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Assessment of Potential Rainfall Distribution Patterns and Their Relationship with Inundation in Tra Vinh Province, Vietnam

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Abstract: This study aimed to develop temporal rainfall distribution patterns of 1-day, 3-, 5-, and 7-consecutive rain days for three meteorological stations in Tra Vinh province (Cang Long, Tieu Can, and Tra Cu), using daily rainfall data from 1978 to 2017. The study follows the Vietnamese National Standards (TCVN 10406:2015: Irrigation Works – Calculation of Design Drainage Coefficients) to determine the frequency of events of various rainfall distribution drainage patterns. Thereafter, the probability method was conducted to identify rainfall pattern design according to a 10-year return period. Only Cang Long meteorological station exhibited enough single events of rainfall patterns (>10) for 3 consecutive days to determine a rainfall distribution drainage pattern, fitting in pattern type 1 and distribution types 2 and 3. However, for all distribution types of rainfall patterns, the one with the highest last-day rainfall is the most adverse pattern. Therefore, this study recommends building a 3-consecutive day design rainfall for Cang Long station of pattern type 1 and distribution type 3 for precautionary purposes.

Keywords: Design rainfall model; Frequency; Rain causing inundation; Rain gauge stations: Tieu Can, Cang Long, Tra Cu.

Introduction

Knowledge of the spatial, temporal and seasonal distribution of rainfall is important for responding to a range of hydrological challenges in Southeast Asian countries (Upal et al., 2020; Joshi et al., 2021). A number of methods have been used to analyse meteorological data in previous studies, including the Mann-Kendall test and the inverse distance weighted (IDW) interpolation method (Joshi & Makhasana, 2021; Sarkar et al., 2021; Upal & Hoque, 2020). Moreover, probability analysis has also been commonly undertaken in a large number of studies (Jagtap et al., 2021; Minh et al., 2022; Hershfield, 1973). Additionally, the analysis of consecutive days' rainfall for different return periods is a fundamental tool for the safe and cost-effective planning and design of small dams, bridges, culverts, irrigation and drainage works. In contrast to urban and industrial areas, irrigated agricultural areas frequently have varied drainage requirements for each object,

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hence rainfall models created for this sector typically employ daily rainfall data for calculations (Thuy, 2020). The actual design of rainfall drainage models is as important as input data in calculating the drainage regime for an irrigation system. The Vietnamese standard (TCVN 10406:2015 (TCVN 10406:2015)) (has specified the rainfall pattern and the method of calculating the drainage coefficient for each type of object that needs to be drained or irrigated, in order to find the design drainage coefficient for the whole drainage system. Additionally, TCVN 10406:2015 states that a rainfall drainage model is employed and that a different formula is applied to compute the coefficient if the drainage object is an industrial park or urban area that drains directly into the irrigation system.

Previously, when selecting a statistical calculation sample, there is only one sample per year representing 1 consecutive day of maximum rainfall, 3 consecutive days of maximum rainfall, 5 consecutive days of maximum rainfall, and 7 consecutive days of maximum rainfall, regardless of the magnitude of each value in each year (Minh et al., 2022). TCVN 10406:2015 overcomes this limitation by allowing the selection of more than one statistical sample (that is by allowing a number of heavy rain events in a single year to be selected). According to the World Meteorological Organization (WMO), heavy rainfall events are classified into three levels based on the total rainfall measured within a 24 hour period: (i) Moderate rainfall between 16 and 50 mm; (ii) Severe rainfall 51 and 100 mm; and (iii) Extreme rainfall greater than 100 mm (General Department of Hydrometeorology, 2021). According to the Vietnamese National Center for Meteorology and Hydrology, heavy rainfall events have a negative impact on human well being and moderate rainfall events typically lead to flooding.

The majority of hydrological events occur as natural phenomena which are only observed once. As rainfall is a random natural phenomenon, using various probability distributions to determine the pattern of occurrence which results in inundation or determine design rainfall patterns (Minh et al., 2022; Upadhaya and Singh, 1998; Barkotulla et al., 2009). As a result, this study assesses rainfall distribution and then determines the design rainfall distribution drainage pattern for 1-day, 3-, 5-, and 7- consecutive days using yearly and daily rainfall from three separate meteorological stations in Tra Vinh province (Cang Long, Tieu Can and Tra Cu), Vietnam.

Methodology

Study Area

The daily rainfall data from meteorological 3 stations located in three districts of Tra Vinh province was used. The dataset covered 39 years for Cang Long, and 37 years for Tieu Can and Tra Cu, respectively.

The dataset from the Cang Long station (1979–2017), the Tieu Can station (1982–2017), and the Tra Cu station (1982-2017).

