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Study on the Effects of Extreme Precipitation for Seven Growth Stages of Winter Wheat in Northern Weihe Loess Plateau, China

Ouk Sereyrorth[1,2], Baowen Yan[1]*, Khem Chunpanha[1,2], Porn Lybun[1,2], Pich Linvolak[1,2]

[1]College of Water Resources and Architectural Engineering, Northwest A&F University, Xianyang, China
[2]Faculty of Hydrology and Water Resources Engineering, Institute of Technology of Cambodia, Phnompenh, Cambodia
Email: ouk_sereyrorth@yahoo.com, *yanbaowen@nwsuaf.edu.cn

Abstract

The research on the characteristic frequency of precipitation is a great significance for guiding regional agricultural planning, water conservancy project designs, and drought and flood control. Droughts and floods occurred in northern Weihe Loess Plateau, affecting growing and yield of winter wheat in the area. Based on the daily precipitation data of 29 meteorological stations from 1981 to 2012, this study is to address the analysis of three different frequencies of annual precipitation at 5%, 50%, and 95%, and to determine the amount of rainfall excess and water shortage during seven growth stages of winter wheat at 5%, 10%, and 20% frequencies, respectively. Pearson type III curve was selected for this study to analyze the distribution frequency of annual rainfall and rainfall amount following seven growth stages of winter wheat crop in 29 stations of Northern Weihe loess plateau. As a result of our study, annual precipitation is gradually increasing from southwest to northeast of Northern Weihe loess plateau. The highest amount of annual precipitation occurred in the Baoji area and the lowest precipitation covered by the northwest area of Northern Weihe loess plateau. Moreover, the amount of rainfall of seven growth stages indicates that excessive rainfall occurs not only in the first stage (sowing to tillering) and seventh stage (flowering to ripening) but also in second stage (tillering to wintering). In the seventh stage, a large amount of excessive rainfall occurred in Changwu, Bin, Qianyang, Fengxiang, Baojiqu, and Baojixian. Moreover, water shortage is distributed in the third stage (from wintering to greening), the fourth stage (from greening to jointing), the fifth stage (from jointing to heading), and the sixth stage (from heading to flowering). Furthermore, the worst water shortages occurred in Hancheng, Heyang, Chengcheng, Pucheng, Dali, Tongchuan, and Fuping in the fourth stage (greening to jointing stage). Even though we study

the crop water requirement under extreme rainfall conditions, the amount of rainwater still supply inadequate in some parts of the winter wheat growth stage. Therefore, this study provides main clues for the next step to study the irrigation water needs of winter wheat crops and to reduce agricultural risks in 29 counties in the northern loess plateau and other regions.

1. Introduction

Drizzle, rain, sleet, snow, graupel, and hail are the main forms of precipitation in the meteorological field [1]. Precipitation is a major component of the hydrological process and its variabilities are associated with drought, flood, and crop studies [2]. The study of the frequency precipitation characteristics is a great significance for guiding regional agricultural planning, agricultural water conservancy project designs and improving the risk aversion ability of agricultural drought and flood conditions [3]. Several researches performed a series of frequency precipitation pattern analysis; likewise Roy *et al.* [4] generated annual time series of seven different indices of extreme precipitation events , including total precipitation, largest 1, 5, and 30 day totals, and the number of daily events above the amount that marks the 90th, 95th, and 97.5th percentiles of all precipitation at each station in India; Zhang *et al.* [5] studied the changes of extreme precipitation in Canada, that provide a framework for mapping extreme events and characterize the spatial and temporal variation of extreme snowfall and rainfall events, Brunetti *et al.* [6] aim to study the trend of precipitation all over Italy by using Italian new datasets of daily precipitation(1951-1996); Feng *et al.* [7] analyzed the variation of spatial-temporal pattern of precipitation over China in the last 33 years (1980 to 2012) with resulting of upward annual precipitation trends; Guo *et al.* [8] studied on spatiotemporal patterns of Rainy-Season precipitation in Waihe river basin; and Li *et al.* [9] analyzed the frequency of precipitation extreme events in Heihe river basin. Fang *et al.* [10] observed changes of the regional extreme precipitation pattern events through the analysis of observed daily data in China; Wang *et al.* [11] extended that the previous analysis of extreme precipitation trends, especially the trends from 1961 to 2001; Zhai *et al.* [12] Studied on trends in annual and seasonal total precipitation in extreme daily precipitation, which resulted in that annual total precipitation has significantly decreased over southern northeast China. According to previous study, many researchers applied the various probability functions to analyze the distribution frequency and some authors evaluated its performance by determining the best fitting results. From Olofintoye *et al.* [13] compared the performance of probability function distribution; the result showed that the Pearson type III gives

the best performance for peak daily rainfall distribution. Sheng *et al.* [14] also compared the efficiency of probability function for annual, seasonal, and monthly rainfall in Japan. The Pearson type III distribution shows the best fit to observe monthly rainfall and spring precipitation and performed very well for short time scale [15]. In recent publication, [16] Parvez *et al.* applied Pearson type III to estimate short duration rainfall to obtain the maximum depth and intensity for various short durations of each station. From Singh *et al.* [17], stated that Pearson type III distribution is the generalized gamma distribution and is one of the most popular distributions for hydrologic frequency analysis such as flood frequency analysis, hourly, monthly and annual precipitation frequency etc.

Plenty of Chinese scholars involved flood and drought in Northern Weihe loess plateau, Shaanxi. The occurrence of drought and flood is between the 8th and the 13th in [18]. Yin *et al.* [19] showed that the differences in natural disasters, such as high occurring frequencies of drought, flood and waterlog disasters, occurred synchronously. The analyzed results of historical data also revealed that, before the Ming Dynasty and Qing Dynasty, the drought, flood and waterlog disasters occurred frequently when the capital city was constructed in northern Weihe loess plateau; otherwise, the occurring frequencies of these natural disasters were significantly reduced. Wu *et al.* [20] determined the extreme value of annual seasonal precipitation trends and analyzed the influence of drought and flood events in the Wei river basin, Shannxi, with the result of a downward trend in the Wei river basin. Therefore, Northern Weihe Loess Plateau of Shaanxi province is selected for this study. Relevance of the previous studies on the impact of flood and drought on agriculture production has mainly focused on quantifying the relationship between the frequency and intensity of drought, flood, and disaster-affected damaged croplands [21]. Due to Chinese book [22], winter wheat crop is major crop productivity, grain yield about 1500 kg/hm^2, in Shaanxi. It is not only the main crop in China in which fulfills the demand for 1/3 Chinese population [23] but also a vital output for the world, with an annual output of 582.7 million tons. The improvement of the effective utilization of precipitation resources on winter wheat crop is strongly concerned. Relevant studies on winter wheat [24], winter wheat evapotranspiration was estimated under drought stress during several growth stages and Yu *et al.* [25] studied the impact of droughts on winter wheat yield in different growth stages. Hong *et al.* [26] determined the amount of water deficit of winter wheat in the different growth stages. Zhenwei *et al.* [27] analyzed crop water requirement and the deficit of winter wheat crop, Zhihong *et al.* [28] and Ting *et al.* [29] studied on rainfall sensitivity on the yield of winter wheat in different growth stages. Sun *et al.* [30] analyzed the spatial distribution characteristics of precipitationin the whole growing period of winter wheat crops. Although the many previous pieces of research have studied rainfalls related to irrigation, they still lack the crucial point, extreme rainfall frequency, which is sensitive to yield production.

Therefore, this paper aims to study about analysis of the three different frequencies of annual precipitation at 5%, 50% and 95%, and determination of

rainfall excess amount and water shortage of winter wheat in seven growth stages frequency 5%, 10%, and 20% of 29 counties in Northern Weihe loess plateau.

