PAPER • OPEN ACCESS

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To cite this article: Shouwen Liu *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **300** 032043

Analysis of Impacts of Extreme Precipitation in Kaizhou on Wanzhou-Dazhou Expressway Transportation

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Abstract. Based on the rainfall data of Kaizhou, the characteristics of extreme precipitation in Kaizhou from 1960 to 2016 and its influence on transportation are analyzed. The results show that, the number of rainy days was noticeably large before 1980s in Kaizhou, and the number of rainy days was more than 200d from 1973 to 1979. However, the number of rainy days decreased rapidly and basically kept stabile below 150d after 1980s. The threshold value of extreme precipitation events is 20mm in Kaizhou, and the annual average value of extreme precipitation events is 18d. The western Pacific subtropical high pressure extended westward in 2006, and inclined to the west and north, compared with the previous years. Besides, it was stable and maintained for a long time. These gave rise to severe drought in Chongqing in 2006 and further resulted in the decrease of extreme precipitation events in Kaizhou in 2006. There are 3 dangerous areas where weather influencing factor is extreme precipitation in Kaizhou section of Wanzhou-Dazhou Expressway, and they are located at S002 K9+593-K20, S002 K0-K9+593, and S002 K20-K30. Kaizhou section of Wanzhou-Dazhou expressway suffered 7 road closure controls due to extreme precipitation from 2011 to 2014. In 2014, 4 road closures were caused due to frequent extreme precipitation. Strengthening the forecast of extreme precipitation events can reduce occurrence frequency of traffic accidents and give play to the maximum effect of road transportation.

1. Introduction

All Due to the impacts of global warming, extreme precipitation frequency and intensity across the country including Chongqing show the obvious strengthening trend. Influenced by East Asian monsoon, southwest vortex, low-pressure trough and cold air systems, the climate in Chongqing is mild and moist; rainfall is plentiful; rainstorm, downpour and other extreme precipitation events occur frequency. High mountains in Chongqing have obvious obstruction effect on the weather system so that the precipitation increases, and the duration of rainfall lengthens, which is more beneficial to generation of extreme precipitation. Rainstorm centers in Chongqing are located in the intersection area of Daba Mountain range and Wushan Mountain range, and the southeast part of Wuling Mountain. In Chongqing, the meteorological disasters which most impact road traffic mainly include extreme precipitation, dense fog, gale, snowfall and low-temperature freezing, etc. Protecting life and property security, avoiding and reducing traffic accident loss have become a common sense of governments at all levels and the public. Objectively, the meteorological department is urgently required to carry out the research on extreme precipitation in the mountainous area of Chongqing, actively implement road traffic meteorological monitoring, warning and forecasting services to enhance scientific scheduling and management of road transportation, reduce disaster loss and give play to the maximum benefit of road transportation.

As the awareness of disaster prevention and reduction is enhanced, domestic and overseas weather researchers have carefully analyzed the variation trend of heavy rainfall climate in various places from multiple aspects [1-10]. Scientific researchers in Chongqing also have carried out lots of scientific research work for distribution characteristics and formation reasons of local heavy rainfall weather [11-18]. However, the studies on the influence of extreme precipitation on transportation in Kaizhou, Chongqing and other mountainous areas from the extreme precipitation index are still few.

2. Data and method

Daily precipitation data of Kaizhou Weather Station in Chongqing from 1960 to 2016 came from ground daily dataset of data sharing platform at Chongqing Meteorological Information Center. The dataset is edited according to the rules of statistical approach document of China's ground climate data.