Tra Vinh is surrounded by the Tien (Mekong) and Hau (Bassac) Rivers and has a natural land area of 2,341 km^2. The Vietnamese East Sea borders the province to the east, Vinh Long province to the west, Soc Trang province to the south, and Ben Tre Province to the north (Figure 1). The climate of Tra Vinh province has a distinct dry and wet season. The wet season is from May to November, whilst the dry season is from December

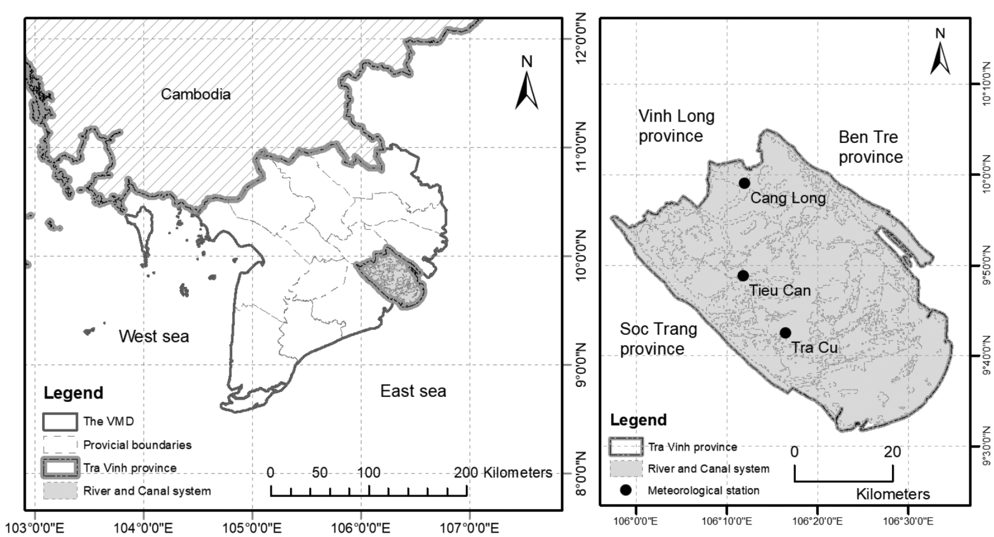

Figure 1: Location of the study area and rainfall stations.

to April. The average temperature ranges from 26 to 27°C, the average humidity from 83 to 85% per year, and the average rainfall is 1,500 mm (Tra Vinh province, 2022). In general, Tra Vinh province is characterized by a tropical monsoon climate with high and stable temperatures. However, the climate's limiting factor is its seasonally concentrated rainfall compounded by its low terrain, which is strongly influenced by winds and high tides, resulting in local flooding and drought (MPI, 2022).

Calculation and Determination of the Design Rainfall Drainage Model

Analyses of the Daily Rainfall and Selected Rainfall Days for Design Resulting in Inundation Based on TCVN

Figure 2 shows the total annual rainfall for the three different stations Cang Long, Tieu Can and Tra Cu. The data highlights years with a large number of high daily rainfall amounts and also total annual rainfall. However, the years with numerous heavy rainfall events do not always coincide with the years with the highest total annual rainfall.

Figure 2 shows that the total annual rainfall at Tra Cu was greater than at Cang Long and Tieu Can. Furthermore, Tra Cu has a higher average total rainfall (1598 mm) than Cang Long (1593 mm) and Tieu Can (1435 mm). However, the occurrence of 1-day or 3-consecutive day rainfall events was higher at Cang Long than at the other two stations (Table 1 and Appendix 1).

According to TCVN 10406:2015 (article 4.1), the rainfall amount used in the calculation is the rain that causes flooding in the drainage area corresponding to the design frequency. Table 2 and Appendix 3 and 4 show the rainfall amounts with the total amount of rain that occurred at Cang Long, Tieu Can and Tra Cu stations corresponding to 1, 3, 5, and 7 days of rain.

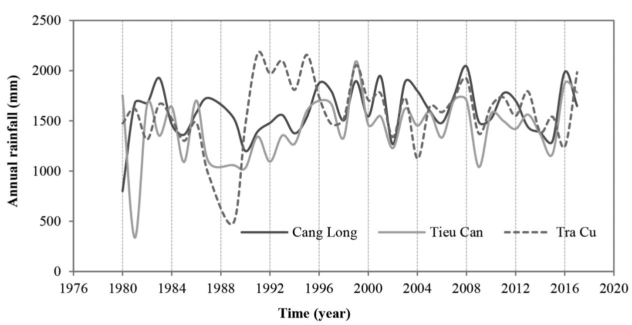

Figure 2: Distribution of annual rainfall at the three stations in the study area.

The results were 1 day rainfall ≥ 51 mm; 3-consecutive day rainfall ≥ 153 mm; 5-consecutive day rainfall ≥ 255 mm; 7-consecutive day rainfall ≥ 357 mm.

Distribution of Rain Pattern Causing Inundation

Based on actual rainfall data in the study area, 5-consecutive days of maximum rainfall and 7-consecutive days of maximum possible inundation based on TCVN were extremely rare. As a result, the study examined the 3-day continuous rain pattern for all three stations in Tra Vinh. The rainfall distribution for each day of a 3-day inundation rainfall can be generalized into three basic types, as shown in Figure 3 (Thuy, 2020).

