

Temporal trends features in consecutive days of extreme precipitation over China, 1951-2017

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सार – इस शोध पत्र में वर्ष 1951 से 2017 के दौरान चीन में अत्यधिक वर्षा (CDEP) वाले लगातार दिनों में कालिक प्रवृत्तियों की विशेषताओं और स्थानिक वितरण का विश्लेषण करने के लिए प्वायसन समाश्रयण को लिया गया है। चीन के मुख्य भाग में 31 प्रांत नगरपालिकाएँ अथवा स्वायत्तशासी क्षेत्र (प्रांतों के बारे में नीचे दिया गया है) हैं। प्राप्त हुए परिणामों से पता चला है कि नक्शे में कालिक रैखिक प्रवृत्तियाँ महत्वपूर्ण हैं। यहाँ 15 प्रांत हैं, जो कुल प्रांतों की संख्या का लगभग आधा है, इनमें कम होने का रुझान है। अन्य 16 प्रांतों में वृद्धि का रुझान दिखा है। 19 प्रांतों ने महत्वपूर्ण परीक्षण पारित किया। FEP के रुझानों के लिए अनहुई, प्रोजिंग, चोंगकिंग, फुजिआन, गुआंगडोंग, गुआंगशी, हैनान, हुनान, जियांगशी, किंगघाई, सिचुआन, झिजियांग, झिजांग और युन्नान सभी वृद्धि की प्रवृत्तियों को दर्शाते हैं जबकि बीजिंग और सिचुआन घटती हुई प्रवृत्तियों को प्रदर्शित करते हैं। अस्थायी प्रवृत्तियों के लिए अत्यधिक वर्षा वाले लगातार दिनों के प्रतिशत 99 के आसपास हैं। वहाँ 9 प्रांत हैं जिन्होंने महत्वपूर्ण परीक्षण पारित किए हैं, वे हैं गुआंगडोंग, गुआंगशी, हुनान, हेबेई, नेमिंगू, शांसी, शिजियांग, किंगघाई और शिजांग। जबकि वहाँ भिन्न-भिन्न थ्रेशहोल्ड पर काफी भिन्नता वाले प्रतिशतक 90 से अधिक हैं और केवल तीन प्रांत हैं जिनका प्रतिशतक 95 है जो CDEP में महत्वपूर्ण कालिक प्रवृत्तियों को प्रदर्शित करते हैं, वे हैं शिजियांग, शिघाई और शिजांग।

ABSTRACT. In this study, Poisson regression has been undertaken to analyze the temporal trends features and spatial distributions in the consecutive days of extreme precipitation (CDEP) over China, 1951-2017. In China mainland, there are 31 provinces, municipalities or autonomous regions (referred to as provinces below). Results showed that the temporal linear trends in MAP is significant. There are 15 provinces, almost half of the total numbers of provinces, showed decreasing trends. The other 16 provinces showed increasing trends. 19 provinces passed the significance test. For the trends of FEP, Anhui, Beijing, Chongqing, Fujian, Guangdong, Guangxi, Hainan, Hunan, Jiangxi, Qinghai, Sichuan, Xinjiang, Xizang and Yunnan all show increasing trends, while Beijing and Sichuan exhibited decreasing trends. For the temporal trends for consecutive days of extreme precipitation over the threshold of the 99th percentile. There are 9 provinces passed significance test, which are Guangdong, Guangxi, Hunan, Hebei, Neimenggu, Shanxi, Xinjiang, Qinghai and Xizang. While there exist much different over different thresholds, over the threshold of the 90th percentile and 95th percentile, there are only three provinces, showing significant temporal trends in CDEP, which are Xinjiang, Qinghai and Xizang.

Key words – Extreme precipitation, Mean annual precipitation, China.

1. Introduction

There have been a number of researches on the trends of precipitation in many countries. In Australia, except the southwest, extreme rainfall events in most of the rest areas have increasing trends [Suppiah and Hennessy (1998)]. However, in Poland, Lupikasza (2010) found that the most indicators he selected of the extreme precipitation showed downward trends. In Korea, the annual rainfall was increasing significantly, which associated with the increasing frequency and intensity of summer heavy rainfall [Jung, *et al.* (2011)].

