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Rainfall Thresholds for Triggering Geohazards in Bac Kan Province (Vietnam)

Duc Ha Nguyen, Thi Hai Van Nguyen, Quoc Hung Le, Van Son Pham and Ho Khanh Nguyen

Abstract

This paper presents the integration of several developed methods to establish rainfall thresholds for triggering any type of geohazards in data-scarce areas. In the developed procedure, it is important to obtain the exact dates of the past disastrous events such as landslides, floods, river bank erosion, debris flows, etc. For the case study area of Bac Kan province, the available data comprises of historic information of 14 geohazard events that occurred in some years from 1986 to 2010 and in 2013, and daily rainfall values during this period. The results show that the relationships between the daily rainfalls and the 7 days-antecedent rainfalls are of very important to trigger series of disastrous events in Bac Kan province. It is a simple and useful approach to applying to the contexts that lack detailed data of a specific geohazard type. This approach is going to be further developed to obtain more accurate thresholds not only for Bac Kan province but also for other areas with similar setting by updating more information on historic geohazard events.

Keywords

Rainfall threshold · Geohazard · Landslide · Flood · Heavy rain

Contents

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1 Introduction

Vietnam is one of the countries that have been deeply affected by global climate change. The abnormal weather phenomena often cause heavy rains, combined with human activities such as deforestation, mining, hill levelling, etc. induce

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lots of negative impacts to the environment, especially more serious for the mountainous areas. Various types of disasters related to geological processes, or so-called geohazards, such as landslide, river bank erosion, debris flow, flash flood, etc. have occurred in most of the mountainous region of Vietnam, causing much more damages and losses to people, infrastructure and the environment. It is urgently required more effort to prevent and mitigate those disasters by implementing one or more approaches to mapping, monitoring, forecasting and warning geohazards.

Studies on the investigation, assessment, zonation, mapping and warning in Vietnam have shown that the occurrences of most geohazard events are closely related to the extreme weather conditions that cause heavy rains or prolonged rains (Tran Van et al. 2002; Nguyen et al. 2011; Le et al. 2014). Establishment of rainfall thresholds is one of the effective measures to give a timely warning of landslides, (flash) floods, debris flows, etc., (Phan Van 2005; Zezere et al. 2005; Guzzetti et al. 2007; Vu et al. 2007a; Jaiswal et al. 2011; Chen and La 2012; Bui et al. 2013; Le et al. 2014). However, it is very difficult to obtain appropriate thresholds due to the lack of necessary data related to each type of the above-mentioned geohazards.

In Vietnam, few researches have studied on the determination of rainfall thresholds that trigger flash floods or landslides (Nguyen et al. 1995; La and Tran 2012; Bui et al. 2013), in which the historic events were identified for occurrences of only landsliding or flooding. The fact shows that disastrous events related to extreme rainfall phenomena are often not separately recorded for only landslides or flash floods or debris flows. The historic information on the occurrences of one type of geohazards (such as flash floods) is often mixed with that of other types (such as landslides, debris flows, river bank erosion, etc.). The reasons were due to the fact that one rain events can trigger several types of geohazards, and they can together happen at the same time or they give domino effects (one disaster can trigger another disaster). Therefore, it would be useful to make use of all collected data of all related geohazard types to establish rainfall thresholds for triggering geohazards in order to prevent a series of disastrous events.

2 Methodology

2.1 Study Area

The method is applied to the case study area of Bac Kan province, which is a mountainous province in the northeast (Fig. 1). This province has a diverse and complicated terrain with a dense river system, which covers an area of 4857.21 km^2, and comprises of hills, mountains and midland. The elevations range from 100 m to nearly 1700 m. The province has a humid monsoon tropical climate that differentiates with the altitudes of the terrain and aspects of the mountain. In Bac Kan, the rainy season starts from May to October that accounts for 70–80% of annual rainfall. Average annual rainfall in the 1400–1600 mm. Bac Kan is one of the mountainous provinces that is threatened by many types of geohazards (Vu et al. 2007b).

2.2 Data and Methods Used

The rainfall thresholds for triggering geohazards in Bac Kan province were established by adjusting several methods that had been developed and applied in many areas in Vietnam and in the world (Phan Van 2005; Zezere et al. 2005; Jaiswal et al. 2011; La and Tran 2012; Bui et al. 2013). The procedures can be briefly described as follows:

- The daily rainfall data were collected from three National Hydro-meteorological Stations in Bac Kan province (namely Bac Kan, Cho Ra and Ngan Son), in which the data from 1961 to 2010 was used for calibration, and the data from May to August 2013 was used for validation.