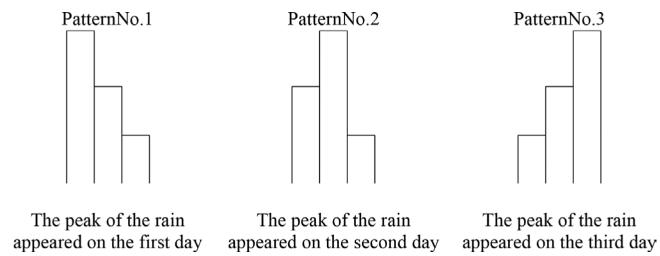

Figure 3: Basic rainfall distribution patterns of 3-consecutive days resulting in inundation.

Each of the previous rainfall patterns was further subdivided into three distribution types, namely, (i) The remaining two rainfall days have equal or greater than 51 mm; (ii) One of the remaining two rainfall days has less than 51 mm of rainfall; and (iii) Type distribution No. 3: Both remaining rainfall days have less than 51 mm of rainfall.

Determine the Design Rainfall Drainage

A probability analysis of consecutive days of annual maximum rainfall was conducted. The probability of rainfall was plotted using FFC 2008 software (Program for analysis and probability plot) (Lam, 2021). The probability (P) was the likelihood of an annual maximum rainfall event occurring with a value equal to or greater than a given value X_0 (Equation 1) (Hershfield, 1973).

$$P(X \geq X_0) = \frac{m}{n+1} \times 100 \tag{1}$$

where m denotes the rank order and n denotes the total number of observations.

- Determination of rainfall drainage pattern: Probability design causing inundation corresponding to 10%.
- Select a typical year: According to QCVN 04-05:2012/BNNPTNT, a typical rainfall pattern is

Appendix 1: Statistics 1-day and 3-consecutive days rainfall in the period from 1982 to 2017 at Tieu Can station

	1-day (mm)	*Day of appearance*	*3-consecutive days (mm)*	*Day of appearance*
1982	59; 59; 59.1; 51; 96; 53; 55; 54; 54; 58	20/5; 3/8; 19/6; 21/7; 10/8; 14/9; 15/9; 18/9; 1/10; 5/10	-	-
1983	64.5; 60.3	21/7; 02/11		
1984	64.4; 117; 97,9; 65; 57.3	1/5; 7/5; 8/5; 13/8; 2/10	214.9	6-8/5
1986	65.5; 65.1; 56.2	1/6; 4/9; 25/9	-	-
1987	55; 52.9	19/3; 24/8	-	-
1989	102.3; 52.4; 60.6; 78.5	3/7; 10/7; 11/10; 17/10	169.6	2-4/7
1990	68.7; 55.4; 59.3	16/7; 11/10; 8/11	-	-
1991	67.9	22/9	-	-
1992	54.7; 68.7; 64.4	13/4; 11/10; 14/11	-	-
1993	65.4; 101.7; 53.1	2/9; 22/9; 28/9	-	-
1995	60.6; 74.4; 52.2; 61.1; 54.6; 52.4	14/5; 26/5; 24/6; 2/9; 24/9; 7/10	-	-
1996	52; 68.7; 61.3; 72.2; 61.7; 62.1; 91	9/5; 29/5; 13/6; 23/7; 30/10; 31/10; 13/11	-	-
1997	51.2; 59.2; 84.6; 56.6; 67.5; 57.2; 87.1	5/7; 8/7; 3/8; 31/8; 04/10; 17/10; 02/11	-	-
1998	118,1; 85,5; 52,9	12/6; 17/8; 18/8	-	-
1999	124,8; 55,8; 53,2; 71.1; 86.5	30/3; 21/4; 18/5; 13/10; 24/10	-	-
2000	65.1	23/4	-	-
2001	53.3; 66.5	19/4; 8/10	-	-
2002	59.5; 60.1; 57.7	11/5; 19/8; 12/10	-	-
2003	61.5	9/9	-	-
2004	105.8; 63.5; 54; 55.7; 56.8; 62	17/5; 8/7; 10/7; 29/9; 5/10; 13/10	-	-
2005	83; 99.6; 63	27/7; 12/9; 9/10	-	-
2006	58.5; 55.2	9/10; 5/12	-	-
2007	64.9; 69.4; 65.3; 61.5; 107.4; 59	23/6; 9/8; 21/8; 5/11; 7/11; 11/11	-	-
2008	89.5; 76; 60; 111; 83; 57.8	29/4; 1/5; 18/5; 9/6; 23/7; 1/8	-	-
2009	57.4; 73.6	8/5; 1/7	-	-
2010	53.7; 64.3; 70.5; 56.8	10/5; 28/7; 11/9; 31/10	-	-
2011	62.5; 52.9; 65.8; 52.8; 72.9	6/5; 8/10; 6/11; 7/11; 18/11	-	-
2012	64.5; 52.6; 60; 83;57.7	26/5; 9/7; 18/7; 10/9; 26/9	-	-
2013	58.5; 54; 52; 84.4	1/5; 13/5; 03/7; 6/8	-	-
2014	73.3; 51.2	11/5; 19/10	-	-
2015	70	14/6	-	-
2016	62.8; 58.5; 178.8; 105.5; 64.8	22/5; 26/7; 26/9; 17/10; 23/10	251.9	25-27/9
2017	68.1; 53.5; 102.3; 68.3; 60.8; 63	21/4; 23/4; 24/5; 05/9; 02/11; 26/12	-	-

