

Studying the characteristics of heavy rainfall in the central coastal provinces of Vietnam (Quang Binh case study)

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Abstract:

This paper explores the maximum amount of rainfall in the Central coastal provinces of Vietnam (Quang Binh case study) for return periods of 5 years, 10 years, 20 years, 50 years, and 100 years, which correspond to frequencies of 20%, 10%, 5%, 2%, and 1%, respectively. The results show that at a frequency of 20%, the maximum intensity of rain during a heavy rain spell can range from 636.6 to 696.0 mm, while the maximum one-day amount received was over 300 mm, which can occur many times in 5 years. At a frequency of 1%, the intensity of rain during a heavy rain spell can range from 1,197.9 to 1,268.3 mm, while the maximum one-day amount ranged from 487.4 to 521.9 mm. However, such values are very rare over the course of 100 years. In addition, in terms of annual rainfall, the spatial distribution of heavy rainfall in coastal areas was significantly smaller than that in mountainous areas. The highest one-day and five-day rainfall have the same pattern of spatial distribution as annual rainfall.

Keywords: frequency of extreme rainfall, heavy rain, temporal and spatial distribution.

Classification number: 5.2

Introduction

Quang Binh, one of the central coastal provinces of Vietnam, has a very complex climate and terrain. The province is the one most affected by natural disasters: tropical cyclones, floods, and flash floods occur with high frequency and severity [1-3]. Typhoons and floods usually occur from September to December, and are concentrated in October and November. Tropical cyclones lead to heavy rain and high tides, resulting in floods in the lowland and flash floods in mountainous areas. Other forms of natural disasters, such as early floods ('Lũ tiểu mãn' or 'Lũ đầu mùa' in Vietnamese), often occur from April to June each year. On average, two or three floods occur in Quang Binh every year [4, 5].

Natural disasters severely affect socio-economic development and human life. In Vietnam, prevention of natural disasters and warnings preceding them are still limited, especially in the provinces, such as Quang Binh, that are frequently and directly affected by them. With this in mind, the Vietnam Red Cross (VNRC) and the German Red Cross (GRC) aim to pilot a new approach called forecast-based financing that uses forecast-based thresholds to automatically release money to pay for pre-planned short-term emergency preparedness action in the critical time period after a forecast but before a disaster [6].

To support that goal, the GRC and the Center for Meteorology and Climatology under the Vietnam Institute of Meteorology, Hydrology and Climate change jointly signed a research contract entitled "Disasters Profile of Quang Binh Province and Review and assessment of the availability and usage of early warning system and Weather forecasts". One of the objectives of this contract was to analyse the disaster profile of Quang Binh, focusing on heavy rains and floods.

This paper is extracted from the contract's outcomes,

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and aims to analyse the characteristics of rain and heavy rain in the research area, including an analysis of frequency of extreme rainfalls, and of the temporal and spatial distribution characteristics of heavy rainfall.

Data and methodology

The data used in this paper are: i) The daily precipitation observed for the period of 1961-2014 at the three meteorological stations of Tuyen Hoa, Dong Hoi, and Ba Don, which is used to calculate the temporal characteristics of the distribution of rainfall (total precipitation, one-day maximum precipitation (RX1day), five-day maximum precipitation (RX5day)); ii) The data set of annual maximum precipitation and one-day maximum precipitation at these three meteorological stations, which is used to calculate the frequency of heavy rain events/one-day maximum intensity; and iii) Data set from 10 gauge stations (with at least 30 years of data) in Quang Binh province and six gauge stations in the neighbouring provinces of Ha Tinh and Quang Tri, which are used to calculate and map the spatial distribution of heavy rainfall [7, 8]. Fig. 1 shows the geographical location and the network of hydro-meteorological observation stations used.



Fig. 1. Geographical location and network of hydro-meteorological observation stations.

The methodologies used are the Gumbel Generalized Extreme Value distribution [9-12] for calculating the maximum amount of rainfall in Quang Binh for return periods of 5 years, 10 years, 20 years, 50 years and 100 years, which correspond to frequencies of 20%, 10%, 5%, 2% and 1%, respectively; and climate statistics and Geographic Information System (GIS) for the temporal and spatial distribution characteristics of heavy rainfall [13-18].

