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Risk assessment of meteorological drought in China under RCP scenarios from 2016 to 2050

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Abstract: Climate change has been a hotspot of scientific research in the world for decades, which caused serious effects of agriculture, water resources, ecosystem, environment, human health and so on. In China, drought accounts for almost 50% of the total loss among all the meteorological disasters. In this article the interpolated and corrected precipitation of one GCM (HadGEM2-ES) output under four emission scenarios (RCP2.6, 4.5, 6.0, 8.5) were used to analyze the drought. The standardized precipitation index (SPI) calculated with these data was used to assess the climate change impact on droughts from meteorological perspectives. Based on five levels of SPI, an integrated index of drought hazard (IIDH) was established, which could explain the frequency and intensity of meteorological drought in different regions. According to yearbooks of different provinces, 15 factors have been chosen which could represent the impact of drought on human being, crops, water resources and economy. Exposure index, sensitivity index and adaptation index have been calculated in almost 2400 counties and vulnerability of drought has been evaluated. Based on hazard and vulnerability evaluation of drought, risk assessment of drought in China under the RCP2.6, 4.5, 6.0, 8.5 emission scenarios from 2016 to 2050 has been done. Results from such a comprehensive study over the whole country could be used not only to inform on potential impacts for specific sectors but also can be used to coordinate adaptation/mitigation strategies among different sectors/regions by the central government.

Keywords: Risk assessment, Climate change, Meteorological drought, RCP scenarios, Vulnerability evaluation, China

1 Introduction

According to IPCC 5th, it has been successively warmer in the past 30 years on the Earth's surface than any decade since 1850 (IPCC, 2013). Climate change has been a hotspot of scientific research in the world for decades, which caused serious effects of agriculture, environment, ecosystem, human health and so on. In China, the temperature has increased remarkably since 1850 (Wang and Chen, 2014; Wei and Chen, 2011). The variations of precipitation in different regions of China for the past hundred years are different and distinguishing, for example, North and Northeast districts of China becoming drier, East and Central districts of China becoming moister (Liu et al., 2011; Ma et al., 2012; Wu et al., 2012). Due to climate change, the disasters related climate become much more serious, which lead to huge losses of lives and economy, destructions of ecology and environment, damage of human health and so on. According to statistical data, drought accounts for almost 50% of the total loss among all the meteorological disasters in China (Liu, 2012). With the variation of precipitation distribution and rising temperature, the intensity and frequency of drought disasters are changing quickly in the whole world (Prudhomme et al., 2014; Burke et al., 2006; Trenberth et al.,2014; Dai, 2012). So it is important to do research on the trend of spatial and temporal distribution of drought under climate change in China.

Drought is a complex and natural phenomenon mainly caused by low rainfall in a constant period which is characterized by several properties such as frequency, intensity and duration (Mishra and Singh, 2010; Wilhite, 2000; Van Loon and Van Lanen, 2012). According to the impact, droughts can be classified into different forms such as meteorological drought, agricultural drought, hydrological drought and socio-economical drought (Tallaksen and Lanen, 2005; Hayes et al., 2007; Van Loon and Laaha G., 2015). Meteorological drought is characterized by lack of precipitation over an extended period; hydrological drought is characterized by persistent reduction in runoff; agricultural drought is characterized by reduction of soil moisture and crops yield (Hisdal and Tallaksen, 2003; Keyantash and Dracup, 2002; Sheffield and Wood, 2008). Along with the reduction of precipitation, runoff and soil moisture, the shortage of water supply for population, livestock, industry, ecology, environment may become much more serious, then socio-economical drought would break out. Meteorological drought is mainly determined by climatic conditions and atmospheric circulations. However, the other three types of drought (agricultural drought, hydrological drought and socio-economical drought) are primarily influenced by both natural and anthropogenic systems, especially socio-economical drought which is affected mostly by human activities (Wilhite, 2000; Wisser et al., 2010). Usually meteorological drought is the base of the other three drought types, so it is important to do research on meteorological drought in large scale which would reveal the potential trends of drought disasters.

A lot of studies are performed to analyze the frequency, intensity and duration of droughts by using different indexes, such as the Standardized Precipitation Index (SPI) (McKee et al., 1993), the Standard Runoff Index (SRI) (Shukla and Wood, 2008), the Palmer Drought Severity Index (PDSI) (Palmer, 1965; Wells et al., 2004), the Standardized Precipitation–Evapotranspiration Index (SPEI) (Vicente-Serrano et al., 2010) and the Supply–Demand Drought Index (SDDI) (Rind et al., 1990). Comparing the different indexes, SPI and PDSI are appropriate for meteorological drought; SRI is proper for hydrological drought; SPEI is good for agricultural drought; SDDI is much better for socio-economical drought. For this research, SPI is chosen to establish integrated drought index, which would evaluate the hazard of drought under the RCP (Representative Concentration Pathways) emission scenarios (Van Vuuren et al., 2011a; 2011b) from 2016 to 2050.

