Assesment of Frequency-Magnitude of Extreme Rainfall Events-Case Study of the MeKong River Delta

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Abstract: Extreme rainfall events are primary natural hazards, which cause a severe threat to people and their properties in populated cities, which are normally located in coastal areas in Vietnam. Analysing these events by using a data series observed over years will support us to draw a picture of how the climate change impact on local environments. The purpose of this report is to understand the characteristics of the extreme rainfall events in MEKONG river delta (south VietNam). Daily rainfall data in the period of 30 years for a meteorological station in each area were collected from the Vietnam National Hydro-meteorological Service. The extreme rainfall events were defined as those exceeding the 95th percentile for each station. The analytical results show that the rainfall values (95th percentile) are 37.4 mm/day at Nam Can station, 27 mm/day at My Thanh station, 22.4 mm/day at Hoa Binh station, 23.8 mm/day at Binh Dai station and 22.7 mm/day at Ben Trai station. The highest rainfall data ever recorded are 246.4 mm/day (Nam Can), 174.5 mm/day (My Thanh), 179 mm/day (Hoa Binh), 187.3 mm/day (Binh Dai) and 136.3 mm/day (Ben Trai) during 1983-2012. The result of the Mann-Kendall tests show that there was a significant creasing of the rainfall at Nam Can, My Thanh station in two periods (1983-2012, 1998-2012) while no clear trend of the rainfall was recorded at Hoa Binh, Binh Dai, Ben Trai station. In order to estimate the return period of the extreme rainfall events, the method General Extreme Value Distribution was used to calculate frequent distribution. The magnitudes of daily maximum rainfall were from 2 to 100 years. The results of return period show that maximum rainfalls are 46.6 mm at Nam Can station (highest) and 31.4 mm at Hoa Binh station (lowest) during 50 years. Similarly, maximum rainfalls are expected to be about 55.1 mm at Nam Can station and 37.2 mm at Hoa Binh station for 100 years.

Key words: Generalized extreme value distribution, MEKONG river delta.

1. Introduction

In recent years, weather and climate tend complicated. The vagaries of weather and climate have a significant impact on the variability of meteorological factors, especially precipitation. The transformation of rainfall will affect the hydrological cycle and water resources in the climate system, leading to alter the mean values of temperature and precipitation, which increases the volatility of the phenomenon of rain strengthening or weakening causing floods or drought, especially for the MEKONG river delta region.

MEKONG river delta region has the tropical climate, hot and humid, influenced by monsoon

comprehensively. Each year there are two main seasons: rainy and dry season. Every year, there is considerable precipitation, average 1,400-2,200 mm/year. The months with rainy days are at least from December to March, varying from 0 to 8 rainy days/month. The months with the highest rainfall days are from May to October, varying from 15 to 21 rainy days/month. Precipitation is about from 78 to 92% in the rainy season.

Compared to other regions in the country, the rainfall in the study area has been changed little. But the remarkable matter is that the region has 2 rainy peaks: the first rainy peak in June, July; the second rainy peak in September, October 10. Between two rainy peak, from late July to early August, there has a short dry period lasting approximately 10 days due to

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the effects of anticyclone gust of winds on the high layer.

In this area, there are the biggest threats including the increasingly frequencies and more intense extreme climate events such as heavy rainfall events. In order to clearly understand the extreme rainfall characteristics and their associated consequences in MeKong river delta, daily rainfall data have been collected and analyzed for 30 years.

2. Material and Methods

Daily rainfall data recorded at 5 Meteorological Stations in MEKONG river delta for the period 1983-2012 (*NamCan-S1, MyThanh-S2, HoaBinh-S3, BinhDai-S4, BenTrai-S5*), they were collected from the Vietnam National Hydro-meteorological Service.

Recent studies indicate that the most useful method for detecting the trend was the non-parametric Mann-Kendall trend test. Mann (1945) originally found the test and then after Kendall (1975) developed and completed the test, which was known as the Kendall's tau statistic [1, 2]. This was the excellent tool for trend detection in different applications [3-5].