2. Materials and Methods

2.1. Materials

2.1.1. Research Area

Northern Weihe loess plateau is one of the regions in Shaanxi province of China and covered approximately 55,500 square kilometers; it shares a border with the Baoji to the west, Tongguan to the east, Qinling mountain to the south and the North Mountain to the north. The main landform is the Weihe Plain and its river terraces covered by loess. The area has been boasted as "Qinchuan with a length of 400 kilometers which covers Xian, Baoji, Xianyang, Weinan, Tongchuan and Yangling districts. It is located between 103˚ - 110˚E and 34˚ - 38˚N with the average elevation of 520 meters. The climate condition in the area is seasonally temperate a semi-humid monsoon with 13.3˚C annual average temperature and annual mean precipitation between 500 to 650 millimeters. The terrain is higher in the southern and northern areas, and lower in the central and eastern areas. The research classifies the Northern Weihe loess plateau into two regions as the maps are presented in **Figure 1**.

2.1.2. Data Collection

1) Precipitation data

All daily precipitation data are presented by the department of the hydrology of Shaanxi province. All boundary data of China were downloaded from Global Administrative Areas (https://www.gadm.org/).

List of all 29 stations of precipitation data from 1981 to 2012 in each county of Nothern Weihe losses plateau is given as **Table 1**.

2) Crop water needs of winter wheat in seven growth stages

Based on Chinese research from Xiao *et al.* [31], studied on relationship between winter wheat production with rainfall and compensation irrigation period
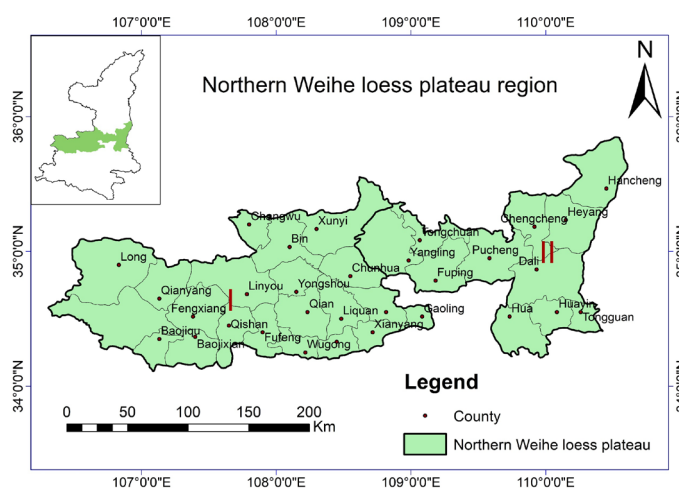
Figure 1. Location map of the study area.

Table 1. List of all county in Northern Weihe losses plateau.

Station ID	County	Longitude	Latitude	Elevation (m)
57035	Qian	108˚14'	34˚33'	636.70
57022	Linyou	107˚47'	34˚41'	1065.70
57040	Gaoling	109˚05'	34˚31'	378.90
53955	Hancheng	110˚27'	35˚28'	458.80
57003	Long	106˚50'	34˚54'	925.10
53929	Changwu	107˚48'	35˚12'	1206.80
53947	Tongchuan	109˚04'	35˚05'	979.70
53948	Pucheng	109˚35'	34˚57'	499.90
57029	Liquan	108˚29'	34˚30'	544.40
53949	Chengcheng	109˚55'	35˚11'	680.10
57054	Tongguan	110˚34'	34˚33'	556.60
57031	Chunhua	108˚33'	34˚49'	1013.50
57030	Yongshou	108˚09'	34˚42'	998.70
57034	Wugong	108˚13'	34˚15'	449.10
57037	Yangling	108˚59'	34˚56'	720.60
53938	Xunyi	108˚18'	35˚10'	1277.90
57026	Fufeng	107˚54'	34˚24'	583.70
57023	Bin	108˚06'	35˚02'	841.30
57024	Qishan	107˚39'	34˚27'	671.10
57042	Fuping	109˚11'	34˚47'	473.20
57016	Baojiqu	107˚08'	34˚21'	610.30
57020	Baojixian	107˚24'	34˚22'	563.70
57043	Dali	109˚56'	34˚52'	368.90
57048	Xianyang	108˚43'	34˚24'	472.80
53950	Heyang	110˚09'	35˚14'	710.10
57049	Hua	109˚44'	34˚31'	342.30
57055	Huayin	110˚05'	34˚33'	352.30
57021	Qianyang	107˚08'	34˚39'	746.40
57025	Fengxiang	107˚23'	34˚31'	781.80

in North Shaanxi and Weibei areas, the study has classified the crop water requirement into five different regions of North Shaanxi and Weibei areas. In this study, only two regions were extracted, as shown in Figure 1. Irrigation supply, precipitation, and groundwater replenishment are the major sources of crop water consumption. However, the groundwater recharge remained stable [22], the crop water need only depends on the amount of irrigation supply and precipitation. The crop water needs in Northern Weihe loess plateau area will be presented as Table 2.

Table 2. Crop water needs of winter wheat in seven growth stages of two regions of Northern Weihe loess plateau in mm.

| | Crop water needs of winter wheat in seven growth stages in mm | |
Stages	I Sowing to tillering	II Tillering to wintering	III Wintering to Greening	IV Greening to Jointing	V Jointing to heading	VI Heading to flowering	VII Flowering to ripening	Total
Planting date	16 October to 17 November	18 November to 19 December	20 December to 05 March	06 March to 28 March	29 March to 23 April	24 April to 16 May	17 May to 06 June	221 days
Region I	32.192	28.168	40.24	60.36	80.48	88.528	72.432	402.4 mm
Region II	38.408	33.607	48.01	72.015	96.02	105.622	86.418	480.1 mm

2.2. Methodology

2.2.1. Person Type III Frequency Distribution

By [32], Person type III was the empirical frequency computational method. It estimated a set of parameters as starting values, adjusted parameters by means of empirical judgment, and selected a frequency curve that closely matches empirical data. In addition, the optimizing curve-fitting method was the best statistical parameter method of frequency curve to solve matching empirical data under certain fitting rules (that is objective functions).

Person type III is selected for this study based on above reviews; therefore, it is a suitable frequency analysis method to apply for determination amount of rainfall following winter wheat growing gaps at extreme value condition. The optimization result of rainfall amount is the main clue to calculate rainfall excess. The annual precipitation at 5%, 50%, and 95% were analyzed to investigate the precipitation characteristic at three different events rainfall condition like 5% as extreme event of precipitation during the rainy season, 50% as normal period, and 95% as a summer rainfall event. And amount of rainfall during seven growth stages of winter wheat in 29 counties of Northern Weihe loess plateau at three different frequencies extreme events 5%, 10%, and 20% in sequence was designed.

Person type III method was conducted in this study to analyze the distribution frequency of precipitation at seven growth stages of winter wheat crop and annual rainfall value of 29 stations to obtain the optimum value based on goodness-fit indicator parameters $\overline{X}$, C_v, C_s and each stage is carried out respect to Table 3.

Pearson-III function has been used in the curve fitting method. It is the probability density function and the formula can be given as below:

$$f(x) = \frac{\beta^{\alpha}}{\Gamma(\alpha)}(x - a_0)^{\alpha - 1} e^{-\beta(x - a_0)} \tag{1}$$

that $\Gamma(\alpha)$ is Γ function; α, β, a_0 were three parameters of the curve. Its formulas can be given as below:

$$\alpha = \frac{4}{C_s^2} \tag{2}$$

Table 3. Annual rainfall frequency of Baojiqu from 1981 to 2012.