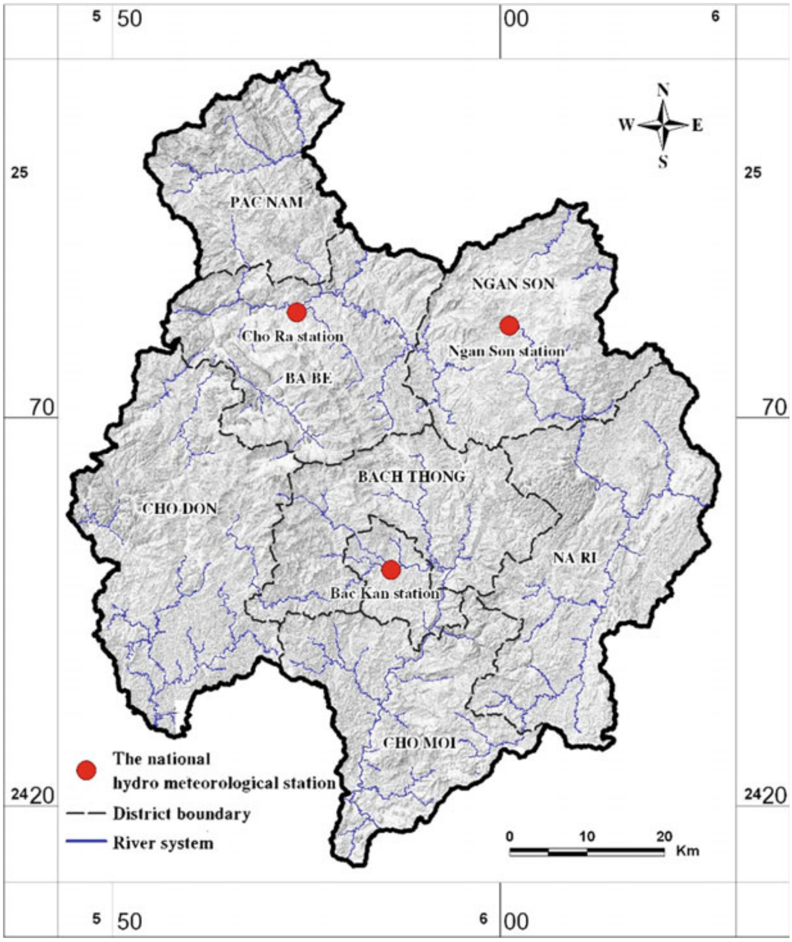


Fig. 1 Sketch map showing Bac Kan province with *red dots* indicating the locations of three national hydro-meteorological stations

- The relationships between the daily rainfall and the occurrences of geohazard events in the study area were analysed by following the procedure as shown in Fig. 2.
- The relationships between the maximum daily rainfall from 1961 to 2010 and their return periods (probability of occurrences) were determined by applying the Gumble method through the analysis of the rainfall data measured at three National Hydro-meteorological Stations in Bac Kan province (Phan Van 2005).
- Daily rainfall values of the dates recorded with geohazard events were analysed to obtain the probability of those rain events as well as the probability of related geohazard events.
- The relationships among the maximum daily rainfall, the daily rainfall on the dates recorded with geohazards, and antecedent rainfall values were calibrated and validated to establish rainfall thresholds by apply the methods developed by Zezere et al. (2005), Marques et al. (2008), Jaiswal et al. (2011), Bui et al. (2013).