one that has already occurred, has a total rainfall that is approximately equivalent to the total design rainfall, has a distribution shape that is usual and is skewed towards drainage disadvantage.

- Scale factor was used to determine the pattern of rain that causes inundation

- Scale factor K_p:

$$K_p = \frac{X_p}{X_{dh}} \tag{2}$$

- Design target rainfall distribution for each day:

Table 1: Statistics on the magnitude of rainfall that may cause inundation in the 1-3-5-7 consecutive days of rainfall pattern at Cang Long station (1979-2017)

Years	*1-day*		*3-consecutive days*		*5-consecutive days*		*7-consecutive days*	
	X1 (mm)	*Date of appearance*	*X3 (mm)*	*Date of appearance*	*X5 (mm)*	*Date of appearance*	*X7 (mm)*	*Date of appearance*
…	-	-	-	-	-	-	-	-
1984	67.2	6/10	168	6-8/10	-	-	-	-
…	-	-	-	-	-	-	-	-
1988	153.1	3/5	205	3-5/5	-	-	-	-
…					-	-	-	-
1990	117.9	9/11	194.5	8-10/11	-	-	-	-
…	-	-	-	-	-	-	-	-
1996	95.1	9/10	157.5	9-11/10	-	-	-	-
1997	122.9	2/11	222.2	2-4/11	-	-	-	-
1998	119.4	18/10	169.8	16-18/10	-	-	-	-
…	-	-	-	-	-	-	-	-
2001	98.9	27/4	187.9	27-29/4	-	-	-	-
…	-	-	-	-	-	-	-	-
2005	87.1	12/9	170.5	11-13/9	-	-	-	-
…	-	-	-	-	-	-	-	-
2008	114.9	24/10	160.2	22-24/10	-	-	-	-
…	-	-	-	-	-	-	-	-
2011	94	18/11	172.5	16-18/11	-	-	-	-
…	-	-	-	-	-	-	-	-
2016	167.5	13/10	173.6	13-15/10	-	-	-	-
…	-	-	-	-	-	-	-	-

$$X_P = K_P x X_{dh} \tag{3}$$

Resuls and Discussion

Statistics of Rainfall Events and its Relation with Inundation in Tra Vinh Province

Many areas of Tra Vinh province were found not to receive any rainfall from January to mid-May, according to the hydrological regime during the dry season in 2020. However, there was an unusual rainfall in mid-April 2020 (Hydrometeorological Station of Tra Vinh province, 2021). On a larger scale, the rainy season in 2020 did not start until the middle of the month of May, 12 days later than in 2019 and significantly later than the norm of many years. For the same year, the rainy season finished on the first weekend of November, which was 20 days and 10 days later than the same time the previous year and the norm over many years. The wet season was predicted to start in May 2021, 10-15 days sooner than it did during the same time last year, which was a rate several years earlier than typical. In particular, from April to May, the total rainfall was 10 to 15% greater overall than the norm, and from June to July, it was roughly typical. The overall amount of rainfall was often 10% less than the average for certain months, This is true, especially in August and September, but during October and November, it is more or less the norm. In addition, Tra Vinh province's rainfall varies significantly across time and space, according to Tâm & Chi (2020). The average rainfall during the five months of the dry season (December to April) was only 6.64%, the highest year is 20.95%, and the lowest year was 0.68% of the total annual rainfall. Rainfall accounts for 10.81%, the highest year for 20.30%, and the lowest year for 1.98% of the total annual rainfall during the transitional months from the dry season to the wet season (April) and from the wet season to the dry season (November). Similar to

Table 2: The number of rainfall events that may cause inundation in the pattern of 1-3-5-7 consecutive days of rainfall (1979-2017)