Definition of extreme precipitation index: World Meteorological Organization proposed a set of extreme climate indexes in the climate change monitoring conference from 1998 to 2001, and they became the uniform standards for climate change research. Among them, 27 indexes are considered as the core indexes. They are calculated through daily air temperature and daily rainfall data, with the features of weak extremity, low noise and strong significance. By referring to the above indexes, 6 extreme climate indexes are chosen to analyze extreme precipitation characteristics, including extreme precipitation events, days of heavy rain, days of rainstorm, precipitation intensity, annual rainy days and annual precipitation. The threshold value of extreme precipitation events is also defined according to the precipitation. 95 percentile value of daily precipitation in Kaizhou from 1960 to 2016 is defined as the threshold value of extreme precipitation events. When the daily precipitation is greater the threshold value, we consi9der extreme precipitation event occurs.

Table 1. Definition of extreme precipitation index.

Code	Name	Definition	Unit
PRCPTOT	Annual precipitation	≥0.1 mm rainfall accumulation	mm
R0.1	Annual rainy days	Days with daily precipitation≥0.1 mm	d
SDII	Precipitation intensity	Days with annual precipitation/≥0.1mm	mm/d
R50	Rainstorm days	Days with daily precipitation≥50 mm	d
R25	heavy rain days	Days with daily precipitation≥25 mm	d
R95p	Extreme precipitation event	Days with daily precipitation> 95% fractile	d

3. Results and analysis

3.1. Variation trend of extreme precipitation events

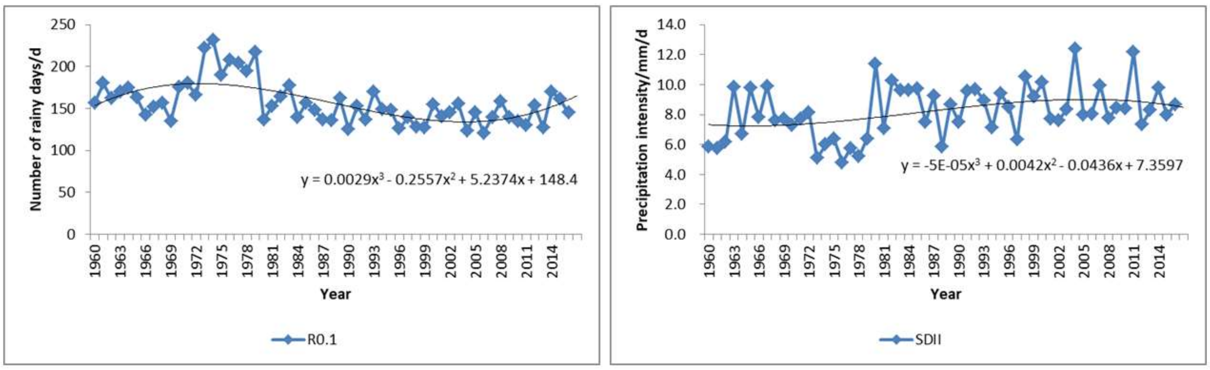
Through statistical analysis of annual precipitation in Kaizhou, it is found that annual mean precipitation of Kaizhou from 1960 to 2016 was 1261.0 mm; annual maximum precipitation was 1716.4 mm, which appeared in 1983; annual minimum precipitation was 795.8 mm which appeared in 1988. The precipitation in Kaizhou from 1960 to 1962 was low, and kept below 1000 mm. The precipitation was high from 1963 to 1967, and then declined. From 1980 to 1983, the precipitation was plentiful, and then started to decrease year by year fast. In 1988, the precipitation was only 795.8 mm, indicating that climate change in Kaizhou accelerated in the whole 1980s, extreme weathers increased and severe drought and flood happened frequently. After 1989, the precipitation in Kaizhou basically kept stable.

