Agricultural drought disaster risk evaluation in Guizhou

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Abstract

The paper established the model of agricultural drought disaster risk evaluation and assessment index system, defined disaster risk threshold value by using the analytic hierarchy process (AHP), weighted synthesis method and natural hazards index method in the case of Xiuwen, Meitan and Xingren County in Guizhou province. Considering factors of natural, social economic, hazard of disaster-causing factors, the exposure and vulnerability of hazard bearing body and drought resistance ability, guided by theory of meteorology, agricultural science, disaster science, natural disaster risk science and other multi-disciplinary theories, scientific of the model is verified by relevance analysis of crop yield losses estimated on the base of agricultural drought disaster temporal series and drought disaster risk index. The result can provide directions and guidance for drought forecast and risk management in Guizhou province and the similar area.

Keywords: agricultural drought disaster, risk evaluation, disaster risk threshold value, Guizhou

1 Introduction

Drought is the most common natural disasters. According to estimates, the global economic loss caused by drought is as high as $6-8 billion dollars every year, far more than the other meteorological disasters [1]. The IPCC in its series assessment report pointed out that drought risk has a rising trend in the future [2]. Drought disaster is one of the major natural disasters in Guizhou province. Since the fall of 2009, precipitation in Yunnan, Guizhou and Sichuan provinces has decreased by 30%~50% compared with all the year round, the average temperature is also increased by more than 1°C. According to the latest statistics, as of the beginning of 2010, cultivated land area of the drought in China have been 6.45 million hectares, increased more nearly 1.8 million hectares than previous years. There are about more than 20 million people for drinking water difficultly due to drought. The southwest is the severe drought disaster area. As reservoir leakage, rivers dry rot, wells dry, farmland irrigation can't be satisfied. Guizhou province suffered the worst droughts in recent years. Drought risk assessment is an effective method to know the risk, which is the premise and foundation of risk control and risk management. Therefore, the natural disaster risk theories combined with risk quantification, risk assessment technology are of great significance for drought disaster relief, risk management.

2 The general situation in the study areas

The study area mainly includes Xiuwen, Meitan and Xingren County three typical areas. Xiuwen County is located in the middle part of Guizhou province, with a total area of 1075.70 square kilometers, an average elevation of 1250 meters, mostly in the hilly terrain, the annual average temperature of 16°C, annual rainfall of 1293 mm. Meitan County is in northern part of Guizhou province with a total area of 1864 square kilometers, an average elevation of 972.7 meters, the annual average temperature 14.9°C, annual average rainfall of 1141 mm. Xingren county is located in the middle of Guizhou province Qianxinan, land area of 1785 square kilometers, an average elevation of 1253 meters, the annual average temperature 15.2°C, annual average rainfall of 1332.1 mm. Three typical areas belong to subtropical monsoon climate, no cold winter and no hot summer. But due to the unique karst topography and serious soil desertification in Guizhou, severe drought disasters influence and damage to the local production and life.

3 Research methods and data sources

3.1 RESEARCH METHODS

The index system is selected based on the elements of drought risk (hazard, exposure, vulnerability and drought resistant ability) and analysis of rationality, scientific, practical utility of research data. The agricultural drought disaster risk values are calculated by synthesis analysis method formed from the analytic hierarchy process (AHP), weighted synthesis method and natural hazards index method. The risk value locates at some interval after a dimensionless processing. The interval is divided into four classes, corresponding to different types of risk.

3.1.1 The analytic hierarchy process (AHP)

The analytic hierarchy process (AHP) is a method system used to calculate weight coefficient of the complex multiple indexes [3]. By this approach, we can do quantitatively and qualitatively analysis of indicators. The indicator weight coefficients are calculated on the base of one-to-one index important comparison. In the paper nine distinguish grades are used to evaluate drought risk. The weight coefficient according to every index is different due to differentiation of influence level of every index to subject investigated.

3.1.2 The weighted synthesis method

The weighted synthesis method distributes the weight coefficient of evaluation index respectively, which is based on differentia importance of impact of the evaluation indexes for evaluating the total target [4]. Add the result that quantitative index multiply corresponding weighted index to donate the level of drought disaster risk. The formula is as follows:

$$P=\sum_{i=1}^{n} A_i W_i \ . \quad (1)$$

In Equation (1): P is the overall evaluation value of the research object; Ai is the quantitative values of the i index; W_i is the weight coefficient of i index ($W_i \geq 0, \sum_{i=1}^{n} W_i = 1$); n is the number of evaluation index.