Frequency (%)	Rainfall (mm)	Frequency (%)	Rainfall (mm)
0.01	1437.15	50	639.12
0.05	1318.12	60	602.79
0.5	1136.12	70	566.21
1	1077.5	80	526.35
2	1015.66	90	476.12
5	928.54	95	438.89
10	856.34	98	416.68
20	775.31	99	378.79
30	721.13	99.9	325.23
40	677.58	99.99	267.17

$$\beta = \frac{2}{C_v C_s \overline{X}} \tag{3}$$

$$a_0 = \frac{C_s - 2C_v}{C_s} \overline{X} \tag{4}$$

Remark: In hydrology, both coefficients need to be greater than or equal to zero, a flow cannot be negative.

2.2.2. Ordinary Kriging Interpolation Method (OK)

The selection of the geostatistical methods of ordinary kriging (OK) is to address the problem of estimating the excess rainfall value in seven winter wheat crop growth stages in the northern Weihe loess plateau. Based on [33], the kriging method uses trends in the map to extrapolate of no data areas, sometimes resulting in a minimum and maximum Z values in the grid that is beyond the values in the data file. This is acceptable in a structural or topographical map, but not in an isolines map where the extrapolation produces negative thickness values. Kriging method has varieties type of calculations. Among them, Ordinary kriging is the most widely used in the kriging method. It serves to estimate a value at a point of a region for which a variogram is known by using data in the neighborhood of the estimation location. Ordinary kriging can also be used to estimate a block value. With local second-order stationarity, ordinary kriging implicitly evaluates the mean in a moving neighborhood. To see this, first, a kriging estimation of the local means is set up; then a simple kriging estimator using this Kriged mean is examined. Ordinary kriging based on the concept of a basic linear regression algorithm. The estimation of the location of interests of value x_0 from the n neighboring sample points of value x_α and combining them linearly with weights x_α can be given as:

$$Z^*(x_0) = \sum_{\alpha=1}^{n} w_\alpha Z(x_\alpha) \tag{5}$$

where: $Z(x_\alpha)$ is the random variable model at the location x_α;

x_α is n data locations;

w_α is the ordinary Kriging weight;

$Z^*(x_0)$ is the estimated value.

3. Results

3.1. Annual Precipitation of Different Frequencies at 5%, 50%, and 95%

Figure 2 illustrates the spatial distribution of three different frequencies of annual precipitation in the Northern Weihe loess plateau from 1981 to 2012. A 5% frequency of precipitation indicates the extreme value of precipitation during the rainy season. The extreme precipitation around 880 mm to 900 mm occurred in the Northwest area of Northern Weihe loess plateau with elevation from 563.70 m to 610.30 m (Table 1), Baoji region (Baojiqu & Baojixian). Within elevation from 458.8 m to 710.1 m, the northern part area, Hancheng, Heyang, Chengcheng, Pucheng, was covered by the lowest precipitation range around 780 mm to 800 mm. 50% frequency of annual precipitation shows the annual average precipitation in the Northern Weihe loess plateau. The southwest-partannual average precipitation ranged between 600 mm to 620 mm, the northeast part was around 500 mm and 520 mm and the middle part was around 540 mm to 560 mm. For the dry season, northwest area within elevation from 368.9 m to 710.1 m, Hancheng, Heyang, Chengcheng, Pucheng, Dali, and Fuping covered by 95% frequency of the annual precipitation, the lowest precipitation, around 335 mm to 350 mm. And the highest precipitation ranges from 400 mm to 425 mm cover over the area with elevation from 563.70 m to 1206.8 m such as Changwu, Linyou, Qianyang, Qishan, and Baoji region (Baoji Qu and Baoji Xian).

3.2. Excess Rainfall and Water Shortage of Seven Growth Stages at Different Frequencies

In this case study, rainfall data were recorded from 1981 to 2012. The amount of excess rainfall and shortage of seven growth stages determined through subtraction between two datasets such as rainfall and crop water need in each stage. Planting time of winter wheat crop was conducted on 16 October 1981 as Table 2 mentioned. The amount of rainfall of each stage is followed by the scheduled planting crops. It started from 16 October 1981 to 30 May 1982 for a whole period and the other period was followed by the time duration. Since the winter wheat crop water needs of each county are different, it classifies into two regions.
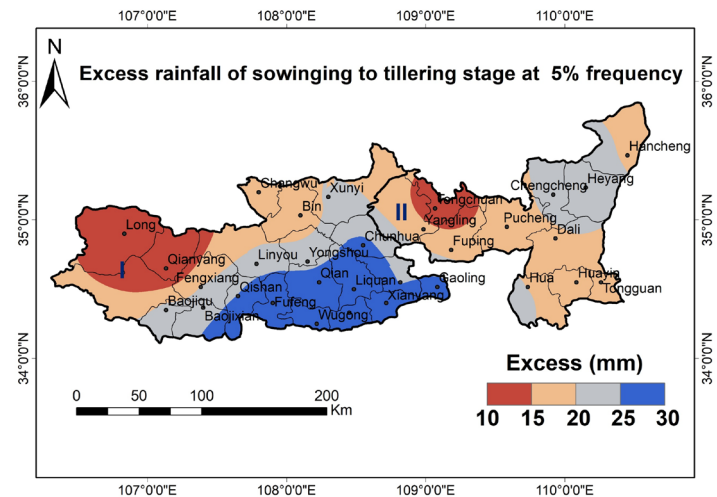
3.2.1. Excess Rainfall of Sowing to Tillering Stage