China has been affected frequently by drought in the past thousand years (Zou et al., 2005; Dai, 2012; Dai et al., 2004; Ma and Fu, 2003). According to the Ministry of Water Resources of China (MWRC, 2011), drought disasters have caused huge yield loss, nearly 39.2 billion kilograms annually. A lot of researches have focused on drought trends and impact of drought under climate change (Xu et al., 2012; Chen et al., 2006; Zhou et al., 2009; Qian et al., 2014), in which changes on scope, intensity, duration and frequency of drought in China at a nationwide scale have been explored (Zhou et al., 2006; Yuan et al., 2012; Chen et al.,2013; Nath et al., 2014). According to Wang et al. (2003) and Wang et al. (2011), the drought affected more and more areas in which severe droughts became much more frequent over the past 60 years, so risk assessment on drought disasters should be carried out as soon as possible. Wu et al. (2011) revealed that almost 30% of the total farmland in China is vulnerable to drought. Zhang et al. (2013a) explored the frequency of extreme drought and analyzed the changes of geographic distributions from 1960 to 2009 in Southwest China. There are a few studies which have analyzed

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the variations of volume and spatial distribution of water resources under climate change in North China, South China and the whole country (Leng et al., 2015; Xu et al., 2009c; Li et al., 2010; Jiang et al., 2007; Qiu, 2010; Yang et al., 2012; Wang et al., 2012; Guo et al., 2002; Wang et al., 2014). However, very few studies have assessed the risk of drought under climate change, especially the vulnerability of drought across the whole country. It is obvious that most researchers pay attention to the natural characteristics of drought, such as scope, intensity, duration, frequency and so on. But the social features of drought are not concerned enough, which is mainly about the hazard-affected bodies, like population, agriculture, industry, cities, water and so on. It is difficult to evaluate the impact of drought on these bodies, especially under climate change drought may become much more intensive and frequent. Risk assessment provides us a good method to evaluate the hazard and vulnerability of drought, which could give us a clear picture of drought distribution and enable more effective drought management plans to be developed.

In this research, a coupled Earth System Model - HadGEM2-ES (Collins et al., 2008) has been used to generate the precipitation under the RCP2.6, 4.5, 6.0, 8.5 emission scenarios in the future. The standardized precipitation index (SPI) was used to establish an integrated index of drought hazard (IIDH), which could explore the frequency and intensity of meteorological drought in different regions. According to yearbooks of different provinces, exposure index, sensitivity index and adaptation index have been calculated in almost 2400 counties and vulnerability of drought has been evaluated. Based on hazard and vulnerability evaluation of drought, risk assessment of drought in China under the RCP2.6, 4.5, 6.0, 8.5 emission scenarios from 2016 to 2050 has been done. Obviously, results from such a comprehensive study over the whole country could be used not only to inform on potential impacts for specific sectors but also can be used to coordinate adaptation/mitigation strategies among different sectors/regions by the central government.

2 Data and methods

2.1 Data

The study area includes the whole mainland China except Taiwan islands because of the unavailability of data from Taiwan. As mentioned above, risk assessment includes two aspects-hazard evaluation and vulnerability evaluation. The data should be collected from the two aspects. On one hand, climate scenarios data (precipitation) are needed for drought hazard evaluation. On the other hand, the data about society, economy, population, water resources, forest and so on in 2373 counties of whole China should be collected and prepared. The vulnerability evaluation of drought is complicated and data sources are various, so it is necessary to carry out reliability test and preprocess the historical and observed data to avoid the distortion of double counting.

In this study, the projected daily precipitation from GCM HadGEM-ES is the simulation result of 1951-2099 under RCP scenarios which is interpolated and corrected. HaGEM-ES (***Had***ley ***G***lobal ***E***nvironment ***M***odel ***2*** - ***E***arth ***S***ystem) is designed to run the major scenarios for IPCC AR5 by the UK Met Office Hadley Centre for CMIP5 (The World Climate Research Programme's Coupled Model Intercomparison Project phase 5) centennial simulations. The horizontal

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resolution of HadGEM2-ES Model's raw output is 1.875°×1.25°. The ISI-MIP (The Inter-Sectorial Impact Model Intercomparison Project) changed the data to 0.5°×0.5° at horizontal resolution with the bilinear interpolation method, and a statistical bias correction algorithm based on probability distribution is used to correct the interpolation result (Piani et al., 2010; Hagemann et al., 2011).

On the other hand, the data for vulnerability evaluation of drought is collected from social-economic Yearbooks of different provinces, water resources bulletins, forest resources bulletins and so on. In the study, counties and districts are set as standard statistical units, which are used for analysis and calculation of exposure factors, sensitivity factors and adaptive capacity factors. There are so many factors which could affect the vulnerability of drought. So it is important for us to choose proper and effective factors in China. Based on the relationship between drought disasters and hazard-affected bodies, the most important factors are selected which could be measurable and comparable. Due to the complexity and diversity of drought vulnerability factors of which the units are different, all the evaluation factors are normalized into non-dimensional by geometric average processing in order to be convenient for utilization.

2.2 Drought Indices

There are several drought indices created to identify the different types of drought disasters. According to McKee et al. (1993), the standardized precipitation index (SPI) is designed to quantify the precipitation deficit for multiple time scales, which could assess the impact of climate change on drought disasters from meteorological perspectives. SPIs in different time scales reflect the degrees of shortage on water resources due to meteorological drought. The changes of ground water, streamflow, underwater and reservoir storage are closely related to the precipitation anomalies in a long term, but soil moisture conditions are connected with the precipitation anomalies in a short term. SPI was testified to be effective to explore the intensity of meteorological drought. It is the most important drought indice to reveal the potential drought trends, which is the basis of judging agricultural drought, hydrological drought and socio-economical drought. For these reasons, the SPIs for 3-month, 6-month, 12-month, 24-month, and 48-month time scales are originally calculated in this article, which are based on the precipitation records in different time scales. According to Edwards and McKee (1997), the long-term record is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero. Positive SPI values indicate it is greater than median precipitation, while negative values indicate it is less than median precipitation. Because the SPI is normalized, wetter and drier climates situations can be represented in the same way.