Each index plays the role of "positive" or "reverse" on evaluated subject, and the corresponding dimension is not identical. The data is normalized in order to calculate conveniently. Specific methods are as follows [5]:

Maximum optimal type: the larger the index is, the higher the risk values, indicating "positive role".

$$X'_{ij} = \frac{X_{ij} - X_{\min}}{X_{\max} - X_{\min}} \ . \quad (2)$$

Minimum optimal type: the larger the index is, the lower the risk values, indicating “reverse role".

$$X'_{ij} = \frac{X_{ij} - X_{\min}}{X_{\max} - X_{\min}} \ . \quad (3)$$

In equations: X_{ij} is the jth index of the ith object; $X^{'}_{ij}$ is the jth index of the ith object after dimensionless processing; $X_{\max}$ and $X_{\min}$ are the maximum and the minimum of the index respectively. So we can get $X^{'}_{ij} \in [0,1]$.

3.1.3 The natural hazards index method

The natural hazards index method analyzes drought risk through the research on serious degree and probability of drought disaster occurrence in the future [6]. Scholars pointed out that the natural disaster risk is mainly composed of hazard of disaster-causing factors, the exposure and vulnerability of hazard bearing body in previous. But the influence degree that drought resistant ability exerts on natural disaster risk value is increasing gradually with people awareness of natural disasters increasing. So the four subsystems of drought disaster risk that is hazard of disaster-causing factors(H), exposure (E) and vulnerability (V) of hazard bearing body, and drought-resistant ability (RE), is essential in researching on the drought disaster forming, the synthesis action of these leads to drought disaster.

3.2 DATA SOURCES

The weather and climate data in the paper is cited from China meteorological science data sharing service web, hydrological data is from water resources gazette in Guizhou and the water resources annals in Guizhou, and social economic data is from Guizhou province statistical yearbook.

4 Agricultural drought disaster risk index selection and model building

4.1 AGRICULTURAL DROUGHT DISASTER RISK INDEX SELECTION

Drought disasters are adverse results in the event of people’s effort on drought resist and relief hazard due to vulnerability of hazard-affected bodies. Exposure of hazard-affected body is the contact area of the risk of disaster-inducing factors and the vulnerability of hazard-affected bodies, which is the precondition of vulnerability. Hazard and vulnerability is the basic reason of the drought disaster. The greater the hazard, vulnerability and exposure are, the greater drought disaster risk is, vice versa. Drought-resistance ability is people’s efforts and action to resist drought disasters, which is "reverse" for drought disaster risk. Agricultural drought disaster risk in typical area is mainly composed of four essential factors (Figure 1).

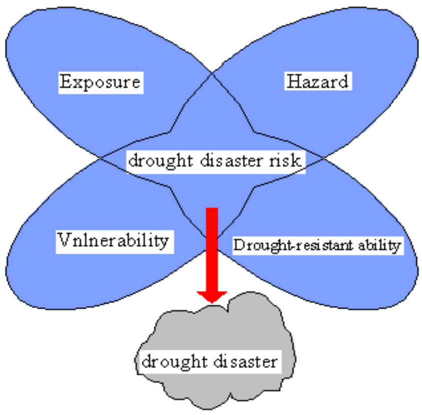

FIGURE 1 The formation factors of agricultural drought disaster risk

Agricultural drought is a kind of extremely complex natural disasters, which involves climate, atmosphere, farming crops, social economic, and natural resources. Therefore index selection is premise and key of agricultural drought risk evaluation [7]. These principles that include purposiveness, systematicness, scientificity, comparability and operability are considered to select indexes, combining with physical circumstances at the same time [8]. Guizhou is typical karst landform, precipitation infiltrates underground and directly outflow, so it can’t be used efficiently. The speeds of soil desertification accelerate, soil layer become shallow, water and soil erosion is serious. In the paper, 15 indexes are selected as evaluation indexes totally.

Hazard is denoted by precipitation from February to September in crop growth period, by continuous no rain days in this time interval which reflects precipitation uniformity or drought duration and by drought frequency that reflects possibility of the drought occur. Exposure is denoted by agricultural crop sown area, the larger sown area is, and the greater the exposure for crops is [9]. Vulnerability is denoted by the population density, the drought area and crop yield per unit area, which reflects degree of crop vulnerability in the study area [10]. Drought-resistant ability is denoted by yields rates of drought or waterlogging and water saving rate in technology level; which is denoted by per capita income and investment in economic level; which is denoted by drought irrigation area and solving temporary population of drinking water in policy and management level.

4.2 THE ESTABLISHMENT OF AGRICULTURAL DROUGHT DISASTER RISK MODEL

According to the mechanism of agricultural drought disaster risk, considering four risk factors and indexes in the typical areas Xiuwen, Meitan, Xingren, drought disaster risk evaluation system is established by using the analytic hierarchy process (AHP) and weighted synthesis methods (Table 1).