No.	*Year*	*Number of rainfall event that may cause inundation*				
		Total	*1-day*	*3-cons. day*	*5-cons. day*	*7-cons. day*
1	1979	2	2		-	-
2	1980	2	2		-	-
3	1981	5	5		-	-
4	1982	3	2		-	-
5	1983	3	3		-	-
6	1984	1	1	1	-	-
7	1985	2	2		-	-
8	1986	3	3		-	-
9	1987	2	2		-	-
10	1988	4	4	1	-	-
11	1989	2	2		-	-
12	1990	3	3	1	-	-
13	1991	1	1		-	-
14	1992	1	1		-	-
15	1993	4	4		-	-
16	1994	2	2		-	-
17	1995	2	2		-	-
18	1996	4	4	1	-	-
19	1997	3	3	1	-	-
20	1998	4	4	1	-	-
21	1999	3	3		-	-
22	2000	2	2		-	-
23	2001	3	3	1	-	-
24	2002	3	3		-	-
25	2003	4	4		-	-
26	2004	6	6		-	-
27	2005	3	3	1	-	-
28	2006	3	3		-	-
29	2007	3	3		-	-
30	2008	7	7	1	-	-
31	2009	3	3		-	-
32	2010	4	4		-	-
33	2011	5	5	1	-	-
34	2012	6	6		-	-
35	2013	2	2		-	-
36	2014	3	3		-	-
37	2015	3	3		-	-
38	2016	5	5	1	-	-
39	2017	2	2		-	-
Total		**123**	**123**	**11**	-	-
Raito (%)			**100**	**8.94**	-	-

the dry season, which runs from early May to around mid-November, the wet season coincides with the peak period for tropical storm activity in the Western Pacific Ocean and the East Sea. Rainfall during the peak six-month wet season accounts for 93.20% of the total annual rainfall, while the wettest year accounts for 99.32%, and the lowest year only accounts for 79.05%.

Statistics of Rainfall that Cause Inundation in the Period of 1-3-5-7 Consecutive Days of Rainfall

Table 1 shows the amount of rainfall in the patterns of 1-3-5-7 consecutive days maximum of rainfall, and Table 2 shows the amount of rainfall that may cause inundation in the pattern 1-3-5-7 consecutive days of rainfall at Cang Long station from 1979 to 2017. Similar to Appendix 1, Appendix 2 shows a table of the magnitude and number of rains that caused waterlogging at Tieu Can station during the period 1-3-5-7 consecutive days (from 1982 to 2017), as well as Tra Cu (from 1982 to 2017).

The statistical data in Tables 1 and 2 show that for Cang Long station, over the 39 years data set, 123 seperate occurrences of 1-day heavy rainfall may result in inundation occurred. Similarly, 11 occurrences of 3-consecutive days of rainfall that may cause inundation occurred, yet there were no continuous rainfall events for 5-consecutive days and 7-consecutive days, which would result in the potential of inundation. Rainfall causing inundation at Cang Long station has the following characteristics: 1-day rainfall pattern causes inundation into the rainfall parttern 3-consecutive days pattern, 5-consecutive days pattern, and 7-consecutive days pattern. Similarly, 3-consecutive days rainfall pattern into a 5-consecutive days pattern; and 5-consecutive days rainfall pattern into 7-consecutive days pattern. Therefore, longer-term rainfall patterns that result in inundation are more dangerous than shorter-term rainfall patterns. However, due to the relatively low number of 1-day rainfall events at the same time as during the 3-consecutive day occurrence (8.94%). Similarly, there was no rainfall pattern of 3-day occurrence during the period of 5-day rainfall occurrence. There was no rainfall pattern of a 5-day occurrence during period of 7-day rainfall occurrence, so the pattern of rainfall that may result in inundation designed for 3-consecutive days of rainfall patterns at Cang Long station.

Tieu Can station: There were in total 128 separate rainfall events that may result in inundation. In detail, 128 occurrences showed a 1-day rainfall pattern, 3 occurrences in 3-consecutive days rainfall pattern, with no events for 5-consecutive days and 7-consecutive

Appendix 2: Statistics 1-day and 3-consecutive daysrainfall in the period from 1982 to 2017 at Tra Cu station

Năm	*1-day (mm)*	*Day of appearance*	*3-consecutive days (mm)*	*Day of appearance*
1982	89,7	29/09	-	-
1983	52,8	22/06	-	-
1984	100	06/05	-	-
1985	-	-	-	-
1986	52	20/05	-	-
…	...	...	-	-
1990	70	22/6	-	-
1991	70	30/06	-	-
1992	120	25/07	-	-
1993	-	-	-	-
1994	55	31/07	-	-
1995	50,9	22/5	-	-
1996	126,5	16/10	-	-
1997	72	10/09	-	-
1998	-	-	-	-
1999	81,6	07/04	-	-
2000	64,9	08/06	-	-
2001	109,6	15/11	-	-
2002	79,6	16/06	-	-
2003	64,9	15/10	-	-
2004	81,1	17/05	-	-
2005	82,2	11/06	-	-
2006	65	08/08	-	-
2007	79,6	05/11	-	-
2008	1116,9	23/07	158.7	29/04
2009	105,2	05/05	-	-
2010	74,4	31/10	-	-
2011	90,2	12/05	-	-
2012	96,2	10/09	-	-
2013	141,6	24/05	-	-
2014	67,4	22/05	-	-
2015	77,4	18/10	-	-
2016	70,7	26/09	-	-
2017	88,6	11/08	-	-

days, with the potential of inundation. The rainfall pattern characteristics at Tieu Can station were similar to Cang Long station. Because the number of occurrences of long-term rainfall that can cause inundation is too low, the study could not conduct the development of a design rainfall pattern that may cause inundation at Tieu Can station.