Results and discussion

Analysis and evaluation the frequency of heavy rainfall in Quang Binh province

Frequency of heavy rain events:

Table 1 shows the results calculated for the maximum amount of rainfall in a heavy rain event based on observations from 1961 to 2014 at three stations (Ba Don, Dong Hoi, Tuyen Hoa) in Quang Binh for return periods of 5 years, 10 years, 20 years, 50 years and 100 years (corresponding to frequencies of 20%, 10%, 5%, 2% and 1%, respectively). Table 2 shows the number of events in the 1961-2014 period in which the total rainfall was equal to or greater than average maximum rainfall in a heavy rain spell for the same return periods shown in Table 1.

Table 1. Calculated maximum rainfall in a heavy rain event for the given return periods at three meteorological stations in Quang Binh province (mm).

Stations	Return periods (years)				
	5	10	20	50	100
Ba Don	636.6	775.4	908.5	1,080.8	1,210.0
Dong Hoi	675.9	802.2	923.4	1,080.3	1,197.9
Tuyen Hoa	696.0	834.5	967.4	1,139.4	1,268.3

Table 2. The number of events during the 1961-2014 period in which the total rainfall was equal to or greater than the value calculated for the given return periods at the three meteorological stations.

Stations	Return periods (years)				
	5	10	20	50	100
Ba Don	9	5	2	2	1
Dong Hoi	13	6	2	0	0
Tuyen Hoa	13	5	3	1	0

For 100-year return period (frequency of 1%), this is very rare occurrence: the calculated maximum rainfall in an event at each of the three stations in Quang Binh ranged from 1,197.9 mm to 1,268.3 mm. In fact, in the 54 years' worth of observed data used in this study, there was only one event, at Ba Don station, in which the total rainfall was greater than the calculated value of the 100-year return period shown in Table 1 (1,350.5 mm in September, 1967). In addition, in September 1978, a heavy rain event at Ba Don station reached 1,169.1 mm, which approximates the calculated rainfall in Table 1. For Dong Hoi and Tuyen Hoa stations, during the 1961-2014 period, there were no extreme rainfall events in which the rainfall was equal to or greater than the calculated threshold of 100-year return period. At Dong Hoi station, the maximum precipitation

in a heavy rain event was 1,021.7 mm, which occurred in September, 1979. At Tuyen Hoa station, the total rainfall of rain events in October 1995 reached approximately 1,236.3 mm, which approximates the calculated rainfall of 100-year return period.

For 50-year return period (frequency of 2%), the calculated maximum rainfall in an event at the three stations in Quang Binh was more than 1,000 mm, with the highest value, at Tuyen Hoa station, reaching 1,139.4 mm. For this frequency, in 1961-2014 period, Ba Don station had two events that exceeded the threshold of 1,000 mm, in 1967 and 1978. Tuyen Hoa station had one occurrence that exceeded this threshold, in 1995 (1,236.3 mm), and two events in which the total rainfall was greater than 1,000 mm (though still under the threshold), in 2009 (1,008.1 mm) and 2010 (1,037.9 mm). At Ba Don station, there were no events in which the total rainfall was equal to or greater than the calculated value, and there was only one event, in 1979, in which the total rainfall was greater than 1,000 mm.

For 20-year return period (frequency of 5%), the calculated maximum rainfall in events at the three stations in Quang Binh were 908.5 mm (Ba Don), 923.4 mm (Dong Hoi), and 967.4 mm (Tuyen Hoa). According to the observations during the 1961-2014 period, there were two events each at Ba Don and Dong Hoi stations and three events at Tuyen Hoa in which the total rainfall was equal to or greater than the calculated value of 20-year return period.

For 10-year return period (frequency of 10%), the calculated maximum rainfall in an event at stations in Quang Binh ranged from 775.4 mm (Ba Don station) to 834.5 mm (Tuyen Hoa station). In 1961-2014, these events occurred five times each at Ba Don and Tuyen Hoa stations, and six times at Dong Hoi station.

For 5-year return period (frequency of 20%), this is more frequent occurrence: the calculated maximum rainfall in an event at each of the three stations in Quang Binh was 636.6 mm, 675.9 mm, and 696.0 mm, at Ba Don, Dong Hoi, and Tuyen Hoa stations, respectively. According to observations from the 1961-2014 period, these events occurred nine times at Ba Don station and thirteen times each at Dong Hoi and Tuyen Hoa stations. In general, the average maximum rainfall in an event in the corresponding return period is in practice comparable to the statistics.