Pavan *et al.* (2008) pointed out that in Emilia-Romagna (a region of northern Italy), the frequency of heavy rainfall in summer was increasing, while decreasing in autumn and winter.

In China, many researches have focused on the precipitation in recent years, but having found no significant trends of annual total precipitation. Precipitation varies greatly by season and region. In most areas of China, the number of rain days has decreased, but the intensity has increased significantly [Zhai *et al.* (2005)]. In the eight climatic regions of China, except the

northwest of China, the frequency of precipitation has decreased in all other regions [Liu *et al.* (2005)]. As for extreme precipitation changes in China, a number of researches have been carried out. Throughout the Loess Plateau region, the extreme precipitation has experienced no significant changes [Li *et al.* (2010)]. In the Yangtze River Basin, the frequency rather than intensity of rainstorm increased [Su *et al.* (2006)]. Wang *et al.* (2013) studied the trends in extreme events of precipitation over Xinjiang, the results indicated that most of the ten indices they employed showed an increasing trend in the north, while a decreasing trend in the south. On the east of Xizang Plateau and in the Hengduan Mountains, the number of rain days increased as a whole [Li *et al.* (2012)]. Wang *et al.* (2013) investigated the precipitation changes in the arid area of northwestern China; they found that most precipitation indices they used indicated increasing trends. Over northeast China, the contribution of extreme precipitation to total precipitation decreased [Wang *et al.* (2013)]. In the Zhujiang River Basin, almost no significant trends in extreme precipitation have been detected [Fischer *et al.* (2011)]. From the national scope, trends in the number of extremes are generally consistent with the trends of total precipitation from non-extreme events, except the southwest of China, where the number of extreme events is increasing, while decreasing in total non-extreme precipitation [Zhai *et al.* (2005)]. Meanwhile, the amount and the days of annual extreme precipitation have increased by 10.9 mm and 0.12 days respectively [Xu *et al.* (2011)]. Qian and Lin (2005) explored the regional trends in precipitation indices over China during 1951 to 2000. Their research indicated that in the last two decades, the persistent wet days and strong rainfall have contributed to the increasing frequency of floods in southeast China and the Xinjiang region.

2. Data and methodology

Daily precipitation data were obtained from 756 stations of Chinese National Meteorological Center from 1951 to 2017. After removing those stations who have many missing values, 647 stations have been preserved. In previous studies of climate extremes, the main methods are simple linear regression, least square method and Mann-Kendall trend test [Jung *et al.* (2011); Gemmer *et al.* (2010); Lupikasza (2010); Jiang *et al.* (2013)]. In this study, we applied Poisson regression to detect trends at all 31 provinces for the consecutive days of extreme precipitation (CDEP). For threshold selection, arbitrary threshold has been used by numerous studies, such as Domroes and Peng (1988) and Groisman *et al.* (1999). But Monton *et al.* (2001) indicated that arbitrary thresholds are inappropriate for regions spanning a broad range of climates. So we used 90th, 95th and 99th percentile of daily

rainfall to represent the threshold of extreme precipitation separately respectively. Extreme precipitation can increase floods probably. Persistent extreme precipitation can cause further damage and injury. So it has practical significance for investigating the trends of consecutive days of extreme precipitation.

In order to model expected outcomes based on information from several variables, regression analysis is an effective way [Gray *et al.* (1992, 1993, 1994); Landsea *et al.* (1994); Nicholls (1999)]. However, using linear regression analysis should satisfy the linearity conditions. When the observed data are a relatively small number of counts from a large sample size, the assumptions break down. The occurrence of rare, discrete events, such as tornado counts, the occurrences of droughts, or cold spells are often modeled by Poisson distribution [Wilks (1995)]. The Poisson distribution often restricts the possible outcomes to non-negative integers, making it ideal for modeling tropical cyclone occurrences [Elsner and Schmertmann (1993)]. In this study, we apply Poisson Regression to explore the temporal trends features of CDEP. We want to analyze the change features of consecutive days of extreme precipitation (CDEP). We should notice that the dependent variables CDEP here are count variables. The variable measures the count of CDEP. Poisson regression is a member of the generalized linear model [Dobson (2002)]. Here, we assume any precipitation event j results in the number of CDEP in any one year from 1951-2017, say N_j . Then, assume the number of precipitation events in any one year, say M . Note that this implies there will be days with no extreme precipitation events (when $M = 0$). The maximum Y_i , in the i^{th} year during 1951-2017, can be found as the Poisson random variables, so that

