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Spatial characteristics analysis of drought disasters in North China during the Ming and Qing Dynasties

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Abstract. This paper studies grade sequence of drought disasters in 21 sites in Ming and Qing Dynasties (1470 – 1912) in North China. Two aspects are explored, in order to study the spatial distribution and characteristics of drought disaster in North China. The reconstruction of the sequence of drought disaster in North China during the Ming and Qing Dynasties was based on Empirical Orthogonal Function (EOF) and on Rotated Empiric Orthogonal Function (REOF). The drought disaster has been divided into several space models and into several sensitive space areas. It can provide an important basis for the better understanding of the spatial distribution of drought disasters in North China during the historical period. The research's results show that: the frequency is high in northern area and is low in southern area of North China. The frequency of drought intensity is high in South-East, low in West China. Meanwhile, the North China can be divided into six main sensitive regions: Middle-east of North China, west of North China, South of North China, East of North China, North-east and North-west of North China.

1. Introduction

With global warming background, the regional drought problem is becoming more and more serious, and yet the North China belongs to arid and semi-arid region, especially in recent decades, the drought is getting more and more obvious in North China, and has attracted extensive attention from experts and scholars severely. "China Science and Technology of the Blue Book No. 5" has classified the drought as the first climate disaster of China, the North China drought occurrence frequency degree is the first in the whole country (Li Jiao, et al. 2013). In recent years, the drought persisting, has already strained the shortage of water in arid and semi-arid regions is very serious. Geographically, the North China present a significance differences in meteorology division, in order to study regional unity this paper treat the integrity and available data. Considering the location of the North China and the contents of the research situation, the administrative boundaries as the main criteria for the classification, this paper has selected Hebei province, Shanxi province, Shandong province, Henan province, Beijing and Tianjin, four provinces and two municipalities were concerned to expand research and discussion. The concerned region is located in the area 31 ° N-43 ° N, 110 ° E-123 ° E. To study the drought region's characteristics change on an historical period is important to understand the future occurrence of drought disaster in the region development, the prevention and control against nowadays drought has a very important significance (Huang Qingxu, et al. 2009).

Up to now, various scholars have conducted researchers on drought disaster in North China. Zhou Liantong (2009) analyzed North summer interannual variation of rainfall characteristics using modern platform precipitation data, and explained the relation between the precipitation in North China and Northwest China and the Middle Yangtze River region. Ma Zhuguo (2007) analyzed the trend characteristics of dry and wet change in North China from 1951 to 2005, he found that nearly 55 experienced wet to dry process, in this transition was found in 20^{th} century around and after 1970, and explored the relationship between the characteristics of the trend of years and the Pacific Decadal Oscillation Index (PDOI). Rong Yanshu et al. (2008) did statistics of the distribution rate of drought from 1997 to 2002, and found that the cause of the persistent drought in North China is the result of the interaction of the sub members of the scale circulation system in the Eurasian region. Li Qingxiang et al. (2002) proposed a new calculation model scheme of dry and wet Index, analyzed the characteristics of index linear variation of the drought in North China in the last half century, indicated that there was a very intense change tendency of drought in North China, and used the singular spectrum analysis method to test the characteristics periodicity of time series. Zhou Dan et al. (2014) used standardized precipitation index of evapotranspiration and analyzed the characteristics of spatiotemporal distribution of drought intensity in North China. Gao Ce et al. (2013) has found the collation and analyzed the historic of Ming Fen River Basin drought by using the county as a unit of drought grade division standard, he used the linear trend estimation method to estimate the spatiotemporal changes of the drought characteristics of Fen River Basin, and used two aspects of frequency and intensity to study the spatial distribution of drought, at the same time, he used the test "t" to test whether there is a change in drought dynamic change according to time. However, the research and measuring device data of on drought in North China are relatively many nearly a half century, and there is less researchers on periodic drought disaster in North China, and these studies focused on the time evolution law of drought and floods, and according to spatial distribution of drought disaster, especially in the use of climate statistical methods to study the spatial characteristics of drought disaster is relatively less. This paper is based on the full absorption of the previous studies on the time and evolution of drought disaster events, view on the historical records of the drought disaster in North China during Ming and Qing Dynasties, and the spatial distribution characteristics of drought disaster in North China during the historic period.