Frequency of one-day maximum precipitation intensity:

Table 3 shows the results calculated for the one-day maximum precipitation intensity based on observed data from the three stations for 1961 to 2014 for the given return periods of 5 years, 10 years, 20 years, 50 years and 100 years (corresponding to frequencies of 20%, 10%, 5%, 2%,

and 1%, respectively). Table 4 shows the number of days in the 1961-2014 period on which the rainfall was equal to or greater than the maximum precipitation intensity for the different return periods presented in Table 3.

Table 3. One-day maximum rainfall intensity for given return periods at the three stations in Quang Binh province (mm).

Stations	Return periods (years)				
	5	10	20	50	100
Ba Don	301.2	354.6	405.9	472.2	521.9
Dong Hoi	292.3	339.5	384.8	443.5	487.4
Tuyen Hoa	329.6	391.6	451.0	528.0	585.7

Table 4. The number of days in the 1961-2014 period on which the rainfall was equal to or greater than calculated intensity for given return period at the three stations in Quang Binh province.

Stations	Return periods (years)				
	5	10	20	50	100
Ba Don	10	6	3	1	1
Dong Hoi	9	3	2	1	1
Tuyen Hoa	11	7	3	1	0

For 100 years return period (frequency of 1%), the calculated one-day maximum rainfall intensity at the three stations was 521.9 mm, 487.4 mm, and 585.7 mm at Ba Don, Dong Hoi and Tuyen Hoa, respectively. However, this is a very rare event with only one occurrence at each of Ba Don and Dong Hoi, and no occurrence at Tuyen Hoa during the 1961-2014 period. In particular, in 54 years' worth of observed data used in this study, the maximum one-day intensity of rainfall was 526.7 mm at Ba Don station (5th October 2010) and 554.6 mm at Dong Hoi station (9th October 1995); these are the two days on which the rainfall intensity at meteorological stations in Quang Binh reached the calculated threshold value of the 100-year return period.

For the 50-year return period (frequency of 2%), the calculated one-day maximum rainfall intensity was 472.2 mm at Ba Don station, 443.5 mm at Dong Hoi station, and 528.0 mm at Tuyen Hoa station. According to the 1961-2014 observations used in this study, such an event has occurred once at each station in Quang Binh. At Ba Don and Dong Hoi stations, such events were mentioned in the 100-year return period, and at Tuyen Hoa station, the maximum rainfall intensity reaches 548.4 mm on 18th October 1993.

For the 20-year return period (frequency of 5%), at Ba Don station, the one-day maximum precipitation intensity reached 405.9 mm - such an event occurred three times in the 1961-2014 period. At Dong Hoi station, the one-day maximum rainfall intensity for the 20-year return period was

384.8 mm, and in the 1961-2014 period there were two days on which rainfall was equal to or greater than the calculated value. At Tuyen Hoa station, the one-day maximum rainfall intensity and the number of days on which it occurred were 451 mm and three days, respectively.

For 10-year return period, at the three stations in Quang Binh, the one-day maximum rainfall intensity ranged from 339.5 mm at Dong Hoi station to 391.6 mm at Tuyen Hoa station. The number of days on which rainfall was equal to or greater than the calculated value for 10-year return period were six, three, and seven days at Ba Don, Dong Hoi, and Tuyen Hoa stations, respectively.

For 5-year return period, the number of days on which rainfall was equal to or greater than the calculated value for 5-year return period was a more frequent occurrence. There were 10 days on which rainfall was equal to or greater than 301.2 mm at Ba Don (one-day rainfall intensity for the 5-year return period), nine days on which rainfall was equal to or greater than 292.3 mm at Dong Hoi, and 11 days on which rainfall was equal to or greater than 329.6 mm at Tuyen Hoa. According to the observation data for the period 1961-2014, the frequency of occurrence of the one-day maximum rainfall intensity in Quang Binh correlates well with the frequency of the calculated result of the Gumbel function.

(the time of ‘Tieu Man’ or early floods, when the gradually strengthening southwest monsoon gradually meets the weak intrusion of cold air). The three months with the highest rainfall occur in autumn (September, October, and November), with the monthly rainfall reaching 400 mm in September and 600 mm in October. The dry season in Quang Binh province occurs from January to April, with monthly rainfall of less than 50 mm at most of the stations (Fig. 2 and Table 5).