Drought intensities reflected from the SPI are defined by the classification system shown in the SPI Values table. According to the define, a meteorological drought event would occur if the SPI is continuously negative and reaches the critical value that the SPI is -1.0 or less. The drought event would end when the SPI becomes positive. Each drought event has a duration defined by its beginning and end. The drought intensity is the positive sum of the SPIs within a drought event, which is to accumulate the magnitudes of drought for all the duration. According to different cases, SPI could be classified into mild drought, moderate drought, severe drought and extreme drought. Based on the standardized SPIs, the rarity of meteorological drought is

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determined by the probability of the precipitation during the duration of drought (Guttman, 1998; Kogan, 1995; Wilhite and Glantz, 1985).

Tab. 1 Drought grades and weighting factor according to SPI

Degree of drought	Value of SPI	Weighting factor
Mild drought	-1.0＜SPI⩽-0.5	0.1
Moderate drought	-1.5＜SPI⩽-1.0	0.2
Heavy drought	-2.0＜SPI⩽-1.5	0.3
Excessive drought	SPI⩽-2.0	0.4

Firstly, the shape parameter and scale parameter (Yuan and Zhou, 2004) at each grid of the whole study area are estimated with the corrected precipitation from HadGEM2-ES in 1971-2000 according to maximum likelihood estimation (MLE). With the above parameters, the SPI is calculated for 12-month time scale from 2016-2050 at each grid. Secondly, the degree of drought intensity is graded according to the value of SPI, and each level is given a particular weighting factor, shown in Table 1. Then, for each grid, the frequencies of different drought (from mild to excessive drought) are counted. Finally, these frequencies are calculated by using the corresponding weighting factors in Table 1 to produce a new dataset, which covers the integrated indexes of drought hazard.

So, based on the four levels of SPI, an integrated index of drought hazard (IIDH) was established, which could explain the frequency and intensity of meteorological drought in different regions.

2.3 Vulnerability evaluation

According to IPCC (2013), vulnerability is defined as the propensity or predisposition to be adversely affected in IPCC 5th report, which is not always corresponding definition in numerous literatures (Houghton et al., 2001; Cannon, 1994; Cutter, 1996a). But the connotation of vulnerability is becoming much clear, which is mainly about the inherent characteristics of acceptors (human being, society, economy, agriculture, water et al.) when they are faced with different coerces or threats, such as climate change, extreme events, disasters and so on. Under climate change, there are a lot of changes on drought trends in China. In some regions, it becomes much more serious and frequency; in other regions, it becomes weakening and declining. But the economic and environmental losses caused by drought disasters are becoming much more tremendous. So it is important to evaluate the impacts of climate change on drought. Vulnerability assessment could reveal the relationship between stress factors and acceptors, distribution of vulnerable areas, and degree of vulnerability. With the increasing knowledge on vulnerability, the vulnerability evaluation model has become stable and clear, which contains three aspects: exposure, sensitivity and adaptive capacity. Most of researchers have accepted the vulnerability evaluation model. In this research, exposure is the extent to which the acceptors are subject to potential drought. Sensitivity is the reaction of acceptors when they suffer the attack of drought; in other words, it is the possibility of potential loss caused by drought. Adaptive capacity is the ability of human being to defend and mitigate the drought disasters. Vulnerability evaluation model is as follows:

$$\text{Vulnerability index}=\frac{\text{Exposure index}*\text{Sensitivity index}}{\text{Adaptive capacity index}}$$

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Many factors can affect the vulnerability of drought, for example, population, Gross Domestic Product, revenue, water resource, sown area, irrigation area and so on. Due to the interaction of multiple factors, the vulnerability of drought in different counties may be very different. The vulnerability evaluation factors should be chosen from multiple impacts factors, which could precisely reveal the characteristics of vulnerability of drought. In this research, 15 factors were selected (table 2), including permanent residents, population density, education level of population, aging rate and so on. The drought trends may change under climate change, which would have an impact on hazard evaluation of drought. But in regard to vulnerability, its trends may be much more complicated in the future, because the vulnerability of drought involves many different aspects, such as human being, economy, environment, society, eco-system and so on. The uncertainty would be very high if the vulnerability factors of drought in the future are predicted. So the recent situations of vulnerability factors of drought are usually treated as the typical situation for future vulnerability evaluation. Based on the available data, the vulnerability factors of drought in 2012 are selected and it is hypothesized that the vulnerability in the future (from 2016 to 2050) is the same as the vulnerability in 2012.