2. Data and Methods

In this paper, the important resources mainly come from " The chronology of drought in North China in recent five hundred years" (Zhang Weibing, 2009) (referred to "Drought chronology") as well as "North China, northeast drought and flood historical data of recent five hundred years " (Central Weather Bureau in North China, 1975) (referred to "Drought and floods historical "), and shaft by Zhang Deer (2004) compiled of" China meteorological records Collections of three thousand years "(referred to " General collection "). In this paper, the selected historical data is from 1470 (Ming Chenghua 6 years) to 1912 a total of 443 years, from the mid-Ming Dynasty to the late Qing Dynasty. 1470 ago (early Ming Dynasty) historical data was relatively scattered, that temporary causes difficulties to sort out the serial data, so it couldn't be put in sequence. To make study on "Drought chronology" and "Drought and floods historical data", in the current administrative division as unit, 21 representative stations have been selected, respectively Beijing, Tianjin, Hebei province (Tangshan, Cangzhou, Baoding, Shijiazhuang, Handan), Shandong province (Jinan, Dezhou, Yantai, Heze, Linyi),Henan province (Anyang, Zhengzhou, Luoyang, Nanyang, Xinyang) and Shanxi province (Datong, Taiyuan, Linfen, Changzhi). "Drought

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Chronology" included a particular year of missing disaster record, contrast to "General collection" and "Drought and floods historical data", the lack of collection vintage filled, if the three aspects of data are not recorded in three areas, then it is determined that the drought has not occurred in the region. This paper used the data for three aspects of information obtained to show the rank sequence of drought in 21 sites during 443 years in Ming and Qing Dynasties from 1470 to 1912. The criteria for the classification of disaster grades are in Table 1. In which level 1 is set as "general disaster", level 2 as a "high drought", level 3 as "heavy drought" and "no drought" disaster is set as level 0.

Table 1 Repartition of standard grade classification of drought disaster

Description of historical data disaster	Drought disaster grade
"Spring drought", "summer drought", "winter and spring without rain", etc.	1
"Summer and autumn high drought", "spring and summer high drought," "Since last year winter solstice, this year it started raining in July", for several months without rain as dry grain, etc.	2
"Scene of utter desolation," "people's food", "even the drought years, the particular age" etc.	3

Empirical Orthogonal Function, EOF (Wu Hongbao, 2005), also known as principal Component Analysis PCA, it is a kind of analysis of the structural characteristics of the matrix data, it is also a main method of extracting data features. From the earliest proposed by Pearson (1902), In 20th century in 1950, Lorenz introduced the method into the Atmospheric science field, then has been widely used so far, it can be irregular meteorological elements of the field and can be decomposed in time coefficient and space vector features, spatial models must reflect the spatial distribution characteristics of the meteorological elements in a certain degree. The transformation of Rotated Empirical Orthogonal Function (REOF) is based on the EOF decomposition, the orthogonal rotation of original matrix (maximum variance rotation), the high load vectors concentrated in a few variables, and the remaining region is close to 0, so that the characteristics of the field in the rotation is more stable over time, spatial distribution structure more clearly, also the local features of abnormal distribution of the element are more prominent (Chen Yuying, et al. 2010). Domestic and foreign Scholars have successfully applied the method of EOF and REOF in climatic zoning, and obtained good results (Han Rongqing, et al 2014; Liu Lin, et al. 2014; Wang Yanjiao, et al. 2014; Liu Honglan, et al. 2014).

3. Results and Analysis

3.1 Drought frequency and spatial distribution intensity

Statistics have been done on 21 sites in Ming and Qing Dynasties in North China during 443 years of existence of drought frequency, a map of drought disaster frequency distribution has been done, as shown in Figure 1.A. In which the round size represent the frequency and occurrence of drought disaster, the greater the radius is, the more the frequency of drought is. In 21 sites studied, the drought frequency is big in Linfen, up to 181 times, during a period of 443 years the drought disaster occurred 181 times, the occurrence rate was 40.9%, an average of every 2.4 years occur 1 time. Drought frequency is the smallest in Nanyang, there were 69, amounted to 15.6%, it occurred once every 6.4

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years. In addition, the frequency of the removal of Nanyang was 69, the rest of the drought occurred more than 100 times, therefore, we can say that the drought disaster in North China is more frequent and the drought is more serious.

As the frequency of drought disaster level only reflects the regional prone, and does not reflect the drought intensity and the size, therefore this paper used the weighted average method, to calculate the drought intensity and average grade of each site, the formula (Gao Ce, et al. 2013) is:

$$I = (a + 2b + 3c)/(a + b + c) \tag{1}$$

Among them: I represents the drought intensity and average grade value for each county, a, b, c represent respectively 1, 2, 3 frequency occurrence of drought occurred.

