The Extreme Precipitation Trend Analysis and Spatial Variation for 50 Years in the Northern Part of Haihe River Basin

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Abstract: The daily precipitation data, from 1962 to 2012, of 20 relative meteorological stations in the Northern part of Haihe River Basin (NHHRB) were collected and analyzed to test the spatial variation and evolution trend of the extreme precipitation in NHHRB. Eight extreme precipitation indexes were selected and calculated to check the sustainability, frequency and intensity of the extreme precipitation in NHHRB and it is hoped to predict the characteristics or the likely types of precipitation causing disasters in the future. The results proved that: (1) the extreme precipitation happening in the plain area have the higher frequency and are more intensive than in mountainous area, and the extreme precipitation in coast area and the mountainous hinterland is of longer duration, while that in flat area and piedmont area are shorter, relatively; (2) through trend test, the sustainability in the flat area is examined to rise and the frequency and the intensity both have decreasing trend. In converse, in the mountain area and piedmont area, the sustainability of the extreme precipitation will re-duce, the moderate rain and rainstorm will happen less frequently while the heavy rain frequency is to rise, and the intensity strengthens. Therefore, it can be concluded that, due to the climate change, human activities and other factors, the characteristics of the extreme precipitation in NHHRB has changed. In the future, the flat area is more likely to suffer the disaster-causing precipitation with long sustainability, weak intensity and low frequency, and the mountain area will encounter with short-time, strong and frequent rainstorm.

Introduction

Climate change aggravates the natural disaster by affecting the occurrence of the extreme weather, and the society and economy will suffer stronger blows from these disastrous events than the normal evolution of regional climate.[1-3] Researches on the spatial variance and evolution rules of the extreme precipitation is necessary and of significance to ensure the safety of human living, the development of society and economy and the flood control and disaster reduction. As the social, economic and political center and also an important granary of China, Haihe River Basin is the core area with high priority of safety insurance, especially the northern part. Studies have improved that the precipitation in Haihe River Basin has decreased in the recent 50 years[4,5], but the reality is that no matter there is rising trend or declining trend, due to the fan-shaped catchment and the loess plateau, as the water source of the main tributaries, with massive sediment, the downstream of Haihe River Basin has poor capacity of flood detention, so that the flood occurs frequently and cause tremendous loss to the Beijing-Tianjin urban compact districts, such as the ur-ban waterlog event of Beijing in July 21th, 2012. At the same time, the upstream mountain area is also likely to encounter the torrent and debris flow [6]. Hence, this article, based on the daily precipitation data for 50 years and the support of GIS and RclimDex, tests the trend and significance of extreme precipitation index time series and gains the spatial variation of the change characteristics of these indexes by spatial interpolation. It will provide scientific support to the measurement of flood control and forecast of disaster precipitation and, on the other hand, it also offers basis to the rea-son analysis of the extreme precipitation evolution.

Overview of Study Area

The Northern part of Haihe River Basin (NHHRB), between 112°E~120°E and 38°N~42°N, crosses five provinces including the entire of Beijing, Tianjin and small part of Hebei province, Shanxi province and the Nei Mongolia Autonomous Region. The areas covers a total area of 83,400 km2, in which mountain area occupies 53,300km2, 62.5 percent of the total area, and the rest 312,000km2 is the flat area, account for 37.5 percent of the total area. The terrain can be divided into plateau, mountain and plain types, with low southeast area and high northwest, for the western part is Shanxi plateau and Taihangshan Mountains, the northern part located the Mongolia Plateau and Yanshan Mountains and the eastern and southeastern part is the tail of North China Plain. The plain area and mountain area join together directly so that the transition area is narrow.

The NHHRB belongs to the temperate zone of East Asia monsoon climate zone: controlled by the Siberian continental air mass, the winter is always with cold weather and less snow; in spring, it is commanded by Mongolian continental air mass with temperature re-increasing fast, strong wind, dry weather and high evaporation and easily leading to drought; summer weather is dominated by the maritime air mass, having wet weather, high temperature, heavy rains, but, on account of the great difference of the advance and retreat time, intensity and the range of influence of the summer Pacific subtropical high, the variance of precipitation is large and it is easy to form flood disaster; as the interim season, autumn always has clear and refreshing weather and less rain. The annual mean precipitation from 1956 to 2000 is 489mm, with maximum 698mm and the minimum 336mm.