Figure 3 presents the spatial distribution of three different frequencies of excessive rainfall during Sowing to the Tillering stage in Northern Weihe loess plateau. The highest excess rainfall of three differents 5%, 10%, and 20% frequencies, were occurred in similar regions such as Chunhua, Qian, Liquan, Xianyang,
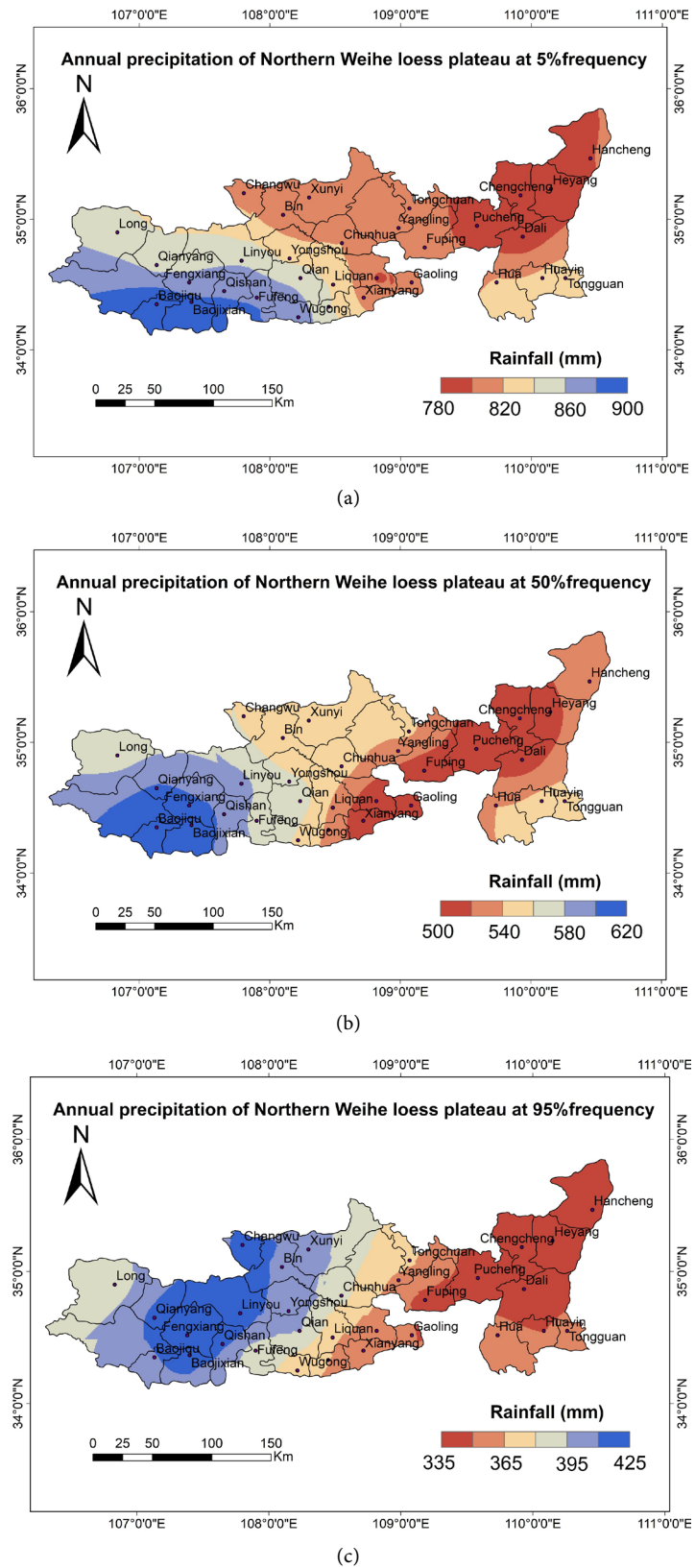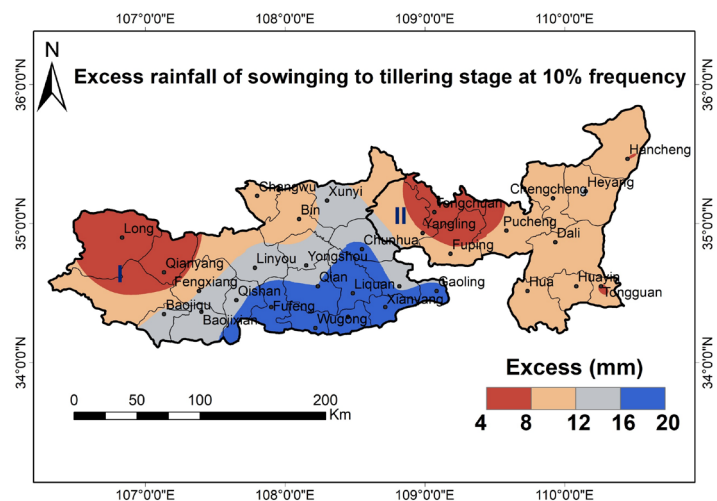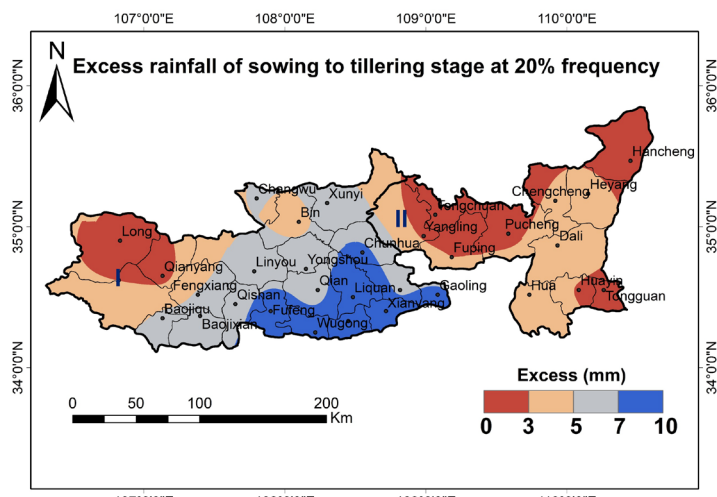
Figure 2. The spatial distribution of the different frequencies of annual precipitation in the Northern Weihe loess plateau, 1981-2012 (unit: mm) ((a), (b) and (c) for 5%, 50%, 95%, respectively).

Figure 3. The spatial distribution of the different frequencies of excess rainfall of sowing to tillering stage in the Northern Weihe loess plateau (unit: mm) ((a), (b) and (c) for 5%, 10%, 20%, respectively).

Fufeng, and Wugong with the value ranged from 25 to 30 mm, 16 to 20 mm, and 7 to 11 mm respectively. However, the lowest condition of three different frequencies distributed in different areas. Long, Qianyang, Tongchuan, Yangling, Fuping with value ranges from 10 to 15 mm, 4 to 8 mm, 0 to 3 mm respectively except Hancheng, Huayin, and Tongguan were only covered by 20% condition with a value of 0 to 3 mm. At 5% frequency, the amount of excess rainfall ranged between 15 mm to 20 mm covered by Changwu, Bin, Yangling, Fupinng, Pucheng, Dali, Huayin, Tongguan, and Hancheng. Moreover, Heyang, Chengcheng, Xunyi, Yongshou, Linyou, Baoji region (Baojiqu and Baojixian) with a value of between 20 mm and 25 mm. Changwu, Bin, Fuping, Hancheng, Heyang, Chengcheng, Pucheng, Dali, Hua, Huayin, Tongguan account for the value range 8 to 12 mm of the 10% frequency excess rainfall. The value ranged between 12 mm and 16 mm, covered by Xunyi, Linyou, Yongshou, Qishan, and Baoji region (Baojiqu and Baojixian). At 20% frequency, the excess rainfall of Heyang, Chengcheng, Dali, Hua, and Fengxiang distributed within 0 to 4 mm and Xunyi, Changwu, Yongshou, Linyou, Qishan, and Baoji region was around 4 mm to 7 mm.

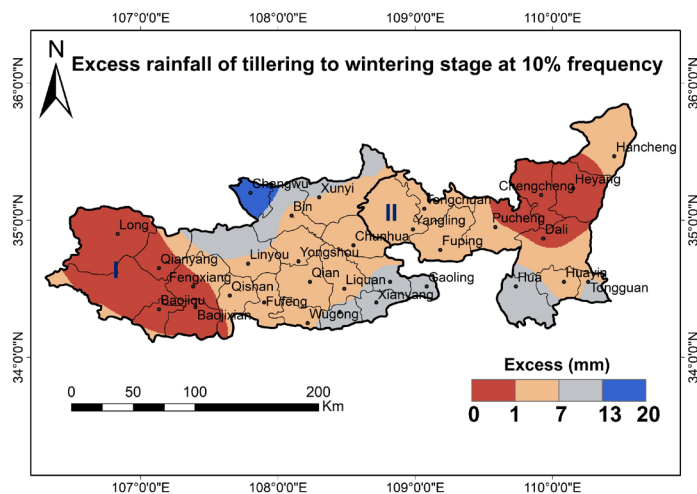### 3.2.2. Excess Rainfall of Tillering to Wintering Stage

Figure 4 shows the spatial distribution of three different frequencies of excessive rainfall during the tillering to wintering stage in Northern Weihe loess plateau. Based on observation, the excess rainfall of Changwu is the highest at 5% and 10% frequencies. Furthermore, Long, Qianyang, Fengxiang, Heyang, Changwu, Dali, and both Baoji regions consist of value within 0 to 10 mm and 0 to 1 mm for 5%, 10% frequencies, respectively 5% and 10% of rainfall excess of Xunyi, Bin, Linyou, Qishan, Fufeng, Wugong, Liquan, Qian, Yongshou, Chunhua, Tongchuan, Yangling, Fuping, Pucheng, Huayin, Tongguan, and Hancheng valued around 10 to 20 mm and 1 to 7 mm. Xianyang, Gaoling, Wugong, and Huavaried from 20 to 30 mm and 7 to 13 mm. However, amount of rainwater of 20% frequency supplied inadequate to winter wheat with the value from 1 to 13 mm. In this case, water shortage appeared in Tillering to Wintering stage at 20% frequency.