Fig.1 shows year distribution diagram of extreme precipitation index in Kaizhou. It can be seen from the figure that, annual mean number of rain days in Kaizhou is 157 d; annual maximum number of rain days is 232 d, which appeared in 1974. But, the precipitation in 1974 was only 1389.6 mm, indicating although the number of rainy days was large in 1974, heavy rain and rainstorm process in the

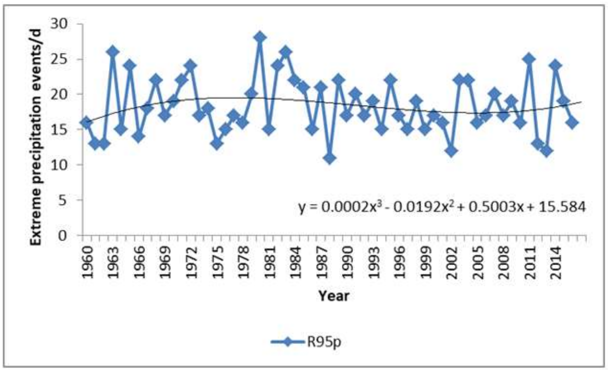
IOP Conf. Series: Earth and Environmental Science **300** (2019) 032043 doi:10.1088/1755-1315/300/3/032043

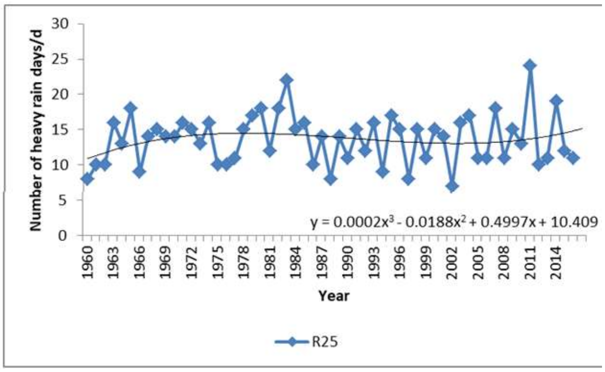
midsummer were not many. The weather was dominated by light rain in spring, autumn and winter. The annual minimum number of rainy days is 121 d, which appeared in 2006. In 2006, Chongqing suffered severe drought, and the continuous high temperature and little rain resulted in fast soil moisture loss. In addition, summer drought developed and aggravated fast. The drought-affected population in Chongqing reached 21 million, and 8.204 million of people were caught in the temporary drinking difficulty. The damage area of crops was 1.327 million hectares, and 375000 ha crops totally failed. The direct economic loss reached RMB 9.07 billion Yuan. Under the general background of global circulation system adjustment in 2006, the western Pacific subtropical high pressure extended westward, and inclined to the west and north, compared with the previous years. Besides, it was stable and maintained for a long time. These gave rise to the severe drought in Chongqing in 2006 and further caused the number of rainy days was only 121 d in this year. On the whole, the number of rainy days in Kaizhou presents the variation trend of “rise-decline-rise”. Before 1980s, the number of rainy days was noticeably large. The number of rainy days decreased rapidly and basically kept stabile below 150d after 1980s. Another noticeable phenomenon is that from 1973 to 1979, the number of rainy days in Kaizhou basically maintained above 200d. In this period, the number of rainy days in Kaizhou was large, which inevitably led to the decrease of fine days and average air temperature. Low temperature, rain and sparse sunlight brought about certain impacts on agricultural production.

The average precipitation intensity in Kaizhou is 8.2 mm/d, and the maximum precipitation intensity is 12.4 mm/d, which appeared in 2004. The minimum precipitation intensity is 4.8 mm/d, which appeared in 1976. On the whole, precipitation intensity presents the rising trend, indicating that extreme precipitation events increase and precipitation intensity rises enviously with global warming, which inevitably brings larger impacts on local traffic. According to the definition in this paper, 95 percentile value of daily precipitation from 1960 to 2016 is defined as the threshold value of extreme precipitation events. When daily precipitation is greater than the threshold value, we consider the extreme precipitation event appears. According to the statistics, the threshold value of extreme precipitation events in Kaizhou is daily precipitation>20 mm, close to heavy rain magnitude. Thus, the change rules of extreme precipitation events in Kaizhou are basically similar to heavy rain change rules. The annual mean value of extreme precipitation events in Kaizhou is 18 d. The annual maximum value of extreme precipitation events is 28 d, which appeared in 1980. The annual minimum value of extreme precipitation events is 11 d, which appeared in 1988. The data of extreme precipitation events in Kaizhou in 1980s changed radically, which verifies the conclusion that climate change in Kaizhou in 1980s accelerated. The annual mean number of heavy rain in Kaizhou is 14 d. The annual maximum number of heavy rain is 24 d, which appeared in 2011. The annual minimum number of heavy rain is 7 d, which appeared in 2002. The annual mean number of rainstorm days in Kaizhou is 4 d. The annual maximum number of rainstorm days is 9 d, which appeared in 1982. The annual minimum number of rainstorm days is 0 d, which appeared in 1960, 1990 and 1997. In other words, there was no rainstorm in Kaizhou in the three years. This may be related to the severe summer drought weather in the years.