Tra Cu station: A total of 85 separate rainfall events that may cause the inundation. Detailed analysis showed 85 1-day rainfall patterns, 1 occurrence in 3-consecutive days rainfall pattern, and no rainfall event for 5-consecutive days and 7-consecutive days, for the potential of Rainfall pattern characteristics at Tieu Can station were similar to Tra Cu and Tieu Can stations. Because the number of occurrences of long-term rainfall that can cause inundation is too low, the study could not conduct the development of a design rainfall pattern that may cause inundation at Tra Cu station.

The 3-Consecutive Days Rainfall Distribution Type Development

According to Hydrometeorological Station of Tra Vinh province. (2020), the total rainfall in Tra Vinh province ranged from 1.175 to 1.475 mm (in 2020). Tra Cu experienced 220 mm more rainfall than the same period in 2019; in contrast, Cang Long displayed 114 mm less rainfall, than the same period in 2019 and 170-330 mm less rainfall than the long-term average. Tieu Can alone represents an average over many years.

The results of the three rainfall patterns at Cang Long station are shown in Table 3. The 3-consecutive days of rainfall at Cang Long station display a peak of rainfall of mainly on the first day (PatternNo.1) 54.5%, followed by the peak of rainfall falling on the 3rd day (Pattern No. 3) 27.3%, and the peak of rain falling on the 2nd day (Pattern No. 2) 18.2%. Within Pattern No. 1, distribution type No. 2 accounts for the largest share, followed by distribution type No. 3. In Pattern No. 2, distribution type No. 2 accounts for the largest share. In Pattern No. 3, the 3 distribution type No. 3 has the most proportion. Thus, the popularity of the model distribution of rain may cause inundation designed for a 3-consecutive day in Cang Long was the peak of rain falling on the first day (Pattern No. 1) with distribution type No. 2.

According to Tâm & Chi (2020), a study of the wet season in Tra Vinh province from 1978 to 2019 revealed that the wet season was 7 months (from May to November) and the monthly rainfall varies greatly. In August, September, and October, the average rainfall is around 230–290 mm, whilst in heavy rain years, the total rainfall can reach nearly 500 mm/month. Furthermore, the annual average rainfall in Tra Vinh varies greatly over time. The difference in rainfall between the wettest and driest years can be up to 300 mm. Moreover,, the average number of rainy days per month is concentrated

Table 3: The number of rainfall distribution patterns of 3-consecutive days that result in inundation at Cang Long Station

No.	*Year*	*No. Rainfall may cause inundation*	*Pattern No. 1*			*Pattern No. 2*			*Pattern No. 3*		
			Type 1	*Type 2*	*Type 3*	*Type 1*	*Type 2*	*Type 3*	*Type 1*	*Type 2*	*Type 3*
1	1979										
…	…										
6	1984	1		1							
…	…										
10	1988	1			1						
…	…										
12	1990	1					1				
…	…										
18	1996	1		1							
19	1997	1		1							
20	1998	1									1
…	…										
23	2001	1		1							
...	…										
27	2005	1					1				
...	…										
30	2008	1									1
...	…										
33	2011	1								1	
...	…										
38	2016	1			1						
39	2017										
Total		**11**	**0**	**4**	**2**	**0**	**2**	**0**	**0**	**1**	**2**
Ratio %			**0**	**36.3%**	**18.2%**	**0**	**18.2%**	**0**	**0**	**9.1%**	**18.2%**
				54.5%			**18.2%**			**27.3%**	

in the months of May to October, which ranges from 17 to 22 days per month; in the changing seasons (April and November), the average number of rainy days is 5 to 10 days per month; and in the dry season months of December to March, the average number of rainy days is only 1 to 5 days per month. In addition, the average number of rainy days in Tra Vinh over many years showed a strong distribution over time. The difference in the number of rainy days between the years with the most, and the least rain is up to 88 days. According to Tam and Chi (2020), statistics on the number of rainy days ≥ 50 mm in the period 1978-2019 revealed that in the year of 2011, there were 13 days with the highest number of rainy days ≥50 mm; however, in 1991, the number of rainy days ≥ 50 mm occurred only once, and the average number of rainy days ≥50 mm was 4.9 days in Tra Vinh. Except for December, January, and February, the maximum daily rainfall in Tra Vinh from 1978 to 2019 was 167.5 mm (September 26, 1979) and the remaining months have more than 100 mm.