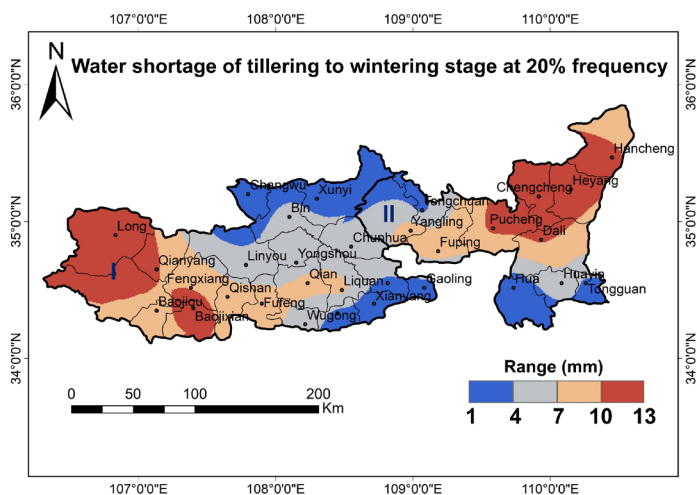### 3.2.3. Water Shortage of Wintering to Greening Stage

As shown, Figure 5 indicates the spatial distribution of three different frequencies of excess rainfall during Wintering to the Greening stage in Northern Weihe loess plateau. Since three different amounts of rainfall frequency distribution insufficiently supplied to winter wheat crops, the water shortage occurred in the Northern Weihe loess plateau. The serious water shortage existed in 20% frequency of amongst the counties of Northern Weihe loess plateau such as Hancheng, Heyang, Chengcheng, Tongchuan, Yangling, Pucheng, Dali, Fuping, Hua, Huayin, and Tongguan with values varied from 29 to 34 mm. And, the least water shortage distributed in the central part of Northern Weihe loess plateau at 5% frequency within the amount of 7 to 11 mm. At 10% frequency, the
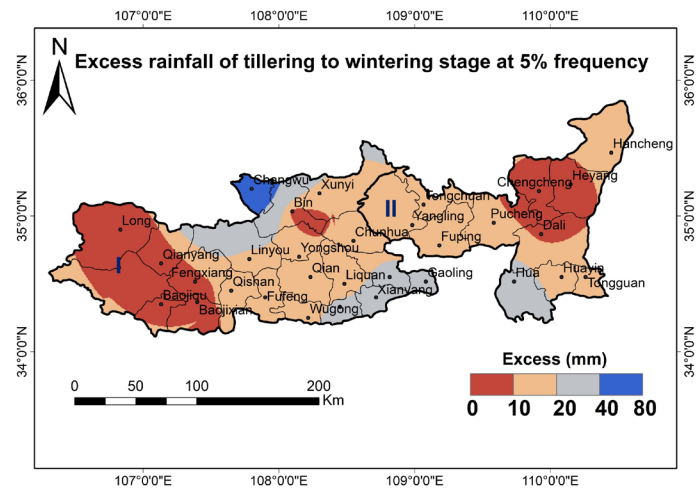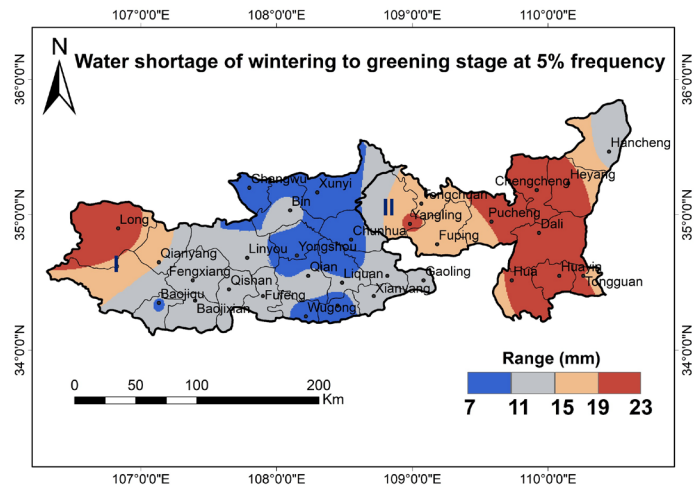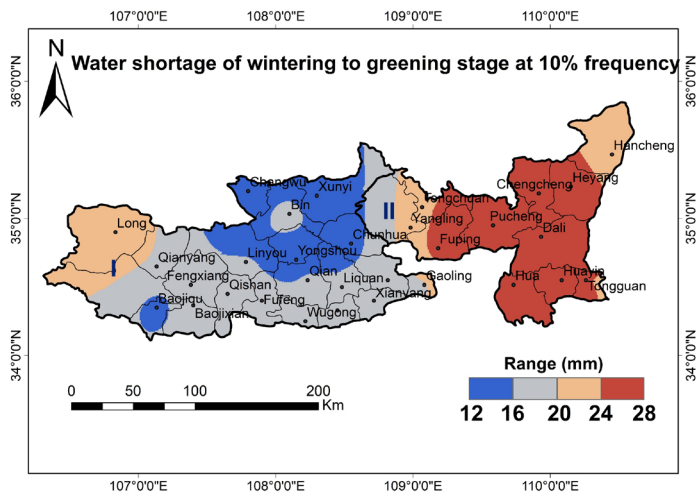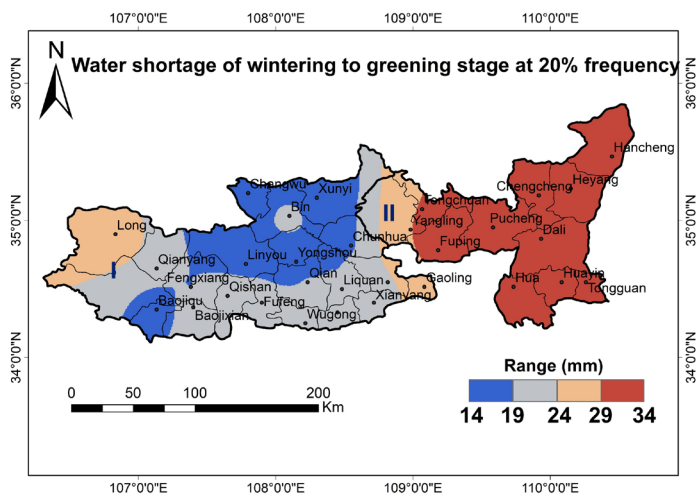
Figure 4. The spatial distribution of the different frequencies of excess rainfall of tillering to wintering stage in the Northern Weihe loess plateau (unit: mm) ((a), (b) and (c) for 5%, 10%, 20%, respectively).

Figure 5. The spatial distribution of the different frequencies of excess rainfall of wintering to greening stage in the Northern Weihe loess plateau, (unit: mm) ((a), (b) and (c) for 5%, 10%, 20%, respectively).

water shortage almost happened in a similar region as the 5% and 20% frequencies with value varied from 12 to 28 mm.