Tab. 2 Vulnerability evaluation index system of Drought

Indexes	Factors	Introduction
Exposure	Permanent residents	The population who live in one county for more than 6 months per year
	Gross Domestic Product	The monetary value of all the finished goods and services produced per year within a county's borders
	Sown area of crops	The area of crops which are planted per year in one county
Sensitivity	Population density	The density of population in one county
	Education level of population	The percentage of residents with inadequate education which are under college level in the whole population which is beyond 6 years old
	Aging rate	The percentage of population which is between 20 years old and 60 years old in the whole population
	Urbanization rate	The percentage of agricultural population in the permanent residents of one county
	Per capita water resources	The volume of water resources per year for one person in one county
	Water consumption for 10000 Yuan of GDP	The volume of water consumption per year for 10000 Yuan of GDP in one county
Adaptive capacity	Local fiscal revenue	The whole fiscal revenue of local government per year in one county
	Effective irrigated areas	The percentage of irrigated area per year in all the arable land of one county
	Water supply capacity	The volume of water supply per year by the pipes in one county
	Water storage capacity	The volume of water storage per year in one county
	Per capita income	The average income of residents per year in one county
	Forest coverage rate	The percentage of forest coverage in one county

2.3.1 Exposure index

Exposure index is an important part of vulnerability evaluation index system, which reveals the extent, quantity and size of acceptors. In one county, human being is usually considered as the first key element, because people-oriented is the core of risk assessment. When drought disasters break out, the survival of human being should be the first place primacy. Then agriculture is considered as another important factor, which is related to the reduction of yield or even total crop failure. In addition, economy is thought to be an indispensable factor, which refers to the potential losses due to drought disasters. In this research, Permanent residents (PR), Gross Domestic Product (GDP) and Sown area of crops (SRC) are selected to be exposure factors of drought.

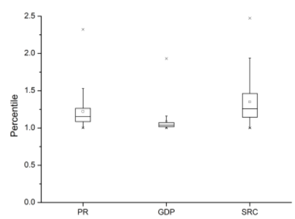

Fig.1 The percentile of PR (Permanent residents), GDP (Gross Domestic Product) and SRC (Sown area of crops) in 2373 counties of whole China

Exposure index (EI) model is established based on the above factors. First, the three factors should be converted into non-dimensional. The percentile distributions of PR, GDP and SRC are shown in Fig.1. Due to the huge gaps of different counties, most numerical values of the three exposure factors are smaller than 1.5, especially in which most numerical values of GDP factor are smaller than 1.25. Then the exposure indexes in 2373 counties of whole China are calculated according to the following model.

$$EI=\sqrt[3]{PR*GDP*SRC}$$

Based on the calculation and percentile distribution, the exposure indexes in 2373 counties are classified into five levels, including highest exposure, high exposure, moderate exposure, low exposure and lowest exposure. Almost 268 counties are under highest exposure; 495 counties are under high exposure; 777 counties are under moderate exposure; 452 counties are under low exposure; 381 counties are under lowest exposure.

2.3.2 Sensitivity

Sensitivity index is the core of vulnerability evaluation index system, which reveals the vulnerable levels of acceptors when they are faced with different stressors (such as extreme events, disasters, human activities and so on). Different stressors may cause different sensitivity indexes for the same acceptor. For example, when crops suffer a serious flood, the main sensitivity indexes may be the flood resistance of crops; but when crops suffer a severe drought, the main sensitivity indexes may be the drought resistance of crops. So it is important to choose the appropriate factors of sensitivity index for drought. In this research, six factors are selected to reveal the sensitivity of drought in different counties, including Population density (PD), Education level of population (ELP), Aging rate (AR), Urbanization rate (UR), Per capita water resources (PWR) and Water consumption for 10000 Yuan of GDP (WCG).

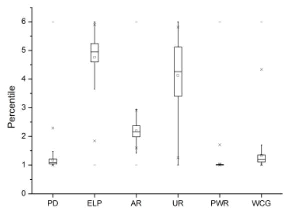

Fig.2 The percentile of PD (Population density), ELP (Education level of population), AR (Aging rate), UR (Urbanization rate), PWR (Per capita water resources) and WCG (Water consumption for 10000 Yuan of GDP) in 2373 counties of whole China

As the same with exposure index, the six factors should be converted into non-dimensional. The percentile distributions of PD, ELP, AR, UR, PWR and WCG are shown in Fig.2, in which the differences among numerical ranges of the six sensitivity factors are revealed. Most numerical values of ELP and UR are bigger than 2.0; most numerical values of PD, PWR and WCG are smaller than 1.5; most numerical values of AR are concentrated in 2.0 ~ 2.5. It is important to reduce the magnitude gaps of different factors for sensitivity evaluation. The sensitivity indexes (SI) in 2373 counties of whole China are calculated according to the following model.

$$SI=\sqrt[6]{PD * ELP * AR * UR * PWR * WCG}$$

Based on the calculation and percentile distribution, the sensitivity indexes in 2373 counties are classified into five levels, including highest sensitivity, high sensitivity, moderate sensitivity, low sensitivity and lowest sensitivity. Almost 340 counties are under highest sensitivity; 442 counties are under high sensitivity; 803 counties are under moderate sensitivity; 463 counties are under low sensitivity; 325 counties are under lowest sensitivity.

2.3.3 Adaptive capacity

Adaptive capacity is the opposite of vulnerability, which reveals the capacity of suffering and defending the stressors. When adaptive capacity is much stronger, the vulnerability will be much lower. Usually adaptive capacity index is connected closely with sensitivity index. For example, education level of population factor could reveal the sensitivity of population with different levels of education, which could also indicate the degrees of adaptive capacity in different counties. In other words, high education level of population in one county is much bigger, the sensitivity may be lower and the adaptive capacity may be higher. So it is necessary to distinguish the sensitivity factors and adaptive capacity factors. In this research, six factors are selected to reveal the adaptive capacity of drought in different counties, including Local fiscal revenue (LFR), Effective irrigated areas (EIA), Water supply capacity (WPC), Water storage capacity (WSC), Per capita income (PCI) and Forest coverage rate (FCR).

