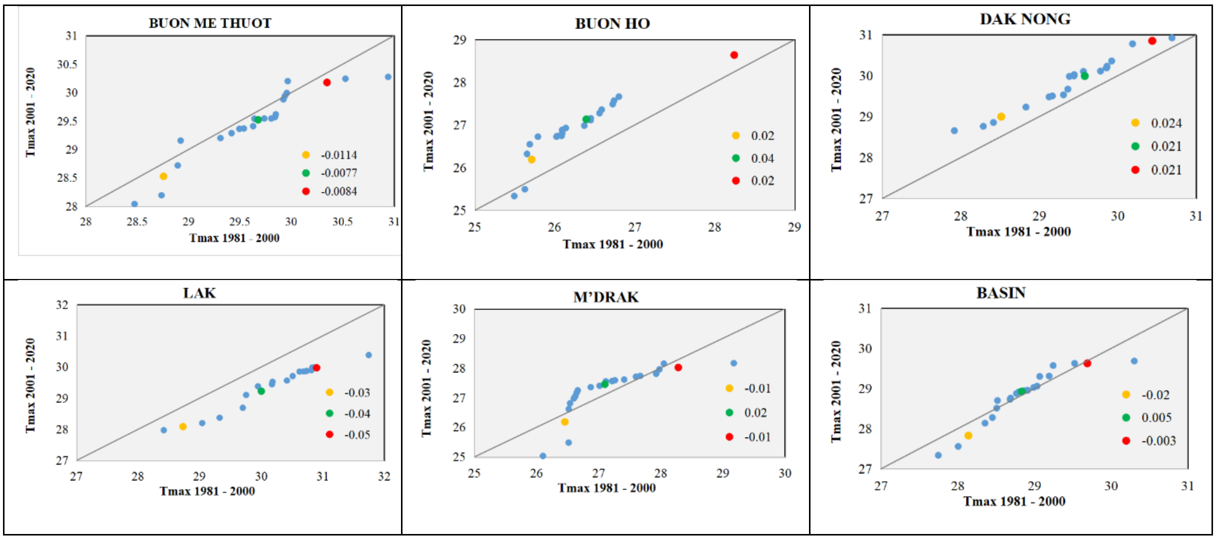


Fig. 7. The ITA results of Tmax, Tmin in the wet season are categorized by low, medium, and high intensities (represented by orange, green, and red points, respectively)



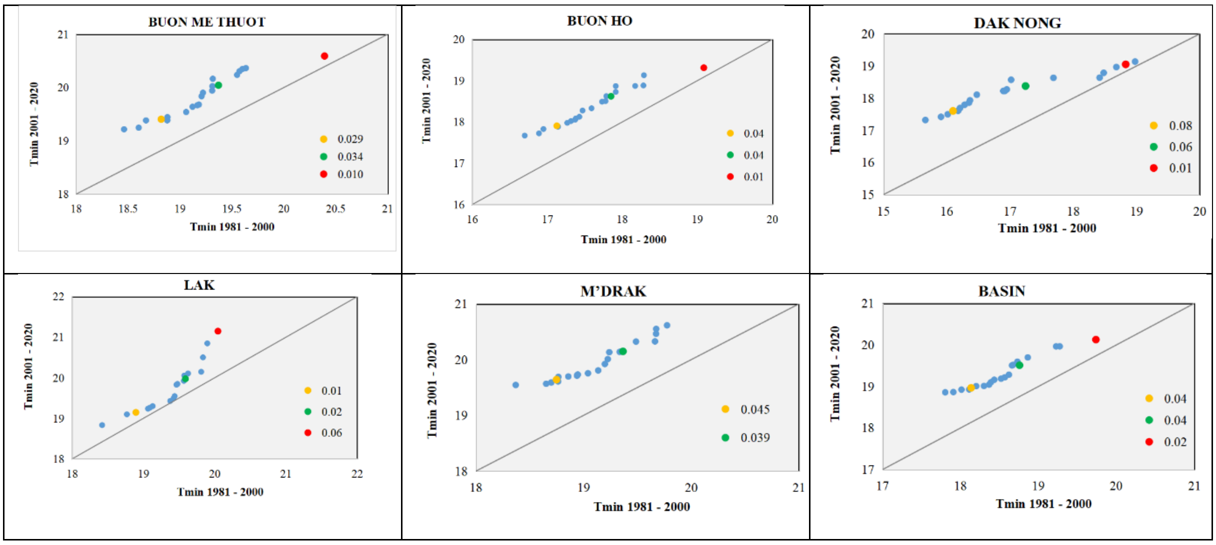
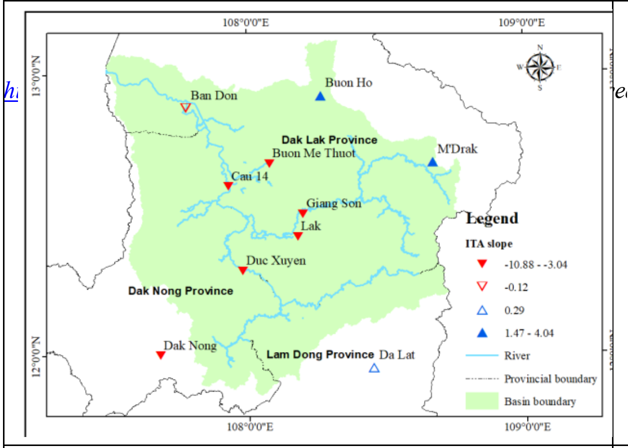
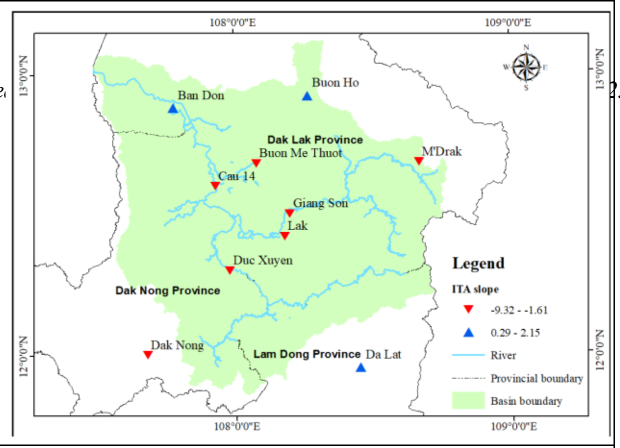


