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Drought hazard assessment and spatial characteristics analysis in China

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Abstract: Based on the monthly precipitation data for the period 1960–2008 from 616 rainfall stations and the phenology data of main grain crops, the spatial characteristics of drought hazard in China were investigated at a 10 km×10 km grid-cell scale using a GIS-based drought hazard assessment model, which was constructed by using 3-month Standard Precipitation Index (SPI). Drought-prone areas and heavy drought centers were also identified in this study. The spatial distribution of drought hazard in China shows apparent east-west difference, with the eastern part of China being far more hazardous than the western part. High hazard areas are common in the eastern and central parts of Inner Mongolian Plateau, the central part of Northeast China Plain, the northern part of Heilongjiang, the southeastern part of Qinghai-Tibet Plateau, the central and southern parts of Loess Plateau, the southern part of North China Plain, the northern and southern parts of Yangtze River Plain, and Yunnan-Guizhou Plateau. Furthermore, obvious differences in drought hazard were found both within and between different agricultural zonings.

Keywords: drought; hazard; spatial characteristics; grid; GIS

1 Introduction

Drought is a normal, recurrent feature of climate, it occurs almost everywhere. Drought is considered by many to be the most complex but least understood of all natural hazards, affecting more people than any other hazard (Hagman, 1984; Wilhite, 2000). The data from Emergency Events Database (www.em-dat.net) show that, throughout the world, droughts account for 5% of the natural disasters, but losses from droughts have caused up to 30% of losses from all disasters, ranking droughts the first among all the natural hazards. A warmer climate, with its increased climate variability, will increase the risk of both floods and droughts (IPCC, 2007). Drought studies have received special attentions in recent years be-

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cause of climate change (Byun and Wilhite, 1999).

In the past decade or so, drought policy and preparedness has received increasing attentions from governments, international and regional organizations, and nongovernmental organizations (Wilhite, 2000).There has also been a shift in drought management from a reactive, crisis management approach to a proactive, risk management approach, which requires planning between periods of drought (Wilhite, 1992; 2000). The National Drought Mitigation Center (NDMC) has learned that one way to identify appropriate drought mitigation actions is to conduct an overall risk analysis as part of drought planning. Generally, drought risk is considered to be the product of the hazard and vulnerability (risk=hazard × vulnerability) (Knutson *et al*., 1998; Downinge *et al*., 1999; Downing and Bakker, 2000; Wilhite, 2000).One of the main aspects of drought planning and mitigation includes hazard assessment (Hayes *et al*., 2004), which describes the physical nature of drought and plays an important role in the relationship between vulnerability and risk.

WDCC defined the hazard as a threatening event (in this case, a drought, a reduction in water supply, or an increase in water demand) that would make supply inadequate to meet demand (Knutson, 1998). For droughts hazard analysis revolves around an understanding of the frequency, intensity, duration, and spatial extent of drought occurrences (Hayes *et al*., 2004). Currently, drought index is the major way to investigate drought characters. During the recent years, various indices such as Precipitation Anomaly (Li, 1996), Standard Precipitation Index (SPI) (McKee, 1993) and Parmer Drought Index (PDSI) (Palmer, 1965), have been developed and used by researchers at regional or national scale to detect and monitor drought. However, few works has been done about drought hazard model construction, which integrated various characters of drought.

China is a drought-prone country, and agriculture is the worst drought-affected sector. Statistical data show that the average area affected by drought is about 21.593 million ha annually, accounting for 60% of the total area in China affected by all types of meteorological disasters. The annual grain losses due to drought are up to 10 billion kg. The drought occurrence frequency and drought-affected area are still increasing (Li, 2003). Therefore, drought hazards assessment is essential for making mitigation plans to reduce the impact of drought in China. A number of studies have been carried out on the impact of droughts on agriculture (Fu, 1991; Pan *et al*., 1996; Fang *et al*., 1997; Wang *et al*., 2002), and the temporal and spatial patterns of drought (Li *et al*., 1996), but few studies have been done on the issue of drought hazard assessment.

The goal of this study is to construct a grid-cell based drought hazard assessment model for major food crops (wheat, corn and rice) by using Standard Precipitation Index (SPI) in a GIS environment. The drought hazard spatial pattern will be identified at a 10 km×10 km grid-cell scale, and other characters such as intensity and frequency will also be investigated. And the China drought hazard map will be made. The result of this study may provide a scientific basis for decision makers to formulate drought management policies and to reduce the impact of drought.

2 Data and methodology

2.1 Background

Drought is defined based on some deficiency of precipitation that results in water shortage for some activities related to use of water (Dracup *et al*., 1980; Wilhite and Glantz, 1985). Precipitation is the primary factor controlling the formation and persistence of drought conditions, along with other variables such as high temperature (Benjamin Lloyd-hughes, 2002; Sonmez, 2005). Due to China's geographic diversity and its diverse atmospheric circulation patterns, precipitation is highly variable in space and time. The average annual precipitation during 1960–2008 of stations was interpolated to indicate the regional distribution (Figure 1). The precipitation decreases from South to North and from East to West. In the South, annual mean precipitation is over 1000 mm, but it is less than 200 mm in the Northwest. Usually regions with annual precipitation exceeding 800 mm are regarded as humid regions, 400–800 mm as sub-humid regions, 200–400 mm as semiarid regions, and less than 200 mm as arid regions (Wu, 2003). The aridity/humidity conditions of China are shown in Figure 1.