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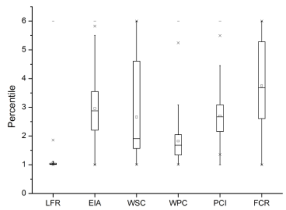

Fig.3 The percentile of LFR (Local fiscal revenue), EIA (Effective irrigated areas), WSC (Water storage capacity), WPC (Water supply capacity), PCI (Per capita income) and FCR (Forest coverage rate) in 2373 counties of whole China

As the same with exposure index and sensitivity index, the six factors of adaptive capacity should be converted into non-dimensional. The percentile distributions of LFR, EIA, PCI, WPC, WSC and FCR are shown in Fig.3, in which the differences among numerical ranges of the six adaptive capacity factors are revealed. The distribution ranges of WSC and FCR are bigger than the other four factors, which cover a wide range of 1.0~5.5. Most numerical values of EIA and PCI are centralized in 2.0~3.5; most numerical values of WPC are from 1.0 to 2.0; most numerical values of LFR are smaller than 0.5. Based on exposure index model and adaptive capacity index model, the adaptive capacity indexes (ACI) in 2373 counties of whole China are calculated according to the following model.

$$ACI=\sqrt[6]{LFR*EIA*PCI*WPC*WSC*FCR}$$

According to the calculation and percentile distribution, the adaptive capacity indexes in 2373 counties are classified into five levels, including highest level, high level, moderate level, low level and lowest level. Almost 288 counties are under highest level; 525 counties are under high level; 766 counties are under moderate level; 446 counties are under low level; 348 counties are under lowest level.

2.4 Risk assessment

Risk is defined as the potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values (IPCC, 2013). It is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur, which is shown as the interaction of hazard and vulnerability. In the past decades, impact assessment is usually a popular research area in the world. Now risk assessment is becoming much more important in the study of climate change and adaptation. Researchers pay more attention to the potential that a hazard caused by climate change will turn into a disaster. Hazard evaluation and vulnerability evaluation are becoming the important parts of risk assessment. The RCP scenarios (Representative Concentration Pathways) give different pictures of future climate, which will lead to different hazards of drought. For example, in presently dry regions, drought frequency will likely increase by the end of the 21st century under RCP 8.5. Risks could be reduced substantially under the assessed scenario with the lowest temperature projections (RCP2.6 – low emissions) compared to the highest temperature projections (RCP8.5 – high emissions), particularly in the second half of the 21st century. In this research, the hazards of drought from 2016 to 2050 under RCP (2.6, 4.5, 6.0, 8.5) scenarios are evaluated. The

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vulnerabilities of drought in 2373 counties of whole China are also evaluated. Based on hazard evaluation and vulnerability evaluation, risk assessment model is established according to the principle of risk proposed by United Nations (UN, 1991).

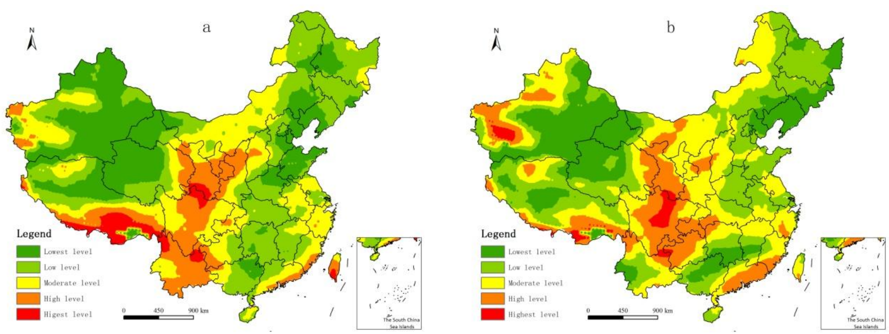
$$R\ (risk) = H(Hazard) \times V(vulnerability)$$

Where, R is risk index of drought in the future; H is hazard index of drought under RCPs scenarios; V is vulnerability index of drought in whole China.

3 Results

3.1 Hazard evaluation

Based on the integrated drought index, hazards of drought under RCP (2.6, 4.5, 6.0, 8.5) scenarios from 2016 to 2050 in China have been evaluated. The hazards of drought are classified into five levels, including highest hazardous, high hazardous, moderate hazardous, low hazardous and lowest hazardous. The distributions of drought hazards under RCP (2.6, 4.5, 6.0, 8.5) scenarios from 2016 to 2050 in China are shown in Fig.4, which reveals the future trends of drought under climate change in China. Comparing the hazards of drought under different RCP scenarios, there are several similar trends. First, a belt around the boundary between Gansu province and Sichuan province will be the most hazardous region under four different RCP scenarios. Second, the most hazardous area is always the smallest and the least hazardous area is always the biggest under four different RCP scenarios. However the difference of hazard trends under four RCP scenarios is more obvious than the similarity. It is the most serious under RCP 6.0 scenario in which the area of highest hazardous and high hazardous is the biggest. It is the least serious under RCP 2.6 scenario in which the area of highest hazardous and high hazardous is the smallest.