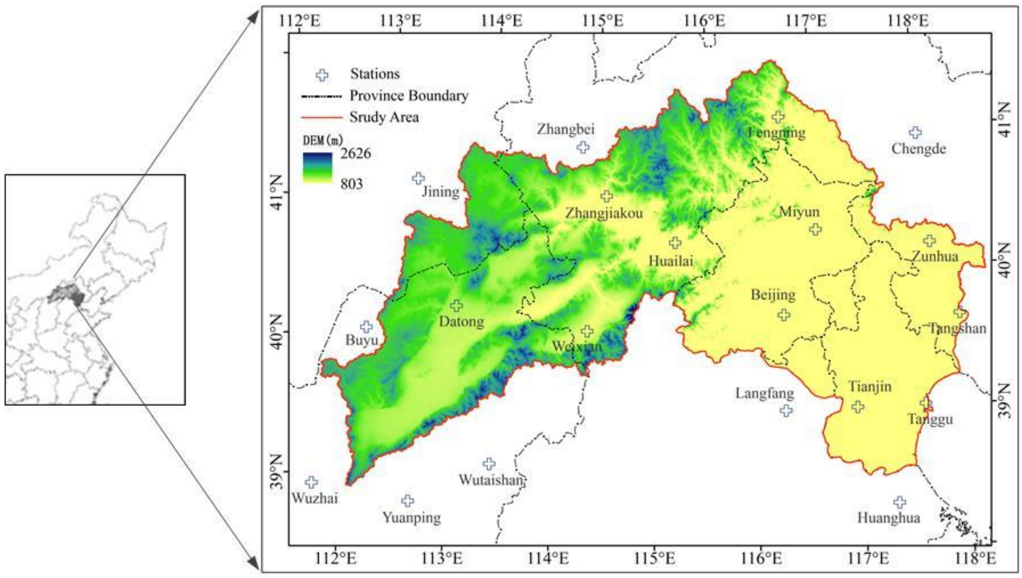


Figure 1. The geological location of the northern part of Haihe River Basin (NHHRB) and DEM (Digital Elevation Model).

Data and Methods

Data Sources. The daily precipitation data from 1962 to 2012 in 20 meteorological stations in and around NHHRB is got from China Meteorological Data Sharing Service System and the station information is listed in the table 1 with annual mean precipitation.

Table 1 The selected 20 stations in NHHRB and the annual mean precipitation (mm)

Code	Station	Long /°	Lat /°	AMP /mm	Code	Station	Long /°	Lat /°	AMP /mm
53399	Zhangbei	114.70	41.15	388.9	54405	Huailai	115.50	40.40	379.3
53478	Youyu	112.45	40.00	422.4	54416	Miyun	116.87	40.38	645.9
53480	Jining	113.07	41.03	361.6	54423	Chengde	117.95	40.98	527.2
53487	Datong	113.33	40.10	375.3	54429	Zunhua	117.95	40.20	723.5
53588	Wutaishan	113.52	38.95	741.8	54511	Beijing	116.47	39.80	559.0
53593	Yuxian	114.57	39.83	405.2	54518	Langfang	116.38	39.12	513.1
53663	Wuzhai	111.82	38.92	473.4	54527	Tianjin	117.07	39.08	540.9
53673	Yuanping	112.72	38.73	423.6	54534	Tangshan	118.15	39.67	614.9
54308	Fengning	116.63	41.22	460.0	54623	Tanggu	117.72	39.05	586.1
54401	Zhangjiakou	114.88	40.78	400.5	54624	Huanghua	117.35	38.37	587.5

Data Processing

Extreme Precipitation Indices. Eight extreme precipitation indexes, accepted and recommended by World Meteorological Organization (WMO) (Table 1) were chosen [](Zhang B., et al, 2014) and could describe the characteristics of the extreme precipitation from different aspects: maximum consecutive wet days (CWD) reveals the sustainability of the extreme precipitation events, count of moderate rain/heavy rain/rainstorm days (Rnn, nn=10,25 and 50) indicate the frequency of extreme precipitation and the very wet days(R95p), extremely wet days(R99p), Max 1-day precipitation amount(RX1day), Max 5-day precipitation amount(RX5day) explain the intensity of the extreme precipitation.