Determine the Design 3-Consecutive Day Rainfall Pattern

A total of 11 events with 3-consecutive day rainfall that may cause inundation were calculated and plotted with the cumulative frequency curve from the software from FFC2008 (Figure 4), showing that the average 3-consecutive day inundation rainfall was 180 mm, the coefficient of variation was, $C_v = 0.11$, and coefficients skewness, $C_s = 1.07$.

Design rainfall determination: for a design frequency of 10%, the value of rainfall for 3-consecutive days that

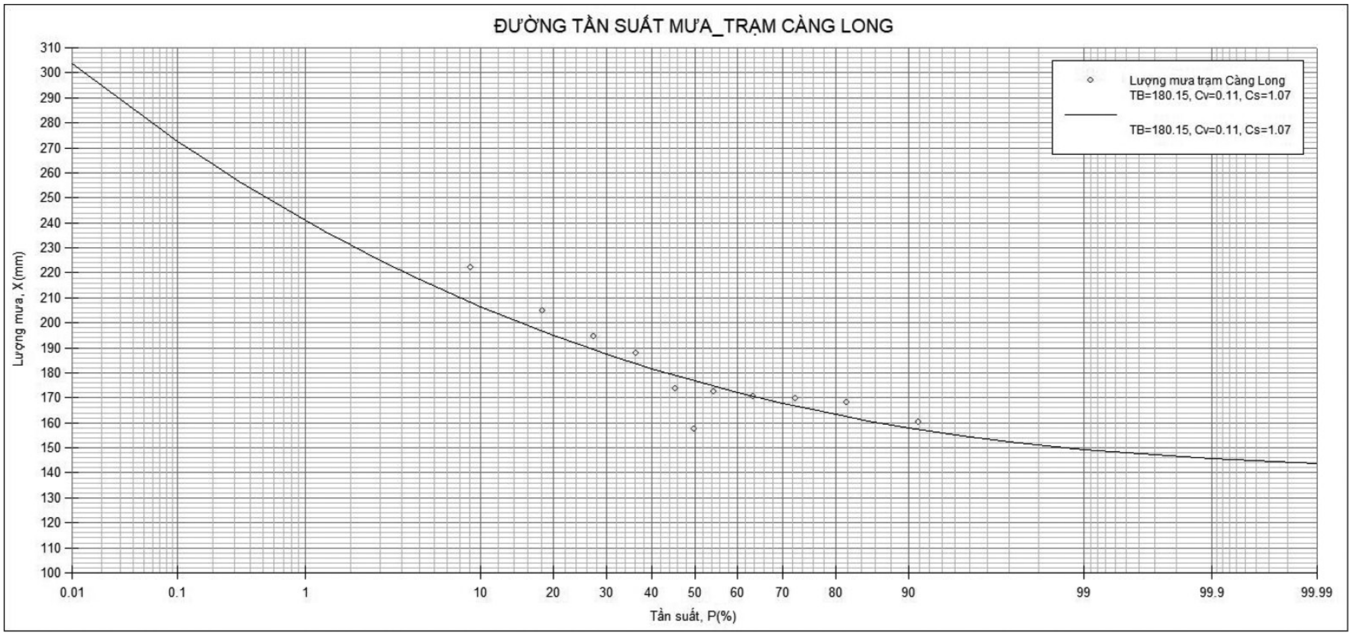

Figure 4: The cumulative frequency for 3-consecutive days of rainfall may cause inundation at Cang Long station, Tra Vinh province.

may cause design inundation was 217.5 mm

Select a typical rainfall distribution pattern year: The selected rainfall distribution pattern has occurred in nature, which means that the total rainfall was approximately equal to the total design of rainfall and similar to the rainfall distribution type. Table 4 shows the two rainfall pattern events that occurred in 1988 and 1997. The 3-consecutive day rainfall value in 1997 was close to the design rainfall with pattern No.1 and distribution type No.2, meanwhile, the rainfall pattern in 1988 deviated from the design rainfall, with pattern No.1 and distribution type No.3.

The most common and unfavourable occurrence was choosing the usual precipitation distribution patterns. The 3-consecutive day rainfall pattern that may cause inundation in Cang Long shows the peak of rainfall value falling on the first day (pattern 1) with the distribution type 2 and 3. However, rainfall with high last-day rainfall is an unfavorable pattern when compared to the distribution patterns of rain patterns (Thuy, 2020). The heaviest day of rainfall occurred on the first day in 1997, while the heaviest day of rainfall occurred on the third day in 1988. As a result, a 3-consecutive day rainfall pattern that may cause inundation in 1988 was chosen. Thereafter, the scale factor was calculated as K_p is 1,061 and Table 5 summarises the results of scaling to determine the design of the rainfall distribution pattern.