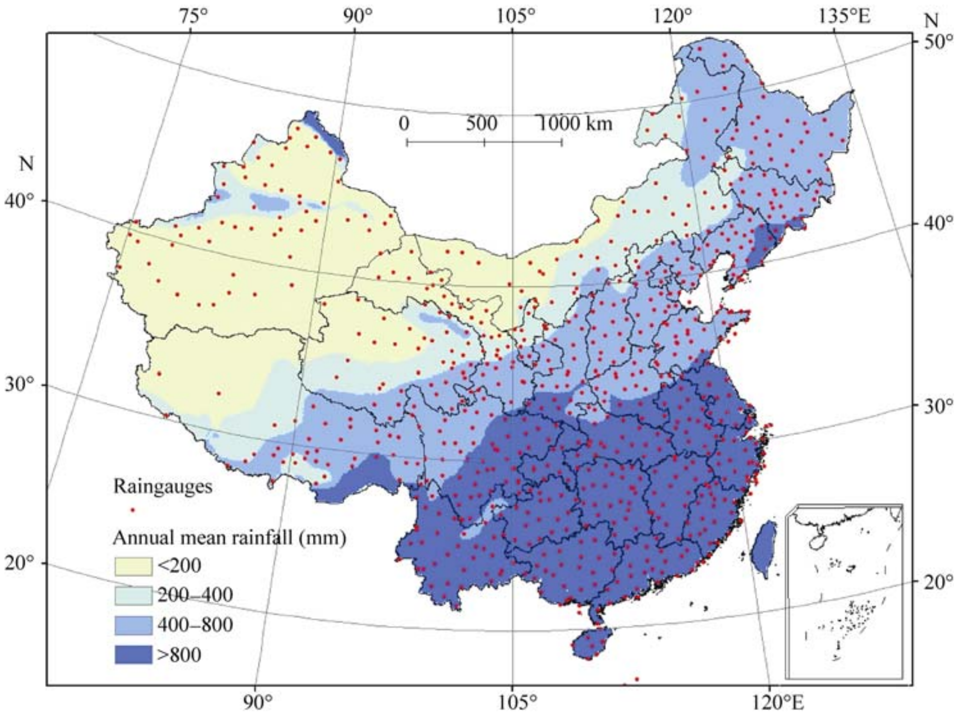


Figure 1 Spatial distribution of raingauges and annual rainfall over China

2.2 Data and processing

The daily rainfall data of 720 stations used in this paper are obtained from China Meteorological Data Sharing Service System. After discarding stations with too much missing data, 616 weather stations covering the period 1960–2008 were selected (Figure 1). A few missing data of the selected weather stations were replaced by an average value from other years. To better illustrate the spatial variation over China, the daily point rainfall data were spatially interpolated using the ANUSPLIN interpolation method (Hutchinson, 1991). The rater data generated were with a 10 km × 10 km resolution.

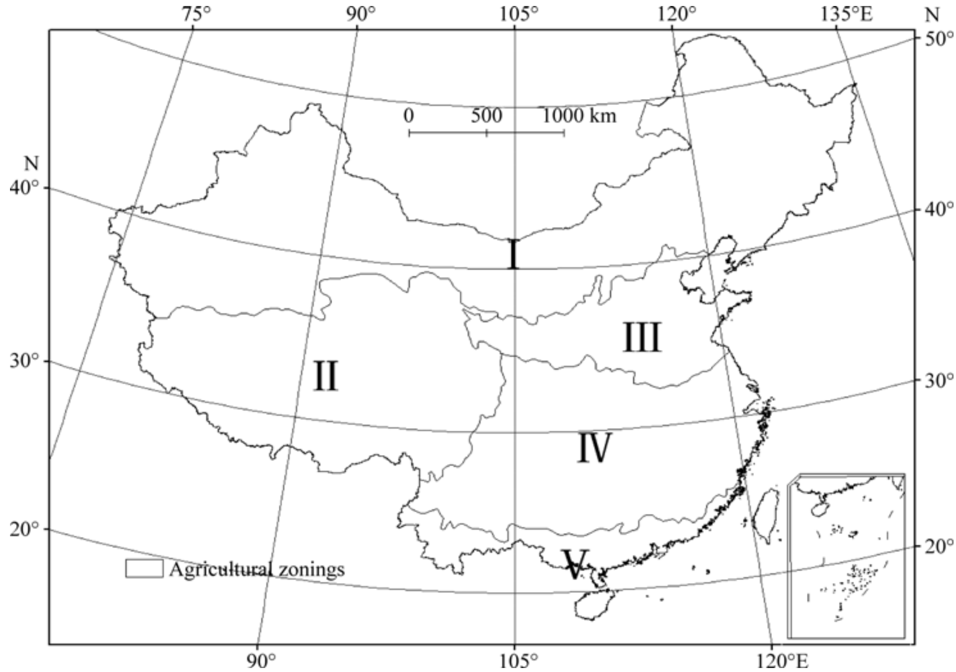


Figure 2 The agricultural zonings of China

Main food crop distribution data (wheat, corn and rice) were extracted respectively from vegetation data provided by the Institute of Geographic Sciences and Natural Resources Research, CAS. Crop phenology data are obtained from the book *China Agricultural Phenology Atlas* compiled by Zhang Fuchun *et al*. (1987). China irrigation data with a 10 km resolution were extracted from Global Irrigation Area Map (GIAM 10 km-8classes: Version2.0) issued by International Water Management Institute (http://www.iwmigiam.org).