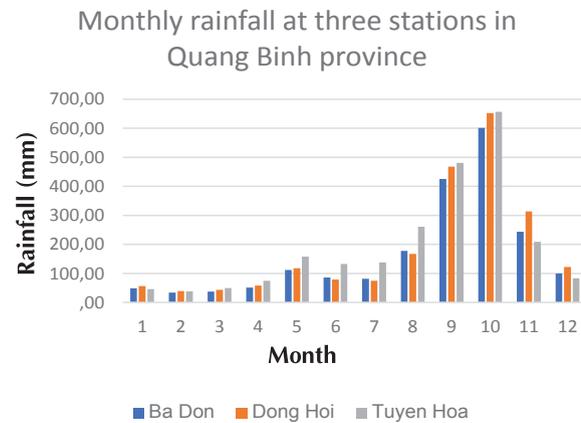


Fig. 2. Annual cycle of rainfall for the period 1961-2014.

Table 5. Rainfall characteristics for the 1961-2014 period.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly
One-day maximum rainfall (Rx1day) (A)													
Ba Don	21.8	14.8	16.6	25.5	51.7	42.6	39.2	83.0	141.1	176.7	80.8	38.6	235.6
Dong Hoi	22.8	17.9	21.8	29.0	51.1	40.5	34.6	74.2	146.7	179.4	94.3	44.8	234.2
Tuyen Hoa	15.5	15.1	21.4	31.8	59.7	54.5	57.3	104.1	150.5	192.7	66.4	25.9	253.4
Five-day maximum rainfall (Rx5day) (B)													
Ba Don	31.7	22.4	22.4	33.2	68.4	63.6	58.5	125.8	247.1	331.6	136.8	61.3	418.2
Dong Hoi	34.5	26.7	28.2	38.1	66.8	58.5	53.4	114.8	268.7	360.6	169.0	74.7	450.7
Tuyen Hoa	25.8	24.5	30.0	41.8	91.4	91.1	87.4	166.1	268.0	366.6	112.4	43.7	462.4
Number of days with rainfall greater than 50 mm (R50) (C)													
Ba Don	0.0	0.0	0.0	0.2	0.5	0.4	0.5	0.9	2.3	3.6	1.2	0.3	9.7
Dong Hoi	0.1	0.1	0.1	0.3	0.7	0.3	0.3	0.9	2.6	4.0	1.8	0.4	11.5
Tuyen Hoa	0.0	0.0	0.0	0.2	0.6	0.5	0.7	1.1	2.8	3.8	0.9	0.1	10.7

Temporal distribution of heavy rainfall in Quang Binh province

Annual evolution:

The rainy season in Quang Binh occurs from August to December [16, 17]. The temporal distribution of rainfall in Quang Binh is a double-peaked annual cycle, with the highest peak in October and an extra peak occurring in May

Over a year, the one-day maximum rainfall at the three stations in Quang Binh ranged from 234.2 mm to 253.4 mm (Table 5A). The one-day maximum rainfall is often observed during the rainy season and is concentrated in September and October. On average, for the 1961-2014 period, the one-day maximum rainfall at the three stations in Quang Binh ranged from 141.1 mm to 150.5 mm in September, and from 176.7 mm to 192.7 mm in October (Fig. 3).

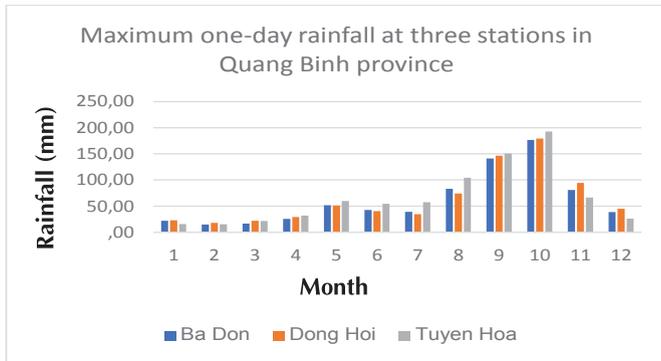


Fig. 3. Annual cycle of the maximum one-day rainfall for the period 1961-2014.