Table 2 Extreme precipitation indexes and their definitions

ID	Indicator Name/Units	Definitions
CWD	Consecutive wet days/d	Maximum number of consecutive days with PRCP >=1mm
R10	Number of moderate rain days/d	Annual count of days when PRCP>=10mm
R25	Number of heavy rain days/d	Annual count of days when PRCP>=25mm
R50	Number of rainstorm days/d	Annual count of days when PRCP>=50 mm
R95p	Very wet days/mm	Annual total PRCP when PRCP >95th percentile
R99p	Extremely wet days/mm	Annual total PRCP when PRCP >99th percentile
RX1day	Max 1-day precipitation amount/mm	Monthly maximum 1-day precipitation
RX5day	Max 5-day precipitation amount/mm	Monthly maximum consecutive 5-day precipitation

Man-Kendall Test. Man-Kendall's rank correlation method (MK) is a kind of non-parameter method and has been fully developed and accepted by a wide range of researchers.[8] It is to test the trend of the extreme precipitation index time series as well as the significance of them. Through hypothesis test, whether there is a trend in the original time series can be judged. Firstly, according to the formula 1, all pairs of the time series are compared and the total rank of the time series is summed up.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i)$$

$$sgn(x_i - x_j) = \begin{cases} 1 & x_i - x_j > 0 \\ -1 & x_i - x_j < 0 \\ 0 & x_i - x_j = 0, \end{cases} \quad (1)$$

The expectation E(S) and variance Var(S) of statistics S are as followed:

$$E(s) = 0$$

$$Var(\tau) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{n-1} t_i \cdot i(i-1)(2i-5)}{18} \tag{2}$$

The statistics (Z) is built according to the formula as followed:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, S > 0 \\ 0, S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, S < 0 \end{cases} \tag{3}$$

With n increasing, U converges to a standard normal distribution fast. Two-sided test is used when the original hypothesis is 'no trend'. According to the given significance level, the critical value U(α/2) is find out from the normal distribution table and when |U|<U(α/2), the original hypothesis is accepted, when |U|<U(α/2), the original hypothesis is refused, which means the original time series has a significant trend.

Line Regression and Spatial Interpolation. Build the line regression model as followed:

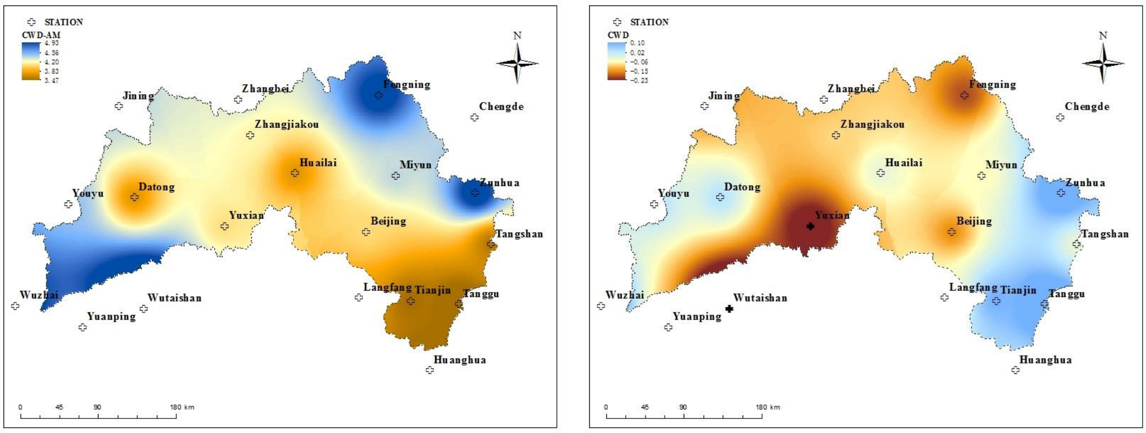
$$X_t = a + bt + \eta_t, t = 1, 2, ..., n \tag{4}$$

And parameters are calculated by least square method and the trend quantity of time series is confirmed.

With the support of GIS, the inverse distance weighting (IDW) interpolation method is applied to the extreme precipitation index annual mean value and their trend and finally form the spatial distribution regularities of the extreme precipitation.