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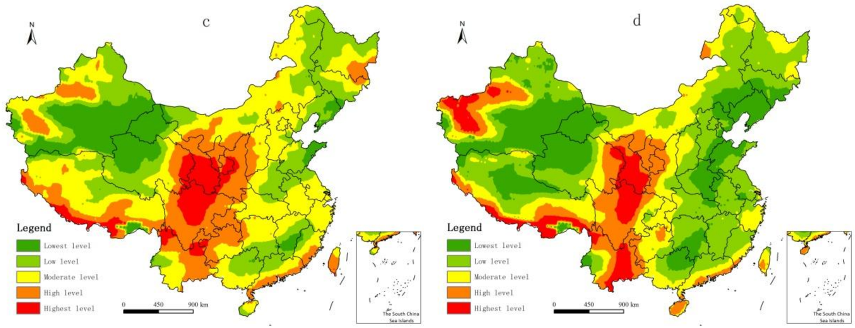

Fig.4 Distribution of drought hazards under RCP (2.6-a, 4.5-b, 6.0-c, 8.5-d) scenarios from 2016 to 2050 in China (Red color represents highest hazardous regions; Orange color represents high hazardous regions; Yellow color represents moderate hazardous regions; Light green color represents low hazardous regions; Dark green color represents lowest hazardous regions)

According to raster calculation in ArcGIS, drought hazard under RCP (6.0) scenario is the most serious, in which the area of highest hazardous regions is almost $5.8\times10^5 km^2$; the area of high hazardous regions is almost $1.79\times10^6 km^2$; the area of moderate hazardous regions is almost $3.45\times10^6 km^2$; the area of low hazardous regions is almost $2.51\times10^6 km^2$; the area of lowest hazardous regions is almost $1.27\times10^6 km^2$. Drought hazard under RCP (8.5) scenario is the second most serious, in which the area of highest hazardous regions is almost $6.6\times10^5 km^2$; the area of high hazardous regions is almost $1.26\times10^6 km^2$; the area of moderate hazardous regions is almost $2.0\times10^6 km^2$; the area of low hazardous regions is almost $3.46\times10^6 km^2$; the area of lowest hazardous regions is almost $2.22\times10^6 km^2$. Drought hazard under RCP (2.6) scenario is the less serious, in which the area of highest hazardous regions is almost $2.78\times10^5 km^2$; the area of high hazardous regions is almost $1.18\times10^6 km^2$; the area of moderate hazardous regions is almost $2.33\times10^6 km^2$; the area of low hazardous regions is almost $3.15\times10^6 km^2$; the area of lowest hazardous regions is almost $2.68\times10^6 km^2$. Drought hazard under RCP (4.5) scenario is the least serious, in which the area of highest hazardous regions is almost $1.7\times10^5 km^2$; the area of high hazardous regions is about $1.39\times10^6 km^2$; the area of moderate hazardous regions is almost $2.92\times10^6 km^2$; the area of low hazardous regions is about $2.93\times10^6 km^2$; the area of lowest hazardous regions is almost $2.2\times10^6 km^2$.

Through the comparison of integrated index of drought hazard (IIDH) under RCP 2.6, 4.5, 6.0, 8.5 emission scenarios from 2016 to 2050, drought hazard under RCP 6.0 is the highest; IIDH under RCP 8.5 is the second most serious; IIDH under RCP 2.6 is the less serious; IIDH under RCP 4.5 is the least serious. Though RCP 8.5 scenario is the highest emission pathway, drought hazard under RCP 8.5 in China is not the most serious; RCP 2.6 scenario is the lowest emission pathway, drought hazard under RCP 2.6 in China is not the least serious; because the different emission processes of RCP scenarios lead to different drought hazards. Taking RCP 8.5 scenarios for example, by the end of 2100 it would be the most serious among the four RCP scenarios, but by the end of 2050 the RCP 6.0 scenario is more serious than RCP 8.5 scenario. As the same reason, the drought hazard under RCP 2.6 scenario is also not the least serious by the end of 2050. In other words, by the end of 2050 the rank of drought hazard under RCP (2.6, 4.5, 6.0, 8.5) emission scenarios is not in accord with the rank of representative concentrations. The results provide us a clear understanding of drought hazards under different RCP scenarios from 2016 to

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2050, which would avoid the assumption of drought hazards.

3.2 Vulnerability evaluation

As mentioned above, vulnerability evaluation includes three indexes-exposure index, sensitivity index and adaptive capacity index, which are calculated separately. According to the three indexes, vulnerability of drought in 2373 counties of whole China has been evaluated, which is also classified into five levels in order to match hazards assessment. The distributions of drought exposure, sensitivity, adaptive capacity and vulnerability in 2373 counties of whole China are shown in Fig.5, which reveal the characteristics of hazard-affected bodies faced with drought disasters.