3.2.4. Water Shortage of Greening to Jointing Stage

Figure 6 showed the spatial distribution of three different frequencies of water shortage during Greening to the Jointing stage in the Northern Weihe loess plateau. The result demonstrated that region II of Northern Weihe loess plateau suffered a water shortage. The largest amount of water shortage specifically is distributed in Hancheng, Heyang, Chengcheng, Tongchuan, Yangling, Fuping, Huayin, and Tongguan with about 55 to 60 mm at 20% frequency. And, another two various frequencies 5% and 10% also occurred the serious water shortage like 20% frequency with the value range between 45 to 50 mm and 50 to 55 mm, respectively.

### 3.2.5. Water Shortage of Jointing to Heading Stage

Figure 7 presented the spatial distribution of three different frequencies of water shortage during jointing to the heading stage in Northern Weihe loess plateau. The largest amount of water shortage of three differents 5%, 10%, and 20% frequencies occurred in similar regions II such as Heyang, Chengcheng, Tongchuan, Yangling, Pucheng, and Dali with the value ranged from 26 to 34 mm, 36 to 44 mm, and 45 to 52 mm respectively except Hancheng was only covered by 20% condition with a value of 45 to 52 mm.

### 3.2.6. Water Shortage of Heading to the Flowering Stage

Figure 8 shows the spatial distribution of three different water shortage frequencies during heading to the flowering stage in Northern Weihe loess plateau. We observed that water shortage in region II is higher than the region I. The water shortage significantly increases from southwest to northeast with value varied from 30 to 90 mm. Hancheng, Heyang, Pucheng, Tongchuan, Yangling, Pucheng, Huayin, and Tongguan highly occurred water shortage in region II at 20%, 10%, and 5% frequencies which account for 80 to 90 mm, 70 to 80 mm, and 60 to 70 mm, respectively. At 10% and 20% frequencies, Changwu, Xunyi, Bin, Chunhua, Linyou, Yangshuo, Qian, Liquan, Gaoling, and Xianyang also exist water shortage, in which the value was around 50 to 60 mm, and60 to 70mm, respectively. Moreover, the amount of water shortage in Qianyang, Fengxiang, Qishan, Fuping, Wugong, Baojiqu, and Baojixian is around 40 to 50 mm, and 50 to 60 mm, respectively. At 5% frequency, the water shortage of Qianyang, Fengxiang, Qishan, Baojiqu, and Baojixian is around 30 to 40 mm. Similarly, at 5% frequency, the water shortage of Long, Changwu, Linyou, Fufeng, Wugong, and Qian region was about 40 to 50 mm, Xunyi, Bin, Chunhua, Yongshou, Liquan, Xianyang, and Gaoling ranges between 50 to 60 mm.

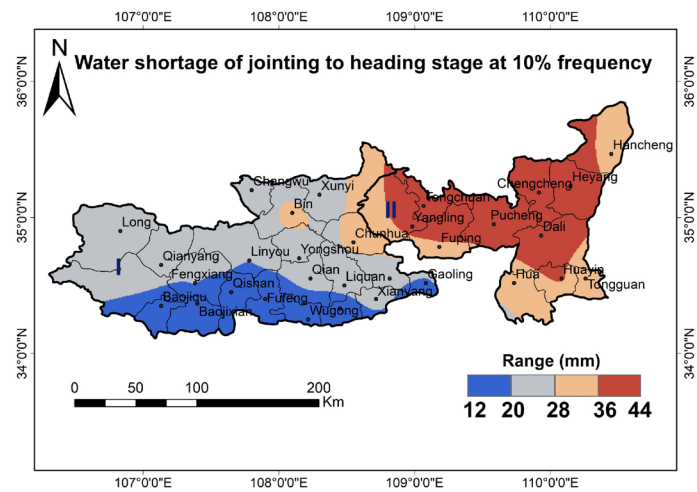### 3.2.7. Excess Rainfall of Flowering to Ripening Stage

Figure 9 presents the spatial distribution of three different frequencies of excess rainfall during flowering to the ripening stage in the Northern Weihe loess plateau.
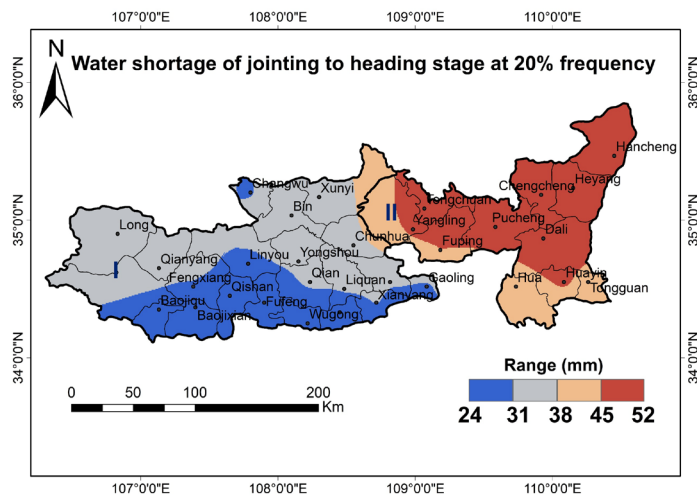
(a)

(b)