Results and Discussion

The trend and spatial variation of the extreme precipitation persistency. The Figure 2 shows the spatial evolution trend of the sustainability of the extreme precipitation by testing the trend of continuous wet days (CWD) and its annual mean value spatial distribution. From the annual mean CWD in Figure 2(a), it is obvious that the extreme precipitation duration is longer in mountainous area and piedmont area than in the flat area where cities are concentrated. And the Figure 2(b) reflects that CWD generally decrease, ranging from -0.22d/10a to 0.1d/10a.The increasing area is small and mainly in the east coast area and west remote mountainous area, and Yuxian and Wutaishan reached the 95% significant level, while the midland area, large part of mountainous area and northwestern part of plain, have CWD decreasing.



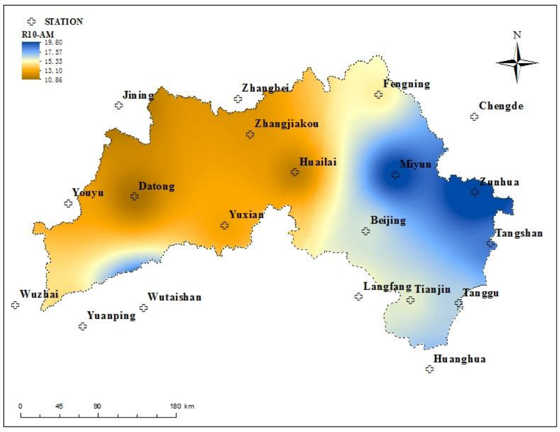
(a). CWD- Annual Mean (b).CWD-ChangeTrend

Figure 2 Sustainability of the extreme precipitation in NHHRB and its spatial variation.
**: ✚ represents those stations significantly changed.

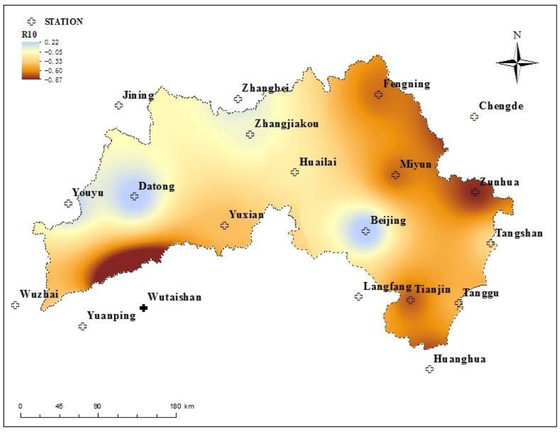
The trend and spatial variation of the extreme precipitation frequency. Figure 3 (a~c) illustrate that the spatial distribution of annual mean value of total moderate rain, heavy rain and rainstorm days (R10, R25, R50): the frequencies of three types of rain are all higher in plain than in mountainous area, and with the intensity aggrandizing, the difference between plain area and mountainous area becomes larger.

The trend of R10 varies from -0.87d/10a to 0.22d/10a (Figure 3(d)), with large percentage of area decreasing, in which Wutaishan reaches the 95% significance level, but in small area, with Beijing and Datong as a center, increases slightly. Figure 3(e) shows that the trend of R25 represent an obvious regional difference: with Huailai as the parting line, the east coast area and plain area decrease, the west mountainous area increase, and the stations located in the boundary (Huailai-Fengning) attain the 95% significance level. The amplitude of R25 in the whole area is from -0.36d/10a to 0.19d/10a. In the whole area, R50 decreases (Figure 3(f)), varying from -0.20d/10a to 0.06d/10a, with only small areas in Tianjin-Langfang and Wuzhai -Youyu rise slightly.

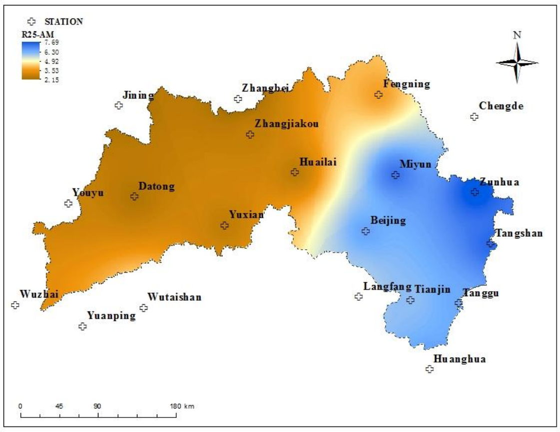
In general, the plain area in NHRRB is more likely to encounter the disaster-causing extreme precipitation than the mountainous area. And the more intense precipitation is, the more likely it occurs in plain area. From the trend aspect, the total moderate rain and rainstorm day decrease, and this trend is global without significant regional difference. However, the trend of the total heavy rain days represents obvious regional difference: that in mountainous area increases and that in plain area decreases.