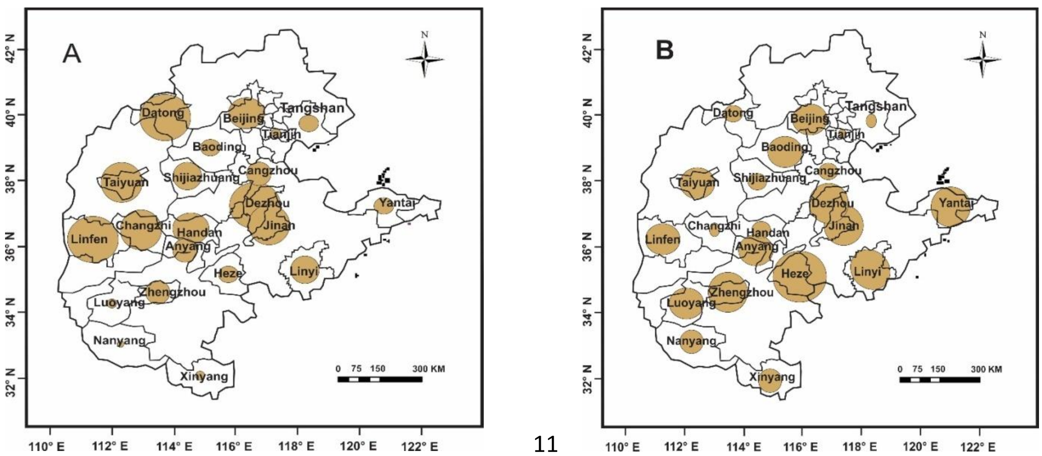

Figure 1: Frequency of drought disaster in North China during Ming and Qing Dynasties (1470-1912): (A) Frequency distribution map, (B) Intensity distribution map

Figure 1.B shows the distribution of the drought intensity of 21 sites in North China during the period of Ming and Qing Dynasties, in which the circular size occur represents the size of drought disaster intensity, the greater the radius of the circle is, the greater is Ming Dynasty drought intensity. From the figure, we can see that the highest drought disaster intensity in Eastern North China is in Shandong Dezhou, Jinan, Heze, Linyi and Yantai districts. In addition, in North China, the drought intensity is low in North East of Tianjin, Tangshan as well as in the middle of North China in Hebei, Handan, Cangzhou, Shijiazhuang, etc. Comparing the two figures we can find that there is no consistency between drought disaster degree and drought disaster intensity. The frequency of drought disaster occurred more frequently in Shanxi district, but the intensity was relatively low, what means although there is more drought in the area, the drought situation is not serious. The frequency of drought disaster occurred less frequency in Shandong province district of Heze, Yantai, Linyi areas etc., but the intensity of drought disaster is higher, it shows that there occurred less drought in that area, but the drought is more serious. In addition in Shandong province districts of Dezhou, Jinan etc. not only the frequency of drought disaster was high but also the drought disaster intensity is high, indicating that the region is not only prone to drought disaster but also more serious.

An Lijuan et al. (2014) found that in the past 50 years of drought disaster in North China, the zone of high frequency is mainly located in Middle south of North China most areas, the frequency center appears in the southeast of Hebei; the large value of cumulative intensity value appears in Middle south of North China, including Hebei, Henan and Shandong three provinces border areas of a center of the large value a cumulative intensity. The conclusions and the results of this paper have some differences in the frequency and intensity distribution of drought in North China during the historical periods, in which the center of frequency occurred eastward and the center of intensity occurred northward. In observing Figure 1 it can be found that in Hebei, Henan and Shandong three provinces border area near Heze, Jinan and other regions drought intensity is relatively high , and An Lijuan and other research results have a certain similarities, indicating that although there was historical period drought in recent years, the drought is characterized by the existence of differences, but there is general consistency of variation, therefore, the study of drought disaster in the historic period is still of great significance to the current and future drought research.