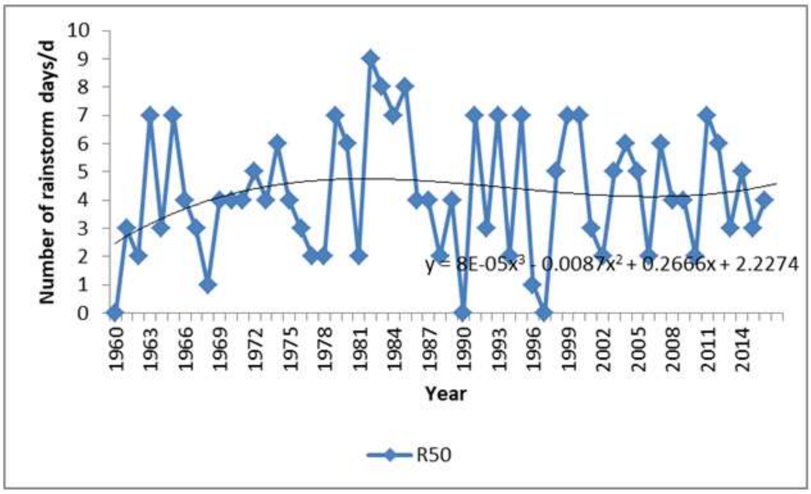


(a) Number of rainy days (b) Precipitation intensity





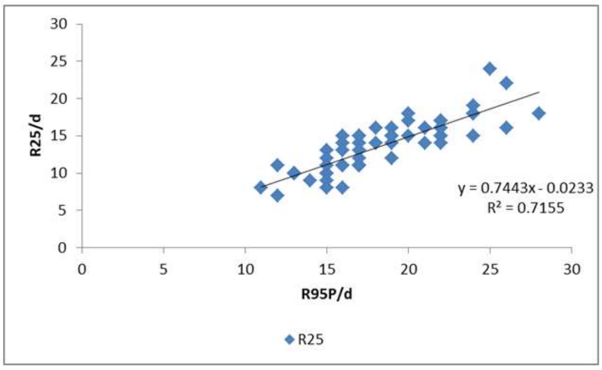
(c) Extreme precipitation events (d) Number of heavy rain days

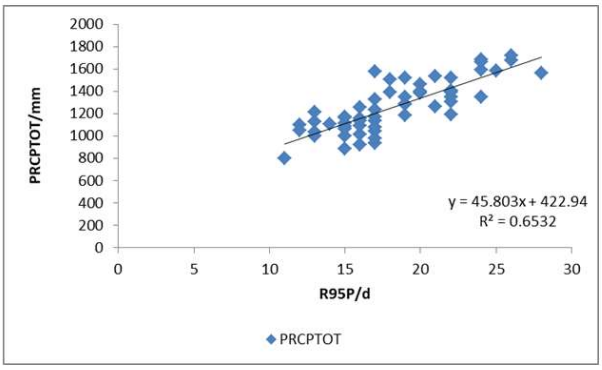


(e) Number of rainstorm days

Figure 1. Year change of extreme precipitation in Kaizhou.