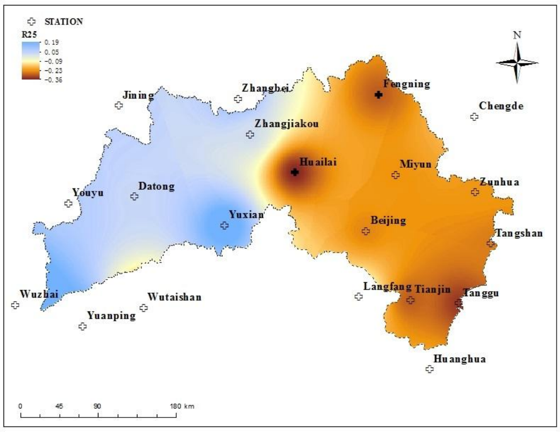
(a). R10-Annual Mean



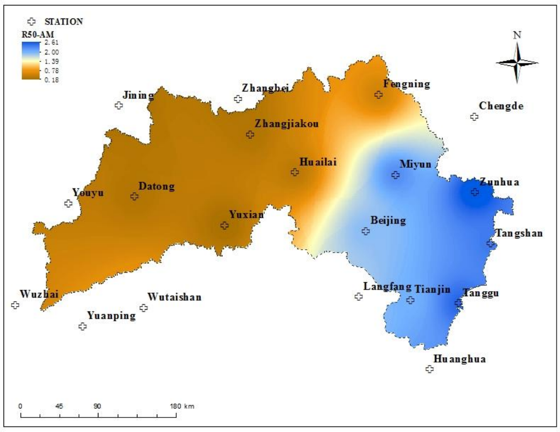
(d). R10-ChangeTrend



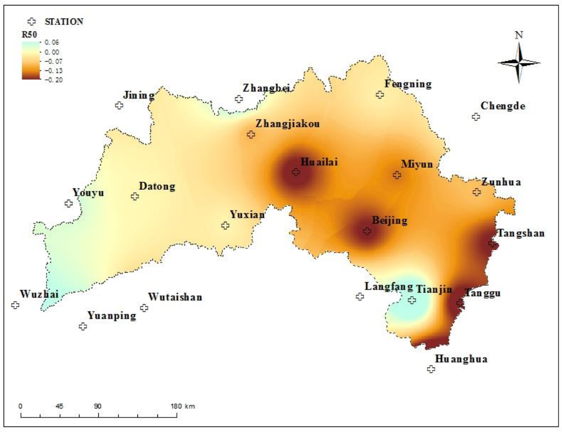
(b). R25-Annual Mean



(e). R25-ChangeTrend



(c). R50-Annual Mean



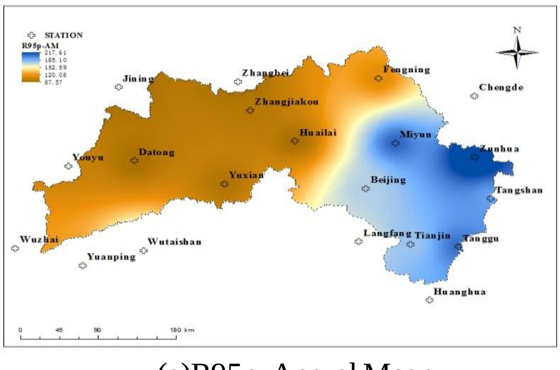
(f). R50-ChangeTrend

Figure 3 Frequency of the extreme precipitation in NHHRB and its spatial variation.
**:✚ represents those stations significantly changed