Table 2 Variance contribution rate and cumulative variance contribution rate of EOF and REOF in the first 14 models of drought disaster in North China during Ming and Qing Dynasties

Model number	EOF		REOF	
	Variance contribution rate /%	Cumulative variance contribution rate /%	Variance contribution rate /%	Cumulative variance contribution rate /%
1	29.37	29.37	9.93	9.93
2	7.91	37.28	4.70	14.63
3	7.57	44.85	7.50	22.13
4	6.14	50.99	5.84	27.97
5	4.75	55.74	10.57	38.54
6	4.26	60.00	6.50	45.04
7	3.99	63.99	4.88	49.92
8	3.59	67.58	5.54	55.46
9	3.46	71.04	5.02	60.48
10	3.41	74.45	5.00	65.48
11	3.05	77.50	4.68	70.16
12	2.97	80.47	5.39	75.55
13	2.74	83.21	4.95	80.50
14	2.69	85.90	5.40	85.90

3.2 Spatial modal distribution of drought characteristics

EOF and REOF in the extraction of meteorological field especially potential signal, has its originality to reflect the spatial distribution characteristics of meteorological field aspects etc. (Li Yaohui, et al. 2000), so this paper use EOF and REOF two statistical analysis methods to explore the degree of spatiotemporal evolution of drought disaster during Ming and Qing Dynasties in North China, focusing on analysis of spatial distribution law, give the distribution level of drought disaster in North China and provide the basis prediction of partition.

The EOF method is used for classification of drought disaster rate for resolving standard anomalies of 21 sites in North China during 443 years of Ming and Qing Dynasties, and obtained the space load vectors. The first "i" vector features for "x" field contribution rate for:

$$\rho_i = \lambda_i \Big/ \sum_{i=1}^{m} \lambda_i \tag{2}$$

The "p" vector features for x field cumulative contribution rate

$$\mathrm{P}_i = \sum_{i=1}^{p} \lambda_i \Big/ \sum_{i=1}^{m} \lambda_i \tag{3}$$

in which "m" represent the number of sites.

The cumulative variance of the above 14 models contribution rate reached 85%. Because of the extension of North China region, complex topography, the difference of drought disaster spatial distribution and significant variability is larger, so the convergence speed of load vector is slow, but each load vector still retain the information of main characteristics of North China regional drought disaster. In this paper North et al. (1982) succeeded to calculate the characteristics value of the error range of the features to make a significant test, margin of error range of characteristic value λj

$$e_j = \lambda_j \left(\frac{2}{n} \right)^{\frac{1}{2}} \tag{4}$$

"n" is the sample size. When adjacent value features λj + 1 are is enough

$$\lambda_j - \lambda_{j+1} \geq e_j \tag{5}$$

Actually, it is considered that these two characteristic values corresponding to the Empirical Orthogonal Function is a valuable signal. The first five models through the test, the cumulative variance contribution rate of 55.74% (Table 2), the article analyzes the given 5 models of spatial distribution. Among them the first model of the maximum contribution rate of the variance is the highest, the first model is the best to reflect the features of spatial distribution of drought.