$$Y_i = \max(N_1, N_2, \dots, N_M) \quad (1)$$

where, CDEP is countable variable and Y_i follows a Poisson distribution [Dunn (2004)]. We calculate CDEP at all stations in every province firstly. Then we can apply Poisson Regression model to analyze the trends features of CDEP over time. Here the probability distribution, that is, the probability of occurrence of exactly y CDEP, is given by:

$$\Pr(Y_i = y) = \frac{\mu_i^y \exp^{-\mu_i}}{y!}, \quad y = 0, 1, 2, \dots, \infty \quad (2)$$

where, μ_i is

$$\ln(\mu_i) = \beta_0 + \beta_1 X \quad (3)$$

Here, X denotes the time sequence from 1951 to 2017, which has been standardized.

TABLE 1

Thresholds of extreme precipitation at 31 provinces (mm)

S. No.	Province	Q90	Q95	Q99
1.	Xinjiang	6.7	10.3	20.4
2.	Qinghai	9.7	13.5	22.5
3.	Xizang	10.9	15.3	25.6
4.	Gansu	11.4	16.8	31.7
5.	Ningxia	12.4	18.9	36.3
6.	Neimenggu	12.3	19.2	39.1
7.	Heilongjiang	14.8	22.4	43.2
8.	Sichuan	15.4	23.8	55.2
9.	Jilin	16.9	25.7	50.7
10.	Shanxi	17.4	25.9	49.7
11.	Shaanxi	18.4	27.6	52.2
12.	Guizhou	18.4	29.4	60.4
13.	Yunnan	20.7	30.1	55.3
14.	Hebei	20.3	31.7	66.1
15.	Chongqing	20.9	32.6	64.7
16.	Henan	22.4	34.9	72.6
17.	Shanghai	24.5	36.0	71.7
18.	Liaoning	23.4	36.5	74.7
19.	Zhejiang	24.7	36.6	72.4
20.	Hunan	24.7	37.0	72.3
21.	Tianjin	23.7	37.2	79.9
22.	Hubei	24.3	37.5	75.0
23.	Beijing	24.6	38.5	79.9
24.	Jiangsu	25.0	39.1	80.95
25.	Shandong	25.1	39.9	82.5
26.	Anhui	26.6	41.0	84.3
27.	Fujian	28.0	41.1	77.5
28.	Jiangxi	28.6	41.8	78.6
29.	Guangxi	29.0	44.9	94.7
30.	Guangdong	32.9	50.4	103.4
31.	Hainan	33.6	53.6	121.3

TABLE 2

List of temporal trends in Mean Annual Precipitation (MAP)

Name	MAP
Anhui	0.01384
Beijing	-0.03729**
Chongqing	0.019903 ***
Fujian	0.025563***
Gansu	-0.013866 ***
Guangdong	0.024078**
Guangxi	0.022420 ***
Guizhou	0.004079
Hainan	0.037214 ***
Hebei	-0.01213·
Heilongjiang	-0.030012 ***
Henan	-0.004744
Hubei	0.004179
Hunan	0.005594
Jiangsu	0.016105*
Jiangxi	0.016416 *
Jilin	-0.02986 ***
Liaoning	-0.020691 **
Neimenggu	-0.021034 ***
Ningxia	-0.009371·
Qinghai	-0.009596 ***
Shaanxi	-0.006893
Shandong	-0.012721
Shanghai	0.02612·
Shanxi	-0.008341
Sichuan	0.000340
Tianjin	-0.006025
Xinjiang	0.0004265
Xizang	-0.005415*
Yunnan	0.014025***
Zhejiang	0.005170

Symbols : '***', '**', '*', '·' indicates that the significance level is 0.001, 0.01, 0.05, 0.1 respectively.