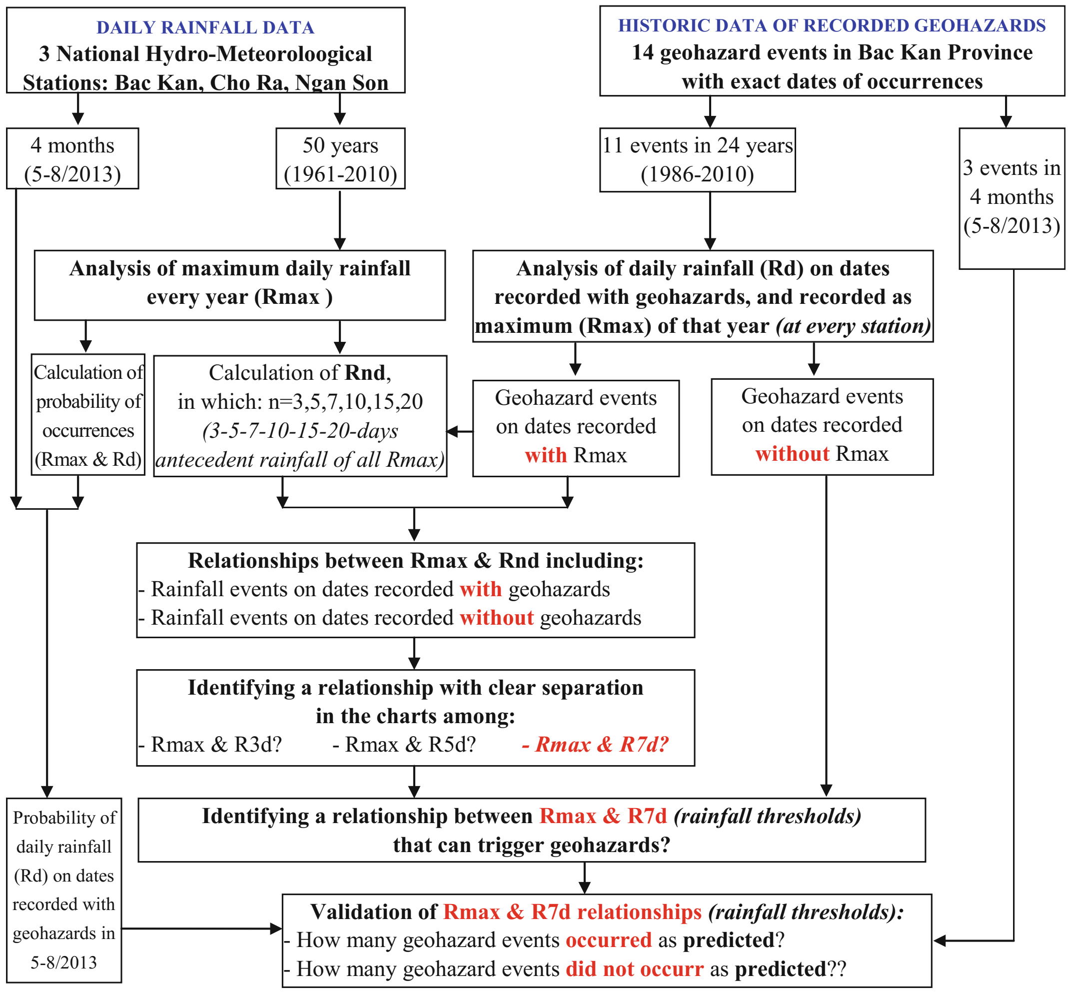


Fig. 2 Procedures of analysing and evaluating the relationships between the rainfall factors (measured at three National Hydro-Meteorological Stations) and the occurrence of geohazard events (recorded by field surveys) in Bac Kan province

3 Results and Discussion

Information on 14 historic geohazard events in the study area was analysed to determine the exact dates of their occurrence for all three stations of Bac Kan province. Then all the geohazards-related values of daily rainfall and 3, 5, 7, 10, 15 and 20-days antecedent were extracted, calibrated and analysed, and their return periods were calculated as shown in Tables 1 and 2; Fig. 3. The field surveys point out that there are many geohazard events that occurred on the days with very low rainfall (e.g. on 17/8/2003 and 31/7/2010), or on the days without rains (or the storms/heavy rains/prolonged rains already finished) (e.g. on 1/7/1986, 27/7/2002, and 10/7/2009). The occurrence of geohazards on those dates can be explained by the influences of the rains on the previous days, which has made the soil and rock mass saturated, or the consequences of flood water from upstreams, etc. Therefore, the antecedent rainfall also plays important to trigger geological disasters.