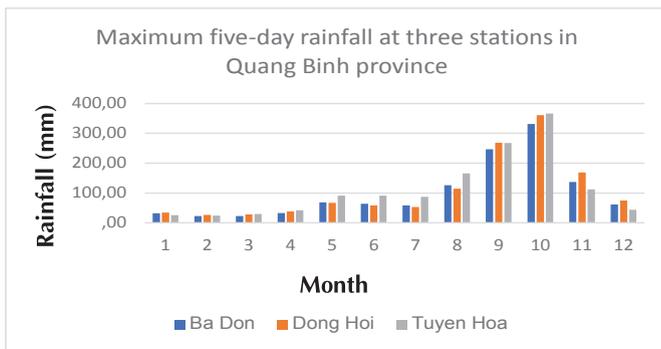


Fig. 4. Annual cycle of the maximum five-day rainfall for the period 1961-2014.

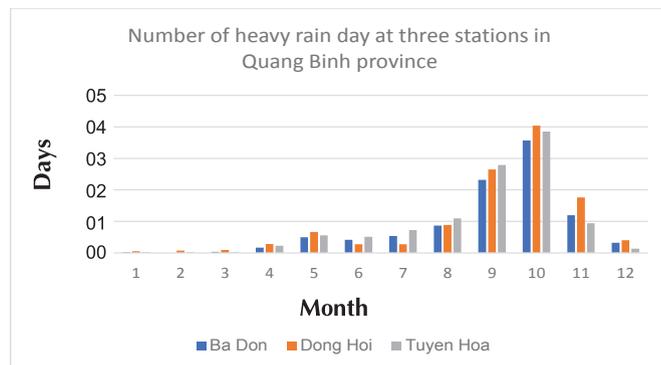


Fig. 5. Annual cycle of the number of rainy days over 50 mm for the period 1961-2014.

On average, for the 1961-2014 period, the annual maximum five-day rainfall at the three stations in Quang Binh province ranged from 418.2 mm to 462.4 mm (Table 5B). The maximum five-day rainfall also occurs in September and October, with values from 247.1 mm to 268.7 mm in September and from 331.6 mm to 366.6 mm in October (Fig. 4).

In terms of the annual occurrence of heavy rainfall, the three stations in Quang Binh province witness approximately 10-11 days of heavy rain (Table 5C). Similar to the maximum daily rainfall, the heavy rain days often occur in the rainy season, especially in September and October. At the three stations, on average for the 1961-2014 period, there were approximately 2-3 heavy rain days in September, and 3-4 in October. From January to April, heavy rain days rarely occur in Quang Binh (Fig. 5).

Analysis of rainfall trends in Quang Binh:

Figure 6 shows the trends in annual rainfall at the three stations for the period of 1961-2014. In general, the trends in annual rainfall vary greatly between stations. Annual rainfall increased by 37.6 mm and 58.9 mm per decade at Ba Don and Tuyen Hoa stations, respectively, while it decreased by approximately 46.2 mm per decade at Dong Hoi station.

Figure 7 shows the trends in annual maximum one-day rainfall at the three stations in Quang Binh province. For the period 1961-2014, the annual Rx1day experienced positive trends at rate of 4-16 mm per decade. The annual Rx1day rate of decrease at Ba Don station was the fastest in the province, approximately 15.98 mm per decade.

Figure 8 shows the trends in annual maximum five-day rainfall (Rx5day) at the three stations in Quang Binh for the period of 1961-2014. It can be seen that, similarly to the annual rainfall, the trend in Rx5day change at the three stations was not uniform but alternated between an

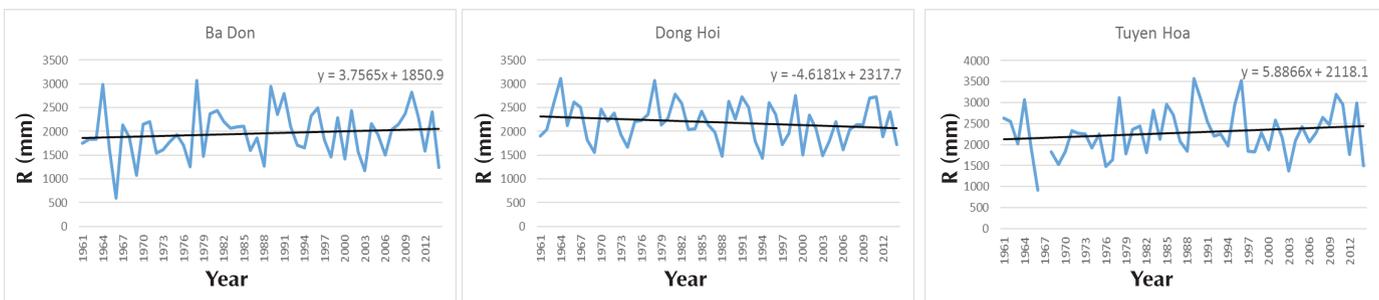


Fig. 6. Trends in rainfall at the three stations in Quang Binh, 1961-2014.