Under the null hypothesis H_0 , a series $\{x_1, \dots, x_N\}$ comes from a population where the random variables are independent and identically distributed (i.e. the null hypothesis is of no trend) the Mann-Kendall test statistic is:

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

$$\text{sign}(x) = 1 \text{ if } x > 0$$

$$\text{sign}(x) = 0 \text{ if } x = 0$$

$$\text{sign}(x) = -1 \text{ if } x < 0$$

A very high positive value of S is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend. However, it is necessary to compute the probability associated, with S and the sample size, n , to statistically quantify the significance of the trend. As such, S is calculated by using the above formula. The calculation of the variance of S , $\text{VAR}(S)$, is made by applying the following Eq. (2):

$$\text{VAR}(S) = \frac{1}{8} [n(n-1)(2n+5) - T] \quad (2)$$

$$T = \sum_{p=1}^g t_p(t_p - 1)(2t_p + 5)$$

Where, n is the number of data points, g is the number of tied groups (a tied group is a set of sample data having the same value), and t_p is the number of data points in the p th group. In the sequence $\{2, 3, \text{non-detect}, 3, \text{non-detect}, 3\}$, $n=6$, $g=2$, $t_1=2$ for the non-detects, and $t_2=3$ for the tied value 3. Computation of a normalized test statistic Z is made as:

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

$$Z = 0, S = 0$$

$$Z = \frac{S+1}{[\text{VAR}(S)]^{1/2}}, S < 0 \quad (3)$$

Then, it is needed to compute the probability associated with this normalized test statistic. The probability density function for a normal distribution with a mean of 0 and a standard deviation of 1 is given by the following Eq. (4):

$$f(z) = \frac{1}{\sqrt{2\pi}} e^{-\frac{z^2}{2}} \quad (4)$$

The trend is said to be decreasing if Z is negative and the computed probability is greater than the level of significance. The trend is said to be increasing if the Z is positive and the computed probability is greater than the level of significance. If the computed probability is less than the level of significance, there is no trend. To find the amount of increase or decrease in 30 years, the authors have adopted the least square linear fit of the data. Advantage of linear regression is that it provides an estimate of slope, confidence interval, and quantifies goodness of fit.

However, it does not handle missing data and may be greatly affected by outliers and cyclic data. As mentioned earlier in our case, the authors have removed the effect of missing days' observation by dividing the actual annual frequency with actual number of observation of that year and then multiplying by the number of days of that year. To

determine the extreme rainfall values for 5, 10, 25, 50 and 100 years, the return periods are calculated. Probabilistic extreme value theory, which primarily deals with the stochastic behavior of the maximum and minimum random variables, extreme and intermediate order statistics and exceedance over (below) high (low) thresholds are determined by the underlying distribution.

Traditionally, the three extreme value distributions are applied to annual maximum daily rainfall. In this study, the authors have used the generalized extreme value (GEV) distribution, which has all the flexibility of all the other extreme value distributions. The GEV distribution was developed by Jenkinson [6], Hosking et al. [7] and Galambos [8]. The cumulative distribution function (CDF) of the GEV distribution is:

$$F(x, \psi, \beta) = \exp(-1 + \zeta \frac{x - \psi}{\beta})^{-1/\zeta} \quad (5)$$

For $1 + \zeta(x - \psi)/\beta > 0$, where ψ , β and ζ are referred to as the location, scale and shape parameters respectively. The particular case of (1) for $\zeta \rightarrow 0$ is the Gumbel distribution:

$$F(x, \psi, \beta) = \exp(-\exp((\psi - x)/\beta)) \quad (6)$$

The median is:

$$\psi - \beta \ln(-\ln(1/2)) \quad (7)$$

The mean is $\psi + \gamma\beta$ where γ - EulerMascheroni constan ≈ 0.577215665 . The standard deviation is $\beta\pi/61/2$. The mode is ψ . Then from the Gumbel distribution with parameters ψ and β , the extreme value (return value) x for a period of n years can be written by the following formula: $x = \psi - \beta \ln [-\ln (F)]$. Note: ψ = average - $\gamma\beta$ (where γ is Euler's constant, approximately 0.557), and $\beta = 0.78\sigma$, with σ is the standard deviation. F is the random variety drawn from the uniform distribution in the interval $[0, 1] = (N-1)/N$.