(c)
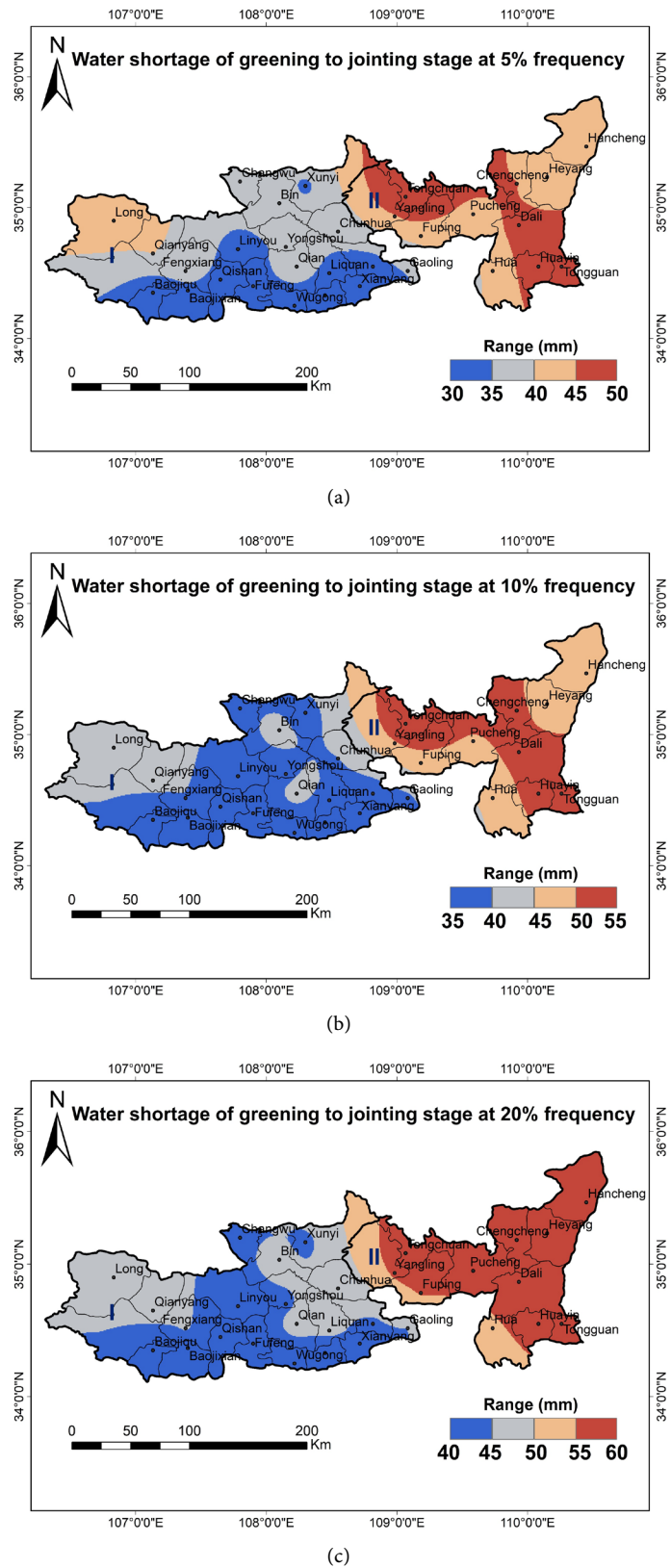
Figure 6. The spatial distribution of the different frequencies of excess rainfall of greening to the jointing stage in the Northern Weihe loess plateau (unit: mm) ((a), (b) and (c) for 5%, 10%, 20%, respectively).
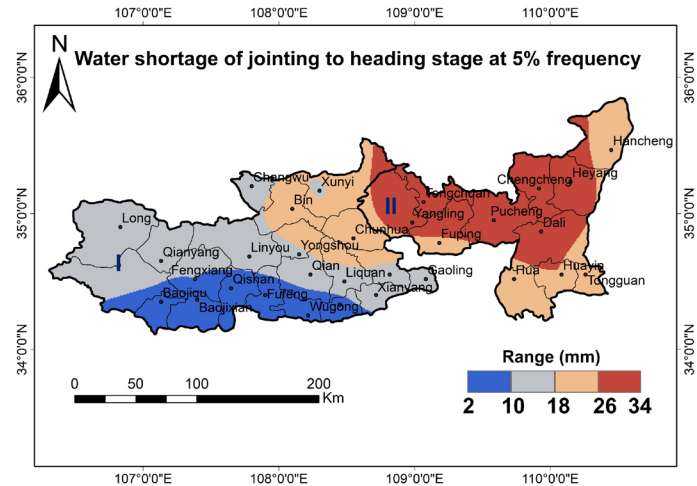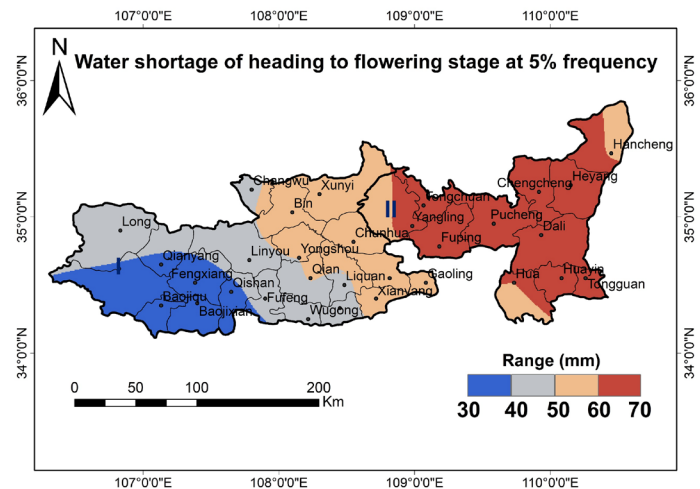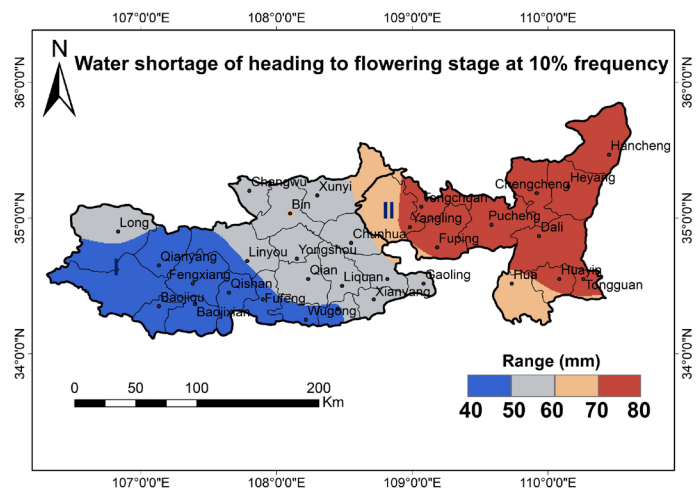
Figure 7. The spatial distribution of the different frequencies of excess rainfall of jointing to heading stage in the Northern Weihe loess plateau, (unit: mm) ((a), (b) and (c) for 5%, 10%, 20%, respectively).
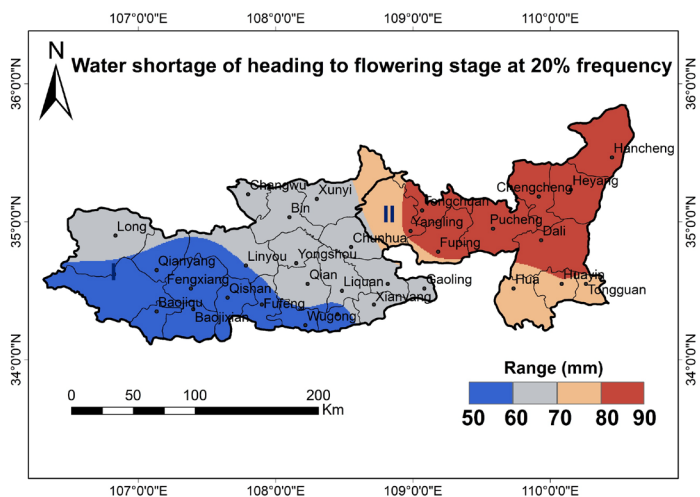
(a)

(b)

(c)

Figure 8. The spatial distribution of the different frequencies of excess rainfall of heading to flowering stage in the Northern Weihe loess plateau, (unit: mm) ((a), (b) and (c) for 5%, 10%, 20%, respectively).