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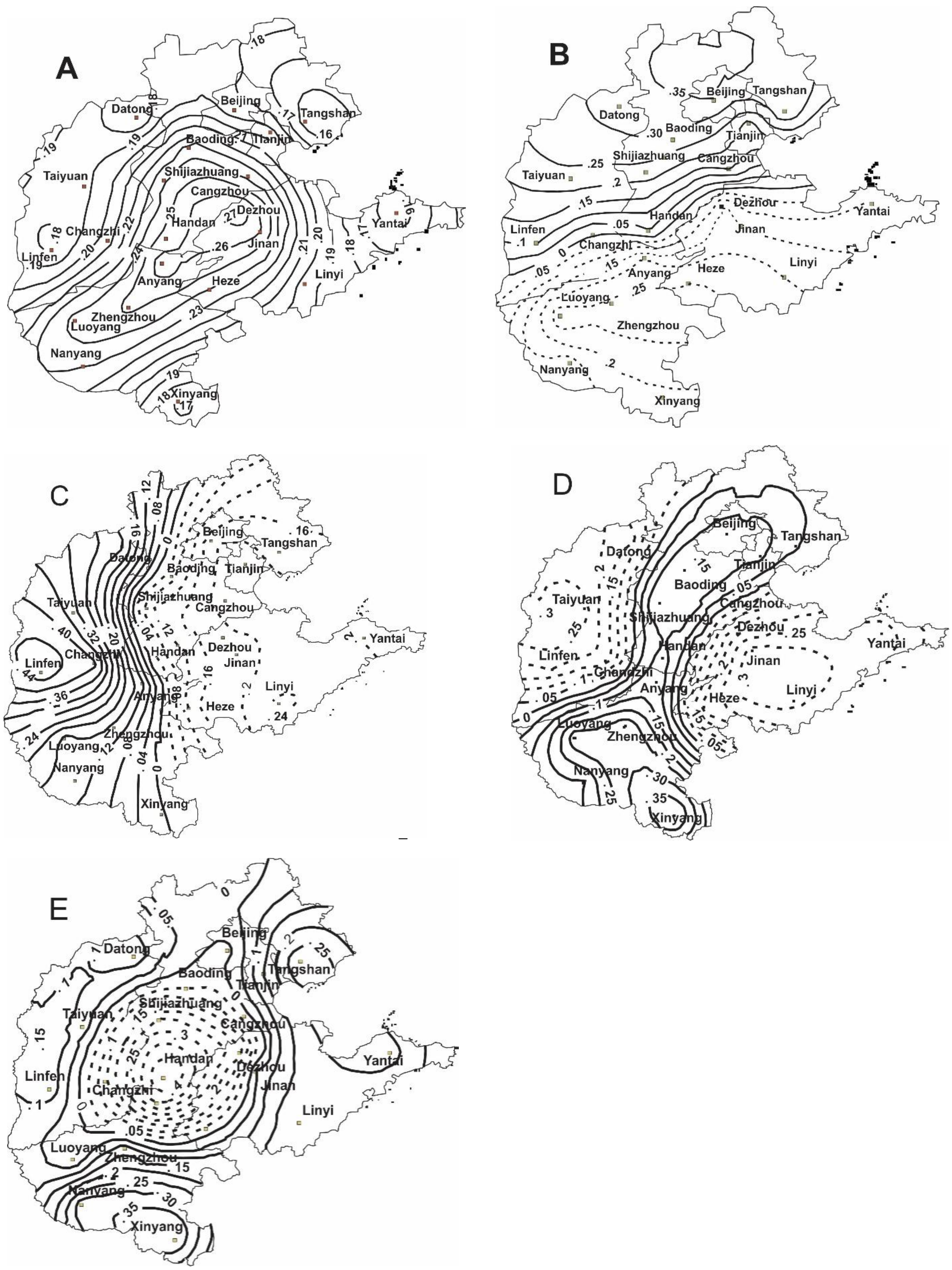

Figure 2: The EOF decomposition of drought grade sequence in North China during Ming and Qing

Dynasties (A. the first model; B. the second model; C. the third model; D. the fourth model; E. the fifth model)

From the first model field spatial distribution (Figure 2.A) we can see that the drought disaster in North China during the Ming and Qing Dynasties is consistent in the whole region. That means the changes of drought in the region are basically identical, shows more partial or less partial characteristics. Its large load value area is located in Dezhou City, Shandong Province, which means that there is the most variable rate of drought disaster in that region. The variance contribution of the first model of is 29.37%, it is more important contribution rate of drought disaster in North China. The changes in time series and the change of grade sequence are almost identical in North China, correlation coefficient is calculated and it is equal to 0.904 and the significance test is 0.01. It shows the first model reflects well distribution characteristics of drought disaster in North China. The second model deal with the spatial distribution field model (Figure 2.B), there is a big difference between the first feature and the second feature field, what show the opposite north-south spatial structural features, and means that the drought is very serious in the southern part; in northern part the drought is rather partial, the drought in southern part is relatively partial while northern part the drought is more severe. The Zero line is located between 36 ° -38 ° N, and across Changzhi, Handan, Dezhou etc. districts. The center of the maximum value is located in the center of the northern part of Beijing District in North China, the center of the maximum negative value is located in south of Henan Province in Zhengzhou, Luoyang districts etc. From the third spatial distribution field model (Figure 2.C) can be seen that things are reversed in drought spatial structure features of North China during Ming and Qing Dynasties, the zero line is located between 114 ° -115 ° E, connecting Xinyang and Handan districts. Its maximum center value is located in Shanxi and Linfen districts in the western region of North China, the maximum negative center is located in eastern Shandong Linyi districts in Northeast of China. From the fourth-model spatial distribution field (Figure 2.D) we can see, that the spatial structure drought features is reversed in North south-Southeast of North China during Ming and Qing Dynasties, there are two positive centers and two negative centers. The center of the maximum value of two positives values in Northern North China is Hebei and Shijiazhuang, Baoding district, as well as the North China southern part of Henan and Xinyang districts, and two maximum negative centers were Shanxi and Taiyuan districts in western part of North China as well as Shandong, Jinan and Linfen in the Eastern part. From the fifth model spatial distribution field (Figure 2.E), drought in North Central region showed the opposite characteristics of the surrounding area, around the middle – four round reverse type. Located in the center of the maximum negative value of Hebei and Handan in North Central region, the maximum value of the center is located in Tangshan, Hebei, Shandong Laiyang, Shanxi Linfen, Xinyang, Henan districts etc.