3. Results

3.1 Trend Analysis

MEKONG river delta: The data analytical results

show that the monthly rainfalls vary from 3 mm to 408 mm within 30 years. Monthly average rainfall is at peaks in rainy season (months from May to October), and very low in other seasons, less than 100 mm (Fig. 1). Annual total rainfall in MeKong river delta are various from 110.5 mm to 2,963.8 mm (Fig. 2). Besides, the characteristic statistics of data in 30 years at 5 stations was shown in Tables 1-15. The measured data was divided into three different periods, each period was examined by the Mann-Kendall trend test (the first 1983-2012: *Period-1*, the second 1983-1997: *Period-2*, the third: 1998-2012: *Period-3*).

Fig. 1 Monthly mean rainfall (mm) at 5 station in MEKONG river delta.

Fig. 2 Annual rainfall (mm) at 5 station in MEKONG river delta (1983-2012).

Table 1 Descriptive statistics of data recorded at Nam Can station (S1).

Statistic	Period-1	Value	Percentile	Value
Sample size		10,950	Min	0
Range		246.4	5%	0
Mean		6.424	10%	0
Variance		240.1	25% Q1	0
Std. deviation		15.5	50% Median	0
Coef. of variation		2.412	75% Q3	4.5
Std. error		0.148	90%	23.19
Skewness		4.197	95%	37.445
Excess kurtosis		26.99	Max	246.4

* Period 1: 1983-2012.

Table 2 Descriptive statistics of data recorded at Nam Can station (S1).

Statistic	Period-2	Value	Percentile	Value
Sample size		5,475	Min	0
Range		246.4	5%	0
Mean		5.975	10%	0
Variance		232.5	25% Q1	0
Std. deviation		15.25	50% Median	0
Coef. of variation		2.552	75% Q3	3.2
Std. error		0.206	90%	21.9
Skewness		4.611	95%	35.6
Excess kurtosis		33.33	Max	246.4

* Period 2: 1983-1997.

Table 3 Descriptive statistics of data recorded at Nam Can station (S1).

Statistic	Period-3	Value	Percentile	Value
Sample size		5,475	Min	0
Range		218	5%	0
Mean		6.874	10%	0
Variance		247.5	25% Q1	0
Std. deviation		15.73	50% Median	0
Coef. of variation		2.288	75% Q3	5.8
Std. error		0.212	90%	24
Skewness		3.824	95%	39.4
Excess kurtosis		21.49	Max	218

* Period 3: 1998-2012.

Table 4 Descriptive statistics of data recorded at My Thanh station (S2).

Statistic	Period-1	Value	Percentile	Value
Sample size		10,950	Min	0
Range		174.5	5%	0
Mean		4.374	10%	0
Variance		139.4	25% Q1	0
Std. deviation		11.81	50% Median	0
Coef. of variation		2.699	75% Q3	1.8
Std. error		0.1134	90%	14.5
Skewness		4.716	95%	27
Excess kurtosis		32.36	Max	174.5

* Period 1: 1983-2012.

Table 5 Descriptive statistics of data recorded at My Thanh station (S2).

Statistic	Period-2	Value	Percentile	Value
Sample size		5,475	Min	0
Range		144.3	5%	0
Mean		4.137	10%	0
Variance		133.4	25% Q1	0
Std. deviation		11.55	50% Median	0
Coef. of variation		2.792	75% Q3	0.3
Std. error		0.156	90%	13.64
Skewness		4.425	95%	26.42
Excess kurtosis		25.84	Max	144.3

* Period 2: 1983-1997.

Table 6 Descriptive statistics of data recorded at My Thanh station (S2).

Statistic	Period-3	Value	Percentile	Value
Sample size		5,475	Min	0
Range		174.5	5%	0
Mean		4.611	10%	0
Variance		145.4	25% Q1	0
Std. deviation		12.06	50% Median	0
Coef. of variation		2.615	75% Q3	2.8
Std. error		0.164	90%	15.3
Skewness		4.967	95%	27.22
Excess kurtosis		37.72	Max	174.5

* Period 3: 1998-2012.

Table 7 Descriptive statistics of data recorded at Hoa Binh station (S3).