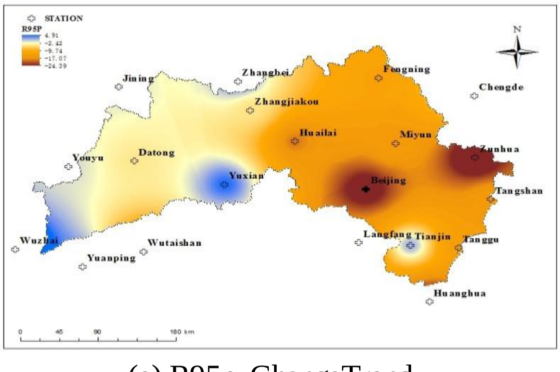
The trend and spatial variation of the extreme precipitation intensity. The intensity of extreme precipitation in NHRB could be described by R95p, R99p, RX1day and RX5day. By liner regression and Kendall trend analysis, the trend quantity and stations reaching to 95% significance level could be detected. In Figure 4(a-d), the spatial interpolation of the four index annual mean values shows the distinction of the extreme precipitation intensity: divided by Miyun-Beijing, the intensity in east plain area is stronger than that in the west mountainous area, in which Zunhua, Tanggu and Miyun has high intensity and in mountainous area, Zhangjiakou, Huailai, Datong and Yuxian has slight intensity.

In Figure 4(e), R95p has a declining trend, and the range is from -24.39mm/10a to 4.91mm/10a. The decreasing area mainly in east plain area, with Beijing reach to 95%significance level and the decreasing tendency in west mountainous area is not that fierce. R99p also decreases (Figure 4(f)), and from west to east, the decreasing trend enhances. R25 of Zunhua, Huailai and Langfang attain the 95% significance. The RX1day trend varies from -16.56mm/10a to 0.09mm/10a, also representing a similar reduction (Figure 4(g)), the east dropping area is concentrated in Beijing, Zunhua and Langfang (up to 95% significance), while Tianjin, Miyun, Fengning and Tangshan increase slightly. The trends of RX5day can be analyzed from Figure 4(h), the variation range is from -18.55mm/10a to 1.05mm/10a, larger than RX1day, and the regional differences are more obvious as well. Separated by Zhangbei-Zhangjiakou-Yuxian line, there is a slight increase in the eastern mountains and the western plains area shows significant reduction.

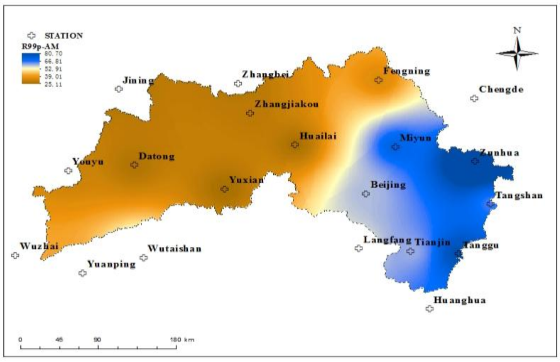
In summary, the overall intensity of extreme precipitation decreases, that in the eastern region reduces more sharply and the downward trend in the western mountains is not so significant, indicating that in the external role of climate change and human activities, in urban areas, extreme rain will be affected greater than that in the mountains.