3.3 Space sensitive areas

Because of the spatiotemporal changes of drought disaster in North China during Ming and Qing Dynasties, the model composition of EOF variance contribution rate is not high, the convergence speed is slow and abnormal features of sub regional is complex. In order to do further studies of regional features, this section will be based on EOF decomposition of REOF analysis.

There are three methods to determination a number “p” of Empirical Orthogonal Function (Wei Fengying, 1999), this paper uses the cumulative variance contribution rate of 85% as the standard to determine the number “p” of feature rotation vector “p”, therefore, this paper take the first 14 features vector rotation, the characteristics of vector variance distribution after a rotation is relatively uniform (Table 2). According to the principle of rotation of factor analysis, the main factor of geographical

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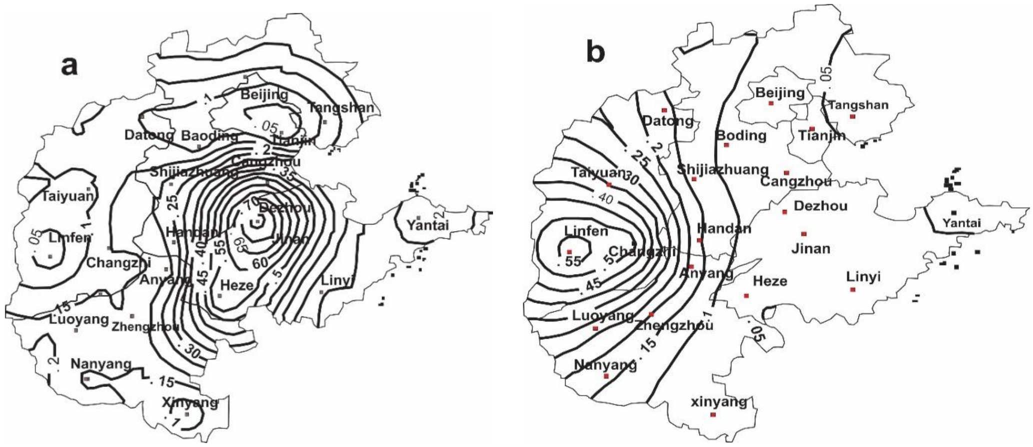
distribution high loads is an important basis for the partition. Using North significance test, the results show that the first 6 models by significant test, and the distribution of the first 6 main factors were given, as shown in Figure 3.

The variance contribution rate of the 1st rotation vector (RLV1) is 9.93%, a large value area is mainly located in the eastern part of North China, the center of the big value of the rotational load vector is mainly located in Shandong and Dezhou in eastern North China, it is called eastern North China model (Figure 3.a) . The variance contribution rate of the 2nd rotation vector (RLV2) is 4.70%, the large value area is mainly located in west part of North China, the center of the big value of the rotational load vector is mainly located in Shanxi and Linfen in the western region of North China, it is called western North China model (Figure 3.b). The variance contribution rate of the 3rd of the rotation vector (RLV3) is 7.50%, a large value area is mainly located in the south of the North China, the center of the big value of the rotational load vector is mainly located in the southern North China in Henan and Xinyang area, it is called southern North China model (Figure 3.c). The variance contribution rate of the 4th rotation vector (RLV4) is 5.84%, a large value area in the eastern part of North China, the center of the big value of the rotational load vector is mainly located in Shandong and Laiyang in eastern North China, it is called eastern North China model (Figure 3.d), Shandong close to Bohai Sea and to the Yellow Sea, and in the Yellow River Delta area, abundant rainfall, in which there is less drought area. The variance contribution rate of the 5th rotation vector (RLV5) is 10.57%, a large value area located in North northeast, the center of big value of the rotational load vector is manly located in Tangshan of North China, northeast, it is called the northeast North China model (Figure 3.e). The variance contribution rate of the 6th rotation vector (RLV6) is 6.50%, a large value area in the northern part of North China, the center of the big value of the rotational load vector is mainly located in Shanxi and Datong in northwest of North China, it is called northwest North China model (Figure 3.f), this area has more mountains and the Great Wall is located in the north, which is a dry area and where the drought is more serious. Therefore, the drought in North China can be divided into 6 regions which are: the Middle east of North China, the West of North China, the South of North China, the East of North China, the Northeast of North China, and the Northwest of North China. Because the REOF method can well reflect the local characteristics of drought in North China, the absolute value of the high load area in the space of each model is higher, in that case, it can intuitively reflect the North China regional characteristics. The Figure 4 is a schematic diagram of the 6 models of REOF decomposition of the drought in North China. Among them, the Northeast of North China is for the first sensitive region, the Middle east of North China for the second sensitive area.