Due to complex environmental conditions, regional cropping systems are quite different in China. Therefore, it is important to implore the impact of drought on agriculture and to illustrate the regional difference over China. After careful consideration of the differences of regional cropping system and major food crops phenology, we divided China into five geographical regions on the basis of China nine agricultural zoning (Figure 1). Regional cropping systems and the main crop growing season are listed in Table 1.

2.3 Methodology

In this work, the Standardized Precipitation Index (SPI) at the three-month time scale was

Table 1 Regional cropping system and crop growing season

Zoning number	Crop planting system	Crop growing season	Agricultural zonings including in new zoning
Ⅰ	Spring wheat, spring maize	April to September	Northeast China, Inner Mongolia, Gansu-Xinjiang Region
Ⅱ	Highland barley	April to October	Qinghai-Tibet Plateau
Ⅲ	Winter wheat, summer maize	October to October the following year	Loess Plateau, North China
Ⅳ	Single cropping of rice	March to October	Central China
Ⅴ	Double cropping of rice	January to December	South China

used to define the drought characters in China. McKee *et al*. (1993) developed the SPI to quantify precipitation deficits on multiple time scales. The SPI is easily applied and has other advantages, as discussed by Hayers *et al*. (1999). For this reason, the SPI is widely used to investigate drought characters across the world (Edwards and McKee, 1997; Wu *et al*., 2001; Benjiamin Lloyd-Hughes and Mark A. Saunders, 2002; Ntale and Gan, 2003; Lana *et al*., 2001; Bonaccorso *et al*., 2003; Quiring and Papakryiakou, 2003; Piccarreta *et al*., 2004; Quiring and Papakryiakou, 2003; Shiau, 2006). The primary advantage of SPI is simplicity. It is based solely on rainfall and not affected adversely by topography. Guttman concluded that SPI is better able to show how drought in one region compares to drought in another region (Guttman, 1998). Another main advantage of SPI is its variable time scales, which enables it to describe drought conditions which are important for a range of meteorological, agricultural, and hydrological applications. There is a general consensus about the fact that the SPI on shorter time scale describes drought events affecting agricultural practices, while on the longer ones it is more suitable for water resources management purpose.

SPI was calculated by fitting precipitation data to an incomplete gamma probability density function and standardizing the transformed data so that they are normally distributed with a mean of zero and a variance equal to one. The outcome is a drought index where values below zero represent dry conditions, and value greater than zero represent wet conditions. McKee *et al*. (McKee, 1993) defined the criteria for a "drought event" for any of the time steps and classified the SPI to define various drought intensities (Table 2). Details about the SPI computation can be found in Guttman's paper (Guttman, 1999; Mckee, 1997).

Table 2 Drought categories defined for SPI value and weights and rating assigned to drought severity themes and features, respectively

SPI	Drought severity	Weight	Percentage of occurrence	Rating
0– −0.99	Slight drought	–	–	–
−1.0– −1.49	Moderate drought	1	High	1
			Less high	2
			Moderate	3
			Low	4
−1.5– −1.99	Severe drought	2	High	1
			Less high	2
			Moderate	3
			Low	4
⩽−2	Extreme drought	3	High	1
			Less high	2
			Moderate	3
			Low	4

The severity of drought depends upon the duration, intensity, and spatial extent of a specific drought episode (Sonamez *et al*., 2005; Wilhite, 2000). A comprehensive drought hazard assessment model needs to be able to fully reflect the multiple characteristics of drought. Drawing on research results at home and abroad, a drought hazard assessment model is developed based on SPI in a GIS environment. This study focuses on drought impacts on agricultural, so the short time scale 3-month step is selected to investigate drought characters of China. In this model, the occurrences of moderate, severe and extreme drought were calculated and classified into three classes using natural breaks method respectively. Then each drought severity theme was given a particular weight and each feature of the theme was given a rating to compute drought hazard. The weights and ratings used for integration are given in Table 2. Drought hazard index (DHI) was calculated as follows:

$$DHI = (MD_r \times MD_w) + (SD_r \times SD_w) + (VD_r \times VD_w)$$

where DHI is the drought hazard index; MD_r is the ratings assigned to moderate droughts occurrence classes; MD_w is the weight given to the theme of moderate drought occurrence theme; SD_r is the ratings assigned to severe droughts occurrence classes; SD_w is the weight given to the theme of severe drought occurrence theme; VD_r is the ratings assigned to very severe droughts occurrence classes; and VD_w is the weight given to the theme of very severe drought occurrence theme.

This composite drought hazard index (DHI) integrates the character of drought intensity and drought occurrence at 3-month time scale. At the same time, the spatial character of drought could be easily described by the application of GIS. Hereafter, for each zoning, the value of SPI and DHI for each single grid are calculated, and the maps of drought occurrence and drought hazard are also produced.