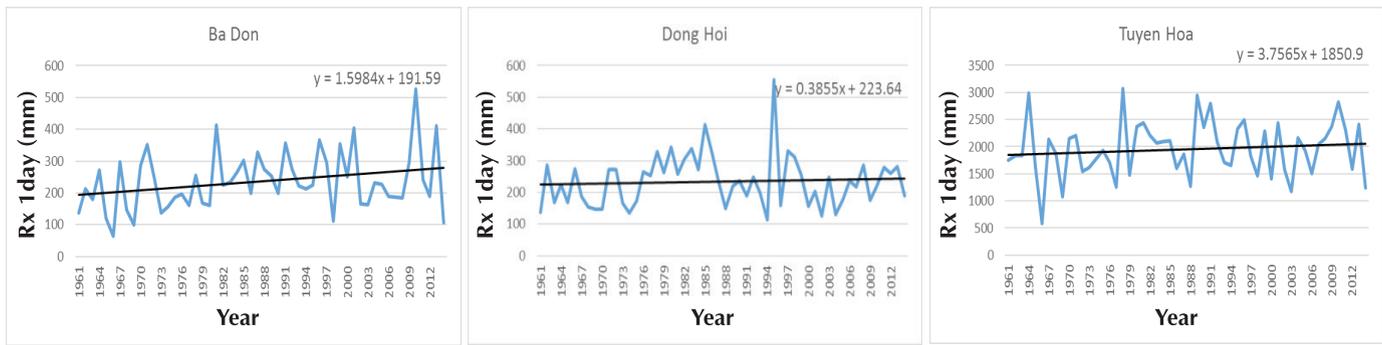


Fig. 7. Trends in Rx1day at the three stations in Quang Binh, 1961-2014.

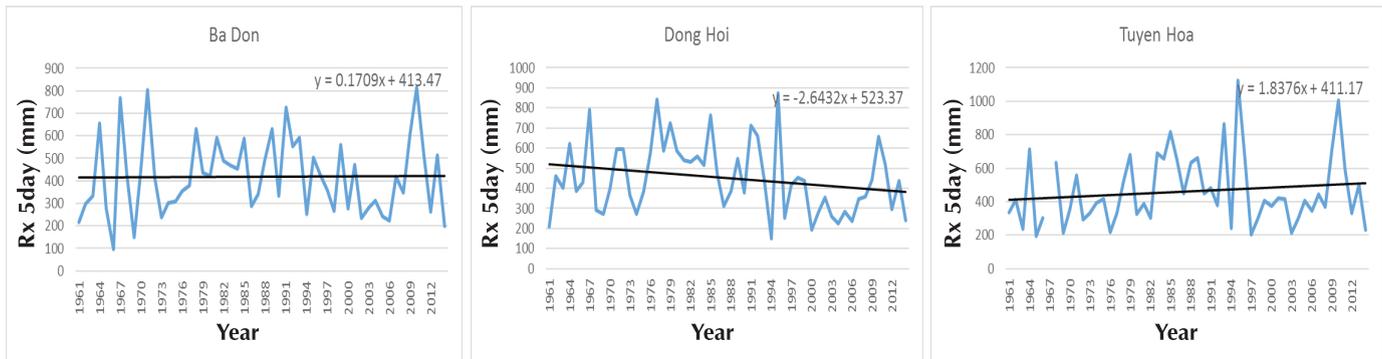


Fig. 8. Trends in Rx5day at the three stations in Quang Binh, 1961-2014.