Figure 9. The spatial distribution of the different frequencies of excess rainfall of flowering to the ripening stage in the Northern Weihe loess plateau (unit: mm) ((a), (b) and (c) for 5%, 10%, 20%, respectively).
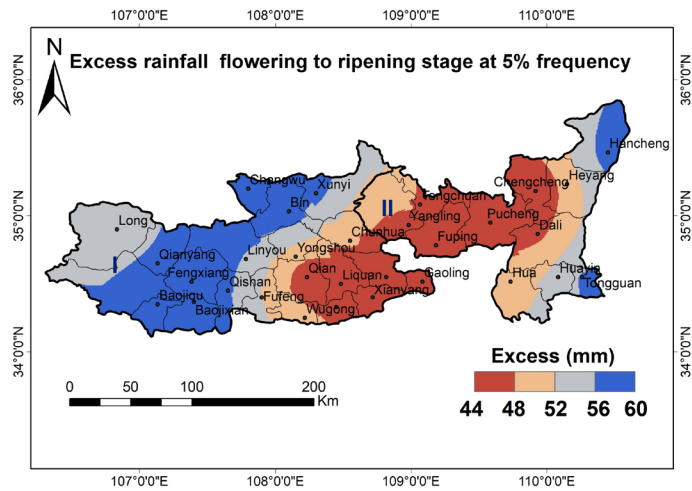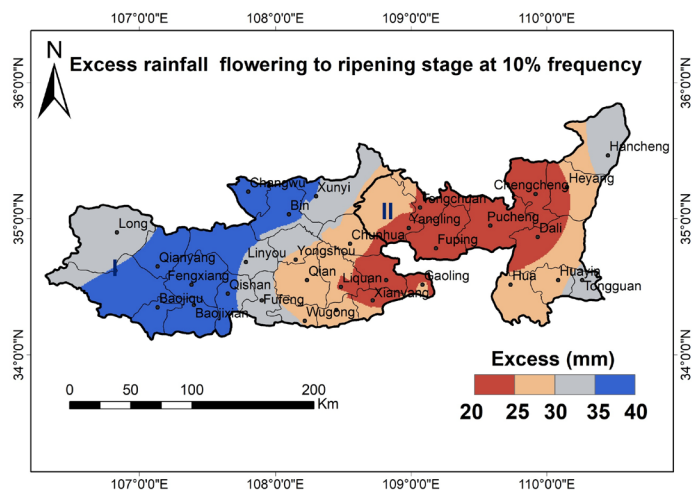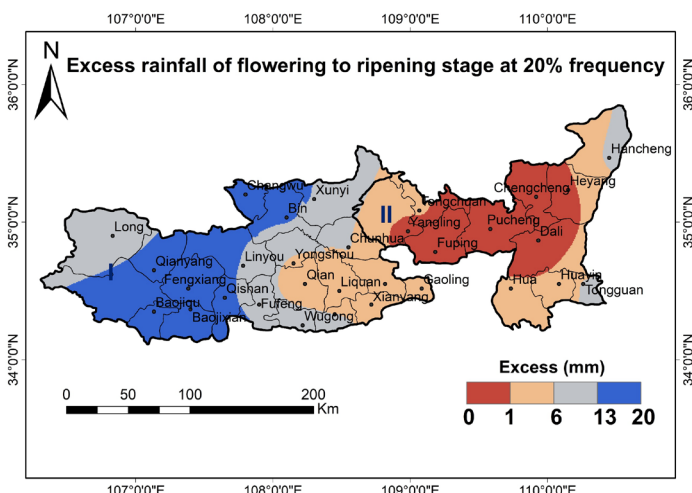
The rainfall excess was classified into four categories. The blue color represents the largest amount of rainfall excess which was covered by the county in region I such as Changwu, Bin, Qianyang, Fengxiang, Baojiqu, Baojixian, and Qishan with value was around 56 to 60 mm, 35 to 40 mm, and 13 to 20 mm at 5%, 10%, and 20%, respectively. Chengcheng, Heyang, Pucheng, Dali, Tongchuan, Yangling and Fuping are fully sufficient for irrigation at 20% frequency during flowering to the ripening stage. At 10% and 5% frequencies, Chengcheng, Heyang, Pucheng, Dali, Tongchuan, Yangling, Fuping, Qian, Liquan, Xianyang, and Wugong of rainwater exceed about 20 to 25 mm, and 44 to 48 mm, respectively. Hancheng, Tongguan, Xunyi, Yongshou, Linyou, Qishan, and Fufeng of 10% and 20% frequencies with value were about 30 to 35 mm and 6 to 13 mm.

4. Discussion

By using the Pearson-III probability function and ordinary kriging method, the spatial distribution characteristics of maps for annual precipitation at 5%, 50%, and 95% were analyzed. And, the amount of rainfall during seven growth stages of winter wheat in 29 counties of Northern Weihe loess plateau at three different frequencies 5%, 10%, and 20% in sequence was discussed. The result of annual rainfall was summarized in Figure 2; rainfall distribution from southeast to the northwest was decreased significantly like the previous study from Zhi *et al.* [34]. Notably, the result indicated the Baoji area was similar in the heaviest annual rainfall to the previous research [35] [36].

Under the same condition frequency 5%, 10%, and 20% of precipitation of the whole growing period, the spatial distribution interpolation maps of rainwater excess and shortage at seven growth stages were analyzed. From Figure 3, the amount of rainwater was greater than crop water needs during the period of sowing to tillering stage (stage I) which was a negative influence on winter wheat crop growing. The amount of rainwater excess under 5% frequency was further beyond 10%, and 20% frequency and it mostly impacts the part of the southwest area in the region II of Northern Weihe loess plateau. The rainwater excess also happened in Figure 4 stage II (tillering to wintering) at the 5% and 10% frequency, in contrast, water shortage occurred at 20% frequency. From our findings, Table 2 represents that crop water needs significantly increased from stage III to VI and the amount of rainfall was lower during the period of each growth stage. Therefore, the water shortage occurred in stage III (wintering to greening) (Figure 5), IV (greening to jointing) (Figure 6), V (jointing to heading) (Figure 7), and VI (heading to flowering) (Figure 8) highly impacts on the winter wheat yields. Due to previous research from Li *et al.* [37] also explained that March precipitation was the main factor of stage IV of winter wheat; water was critical to winter wheat during this period, and its yield was decreased sharply if the water was insufficient. If the amount of precipitation was sufficient, the water supply could be accordingly increased to ensure crop yield. From Wang *et al.* [38] also mentioned about water shortage during stage IV, V, and VI and influence to winter wheat growth and yield formation. During a period of flowering

to ripening ([Figure 9](#)), crop water needs of winter wheat remarkably decrease, rainfall excess existed at this stage. Even though we studied the crop water requirement under extreme rainfall conditions, the amount of rainwater still supplied inadequate in some parts of the winter wheat growth stage. Therefore, irrigation management should be designed to improve the crop yields of winter wheat.

5. Conclusions

Based on the daily precipitation data of 29 stations from 1981 to 2012, this paper analyses the spatial distribution of three different frequencies of annual precipitation at 5%, 50%, and 95% and rainfall excess of seven growth stages of winter wheat crop at 5%, 10%, and 20% in Northern Weihe loess plateau. The main conclusions were given as below:

1) A study of the distribution of annual precipitation in the Northern Weihe loess plateau shows that the lower of 5%frequency of annual rainfall gradually increases from the southwest to the northeast of Northern Weihe loess plateau. The highest annual rainfall occurred in the Baoji area and the lowest annual rainfall exists in Hancheng, Heyang, Chengcheng, Pucheng, and Dali. At 50% frequency, the largest amount of annual rainfall also happened in Baoji area. And the minimum rainfall occurred in Chengcheng, Pucheng, Fuping, Gaoling, and Xianyang. At the high frequency of 95%, the maximum annual rainfall was in Changwu, Qianyang, Fengxiang, Linyou, Baoji, and the minimum annual rainfall was in Hancheng, Heyang, Chengcheng, Pucheng, Dali, and Fuping. Normally, the water shortage happened in 95% frequency and the flood event occurred in 5% frequency.

2) The rainfall excess not only occurred in stage I (sowing to tillering) at 5%, 10%, and 20%, but also happened in stage II (tillering to wintering) at 5%, 10%, and stage VII (flowering to ripening) at 5%, 10%, and 20%. A large amount of rainfall excess exists in stage VII of 5% frequency and was covered by region I such as Changwu, Bin, Qianyang, Fengxiang, and Baoji region (Baojiqu and Baojixian). Since the rainwater was inadequate for the crop water balance of other growth stages, the water shortage is distributed in stage III (wintering to greening), stage IV (greening to jointing), stage V (jointing to heading), and stage VI (heading to flowering). Moreover, the serious water shortage occurred in Hancheng, Heyang, Chengcheng, Pucheng, Dali, Tongchuan, and Fuping at 20% frequency of stage IV (greening to jointing stage). In conclusion, this research study may be useful for the next research for water requirement manipulation of winter wheat crops and reduce the rainfall-induced risk to agriculture in the climatically vulnerable of 29 counties of Northern Weihe loess plateau.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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