The daily rainfall (R_t) of 11 geohazard events that occurred from 1986 to 2010 was calibrated in the relation with the 7 days-antecedent rainfall

Table 1 Maximum daily rainfall and antecedent rainfall related to the geohazard events that were recorded in Bac Kan province from 1986 to 2013

Dates recorded with geohazards (dd/mm/year)	Daily rainfall	Return period	Antecedent rainfall					
			3 days	5 days	7 days	10 days	15 days	20 days
Bac Kan station								
01/07/1986			0	0.2	31.1	80.1	131.1	206.7
22/09/1990	193.7	12	183.5	183.5	186.3	206.2	206.2	223.5
05/10/2000	46.2	1.1	1.2	17.9	33.6	91.4	92.8	92.8
27/07/2002			21.6	27	84.6	84.7	113.8	125.2
17/08/2003	0.9	1	67.6	92.5	100.9	190.2	191.4	191.4
17/07/2006	176.6	8.3	7.2	10	67.1	91.8	121.9	201.1
13/04/2008	43.1	1.1	1.1	1.1	1.2	1.3	14.1	14.8
13/08/2008	11.2	1	34.3	137.6	159.6	162.7	175.3	222.1
04/07/2009	53.3	1.1	39.7	42.6	43.8	84.2	120.8	155.7
10/07/2009			1.6	39.4	99.8	132.4	176.9	213.5
31/07/2010	0.5	1	33.4	36	85.1	131.9	194.2	199.7
30/05/2013	134.4	3.5	51	65.8	65.8	82.6	82.6	85.3
29/07/2013	27.8	1	59.4	62.5	101.3	149	185.6	238.8
04/08/2013	15.2	1	101.3	104.6	151.4	191.8	269	313.7
Cho Ra station								
01/07/1986			0.2	0.2	0.4	129.5	183.9	262.3
22/09/1990	21.7	1	101.2	101.2	109	121	121	137
05/10/2000	32.6	1	9.1	31.2	42.6	53.9	68.1	68.1
27/07/2002			21.5	27.1	166.6	166.7	231.9	235.7
17/08/2003	2.8	1	68.2	99.5	104.8	112.9	113.8	115.7
17/07/2006	210.9	112	37	45.1	79.5	119.3	179.5	249
13/04/2008	50.9	1.1	0.6	0.6	0.7	0.9	43.8	45.7
13/08/2008	78.9	1.5	18.5	158.9	166.2	185.4	198,4	210.4
04/07/2009	138.1	8.6	46.9	71.7	79.4	109.5	136.8	157.6
10/07/2009	0.4	1	1.7	47	192.8	232.3	294.6	321.9
31/07/2010	2.6	1	69.2	69.5	118.8	154.4	213.5	220.3
30/05/2013	51.1	1.1	16.3	17.3	20.7	49.5	49.9	57
29/07/2013	25.7	1	65.7	73.1	112.1	145.3	214.1	234.8
04/08/2013	47.2	1	62.9	63	91.8	161.8	209	280
Ngan Son station								
01/07/1986			6.7	13.5	14.9	45	104.7	218.8
22/09/1990	63.2	1.1	249.3	249.3	249.3	256.6	271	271
05/10/2000	110	2.2	41.3	53.3	100.6	193.2	215.9	215.9
27/07/2002			10.9	16.5	79.8	84.7	102.6	119.7
17/08/2003	1.9	1	116.6	125.5	137.5	172.5	172.5	178
17/07/2006	165.6	8.1	0.9	4.9	55.3	75,2	119.4	295.6

(continued)

Table 1 (continued)

Dates recorded with geohazards (dd/mm/year)	Daily rainfall	Return period	Antecedent rainfall					
			3 days	5 days	7 days	10 days	15 days	20 days
13/04/2008	51	1.1	1.2	1.2	1.5	2.6	22.9	24
13/08/2008	33.3	1	19.7	186	209.3	222.5	232.6	346.1
04/07/2009	89.5	1.6						
10/07/2009	0.3	1	4.2	30.1	127.1	153.7	221.7	278.8
31/07/2010	19.2	1	32	85.4	107.8	138.4	232.2	286.2
30/05/2013	50	1.1	38.7	49.2	54.7	86.4	88.5	113.5
29/07/2013	13.8	1	46.4	52.2	70.1	101.2	145.3	177.9
04/08/2013	30	1	118.8	118.9	148.9	179.4	214.8	260.3

(R_{7d}). Results showed that they have correlation through three threshold equations as shown in Fig. 4. To validate those rainfall thresholds, daily rainfall from 01/05/2013 to 31/08/2013 measured at 3 stations were used in combination with geohazard events recorded by the field surveys. The validation as shown in Fig. 5 points out that the actual rainfall observed during this period at 3 stations in Bac Kan province were exceeded many times. Compared with rainfall data during the period from 01/05/2013 to 31/08/2013, we can see that the events occurred on 30/05/2013 and at night of 3/8/2013 and early morning of 04/08/2013 exceeds the thresholds the most.