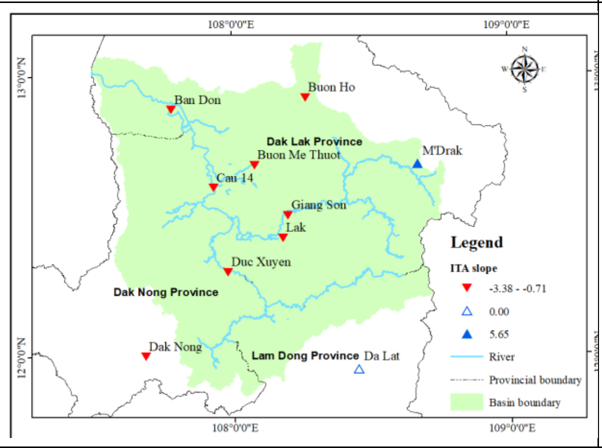
Fig. 8. The ITA results of Tmax, Tmin in the dry season are categorized by low, medium, and high intensities (represented by orange, green, and red points, respectively)



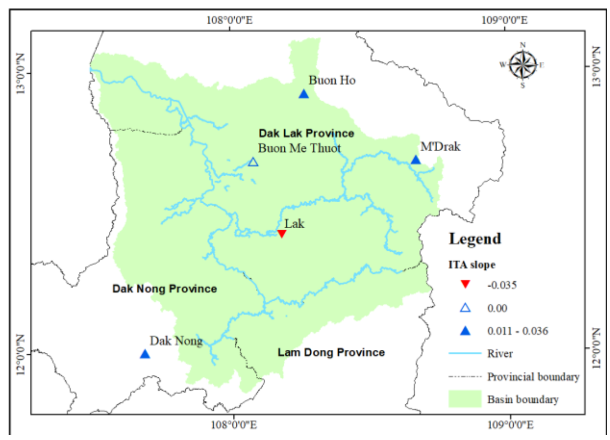
a) Average annual rainfall



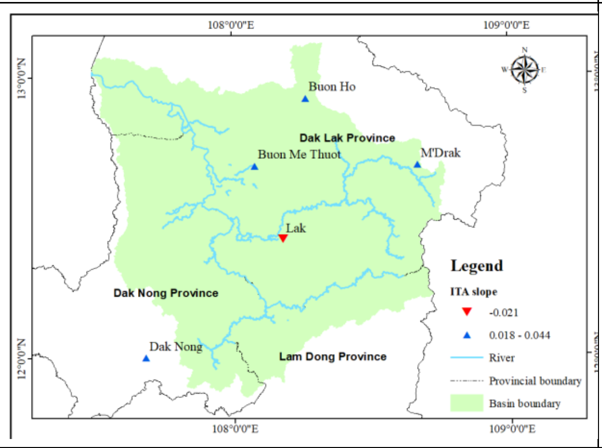
b) Rainy season rainfall



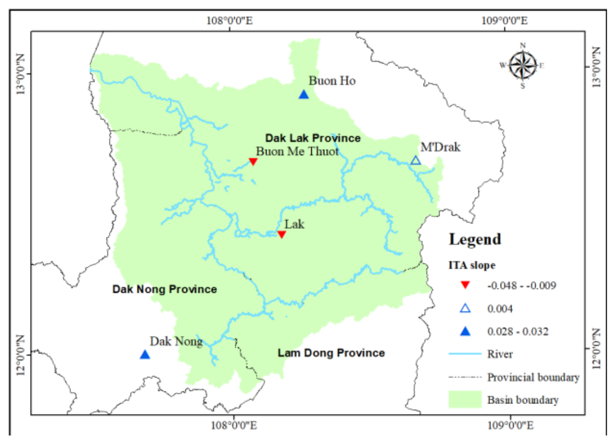
c) Dry season rainfall