3 Result and discussion

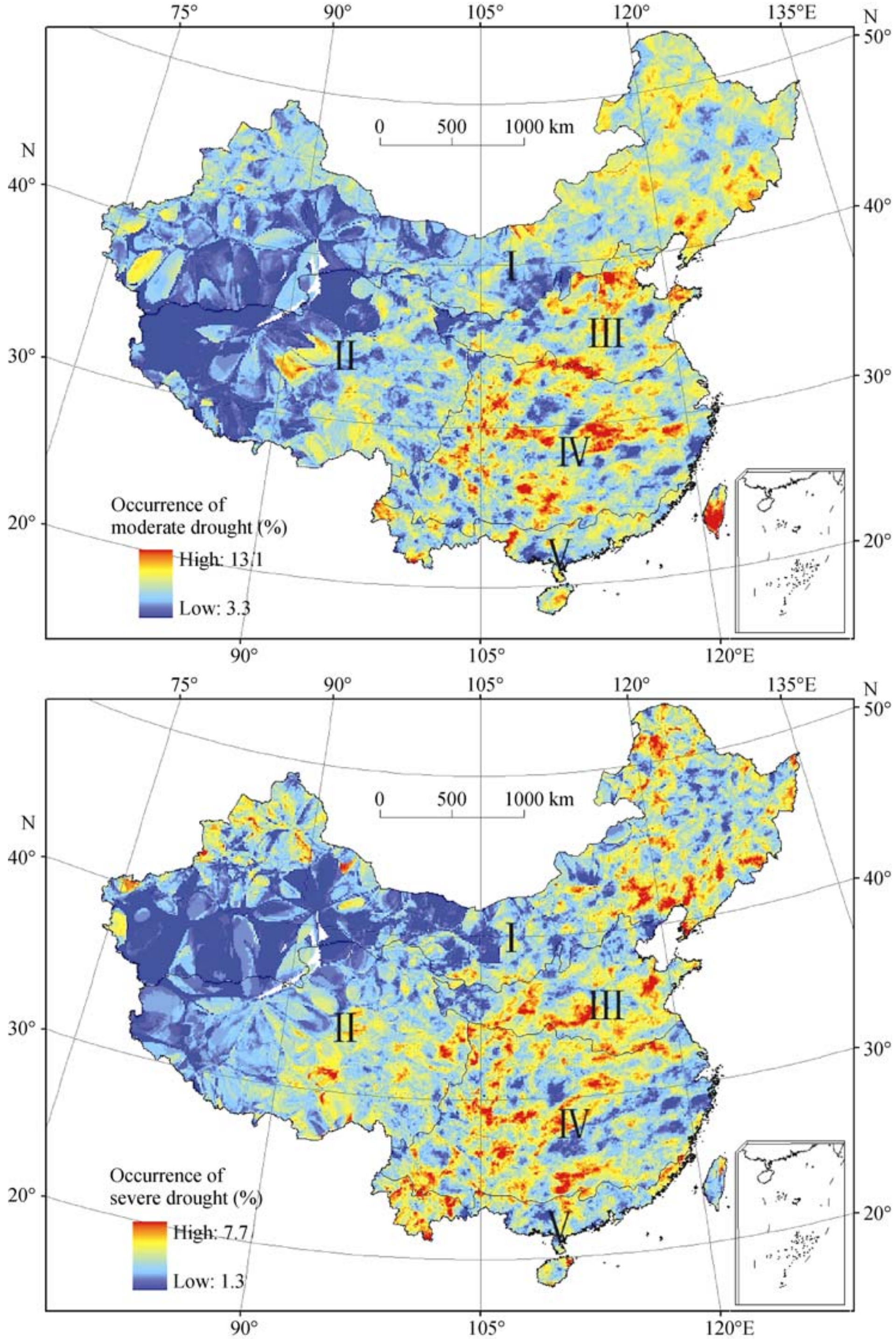
3.1 Spatial characters of drought in China

The occurrences of droughts in each zoning were identified from 3-month SPI. For each single grid, percentage of drought occurrence was obtained by taking ratio of drought occurrences in 3-month time scale to the total drought occurrences in the same step and drought category. Figure 3 shows the spatial extent of moderate, severe and extreme drought occurrences at 3 months time step for five zoning in China. We found that some irregular geometries emerged in the areas of southern Xinjiang, northwestern Qinghai-Tibet Plateau, and western Inner Mongolia, which are areas belonging to arid zone. The main reason for this phenomenon is the sparse distribution of raingauge stations in these regions. However, there are relatively few agricultural production activities in these regions, so the existence of this problem has little effect on our study. The spatial characters of moderate, severe and extreme drought occurrences have been identified for each zoning.

Zoning Ⅰ: The main geographic units distributed in this zoning include Northeast China Plain, Inner Mongolia and large arid zoning in Xinjiang. Moderate drought is mainly in southeastern part of Northeast China Plain and eastern and central parts of Inner Mongolian Plateau. Compared to moderate drought, severe drought is found to move to the west, and mainly occurs in the western part of Inner Mongolian Plateau. Central part of Northeast China Plain, southern part of Inner Mongolian Plateau and northern part of Xinjiang are often affected by extreme drought.

Zoning Ⅱ: The Qinghai-Tibet Plateau is the main geographic unit of this zoning, and the most parts of it are represented by rangelands except some agricultural production with highland barley planting. So drought mainly has impact on ranchers who involved in range livestock production. The spatial distributions of moderate, severe and extreme droughts are quite similar, and mainly occur in eastern, southeastern and southern parts of Qinghai-Tibet Plateau.