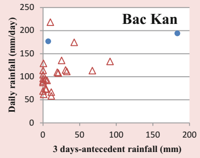
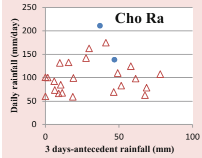
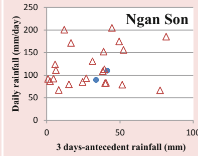
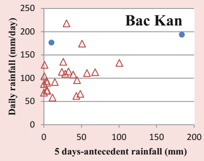
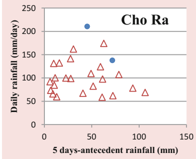
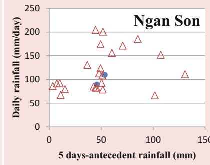
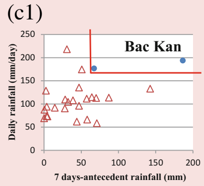
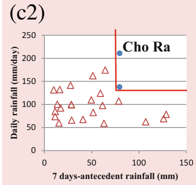
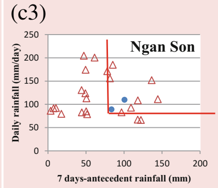
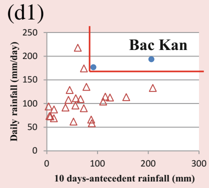
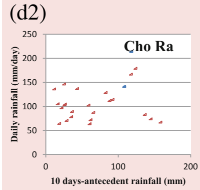
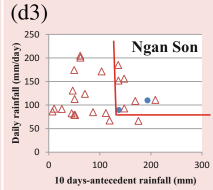
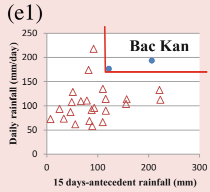
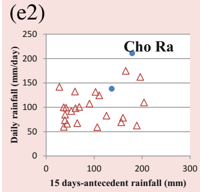
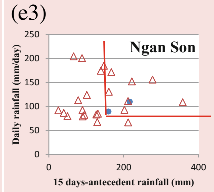
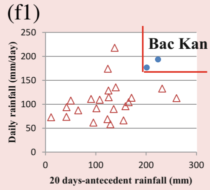
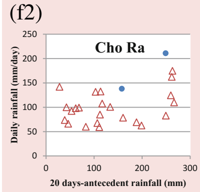
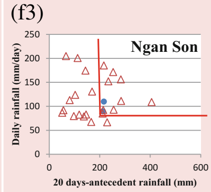
The correlations between daily rainfall and 3, 5, 7, 10, 15, 20-days antecedent rainfall measured at three Hydro-Meteorological Stations of Bac Kan, Cho Ra and Ngan Son as shown in Table 2 figure out that:

- At Bac Kan Station: there is a clear separation in the distribution of the relationship of 7, 10, 15 and 20-days antecedent rainfall with the daily maximum rainfall on dates recorded *with* geohazard events from that relationship with the ones recorded *without* geohazard events.
- At Cho Ra Station: there is a clear separation in the distribution of the relationship of only 7-days antecedent rainfall with the daily maximum rainfall on dates recorded *with* geohazard events from that relationship with the ones recorded *without* geohazard events.
- At Ngan Son Station: there is no separation in the distribution of relationship of only 7-days antecedent rainfall with the daily maximum rainfall on dates recorded *with* geohazard events from that relationship with the ones recorded *without* geohazard events.

The obtained rainfall thresholds were mainly based on only daily rainfall of three different rain gauge stations. Therefore, the thresholds established for this station/one area cannot be affirmed to be applicable to other station/areas if those stations/areas have different characteristics. To improve the accuracy of these thresholds, and to use them effectively in prediction models, it is necessary to collect more sufficient data on the past events, particularly the exact dates of occurrences.