Through analysis of scatter diagram of extreme precipitation events, the number of heavy rain and annual precipitation in Kaizhou (Fig.2), it can be seen that extreme precipitation events in Kaizhou have obvious positive correlation with the number of heavy rain and annual precipitation. The multiple correlation coefficients are 0.72 and 0.65 respectively, indicating that as the number of heavy rain in Kaizhou increases and the annual precipitation rises, extreme precipitation events increase obviously.





(a) Number of heavy rain days (b) Annual precipitation

Figure 2. Correlation analysis of extreme precipitation events in Kaizhou.

3.2. Analysis of extreme precipitation event period

There was 2-4 years of obvious strong oscillation period in 1960-1968, 1980-1989 and 2010-2016. There was 8-16 years of strong oscillation period in 1970-1990. The oscillation period was not obvious in 2000-2009. The strongest 2-4 years of oscillation period appeared in 2010-2016, and the peak appeared in 2013.

4. Impacts of extreme precipitation in Kaizhou on transportation

4.1. Reason analysis

Extreme precipitation will severely impact expressway traffic safety. Extreme precipitation makes road surface slippery, lowers the friction coefficient between tyres and road surface, and increases braking distance, thus triggering traffic accidents. In addition, extreme precipitation makes the side slope of expressway instable, thus further causing landslide, collapse, debris flow and other secondary geological disasters. The research of Li Tao et al. indicates that extreme precipitation will lead to the rise of water line in the side slope. The rising speed in the early stage of rainfall is larger than that in the later period. After rainfall stops, the water line lowers gradually, and the continuous seepage surface forms on the surface of side slope. Under the action of rainfall infiltration, internal water pressure and moisture content of side slope increase gradually. After rainfall stops, rain water seepage gradually lowers. Waterproof and drainage facilities of side slope play an important role in keeping the stability of side slope, and can obviously reduce the occurrence of landslide, collapse, debris flow and other secondary geological disasters[19]. Since extreme precipitation can easily form rain and fog, the visibility lowers, and the field of view becomes worse, thus triggering expressway traffic accidents. The research of Wu Jianjun et al. indicates that when rainfall intensity is small, the visibility will lower fast with the rise of extreme precipitation. When rainfall intensity>1 mm/min, the visibility slows down as the rainfall intensity becomes small. But, the visibility is very low. When rainfall intensity>2 mm/min, the visibility is only 50-100 m. The visibility distance of expressway and extreme precipitation intensity present power function relationship. The specific fitting function is shown in Formula (1), in which Vh is visibility and R is 1min rainfall intensity[20].

$$V_h=294.8*R^{-1.1} \quad 4.0\geq R\geq 1.0 \tag{1}$$

4.2. Data analysis of dangerous section and closed road of Kaizhou expressway

Within the territory of Kaizhou, Wanzhou-Dazhou expressway passes through the hwole district from the west to the east. The overall length of Wanzhou-Dazhou expressway is 139km. It is connected with Guangyuan-Bazhong-Dazhou expressway in the west, and connected with Wanzhou-Kaizhou expressway in the east. Wanzhou-Dazhou expressway is a high-speed channel of northeast area of Chongqing connected with Sichuan. There are 3 dangerous areas where weather influencing factor is extreme precipitation in Kaizhou section of Wanzhou-Dazhou expressway, and they are located at S002 K9+593-K20, S002 K0-K9+593, and S002 K20-K30.