Zoning Ⅲ: The Loess Plateau and North China Plain are in this zoning. Winter wheat and



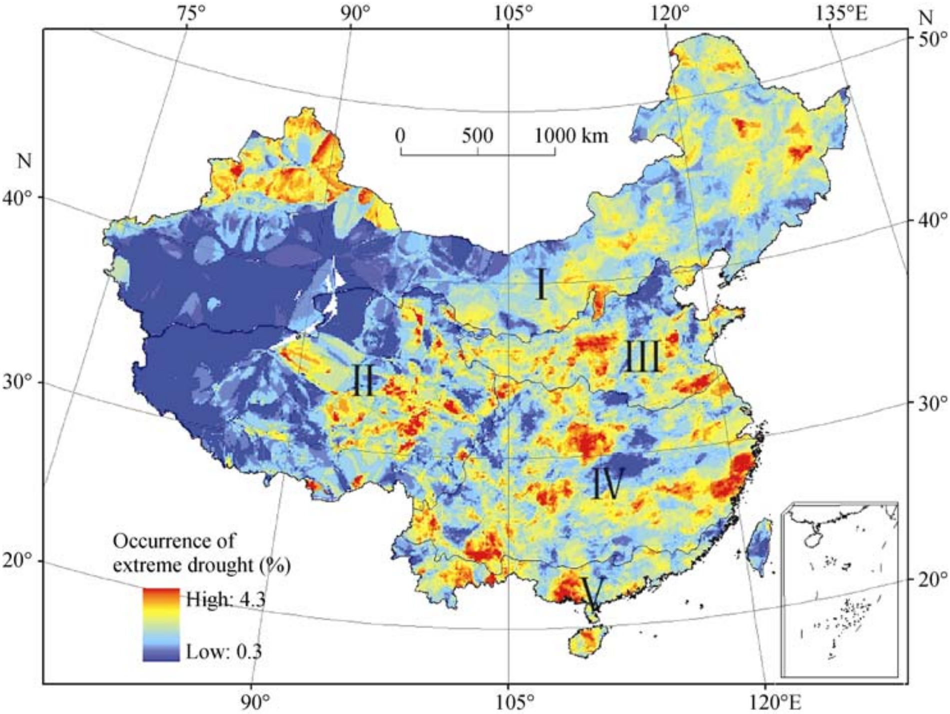


Figure 3 Spatial extent of moderate, severe and extreme drought occurrences at 3-months time step in China

summer corn rotation is the major cropping system here. In this zoning, moderate droughts usually occur in the northern part of North China Plain, however, severe and extreme droughts often happen in the southern part of North China Plain and the central part of Loess Plateau.

Zoning Ⅳ: This zoning is located in central China, including Yangtze River Plain, part of Yunnan-Guizhou Plateau and hilly area to the north of the line formed by Nanling-Wuyi mountains. Single cropping of rice cultivation is prevailed over this district. In this zoning, moderate drought occurs mainly in Chengdu Plain, Hubei and Hunan Plain, Poyang Lake Plain, Jiangsu and Anhui Plain, and the eastern and northern parts of Yunnan-Guizhou Plateau. Similar trend is found for severe drought. Extreme drought is mainly distributed in the Jianghan Plain, the south-east coastal areas such as Zhejiang Province, Fujian Province, as well as the eastern and southern parts of Yunnan-Guizhou Plateau.

Zoning Ⅴ: This zoning is in the south coast of China, including Yunnan, Guangxi, Guangdong and Fujian provinces, as well as Taiwan area. Because of the low latitude, water and heat resources are very abundant here, double rice cropping is adopted by farmers. The occurrences of moderate drought are high in southern part of Taiwan; high incidences of severe drought are mainly distributed in Yunnan Province; and extreme droughts are mainly in the southern part of Guangxi.

Through the above analysis we can find that drought-prone areas are mainly distributed in Northeast China Plain, the central and eastern parts of Inner Mongolian Plateau, the south-eastern part of Qinghai-Tibet Plateau, the northern and southern parts of North China Plain, the central and southern parts of Loess Plateau, the central part of Yangtze River Plain, and

Yunnan-Guizhou Plateau. In terms of the distribution of extreme drought, we also defined the heavy drought centers, areas where often high level intensity droughts occurred, such as the Northeast China Plain, the northern part of Xinjiang, the southern part of North China Plain, the central part of Loess Plateau, Jianghan Plain, the southeast coast of China, and the eastern and southern parts of the Yunnan-Guizhou Plateau. A number of studies have been carried out on the temporal and spatial patterns of drought (Fu, 1991; Pan *et al*., 1996; Fang *et al*., 1997; Wang *et al*., 2002; Li *et al*., 1996) using drought indices and drought loss data. For example, Li Kerang defined the drought-prone regions and heavy drought centers of China respectively by using Precipitation Anomaly. Three drought-prone regions were found in his study, which are North China Plain, the eastern coastal provinces (Fujian, Guangdong, Guangxi), and the southwestern part of China; The heavy drought centers are distributed in the middle and lower reaches of the Yellow River and Haihe River basins, including Hebei, Shandong, Shaanxi, Ningxia, Inner Mongolia and Shandong. Other areas, such as Yunnan and Sichuan in Southwest China, Fujian and Guangdong in southeastern coastal region are also heavy drought centers. Compared to these studies, our research aimed to reveal the impacts of drought on agriculture and better describe the spatial pattern of drought in China. Furthermore, our study comprehensively discloses various characters of drought, such as intensity, frequency, duration and so on. In addition, at a grid-cell scale, the characters of drought were studied from the point of view of spaces and that from small areas to large areas.