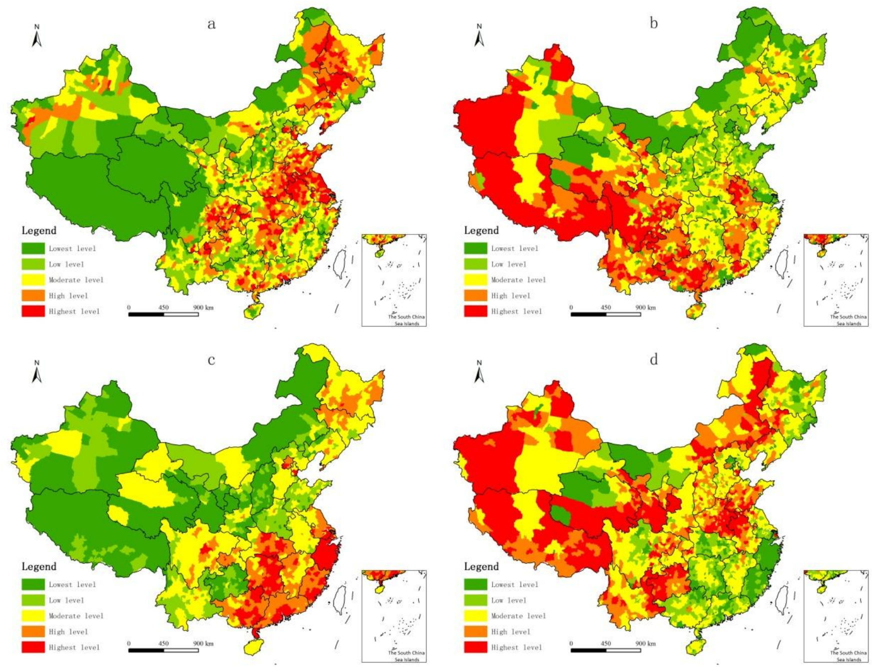

Fig.5 Distribution of drought exposure (picture a), sensitivity (picture b), adaptive capacity ((picture c)) and vulnerability (picture d) in 2373 counties of whole China (Red color represents highest level; Orange color represents high level; Yellow color represents moderate level; Light green color represents low level; Dark green color represents lowest level)

According to vulnerability evaluation of drought, the most vulnerable area mainly distributes in North China, Northeast China and Southwest China, including east of Henan, north of Anhui, south of Shandong, south of Gansu, north of Yunnan, northeast of Inner Mongolia, east of Jilin. Exposure evaluation reveals that the major grain production bases are most vulnerable to expose to drought hazard, such as Northeast China, North China and Central China, in which the population and crop planting area are huge. Due to different properties of population, Urbanization and water resources, West China is most sensitive to drought hazard, including Yunnan, Sichuan, Guizhou, Guangxi, Gansu, west of Xinjiang and so on. Due to higher level of economic development and abundant water resources in Southeast China, the adaptive faculty

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to drought is much better than anywhere else, such as Guangdong, Fujian, Zhejiang, Jiangxi and so on.

3.3 Risk assessment

According to risk assessment model proposed by UN, risks of drought under RCP (2.6, 4.5, 6.0, 8.5) scenarios from 2016 to 2050 in China have been evaluated. As the same with hazard index and vulnerability index, risks of drought have been classified into five levels, including highest risk, high risk, moderate risk, low risk and lowest risk. The distributions of drought risks under RCP (2.6, 4.5, 6.0, 8.5) scenarios from 2016 to 2050 in China are shown in Fig.6, which reveals the future challenges faced with drought disasters under climate change in China. Comparing the risks under four RCP scenarios, the highest risk area is concentrated on several regions, including Gansu, Ningxia, Shanxi, Sichuan, Chongqing, Guizhou, Yunnan and the east edge of Qinghai-Tibetan Plateau. Besides, west of Xinjiang, coast zone of Guangdong and Fujian are also under high risk of drought.

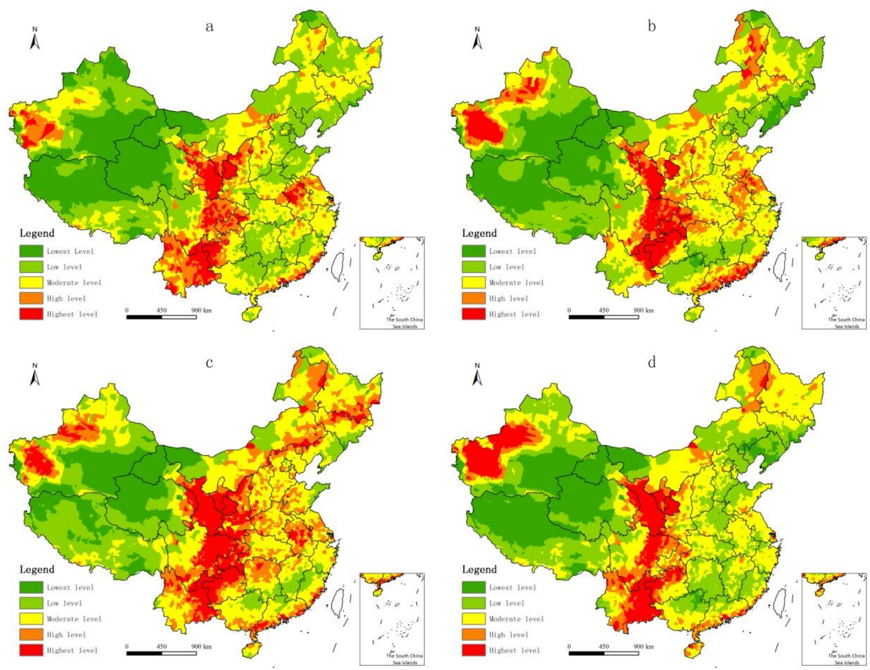

Fig.6 Distribution of drought risks under RCP (2.6-a, 4.5-b, 6.0-c, 8.5-d) scenarios from 2016 to 2050 in China (Red color represents highest risk; Orange color represents high risk; Yellow color represents moderate risk; Light green color represents low risk; Dark green color represents lowest risk)