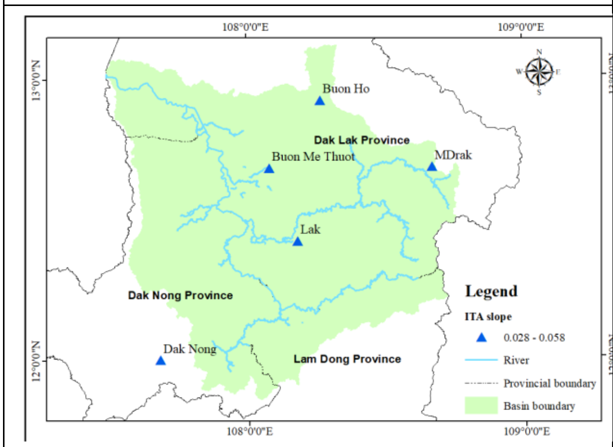
d) Average annual Tmax



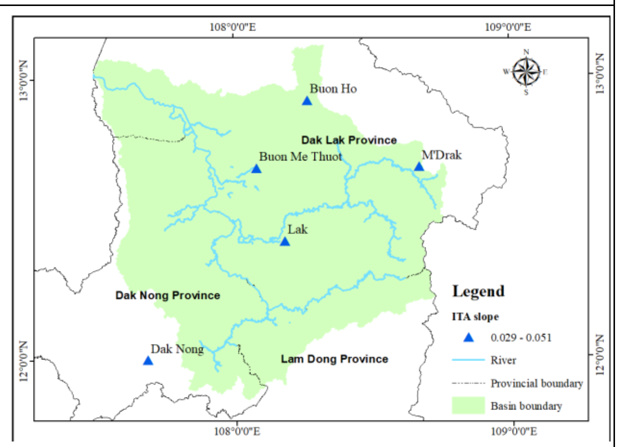
e) Rainy season Tmax



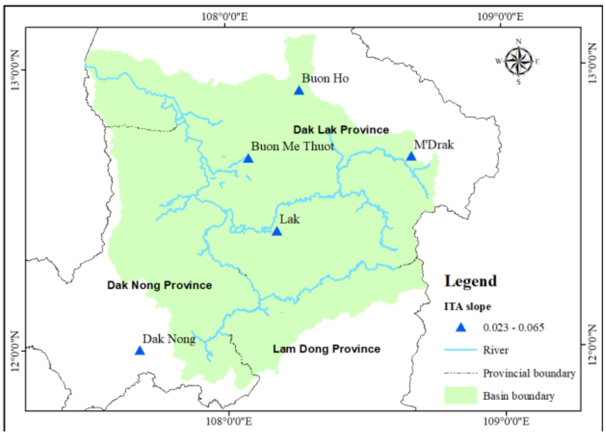
f) Dry season Tmax



g) Average annual Tmin



h) Rainy season Tmin



i) Dry season Tmin

Fig. 9. Maps illustrate distribution trend of the ITA for rainfall and temperature during the period 1981-2020

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