The observation of meteorological factors in the area of pilot studies should have a long enough period of monitoring and a full complement of accurate information about events occurring geological hazards in the area research. Therefore, the relationship set for rainfall stations in the study area cannot be affirmed applicable to monitoring stations in other areas or not. The observation of meteorological factors in the area

Table 2 Maximum daily rainfall and 3, 5, 7, 10, 15 and 20 days-antecedent rainfall measured at three National Hydro-Meteorological Stations of Bac Kan province from 1986 to 2010, in which: green-dot notations for the values with information of geohazards, and the red triangle notations for the values without information of geohazards

Measured rainfall	Bac Kan station	Cho Ra station	Ngan Son station
(a) Daily rainfall versus 3 days-antecedent rainfall	(a1) 	(a2) 	(a3) 
(b) Daily rainfall versus 5 days-antecedent rainfall	(b1) 	(b2) 	(b3) 
(c) Daily rainfall versus 7 days-antecedent rainfall	(c1) 	(c2) 	(c3) 
(d) Daily rainfall versus 10 days-antecedent rainfall	(d1) 	(d2) 	(d3) 
(e) Daily rainfall versus 15 days-antecedent rainfall	(e1) 	(e2) 	(e3) 
(f) Daily rainfall versus 20 days-antecedent rainfall	(f1) 	(f2) 	(f3) 

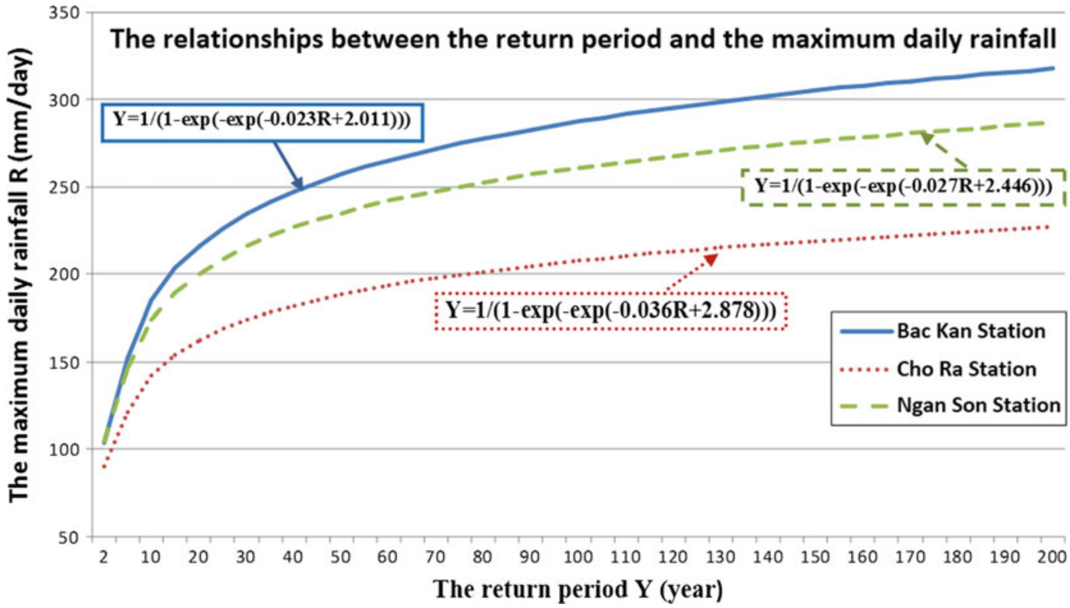


Fig. 3 Graphs showing the relationships between the return period (Y) and the maximum daily rainfall (R) measured at three National Hydro-Meteorological Stations: Bac Kan, Cho Ra and Ngan Son