Based on the analysis of risk, drought risk under RCP (6.0) scenario is the most serious, in which the area of highest risk regions is almost $1.1\times10^6 km^2$; the area of high risk regions is almost $1.72\times10^6 km^2$; the area of moderate risk regions is almost $2.79\times10^6 km^2$; the area of low risk regions is almost $2.59\times10^6 km^2$; the area of lowest risk regions is almost $1.38\times10^6 km^2$. Drought hazard under RCP (8.5) scenario is the second most serious, in which the area of highest risk regions is almost $9.3\times10^5 km^2$; the area of high risk regions is almost $9.1\times10^5 km^2$; the area of moderate risk regions is almost $2.61\times10^6km^2$; the area of low risk regions is almost $3.3\times10^6km^2$; the area of lowest risk regions is almost $1.84\times10^6km^2$. Drought hazard under RCP (2.6) scenario is the less serious, in which the area of highest risk regions is almost $5.47\times10^5km^2$; the area of high risk regions is almost $9.95\times10^5km^2$; the area of moderate risk regions is almost $2.73\times10^6km^2$; the area of low risk regions is almost $3.25\times10^6km^2$; the area of lowest risk regions is almost $2.06\times10^6km^2$. Drought hazard under RCP (4.5) scenario is the least serious, in which the area of highest risk regions is almost $7.7\times10^5km^2$; the area of high risk regions is almost $1.19\times10^6km^2$; the area of moderate risk regions is almost $2.76\times10^6km^2$; the area of low risk regions is almost $3.0\times10^6km^2$; the area of lowest risk regions is almost $1.87\times10^6km^2$.

4 Discussion and conclusion

Climate change has been a hotspot of scientific research and governmental decision in the world for decades. Due to climate change, the disasters become much more serious, which lead to huge losses of lives, economy, ecology and environment. Based on the assessment of drought hazard, vulnerability and risk under RCP (2.6, 4.5, 6.0, 8.5) scenarios from 2016 to 2050 in China, the distributions of drought disasters in future are revealed. In summary, there are several conclusions of this study which need to be discussed.

First, many researchers have focused on the analysis of the frequency, intensity and duration of extreme events based on the Coupled Model Intercomparison Project (such as CMIP3/5), which reveal the uncertainties of climate models for the future projections (Touma et al., 2015; Gu et al., 2014; Mehran et al., 2014). According to IPCC 3th to 5th, the risk assessment of climate change on different extreme events becomes much more important, which is taken as the bridge between impacts and adaptation. In this study, it is the most important to evaluate the risk of drought under RCP scenarios. It is meaningful to integrate the hazard and vulnerability of drought under climate change. We try to explore a feasible method of combining the physical factors and social-economic factors together to assess drought disasters. The spatial distributions of drought risk are accomplished under RCP scenarios based on PRECIS, which revealed the most risky regions threatened by meteorological drought in the future. But it is not discussed in this study that the simulations of different global climate models would also bring about another type of risk, which is mainly about the uncertainties of hazards of drought. It may be a good choice for us to seek in the future work.

Second, according to this study, the distributions of drought hazard on the highest level and high level under RCP scenarios from 2016 to 2050 are mostly concentrating in the similar regions, most of which locate in the middle part of China, including Gansu, Ningxia, Shanxi, Sichuan, Chongqing, Guizhou and Yunnan provinces. Except the middle part, it is also distributed in west of Xinjiang, south of Tibet, coast of Guangdong and Fujian. Comparing with the past researches, some researchers conclude that the increasing drought hazard in Southwest China and the Qinghai-Tibetan Plateau is much more serious than other parts of China in the future (Wang and Chen, 2014; Leng et al., 2015). Due to different climate models, the distributions of drought hazard are not completely identical, but most of the studies approved that moderate or severe drought according to current climate standards will become the norm in the future. In this study, the similar trend is found out. Further on, the distributions of drought hazard under RCP scenarios from 2016 to 2050 are in accordance with the drought situation in the past few years.

For example, Southwest China was subjected to severe drought disasters in a-hundred-year return period from 2009 to 2013, including Sichuan, Chongqing, Guizhou and Yunnan provinces. So it is important for the national and local government to take effective and targeted measures in different regions, which could prevent the drought hazards to become disasters in advance.

Third, vulnerability evaluation index system is very complicated for any disaster which reflects the relationship between hazards and hazard-affected bodies. There are so many factors which could affect the exposure index, sensitivity index, adaptive capacity index and vulnerability of drought hazard, including population, economy, society, agriculture, forest, ecological environment, water resource facilities and so on. In this study 15 factors were selected from multiple impacts factors, which could precisely reveal the characteristics of vulnerability of drought. The 15 factors are independent of which the interrelationships are avoided as much as possible. Due to the demand of accuracy and completeness of data in 2373 counties of whole China, some factors are not chosen in this study, such as water resource facilities, water conservancy projects, relief materials reservation and so on. In the future research, the vulnerability evaluation index system of drought will be improved and consummated to make it much precise and credible. On the other hand, in this study the vulnerability of drought in 2013 is evaluated for the future risk assessment from 2016 to 2050. The future simulation of 15 vulnerability factors would enormously increase the uncertainty of vulnerability evaluation which may lead to huge deviations or even big errors. Therefore the vulnerability of drought in 2013 is regarded as the basis of risk assessment which could reveal the differences of risk distribution from 2016 to 2050 under different RCP scenarios.

Based on the conclusion and discussion, the measures of coping with drought disasters are proposed, which could provide scientific basis for the prevention and mitigation of future drought disasters in China. On one hand, it is urgent to speed up water infrastructure construction in regions faced with high risk of drought in the future. At the same time, improving the non-engineer measures in regions faced with moderate and low risk of drought in the future. On the other hand, strengthening the protection of ecological environment in whole country is necessary to promote the resilience of natural system. From this study, we can see the drought disaster will still be a big challenge in the future in China. So the research on risk assessment of drought in the future will need much more attention in the future.

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