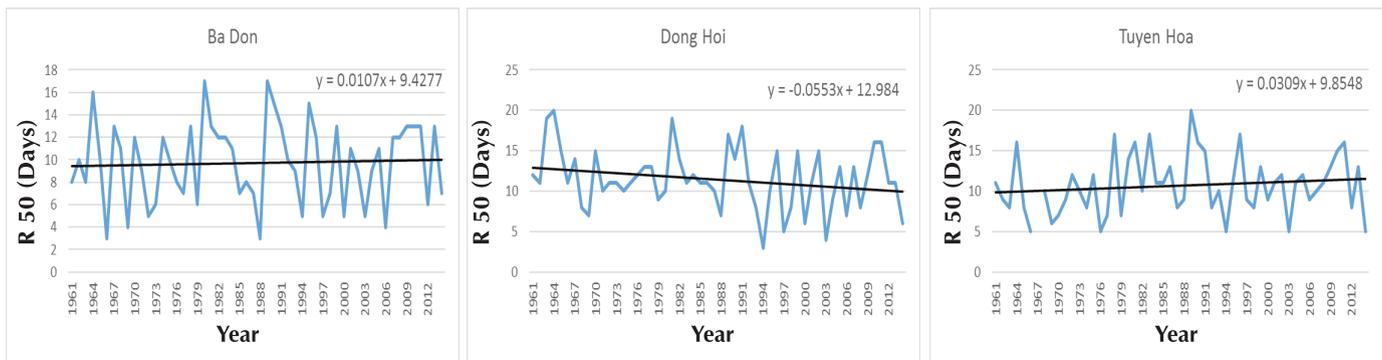


Fig. 9. Trends in R50 at the three stations, 1961-2014.

upward trend and a decline over the 54 years. Specifically, the Rx5day tended to increase at Ba Don and Tuyen Hoa stations, with increases of 1.7 mm/decade and 18.4 mm/decade, respectively, while a downward trend occurred at Dong Hoi station, at 26.4 mm/decade.

Figure 9 shows the trends in number of heavy rain days (R50) at the three stations for the period of 1961-2014. Similar to the annual rainfall, R50 showed increasing trends at Ba Don and Tuyen Hoa stations, at a rate of 0.1 and 0.3 days per decade, respectively, and a decreasing trend at Dong Hoi station, at a rate of approximately 0.55 days per decade.

Spatial distribution of heavy rain in Quang Binh province

Distribution of the annual average total rainfall:

The average total rainfall is in the 2,000 to 2,400 mm range in Quang Binh province. Rainfall in coastal areas is significantly lower than in mountainous areas. For instance, the lowest annual average rainfall is in the coastal district of Quang Trach, with a value of about 1,900 mm. The highest rainfall is concentrated in two regions: the mountainous areas along the border with Laos and the northern border abutting the Ky Anh heavy rain centre (one of the highest rainfall centres in Vietnam is located in Ky Anh province), with rainfall from 2,200 to over 2,800 mm (Fig. 10).

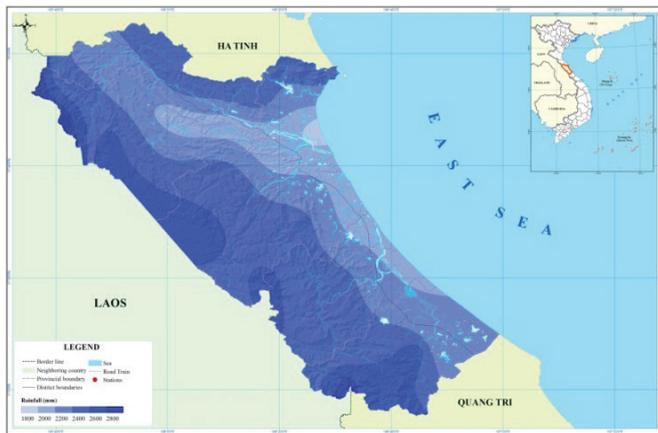


Fig. 10. Spatial distribution of the average total rainfall in Quang Binh province.

Distribution of the maximum one-day rainfall:

The maximum one-day rainfall in Quang Binh province ranges from 230 and 280 mm (Fig. 11). The RX1day shows obvious differentiation, with the highest values in the north and west of Quang Binh, and the lowest values in the east. The largest value for RX1day was found at Dong Tam station (Tuyen Hoa district), while the lowest value was found at Dong Hoi station (Dong Hoi city).