3.2 Spatial pattern analysis of drought hazard

Using the drought hazard evaluation model established by this paper, the drought hazard of

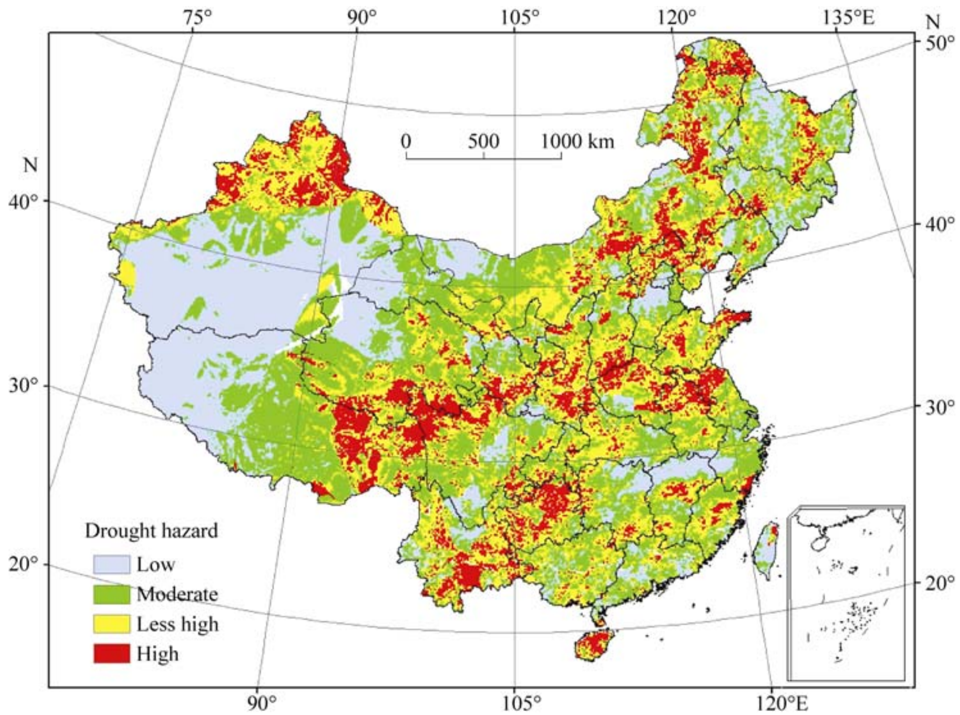


Figure 4 Map showing drought hazards in China

China was assessed and mapped at a 10 km grid-cell scale (Figure 4). We found that the distribution of drought hazard in China shows apparent east-west difference. The low and moderate hazard areas are mainly in the western part of China, while the areas with less high and high hazard to drought are mainly concentrated in the eastern part.

The low-hazard areas are mainly found in the southern part of Xinjiang, the northwestern part of Qinghai-Tibet Plateau, and the western part of Inner Mongolian Plateau, and scatters in the Xiao Hinggan areas, the southern part of Yangtze River Plain, the southeastern coast areas, and so on, which cover 25.6% of the total land area of China. These areas are mainly distributed in arid areas, with intensive radiation and little precipitation. Because of the defective coordination of light, heat, water and soil resource, there is only a small amount of livestock production here.

The class of moderate hazard is the largest class in China, which covers 31.3% of the total land area. It occurs mainly in arid and semi-arid areas, such as central Xinjiang, the eastern and western parts of Inner Mongolian Plateau, the western, northern and southeastern parts of Qinghai-Tibet Plateau. In addition, parts of Northeast China Plain and Yangtze River Plain in humid areas are also characterized with moderate class. The largest portion of moderate hazard class is represented by grassland, so drought has greater impact on livestock.

The class of “less high” hazard covers 28.8% of the total land area. It is widely distributed in semi-arid, semi-humid and humid areas, such as the eastern part of Northeast China Plain, the central part of Inner Mongolian Plateau, the northern part of Xinjiang, the southern part of North China Plain, the central part of Loess Plateau, the northern part of Yangtze River Plain, the central part of Yunnan-Guizhou Plateau, and Lingnan and Wuyi mountains areas.

The high hazard area covers 14.3% of the total land area and mainly occurs in the eastern and central parts of Inner Mongolian Plateau, the central part of Northeast China Plain, the northern part of Xinjiang, the southeastern part of Qinghai-Tibet Plateau, the central and southern parts of Loess Plateau, the southern part of North China Plain and Yunnan-Guizhou Plateau.

To study the location relationship between crop distribution and agricultural hazard, the spatial distribution data for wheat, corn and rice are extracted from a 1:100 million vegetation map of China. Combining with the drought hazard map, we find that 17% of total wheat growing area is located in high hazard area; corn and rice are 16% and 13% respectively (Table 3). Drought loss is a direct reflection of drought impact on agriculture. Fu Bojie (1991) studied the spatial characters of drought in China by using agricultural loss data, and figured out that the North China Plain, the Loess Plateau, the Northeast region, and the Sichuan basin are the drought seriously affected areas. Wang Jing’ai carried out similar studies in China, and pointed out that heavy drought area in northern China is relatively concentrated in the western part of Heilongjiang, the central part of Inner Mongolia, the northern part of Hebei, the northern parts of Shaanxi and Ningxia; heavy drought areas in southern China are mainly distributed in the central five provinces (Anhui, Hubei, Hunan, Jiangxi and Henan) and the eastern part of Sichuan, Guizhou and Yunnan (Wang *et al.*, 2002). Comparing these results to our study, we find that areas where were seriously affected by drought in the history are mainly located in the high hazard areas.