Statistic	Period-1	Value	Percentile	Value
Sample size		10,950	Min	0
Range		179	5%	0
Mean		3.671	10%	0
Variance		114.1	25% Q1	0
Std. deviation		10.68	50% Median	0
Coef. of variation		2.91	75% Q3	0.1
Std. Error		0.102	90%	11.5
Skewness		5.11	95%	22.445
Excess kurtosis		37.92	Max	179

* Period 1: 1983-2012.

Table 8 Descriptive statistics of data recorded at Hoa Binh station (S3).

Statistic	Period-2	Value	Percentile	Value
Sample size		5,475	Min	0
Range		130.3	5%	0
Mean		3.344	10%	0
Variance		98	25% Q1	0
Std. deviation		9.899	50% Median	0
Coef. of variation		2.961	75% Q3	0
Std. error		0.134	90%	10.6
Skewness		5.257	95%	20.3
Excess kurtosis		38.16	Max	130.3

* Period 2: 1983-1997.

Table 9 Descriptive statistics of data recorded at Hoa Binh station (S3).

Statistic	Period-3	Value	Percentile	Value
Sample size		5,475	Min	0
Range		179	5%	0
Mean		3.998	10%	0
Variance		130.1	25% Q1	0
Std. deviation		11.41	50% Median	0
Coef. of variation		2.853	75% Q3	0.4
Std. error		0.154	90%	12.7
Skewness		4.943	95%	24.94
Excess kurtosis		36.51	Max	179

* Period 3: 1998-2012.

Table 10 Descriptive statistics of data recorded at Binh Dai station (S4).

Statistic	Period-1	Value	Percentile	Value
Sample size		10,950	Min	0
Range		187.3	5%	0
Mean		3.942	10%	0
Variance		128.8	25% Q1	0
Std. deviation		11.35	50% Median	0
Coef. of variation		2.879	75% Q3	1
Std. error		0.109	90%	12.69
Skewness		5.106	95%	23.8
Excess kurtosis		37.12	Max	187.3

* Period 1: 1983-2012.

Table 11 Descriptive statistics of data recorded at Binh Dai station (S4).

Statistic	Period-2	Value	Percentile	Value
Sample size		5,475	Min	0
Range		133.6	5%	0
Mean		3.576	10%	0
Variance		115.4	25% Q1	0
Std. deviation		10.74	50% Median	0
Coef. of variation		3.004	75% Q3	0
Std. error		0.145	90%	11.6
Skewness		5.07	95%	22.62
Excess kurtosis		34.65	Max	133.6

* Period 2: 1983-1997.

Table 12 Descriptive statistics of data recorded at Binh Dai station (S4).

Statistic	Period-3	Value	Percentile	Value
Sample size		5,475	Min	0
Range		187.3	5%	0
Mean		4.308	10%	0
Variance		141.9	25% Q1	0
Std. deviation		11.92	50% Median	0
Coef. of variation		2.766	75% Q3	2
Std. error		0.161	90%	13.9
Skewness		5.095	95%	24.64
Excess kurtosis		38.03	Max	187.3

* Period 3: 1998-2012.

Table 13 Descriptive statistics of data recorded at Ben Trai station (S5).

Statistic	Period-1	Value	Percentile	Value
Sample size		10,950	Min	0
Range		219	5%	0
Mean		3.975	10%	0
Variance		133.1	25% Q1	0
Std. deviation		11.54	50% Median	0
Coef. of variation		2.903	75% Q3	1.1
Std. error		0.11	90%	13
Skewness		5.342	95%	24.645
Excess kurtosis		43.76	Max	219

* Period 1: 1983-2012.

Table 14 Descriptive statistics of data recorded at Ben Trai station (S5).

Statistic	Period-2	Value	Percentile	Value
Sample size		5,475	Min	0
Range		136.3	5%	0
Mean		3.561	10%	0
Variance		107.8	25% Q1	0
Std. deviation		10.38	50% Median	0
Coef. of variation		2.916	75% Q3	0.5
Std. error		0.14	90%	11.3
Skewness		4.808	95%	22.72
Excess kurtosis		31.18	Max	136.3

* Period 2: 1983-1997.

Table 15 Descriptive statistics of data recorded at Ben Trai station (S5).