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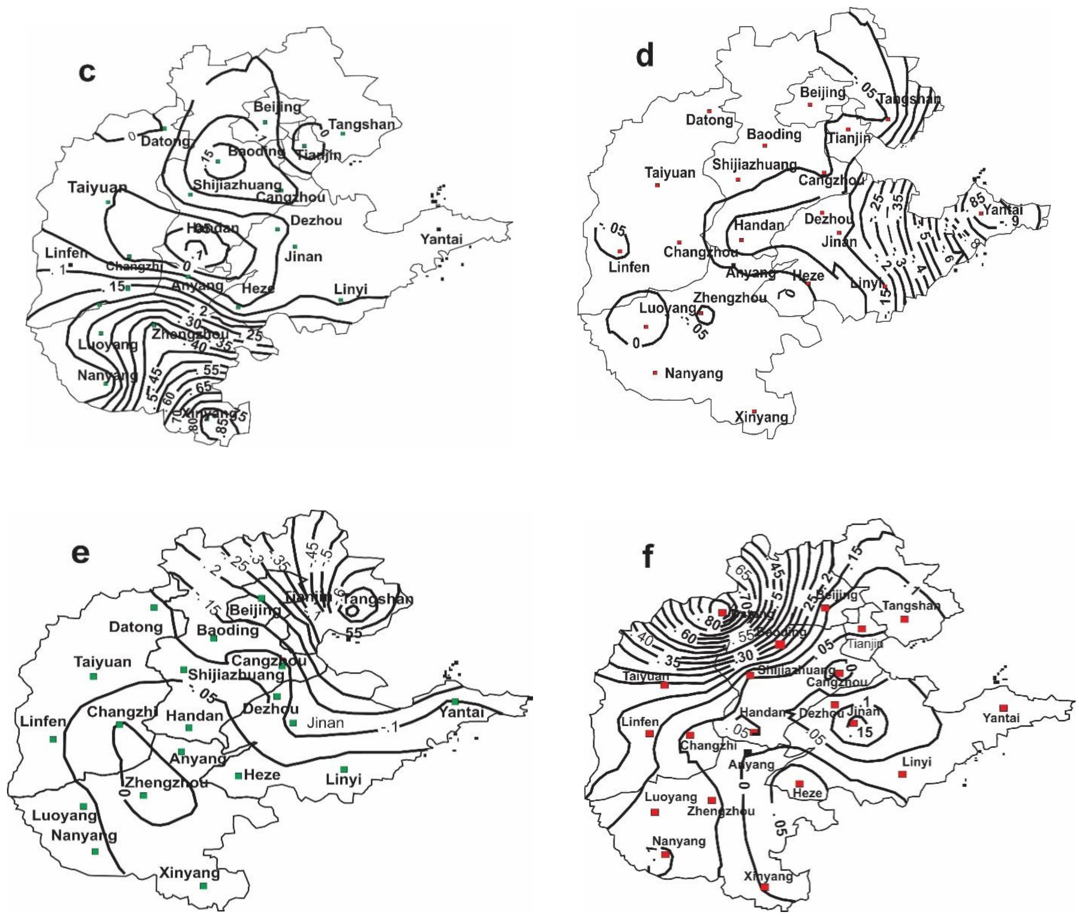

Figure 3: REOF drought rank sequence decomposition of in North China during Ming and Qing Dynasties (a. The 1st rotation vector; b. the 2nd rotation vector; c. the 3rd rotation vector; d. the 4th rotation vector; e. the 5th rotation vector; f. the 6th rotation vector)

Rong Yanshu (2004) considered the climate of North China on different angles division and studied the precipitation from 1957 to 2002, he used a similar method to determine the rainfall of North China and divided it into 5 regions, North of North China, northeast of North China, middle of North China, South of North China, East of North China (see Figure 5). Because of the differences in the studying area in North China, Rong Yanshu (2004) removed to North China the northern region, and remaining 4 regions (northeast of North China, Middle of North China, south of North China and East of North China) concerned by the results of this study. And in this article the basis is that, the Middle North China is divided into Middle East North China, West North China and Northwest North China.