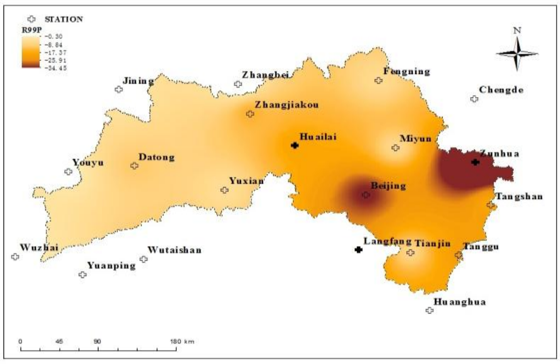
(a)R95p-Annual Mean



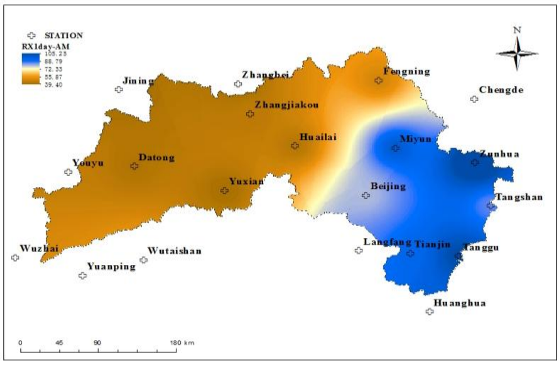
(e) R95p-ChangeTrend



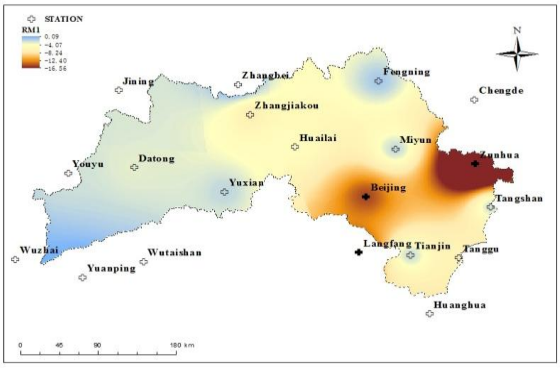
(b)R99p-Annual Mean



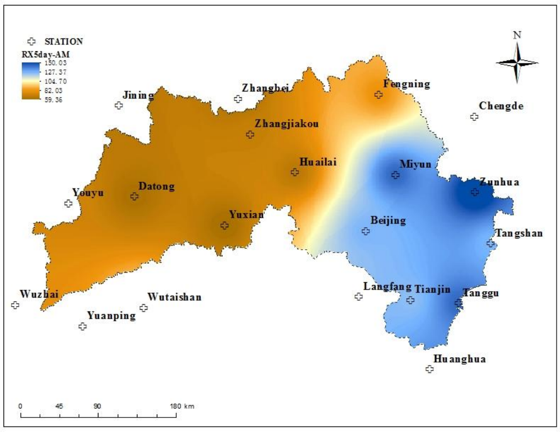
(f) R99p-ChangeTrend



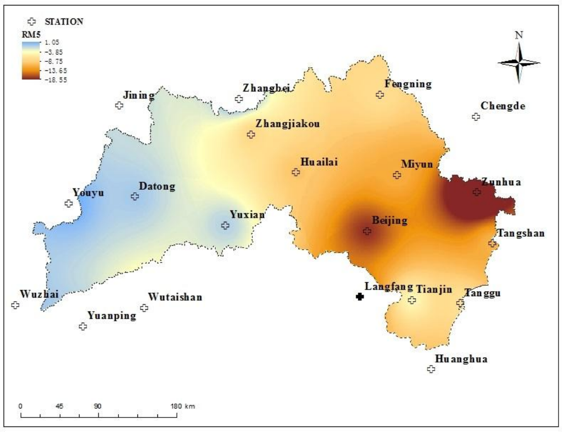
(c)RX1day-Annual Mean



(g) RX1day-ChangeTrend



(d)RX5day-Annual Mean



(h) RX5day-ChangeTrend

Figure 4 Intensity of the extreme precipitation in NHHRB and its spatial variation (Left column represent the annual mean value of index and right column represent the trend of them).

*: ✚represents those stations significantly changed

Conclusions

By extreme precipitation index of NHHRB trend analysis and spatial interpolation, it can be concluded that:

(1) In NHHRB, the presentation duration of extreme precipitation is shorter in east and plain area than in western mountains; precipitation intensity is stronger in eastern area than in western area; the frequency is higher in eastern plain than in western mountains. These features make the western mountainous areas prone to flash floods and debris flows, while the eastern plains prone to flood and urban waterlogging disasters, which is consistent with the facts.

(2) The test result of extreme precipitation sustainability index shows that the extreme precipitation persistent is weakening, the downward trend is the most powerful in mountain and mountain plain transition zone, while the western edge and the coastal region have slight uptrend.

(3) The trend analysis and significance tests of the extreme precipitation frequency index time series show that the extreme precipitation frequency in general decreases. The plains reduce speedy, but there is no significant decline in the mountains, even in some areas there is a slight increasing trend. This is consistent with the overall drying trend in precipitation.

(4) The trend analysis and significance tests of extreme precipitation intensity index time series show that extreme precipitation intensity is generally lower, but in the western mountains, the birthplace of major river tributaries, there is increasing trend, and in the eastern city compact districts, the overall storm strength is weakening, but the difference in different time-scale exists.

(5) To a certain extent, extreme precipitation features in NHHRB has been transformed. In the future, the disaster-causing rainfall the mountains in NHHRB will face is of rising frequency, short duration and strong intensity. The opportunity plain area suffering from long-term heavy rain is gradually rising, which exacerbate the difficulty and pressure of flood control and disaster mitigation.

Acknowledgements

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