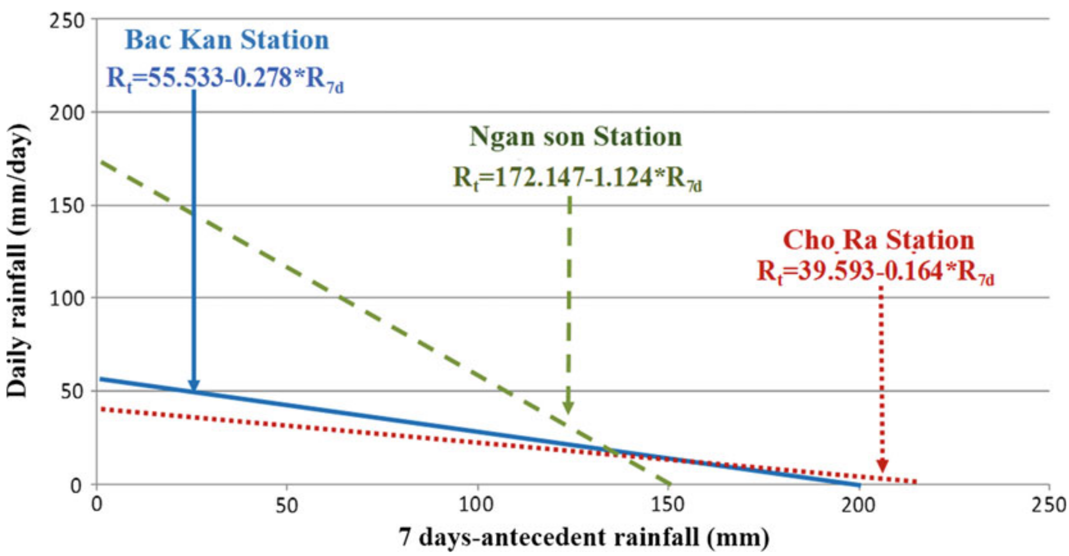


Fig. 4 Rainfall thresholds for triggering geohazards were established by correlating daily rainfall (Rt) with the 7 days-antecedent rainfall from 1986 to 2010 that were measured at three National Hydro-Meteorological Stations

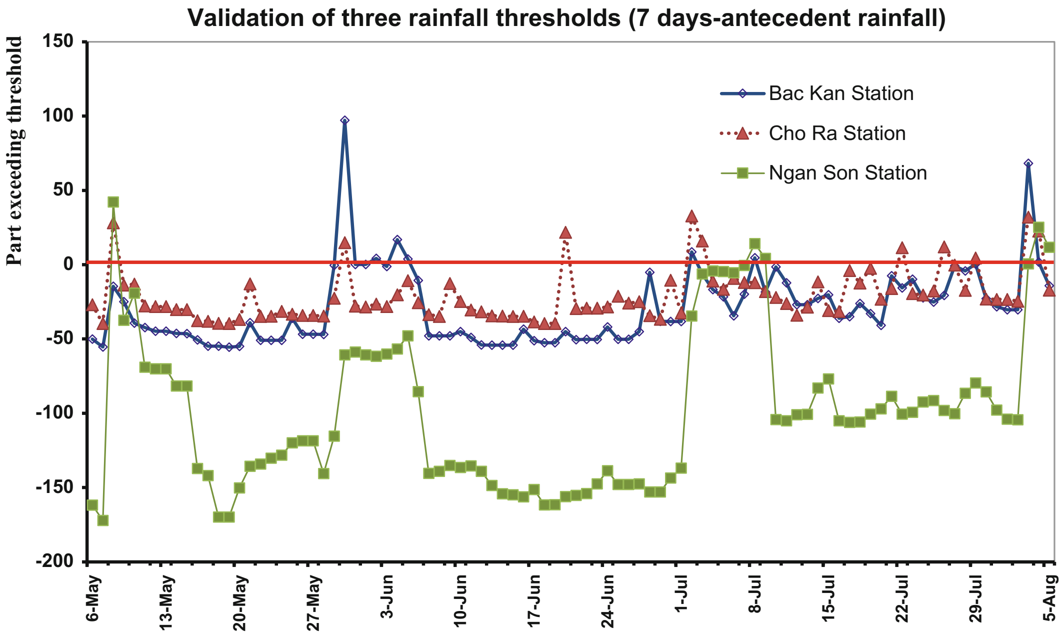


Fig. 5 Validation of three rainfall thresholds for triggering geohazards by using rainfall data from 1st May to 31st August 2013 that were measured at three National Hydro-Meteorological Stations (namely Bac Kan, Cho Ra and Ngan Son Stations)

of pilot studies should have a long enough period of monitoring and a full complement of accurate information about events occurring geological hazards in the area research.

4 Conclusion

Timely forecasting and warning of any type of geohazards play an important role in the prevention, mitigation and reduction of geohazard risk. The determination of geohazard-triggered rainfall thresholds for any specific area will improve the efficiency of forecasting and disaster warnings. This study presents an integration and adjustment of developed methods to establish the thresholds for the testing area in Bac Kan province. The results showed that the daily rainfall is rather correlated with the 7 days-antecedent rainfall to trigger a series of geohazard events in Bac Kan during the period of 1986–2010. This result is in accordance with the actual situations of the geohazard occurrences in Bac Kan province. Thus, the methodology can be improved to obtain more accurate thresholds for this case study area with more supplementary data, or can be applied to other places with suitable adjustments.

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