Statistic	Period-3	Value	Percentile	Value
Sample size		5,475	Min	0
Range		219	5%	0
Mean		4.388	10%	0
Variance		158.1	25% Q1	0
Std. deviation		12.57	50% Median	0
Coef. of variation		2.865	75% Q3	1.9
Std. error		0.17	90%	14.44
Skewness		5.517	95%	26.5
Excess kurtosis		47.06	Max	219

* Period 3: 1998-2012.

The first period (1983-2012) with 10,950 samples at two S1 and S2 station, sign (Z) factor are also positive (index for a creased trend). That means existing the trend in two stations above with the level

of significance more than 0.95. There is no trend in other stations (S3, S4, S5) because $f(z)$ values are less than 0.95 (Table 16).

The second period (1983-1997) the number of sample is 5,475 but all $f(z)$ values are less than 0.95. Therefore, there is also no trend in all stations in this period (Table 17).

The third period (1998-2012), the number of sample is 5,475, there is no trend in three stations (S3, S4, S5) because $f(z)$ values of them are also less than 0.95. Existing the trend in two stations (S1 and S2) and these are the positive trends (sign (Z) factors having positive values, index for a creased trend) (Table 18).

3.2. Frequency Magnitude of Extreme Rainfall

With respect to the definitive period of N (year) (or F), it could be calculated X_0 (the value exceeds X determinant value). It means that, if X_0 , calculation of n can be made (this helps to confirm that after many years, X value would have occurred over the threshold $X_{01}, X_{02}, X_{03}, \dots$). On the other hand, the authors can do the same procedure for the extreme values. However, the increase of n goes with the increase of X value, and this increasing is limited.

The calculated results show that: the tends of rainfall on the maximum value within 5 years with value of 17.58 mm can occur by probability 20%, the maximum threshold may be reached 26.65 mm during

Table 16 The trend of extreme rainfall in period-1.

Station	S1	S2	S3	S4	S5
Sign (Z)	+	+	-	-	-
$f(Z)$	0.97	0.95	0.91	0.85	0.87

Table 17 The trend of extreme rainfall in period-2.

Station	S1	S2	S3	S4	S5
Sign (Z)	+	+	-	+	-
$f(Z)$	0.92	0.73	0.92	0.67	0.36

Table 18 The trend of extreme rainfall in period-3.

Station	S1	S2	S3	S4	S5
Sign (Z)	+	+	+	-	-
$f(Z)$	0.98	0.96	0.87	0.38	0.40

Table 19 Results of the return period based on GEV distribution at 5 stations.

Gen. extreme value (mm/day)						
Year	P*	S1	S2	S3	S4	S5
2	0.500	3.9	2.4	1.9	2.1	2.1
3	0.333	10.4	7.4	6.4	6.8	6.9
4	0.250	14.5	10.5	9.2	9.9	10.0
5	0.200	17.6	12.9	11.4	12.1	12.3
6	0.167	20.0	14.7	13.0	13.9	14.1
7	0.143	22.1	16.3	14.4	15.4	15.6
8	0.125	23.8	17.6	15.6	16.7	16.9
9	0.111	25.3	18.8	16.7	17.8	18.0
10	0.100	26.7	19.8	17.6	18.8	19.0
15	0.067	31.8	23.7	21.1	22.5	22.8
20	0.050	35.4	26.4	23.6	25.1	25.5
25	0.040	38.1	28.5	25.5	27.2	27.6
30	0.033	40.4	30.2	27.1	28.8	29.2
35	0.029	42.3	31.7	28.4	30.2	30.6
40	0.025	43.9	32.9	29.5	31.4	31.9
45	0.022	45.3	34.0	30.5	32.4	32.9
50	0.020	46.6	35.0	31.4	33.4	33.9
55	0.018	47.8	35.9	32.2	34.2	34.8
60	0.017	48.8	36.7	32.9	35.0	35.6
65	0.015	49.8	37.4	33.6	35.7	36.3
70	0.014	50.7	38.1	34.2	36.4	37.0
75	0.013	51.6	38.8	34.8	37.0	37.6
80	0.013	52.3	39.4	35.3	37.6	38.2
85	0.012	53.1	39.9	35.8	38.1	38.7
95	0.011	54.4	41.0	36.8	39.1	39.7
100	0.010	55.1	41.4	37.2	39.6	40.2

Probability density function (P).