3. Results and discussion

In China mainland, there are 31 provinces. Annual rainfalls of 31 provinces vary greatly. For the period over

1951-2017, the maximum daily precipitation of Hainan is 633.8 mm, while Xinjiang is only 79.7 mm. The distribution of precipitation at 31 provinces is in deeply imbalance. Most studies adopt a percentile as the

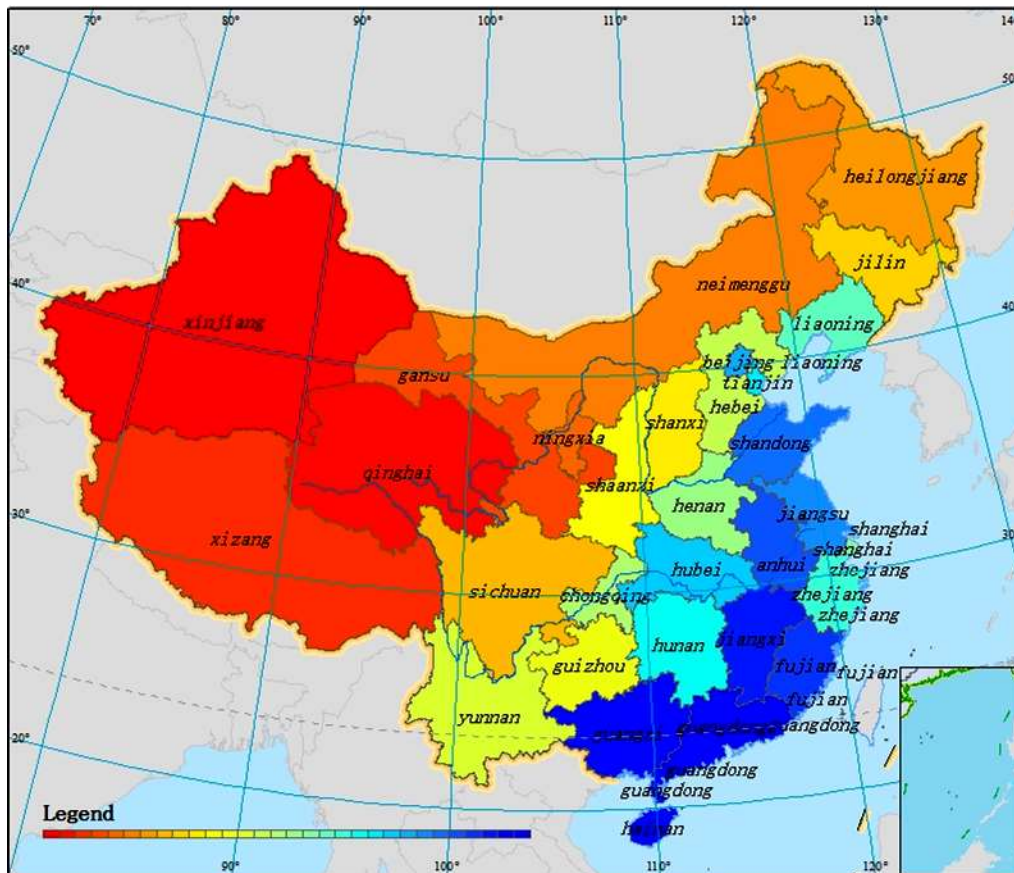


Fig. 1. Thresholds of extreme precipitation in 31 provinces

threshold for an extreme value. Threshold of extreme precipitation is a very important factor. It determines the extreme degree and damage degree. In this study, we adopt the 90th, the 95th and the 99th percentile of the daily rainfalls during the whole time series from 1951 to 2017 as the threshold for the extreme precipitation respectively.

Table 1 shows the thresholds of extreme precipitation at 31 provinces. The thresholds of extreme precipitation vary greatly both in different provinces and percentiles. For example, the minimum is only 6.7 mm as the 90th percentile in Xinjiang, whereas, it is 20.4 mm as the 99th percentile. The maximum is 33.6 mm in Hainan as the 90th percentile, while it is 121.3 mm as the 99th percentile. The thresholds for the 95th percentile of extreme precipitation in Xinjiang, Qinghai, Xizang, Gansu, Ningxia and Neimenggu are lower than 20 mm. The six provinces are all located in the northwest of China. Fujian, Anhui, Jiangxi, Guangxi, Guangdong and Hainan possesses thresholds higher than 40 mm. Except Anhui province, all the others are coastal provinces. And the six provinces are seated in the southeast of China. The

threshold of the 90th percentile is much lower. It is lower than 10 mm in Xinjiang and Qinghai. While the threshold of the 99th percentile is much higher, it is high up to 103.4 mm and 121.3 mm in Guangdong and Hainan. There are only 8 provinces whose threshold of the 99th percentile is lower than 50 mm.