Based on the above analysis, we conclude that less high and high drought hazard areas are also the main animal husbandry and agricultural production areas in China. Pan Yaozhong’s study also pointed out that main animal husbandry and agricultural production areas where have higher population intensity are drought-prone areas (Pan *et al*., 1996). This is the main reason for China that has heavy loss in agriculture caused by drought. Therefore, scientific methods should be taken to reduce the impact of drought.

Table 3 Relationship between drought hazard distribution and main grain crop planting

Drought hazard	Main crop		
	Wheat	Corn	Rice
Low	0.16	0.14	0.17
Moderate	0.31	0.32	0.34
Less high	0.36	0.38	0.36
High	0.17	0.16	0.13

3.3 Analysis of drought hazard in different agricultural zonings

Great differences in the drought hazard can be found by comparing the five zonings. As illustrated by Figure 5 and Table 4, zonings Ⅰ and Ⅱ are mainly low and moderate hazard, zonings Ⅲ, Ⅳ and Ⅴ are mainly moderate and less high hazard.

Furthermore, within each zoning variations in drought hazard are also apparent. For example, the hazard in zoning Ⅰ shows significant east-west differences, as the eastern area has less high and high hazard, and the western part is mainly low hazard. Similarly, hazard in the northwestern part of zoning Ⅱ is lower than the southeastern part. In zoning Ⅲ, the northern part has lower hazard than the southern part. Zoning Ⅳ is totally different, with

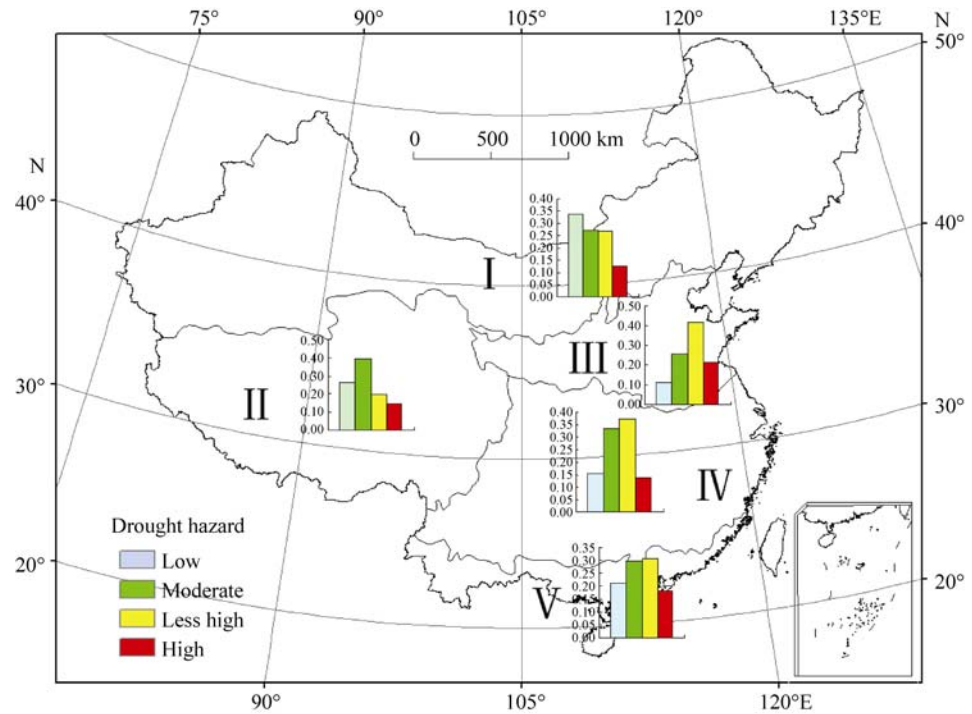


Figure 5 Regional discrepancy of drought hazard in China

Table 4 Regional discrepancy of drought hazard

Zoning	Area ratio of each drought hazard class			
	Low	Moderate	Less high	High
Ⅰ	0.34	0.26	0.27	0.13
Ⅱ	0.27	0.38	0.20	0.15
Ⅲ	0.11	0.26	0.42	0.21
Ⅳ	0.16	0.34	0.36	0.14
Ⅴ	0.21	0.30	0.31	0.18

low hazard in central part and high in surrounding areas. The high hazard parts of zoning Ⅴ are mainly located in the west and south.

Drought is a complex system involving drought hazard and the social and physical vulnerability. The impact of drought depends not only on the intensity of hazard, but also depends on the agricultural vulnerability. Therefore, to reduce drought risk, there must be an understanding of the hazard using climatology, improved operational monitoring, and an analysis of vulnerability to understand how people and sectors may be most affected by drought. The risk of drought hazards mainly depends on variations under the climate conditions which will not change in the short-term. Consequently, to effectively reduce the impacts of drought, the key factors should be identified to reduce drought vulnerability. Vulnerability to drought is dynamic and influenced by a multitude of factors, including increasing regional shifts in population, urbanization, technology, government policies, land use and other natural resource management practices, desertification processes, water use trends, and increasing environmental awareness. At present, irrigation is the most direct and effective way to defend against and mitigate drought. However, from China irrigation map, we found that the distribution of China irrigation and drought hazard do not match in space. Figure 6 shows that irrigated areas are mainly distributed in plain areas, such as Northeast China Plain, North China Plain, Chengdu Plain, the Yangtze River Plain, while for some other high drought hazard areas such as Inner Mongolian Plateau, Loess Plateau, and Yunnan-Guizhou Plateau, the irrigation ratio is low due to shortage of water resource and the difficulty for available irrigation. The aim of this study is to help people and sectors to understand the spatial characters of drought hazard, and then to take effective way to reduce drought impacts and to strengthen the management of drought.