Table 4: A number of 3-consecutive days may cause inundation to occur in reality with rainfall approximately equal to the designed rainfall

Year	*X (mm)*	*Appearance time (from day/month to day/month)*	*Rainfall distribution for each day*		
			First day	*Second day*	*Third day*
1988	205	3/5 ÷ 5/5	153.1	13.6	38.3
1997	222.2	2/11 ÷ 4/11	122.9	54.4	44.9

Table 5: Typical rainfall distribution pattern design that may cause inundation

Rainfall distribution pattern	*Rainfall daily*			*Total of rainfall (mm)*
	The first	*The second*	*The third*	
Typical distribution pattern	153.1	13.6	38.3	205
Design distribution pattern (p=10%)	162.43	14.43	40.64	217.5

Appendix 3: The number of rainfall that may cause inundation in the pattern of 1-3-5-7 consecutive days of rainfall at Tieu Can station (1982-2017)

No.	*Year*	*No. Rainfall event may cause inundation*				
		Total	*1-day*	*3-cons. days*	*5-cons. days*	*7-cons. days*
1	1982	10	10	0	0	0
2	1983	2	2	0	0	0
3	1984	5	5	1	0	0
4	1985	0	0	0	0	0
5	1986	3	3	0	0	0
6	1987	2	2	0	0	0
7	1988	0	0	0	0	0
8	1989	4	4	1	0	0
9	1990	3	3	0	0	0
10	1991	1	1	0	0	0
11	1992	3	3	0	0	0
12	1993	3	3	0	0	0
13	1994	0	0	0	0	0
14	1995	6	6	0	0	0
15	1996	7	7	0	0	0
16	1997	7	7	0	0	0
17	1998	3	3	0	0	0
18	1999	5	5	0	0	0
19	2000	1	1	0	0	0
20	2001	2	2	0	0	0
21	2002	3	3	0	0	0
22	2003	1	1	0	0	0
23	2004	6	6	0	0	0
24	2005	3	3	0	0	0
25	2006	2	2	0	0	0
26	2007	6	6	0	0	0
27	2008	6	6	0	0	0
28	2009	2	2	0	0	0
29	2010	4	4	0	0	0
30	2011	5	5	0	0	0
31	2012	5	5	0	0	0
32	2013	4	4	0	0	0
33	2014	2	2	0	0	0
34	2015	1	1	0	0	0
35	2016	5	5	1	0	0
36	2017	6	6	0	0	0
Total		128	128	3	0	0
Ratio (%)		100	100	2.344	0	0

Appendix 4: The number of rainfall that may cause inundation in the pattern of 1-3-5-7 consecutive days of rainfall at Tra Cu station (1979-2017)

No.	*Year*	*No. Rainfall event may cause inundation*				
		Total	*1-day*	*3-cons. days*	*5-cons. days*	*7-cons. days*
1	1982	3	3	-	-	-
2	1983	1	1	-	-	-
3	1984	1	1	-	-	-
4	1985	1	1	-	-	-
5	1986	2	2	-	-	-
6	1987	1	1	-	-	-
7	1988	-	-	-	-	-
8	1989	-	-	-	-	-
9	1990	-	-	-	-	-
10	1991	1	1	-	-	-
11	1992	2	2	-	-	-
12	1993	1	1	-	-	-
13	1994	2	2	-	-	-
14	1995	1	1	-	-	-
15	1996	1	1	-	-	-
16	1997	5	5	-	-	-
17	1998	4	4	-	-	-
18	1999	6	6	-	-	-
19	2000	4	4	-	-	-
20	2001	1	1	-	-	-
21	2002	1	1	-	-	-
22	2003	3	3	-	-	-
23	2004	2	2	-	-	-
24	2005	3	3	-	-	-
25	2006	4	4	-	-	-
26	2007	1	1	-	-	-
27	2008	6	6	1	-	-
28	2009	1	1	-	-	-
29	2010	4	4	-	-	-
30	2011	5	5	-	-	-
31	2012	2	2	-	-	-
32	2013	5	5	-	-	-
33	2014	3	3	-	-	-
34	2015	3	3	-	-	-
35	2016	2	2	-	-	-
36	2017	4	4	-	-	-
Total		85	85	1	-	-
Ratio %			100	1.18		

Thus, the rainfall distribution pattern from May 3 to 5, 1988 was chosen as the typical rainfall distribution pattern that may cause inundation (X_{dh}) to determine the rainfall distribution pattern design with scale factor, K_p = 1.061.

Conclusion

In the case of the Cang Long station, the rainfall distribution pattern that may result in inundation with 3- consecutive day of rainfall with a peak occurring on the second or third day of with first rainfall day of less than 51 mm. The rainfall distribution pattern that was selected in favour of precaution was Pattern No. 1 with distribution type No. 3. It is extremely rare for a 3-consecutive day rainfall to result in inundation at Tieu Can and Tra Cu stations. Furthermore, the study discovered no long-term (5-consecutive day, 7-consecutive day) rainfall events at all three investigated stations in Tra Vinh. As a result, the study area needs to pay closer attention to the high intensity short-term rainfall events that result in inundation.

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