Fig. 1 shows the spatial distribution of thresholds for the 95th percentile, which increased gradually from west to east and from north to south. The west parts have the lowest thresholds and the southern coastal areas have the highest one. Colors in Fig. 1 change from red to yellow and then to blue, representing the thresholds ranging from low to high.

The temporal linear trends in Mean Annual Precipitation and Frequency of Extreme Precipitation over 31 provinces are tested and shown in Tables (2&3) respectively. Mean annual precipitation is referred to as MAP. There are 15 provinces, almost half of the total numbers of provinces, showed decreasing trends. The other 16 provinces showed increasing trends. 19 provinces passed the significance test.

TABLE 3

List of temporal trends infrequency of extreme precipitation (FEP)

Name	FEP(Q90)	FEP(Q95)	FEP(Q99)
Anhui	0.05802***	0.030157**	0.006959
Beijing	-0.03799*	-0.03771 **	-0.018597**
Chongqing	0.02272	0.02125·	0.009883 *
Fujian	0.04206*	0.02811*	0.007888*
Gansu	0.002107	-0.005410	-0.002200
Guangdong	0.04005*	0.024951*	0.004988·
Guangxi	0.03316*	0.023285*	0.008125**
Guizhou	-0.003534	0.005562	0.004537
Hainan	0.04009*	0.02612 *	0.005637
Hebei	-0.008313	-0.004571	-0.002800
Heilongjiang	0.008222	0.003894	0.000116
Henan	0.007647	0.002439	-0.001382
Hubei	0.02582	0.01409	0.004497
Hunan	0.03064·	0.02080·	0.009577*
Jiangsu	0.01625	0.013150	0.005321
Jiangxi	0.05906**	0.03352*	0.007313·
Jilin	-0.001843	-0.0006307	-0.000732
Liaoning	-0.01099	-0.007803	-0.002840
Neimenggu	0.003038	-0.0008047	-0.001519
Ningxia	0.005886	0.004325	-0.002522
Qinghai	0.09086***	0.045237***	0.009354***
Shaanxi	0.008445	0.004931	0.004045·
Shandong	-0.009189	-0.005731	-0.002671
Shanghai	0.04602	0.02030	0.01448
Shanxi	0.006352	-0.004335	-0.001376
Sichuan	-0.020563 *	-0.012382*	-0.004846*
Tianjin	-0.02121	-0.014732	-0.0009272
Xinjiang	5.751e-02***	0.028909***	0.006565***
Xizang	0.05867***	0.032665***	0.010231***
Yunnan	0.02541 *	0.021075 **	0.006824***
Zhejiang	0.002408	-0.0001083	0.0002815

Symbols: '****', '***', '**', '·' indicates that the significance level is 0.001, 0.01, 0.05, 0.1 respectively.

TABLE 4

List of temporal trends in consecutive days of extreme precipitation (CDEP)

Province	CDEP(Q90)	CDEP(Q95)	CDEP(Q99)
Anhui	-	-	-
Beijing	-	-	-
Chongqing	-	-	-
Fujian	-	-	-
Gansu	-	-	-
Guangdong	-	-	0.05574·
Guangxi	-	-	0.07513*
Guizhou	-	-	-
Hainan	-	-	-
Hebei	-	-	-0.09534·
Heilongjiang	-	-	-
Henan	-	-	-
Hubei	-	-	-
Hunan	-	-	0.05577·
Jiangsu	-	-	-
Jiangxi	-	-	-
Jilin	-	-	-
Liaoning	-	-	-
Neimenggu	-	-	-0.05692·
Ningxia	-	-	-
Qinghai	0.07488***	0.065230**	0.12676***
Shaanxi	-	-	-
Shandong	-	-	-
Shanghai	-	-	-
Shanxi	-	-	-0.10365*
Sichuan	-	-	-
Tianjin	-	-	-
Xinjiang	0.08346***	0.10334***	0.19058***
Xizang	0.05441*	0.05868·	0.11862**
Yunnan	-	-	-
Zhejiang	-	-	-

Symbols: '****', '***', '**', '·' indicates that the significance level is 0.001, 0.01, 0.05, 0.1 respectively.