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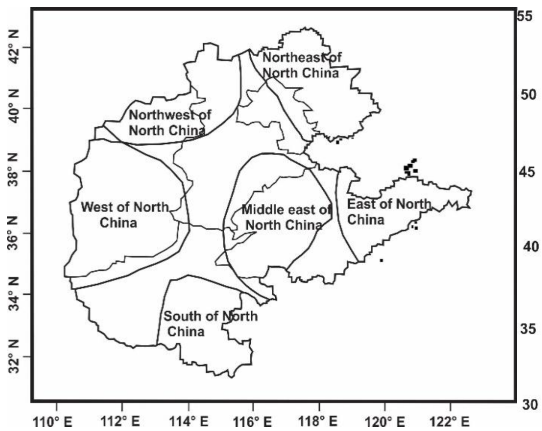

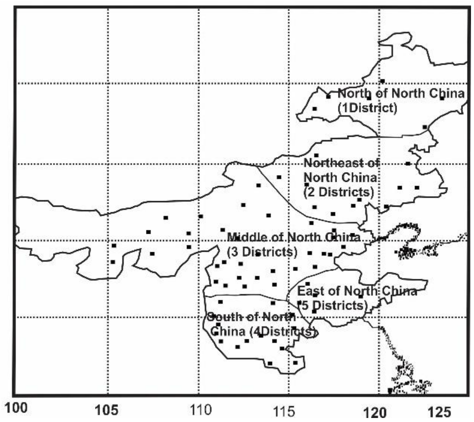

Figure 4: Schematic Partition of REOF analysis of drought in Ming and Qing Dynasties in North China

Figure 5 Partitions of 5 regions of rainfall in North China according to Rong Yanshu

4. Conclusions

Drought and floods are different, they don’t have a sudden occurrence, and there is a formation, occurrence and development of process, the cause of the drought is very complex, it includes existing of precipitation, influence of geographical conditions and other natural factors, but also the impact of economic, social and human factors etc. The North China is in the humid and semi-humid area, with big difference of annual average of temperature, the precipitation is concentrated and the variation rate is high, there is fast evaporation and little precipitation. There is a big impact of Global climate change in North China, the precipitation in North China mainly depends on the precipitation of water vapor from East Monsoon brought by the Pacific Ocean, lack of water vapor transport and atmospheric circulation anomalies in North China drought-prone. In addition, the solar activity and ENSO also have an effect on the drought in North China. ENSO in different position of development in China the effect of drought and floods is quite different, when ENSO is strong, the drought emerge in North China; when ENSO is weak, the North China receive more precipitation (Ye Duzheng, et al. 1996).

The drought disaster occurred more frequently in North China during Ming and Qing Dynasties, and the occurrence degree is more serious. The most frequent occurrence of drought disaster in West of North China appear in Datong, Taiyuan, Linfen, Changzhi districts in Shanxi province as well as in East of North China in Dezhou and Jinan districts in Shandong province, the frequency of drought disaster occurrence is the smallest in South of North China in Henan, Luoyang, Xinyang and other districts. Overall, the frequency of drought disaster in North China is high in North part, low in South part. The highest intensity of drought disaster in North China is in the eastern part in Dezhou, Jinan, Heze, Linyi, Laiyang district of Shandong province. The drought intensity is the lowest in northeast part of North China in Tianjin as well as in the middle part of Hebei province in Handan, Cangzhou, Shijiazhuang etc. districts. Overall, the drought intensity distribution is high in southeastern part of North China and low in the northwest. Meanwhile, the degree of drought prone and the drought disaster intensity are not consistent.

The drought disaster in North China is mainly consistent in the whole region, the change of drought disaster is basically the same as. The characteristics are shown that the consistency of features is high or law. And other typical field mainly displays the local differences of the whole region, such as reverse South-North reverse, East-West reverse, Northsouth-Eastwest reverse, the middle-all sides reverse etc. Meanwhile, the North China can be divided into 6 spatial sensitive regions: the Middle east of North China, the west of North China, the South of North China, the East of North China, the Northeast and North West of North China. Among which the northeast part of North China and the Middle East part of North China are the first two level most important spatial sensitive area of drought disaster.

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Author Contributions

Shuoben Bi, Changchun Chen, and Yanping Li conceived and designed the experiments; Yanping Li and Weiting Wu performed the experiments; Shuoben Bi, Yanping Li and Weiting Wu wrote the chinese paper; Shengjie Bi and Athanase Nkunzimana translated the paper.

Conflicts of Interest

The authors declare that they do not have any commercial or associative interest that represents a conflict of interests in connection with the paper they submitted.

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