10 years by probability 0.1. Probability of this event can be reducing to 0.05, 0.03, 0.02 and 0.01 in 20 years, 30 years, 50 years and 100 years later and the peaks of rainfall thresholds are 35.35 mm, 40.35 mm, 46.61 mm and 50.1 mm, respectively (Table 19, Fig 3).

3.3. Partial Duration Series in MEKONG River Delta

Another approach is to assemble the largest values regardless of their year of occurrence. This approach is generally known as peaks-over-threshold (POT) or partial-duration data. The POT approach and its associated Generalized Pareto (GP) model are sound. Selecting a proper threshold is most critical in POT.

Fig. 3 Probability density function at 5 stations in MEKONG river delta.

The POT time series over the annual 90th percentile has been considered and analyzed. The exceedances or partial duration (PD) series approach were adopted and Generalized Pareto (GP) model was fitted to the resulting series to estimate the recurrence interval (1 in 5, 10, 25 and 50 years). The results of the analysis are presented in Table 20 and the calculated parameters are given in Table 21. The highest variation of extreme rainfall at S1 station: About 52.3 mm rainfall is expected to occurrence in 50 years and 58.1 mm for the return period in 100 years. The lowest variation of extreme rainfall at S5 station: About 34.2 mm rainfall is expected to occurrence in 50 years and 41.8 mm for the return period in 100 years. The average for 5 stations: about 38.96 mm for the period of 50 years and 46.2 mm for the period of 100 years.

4. Conclusions

Extreme precipitation event is one of the most

Table 20 Estimation of return periods based on Generalized Pareto (GP) model

Gen. pareto value (mm/day)						
Year	P*	S1	S2	S3	S4	S5
02	0.500	3.86	2.62	1.93	2.11	2.05
05	0.333	16.4	13.1	12.0	12.7	14.1
25	0.250	40.2	29.3	28.7	28.6	27.8
50	0.200	52.3	38.2	35.4	34.7	34.2
100	0.167	58.1	45.4	43.6	42.1	41.8

Table 21 Parameters of General Pareto distribution fitted to Partial Duration Series (POT > 90%)

No parameters	Kolmogorov smirnov	Anderson darling	Chi squared
k = 0.66398			
S1 $\sigma = 2.4371$ $\mu = -0.82841$ k = 0.72243	0.38771	1,639.6	7,871.8
S2 $\sigma = 1.3496$ $\mu = -0.4883$ k = 0.75525	0.43242	2,006.7	9,443.2
S3 $\sigma = 0.98891$ $\mu = -0.36977$ k = 0.74833	0.46926	2,281.6	11,004.0
S4 $\sigma = 1.094$ $\mu = -0.40475$ k = 0.75079	0.44192	2,067.0	9,745.9
S5 $\sigma = 1.0913$ $\mu = -0.40463$	0.43817	2,038.7	9,626.5

recurrences at 5 stations in MEKONG river delta. In this study, the daily rainfall data measured at 5 stations for 30 years were analyzed and the recurrence interval of extreme events was calculated by using various probability distributions. Analytical results show that the extreme rainfalls (95th percentile) are about 37.4 mm/day at S1 station, 27 mm/day at S2 station, 22.4 mm/day at S3 station, 23.8 mm/day at S4 station and 24.6 mm/day at S5 station, respectively. The highest rainfalls ever were 246.4 mm/day at S1, 174.5 mm/day at S2, 179 mm/day at S3, 187 mm/day at S4 and 219 mm/day at S5. The Mann-Kendall tests indicated that there were significant creasing trends of rainfall at S1 station and S2 station during the first period and the third period with probability about 95-98%. Whereas, there was no statistically significant trends of rainfall at other stations. In order to estimate the return period of extreme rainfall events, the GEV distributions were used to calculate frequency distribution. The magnitudes of daily

maximum rainfall were from 2 to 100 years. The results of return period show that maximum rainfalls of 50 years are 46.6 mm at S1 station (the highest) and 31.4 mm at S3 station (the lowest). Similarly, maximum rainfalls are expected to be for 100 years about 55.1 mm at S1 and 37.2 mm at S3.

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