Frequency of extreme precipitation is referred to as FEP. The trends of FEP are also obvious increasing. For instance, considering the temporal trends in frequency of extreme precipitation over the thresholds of the 95th

percentile, there are 14 provinces passed the significance test. The 14 provinces are Anhui, Beijing, Chongqing, Fujian, Guangdong, Guangxi, Hainan, Hunan, Jiangxi, Qinghai, Sichuan, Xinjiang, Xizang, Yunnan. Except



Fig. 2. Provinces with significant changes in CDEP

Beijing and Sichuan, the other 12 provinces all exhibited an increasing trend, which is different from the trends of MAP. Moreover, there are very few changes in the trends over different thresholds.

In this part, we focus on the consecutive days of extreme precipitation (CDEP) at the 31 provinces during 1951-2017. Extreme precipitation itself is a double-edged sword, which is especially true for persistent extreme precipitation. For water-lacked provinces, heavy precipitation may supply freshwater resources. But for coastal areas, it may cause severe disasters. Results are showed in Table 4. Among 31 provinces, there are only 9 provinces passed significance test for the trends in consecutive days of extreme precipitation over the threshold of the 99th percentile. The 9 provinces are Guangdong, Guangxi, Hebei, Hunan, Neimenggu, Qinghai, Shanxi, Xinjiang and Xizang. While for the trends in consecutive days of extreme precipitation over the threshold of the 90th percentile and 95th percentile, there are only three provinces, Qinghai, Xinjiang, Xizang, which show increasing trends. Moreover, Qinghai, Xinjiang, Xizang are all located in the Northwest of China.

Guangdong, Guangxi and Hunan are adjacent to each other and located in the south of China. Hebei, Neimenggu and Shanxi are next to each other and in the north of China. There are remarkable regional features as shown in Fig. 2.

As showed by Fig. 2, the provinces showing significant decreasing trends in CDEP are Neimenggu, Shanxi and Hebei, which show yellow. The provinces have significant increasing trends in CDEP are Xinjiang, Xizang, Qinghai, Hunan, Guangdong and Guangxi, which show blue.

4. Conclusions and recommendation

Based on historical observation data and Poisson Regression, the study analyzed the temporal trends of MAP, FEP, CDEP and spatial distributions. Results showed that the temporal linear trends in MAP is significant. There are 15 provinces, almost half of the total numbers of provinces, showed decreasing trends. The other 16 provinces showed increasing trends. 19 provinces passed the significance test. For the trends of FEP, there

are very few changes over different thresholds. There are 14 provinces passed the significance test. The 14 provinces are Anhui, Beijing, Chongqing, Fujian, Guangdong, Guangxi, Hainan, Hunan, Jiangxi, Qinghai, Sichuan, Xinjiang, Xizang, Yunnan. Except Beijing and Sichuan, the other 12 provinces all exhibited an increasing trends.

For the temporal trends for consecutive days of extreme precipitation over the threshold of the 99th percentile. There are 9 provinces passed 90% significance test. While there exist much different over different thresholds, over the threshold of the 90th percentile and 95th percentile, there are only three provinces, who show significant temporal trends in CDEP. For Xinjiang, Qinghai and Xizang, they all show decreasing trends in MAP, while significant increasing trends in FEP and CDEP. However, since they have the lowest thresholds of extreme precipitation in China, the extreme precipitation won't cause much harm to them. For Guangdong, Guangxi and Hunan, the trends of CDEP are increasing and the threshold of the 99th percentile of extreme precipitation are up to 103.4 mm, 94.7 mm and 72.3 mm respectively. The consecutive occurrence of extreme precipitation may probably cause damage. So relevant department of governments should take seriously and work out effective measures. The other three provinces, Hebei, Neimenggu and Shanxi, showing decreasing trends in CDEP.

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