4 Discussion and conclusions

Droughts are recurrent phenomena in China, and have great impact on various socio-economic sectors, especially on agriculture. In this study, based on the division zoning which is done according to the distribution and phenology of main crops, we assessed the overall characters of drought in China at a 10 km grid scale by using 3-month SPI. After that, a comprehensive drought assessment model was constructed and the spatial pattern of drought hazard in China was explored at a 10 km scale. Conclusions below are obtained from our study:

For each of the five zonings, the moderate, severe and extreme droughts show different spatial patterns. Drought-prone areas are mainly distributed in Northeast China Plain, the

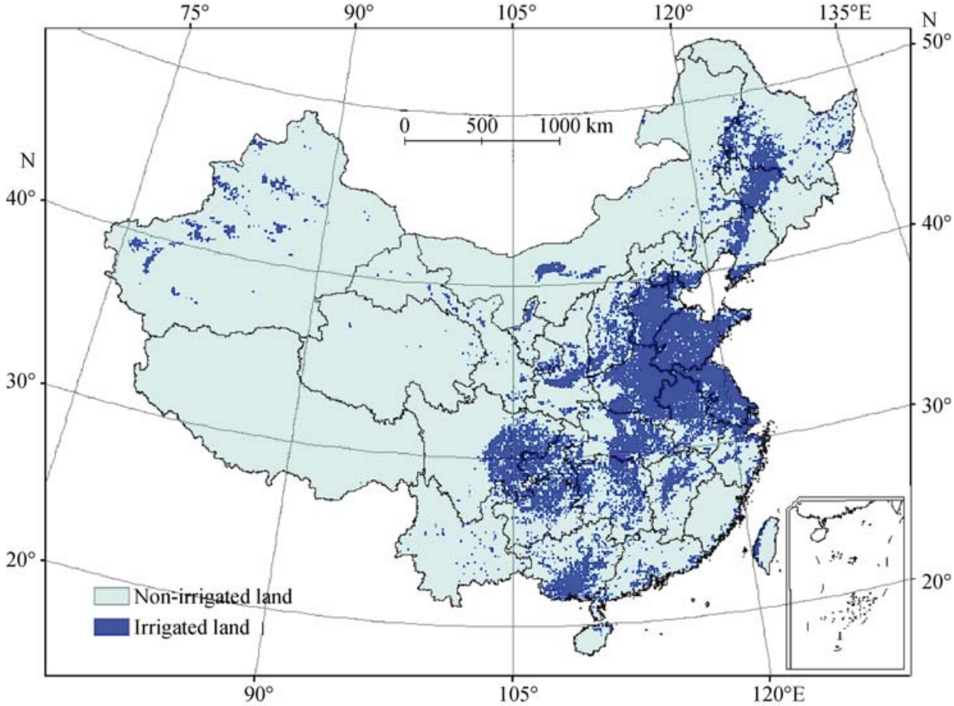


Figure 6 Irrigation map of China

central and eastern parts of Inner Mongolian Plateau, the southeastern part of Qinghai-Tibet Plateau, the northern and southern parts of North China Plain, the central and southern parts of Loess Plateau, the central part of Yangtze River Plain, and Yunnan-Guizhou Plateau. Heavy drought centers are concentrated in the Northeast China Plain, the northern part of Xinjiang, the southern part of North China Plain, the central part of Loess Plateau, Jianghan Plain, the southeast coast of China, and the eastern and southern parts of Yunnan-Guizhou Plateau.

The spatial distribution of drought hazard in China shows apparent east-west differences, with the eastern part of China being far more hazardous than the western part. High hazard mainly occurs in the eastern and central parts of Inner Mongolian Plateau, the central part of Northeast China Plain, the northern part of Heilongjiang, the northern part of Xinjiang, the southeastern part of Qinghai-Tibet Plateau, the central and southern parts of Loess Plateau, the southern part of North China Plain, the northern and southern parts of Yangtze River Plain, and Yunnan-Guizhou Plateau. Comprehensive analysis shows that high drought hazard areas are also the main animal husbandry and agricultural production areas in China.

Obvious differences in drought hazard have been found both within and between different agricultural regions. Due to the water shortage and the difficulty to available irrigation, the distributions of China irrigation and agricultural hazard do not match in space.

At a grid scale, this study constructed a simple model for drought hazard assessment. Using the simple model, we can study drought hazard moving from the point of view of spaces and that from small areas to large areas. The conclusions reached in this study can be an essential step toward addressing the issue to drought hazard in the country and can be a guide to drought management strategies for mitigation purpose. Identifying regional hazard can lead to adjustment in practices in water-dependent sectors and can help decision makers to take drought into natural resource planning. Furthermore, this study provides a scientific basis for further study of drought risk assessment, which will benefit the improvement of drought risk management in China.

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