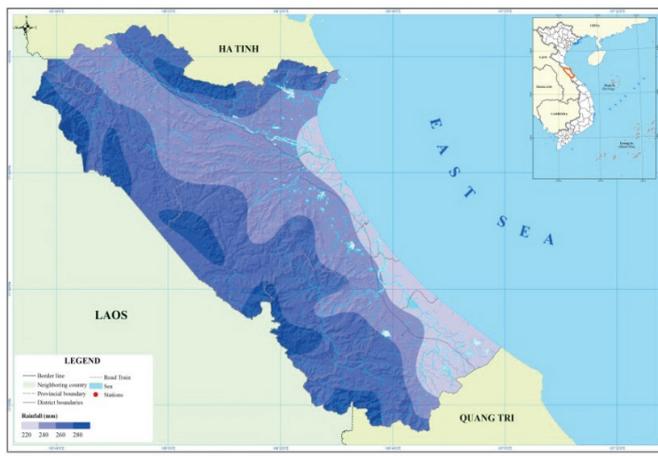


Fig. 11. Spatial distribution of the maximum one-day rainfall in Quang Binh province.

Distribution of the maximum five-day rainfall (RX5day):

The maximum consecutive five-day rainfall (RX5day) in Quang Binh ranges from 400 to 500 mm (Fig. 12). The distribution of RX5day is quite similar to that of the RX1day - the largest values are in the north and west and the lowest values in the east. The largest value for RX5day was found at Dong Tam station (Tuyen Hoa district), while the lowest value was found at Ba Don station (Quang Trach district).

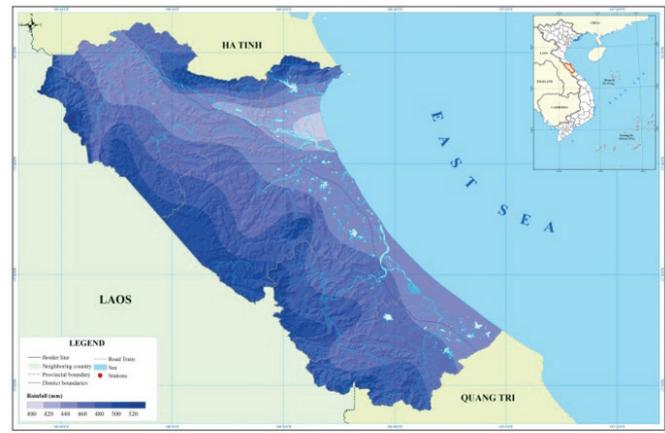


Fig. 12. Spatial distribution of the maximum consecutive five-day rainfall in Quang Binh province.

Distribution of the number of days with rainfall greater than 50 mm (R50):

Figure 13 shows the spatial distribution of the number of days with rainfall greater than 50 mm in Quang Binh. The values for R50 range from about 10 to 13 days per year for the whole of Quang Binh province. The lowest value was found at Minh Hoa and Ba Don stations with 9.7 days, while the highest is 13.4 days at Kien Giang station.



Fig. 13. Spatial distribution of the number of days with rainfall greater than 50 mm in Quang Binh province.

Conclusions

Quang Binh province is greatly affected by natural disasters, with tropical cyclones, floods, and flash floods occurring at high frequency and severity. In-depth study of heavy rainfall is highly relevant for supporting socio-economic development and human life in Vietnam in general and in Quang Binh in particular.

The maximum rainfall during one heavy spell of rainfall and the one-day heavy rainfall were calculated

according to the frequency of occurrence of 20%, 10%, 5%, 2%, and 1% (i.e., the 5-year, 10-year, 20-year, 50-year, and 100-year return periods). The results show that at the frequency of occurrence of 20%, the maximum intensity of a heavy rain spell can reach from 636.6 to 696.0 mm, and this can occur many times in five years. Conversely, at a frequency of 1%, the intensity of a heavy rain spell can reach 1,197.9 to 1,268.3 mm; however, this value is very rare in 100 years.

In terms of the maximum one-day rainfall, at the frequency of occurrence of 20%, the maximum one-day reached over 300 mm, and this can occur many times in five years. Conversely, at a frequency of 1%, the maximum one-day can reach from 487.4 to 521.9 mm; however, this value is very rare in 100 years.

For the period 1961-2014, the average annual rainfall in Quang Binh ranged from 2,000 to over 2,400 mm, with the rainy season lasting from August to December and peaking in October. In terms of spatial distribution, rainfall in coastal areas was significant lower than in mountainous areas. The highest rainfall was concentrated in two regions: the mountainous areas along the border with Laos and the northern area bordering on the Ky Anh heavy rain centre, where rainfall from over 2,200 mm to over 2,800 mm was recorded. The highest one-day and five-day rainfall has the same pattern of distribution as the annual rainfall.

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The authors declare that there is no conflict of interest regarding the publication of this article.

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