Through analysis of road closure data in Kaizhou section of Wanzhou-Dazhou expressway from 2011 to 2014, Kaizhou section suffered 7 road closure controls due to extreme precipitation from 2011 to 2014: on July 24, 2011, the entrance to Kaizhou section of Wanzhou-Dazhou expressway due to rainstorm was controlled; on November 7, 2011, all entrances of Wanzhou-Dazhou expressway were closed due to heavy rain; on September 1, 2012, the toll station entrance from Kaizhou to Minguochang in Wanzhou-Dazhou expressway was controlled due to rainstorm; on March 27, 2014, toll station entrances of Kaizhou, Minguochang and Zhaojia in Wanzhou-Dazhou expressway were controlled due to rainstorm; on August 11, 2014, toll stations entrances of Zhaojia and Kaizhou in Wanzhou-Dazhou expressway were controlled due to rainstorm; on September 1, 2014, toll station entrances of Kaizhou and Zhaojia in Wanzhou-Dazhou expressway were controlled due to rainstorm; on September 12, 2014, the entrances of Kaizhou Starion, Zhaojia Station and Minguochang Station in Wanzhou-Dazhou section were closed for the time being due to rainstorm. Through the analysis, it is found that Kaizhou expressway control is mainly caused by rainstorm. As long as one rainfall reaches the level of heavy rain, the road will be controlled. Besides, control frequency is obviously positively correlated with extreme precipitation events. Extreme precipitation was strong in 2011, and there were two controls. In 2012 and 2013, extreme precipitation decreased obviously, and the annual precipitations in Kaizhou were only 1127.6 mm and 1051.6 mm respectively, reducing obviously. In 2012, the number of extreme precipitation event days in Kaizhou was only 13 d; the number of heavy rain days was 10 d; the number of rainstorm days was 6 d. In 2013, the number of extreme precipitation event days in Kaizhou was only 12 d; the number of heavy rain days was 11 d; the number of rainstorm days was 5 d. Thus, the road closure times in Kaizhou in 2012 and 2013 decreased obviously. Only on September 1, 2012, the toll station entrance from Kaizhou to Minguochang was controlled due to rainstorm. In 2014, extreme precipitation in Kaizhou increased significantly. In this year, annual precipitation in Kaizhou was as high as 1659.4 mm. The number of extreme precipitation events was as many as 24 d; the number of heavy rain days was 19 d; the number of rainstorm days was 5 d. In 2014, the expressway was closed frequently due to extreme precipitation. In the whole year, 4 road closure events happened. The occurrence time was also ahead of time obviously. According to the analysis, the meteorological department should enhance forecast and warning of extreme precipitation events, reduce traffic disaster loss and give play to the maximum benefit of road transportation.

5. Conclusion and discussion

Based on the rainfall data in Kaizhou, change features of extreme precipitation in Kaizhou from 1960 to 2016 and its impacts on transportation are analyzed. The main conclusions are as below:

The number of rainy days was noticeably large before 1980s in KaiZhou, and the number of rainy days was more than 200d from 1973 to 1979. The features of low temperature, rain and sparse sunlight are obvious. After 1980s, the number of rainy days decreased rapidly and basically kept stabile below 150d. The threshold value of extreme precipitation events is 20mm in Kaizhou, and the annual average value of extreme precipitation events is 18d. Under the general background of global circulation system adjustment in 2006, the western Pacific subtropical high pressure extended westward, and inclined to the west and north, compared with the previous years. Besides, it was stable and maintained for a long time. These gave rise to the severe drought in Chongqing in 2006 and further caused the reduction of extreme precipitation events in this year.

There are 3 dangerous areas where weather influencing factor is extreme precipitation in Kaizhou section of Wanzhou-Dazhou Expressway, and they are located at S002 K9+593-K20, S002 K0-K9+593, and S002 K20-K30. Kaizhou section of Wanzhou-Dazhou expressway suffered 7 road closure controls due to extreme precipitation from 2011 to 2014. In 2014, 4 road closures were caused due to frequent extreme precipitation. Strengthening the forecast of extreme precipitation events can reduce occurrence frequency of traffic accidents and give play to the maximum effect of road transportation.

From the climate perspective, change features of extreme precipitation in Kaizhou in recent 57 years are analyzed. In the future, time-space change rules and forecast of extreme precipitation in Kaizhou will be further studied from the aspects of numerical forecast, weather flow field and climate simulation to gain more significant research conclusions.

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