TABLE 1 Index system and weights of agricultural drought disaster risk assessment

	Factor	Index system	Weight
Index system of agricultural drought disaster risk assessment	Hazard(H) 0.412	2-9 month precipitation(mm)	0.286
		2-9 month continuous no rain (d)	0.194
		Drought index	0.137
		Drought frequency (%)	0.137
		Average wind speed (m/s)	0.144
	Exposure(E) 0.125	Agricultural crop sown area (ha)	1
	Vulnerability(V) 0.278	The drought area ratio (%)	0.326
		Density of population	0.425
		Drop yields (kg/ha)	0.249
	Drought resistant ability(RE) 0.185	The drought and flood insurance yield (%)	0.161
		Per capital net income (Yuan/person)	0.185
		Water-saving percentage (%)	0.243
		Irrigation area (%)	0.129
		Drought relief funds (Yuan)	0.141
		Solve temporary drinking water	0.141

Drought disaster risk reflects the potential risk and direct harm of natural disasters exerting on hazard-affected bodies. The models are established based on the theory of disaster risk assessment, considering hazard of disaster-causing factors, the exposure and vulnerability of hazard bearing body and drought resistance ability, totally [12].

$$Risk=\left(H^{WH}\right)+\left(E^{WE}\right)+\left(V^{WV}\right)+\left(RE^{WR}\right), \quad (1)$$

$$H=\sum_{i=1}^{n=5}X_{hi}W_{hi}\ , \quad (2)$$

$$E=\sum_{i=1}^{n=1}X_{ei}W_{ei}\ , \quad (3)$$

$$V=\sum_{i=1}^{n=3}X_{vi}W_{vi}\ , \quad (4)$$

$$RE=\sum_{i=1}^{n=6}X_{ri}W_{ri}\ . \quad (5)$$

In Equations, Risk is an agricultural drought disaster value, which is used to represent the drought disaster risk degree. H , E , V and RE represent values of hazard, exposure vulnerability and drought resistant ability respectively. W_h , W_e , W_v , W_r represent values of index weight coefficient of hazard, exposure, vulnerability and drought resistant ability respectively. X_i is the quantitative value of each index. W_i is weight coefficient of each evaluation index [13]. The comprehensive drought risk value is calculated by those equations in these typical areas, which reflect drought risk level directly.

5 Agricultural drought disaster risk evaluation and risk threshold determination

Selecting period from 1990 to 2007 as time scales of research, agricultural drought disaster risk values are gotten in Xiuwen, Meitan, Xingren based on the indexes selected and the model built. As shown in Figure 2.

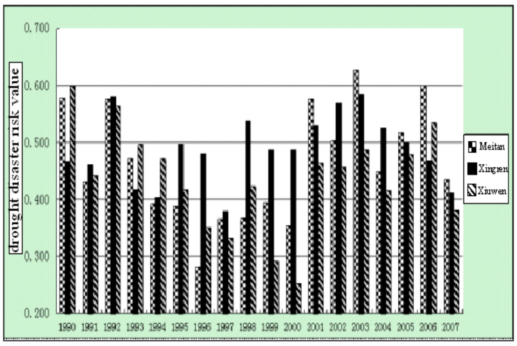

FIGURE 2 Comparable chart of drought disaster risk value in typical areas

Frequency of calendar year drought disaster risk values in Xiuwen, Meitan, Xingren three typical areas are analyzed in the order from smallest to largest. As shown Figure 3, Figure 4, Figure 5.

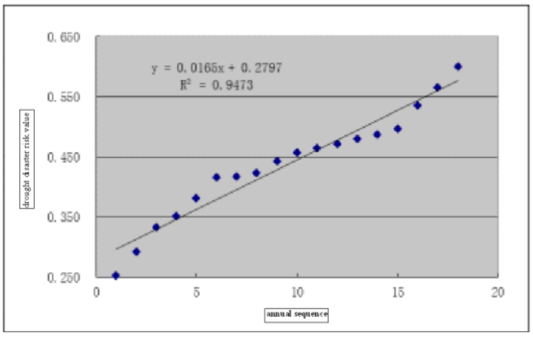

FIGURE 3 The scatter of agricultural drought disaster risk value in Xiuwen County

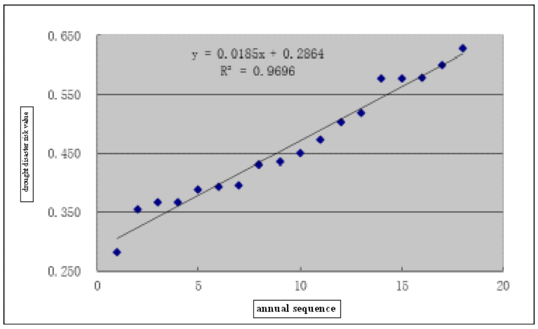

FIGURE 4 The scatter of agricultural drought disaster risk value in Meitan County

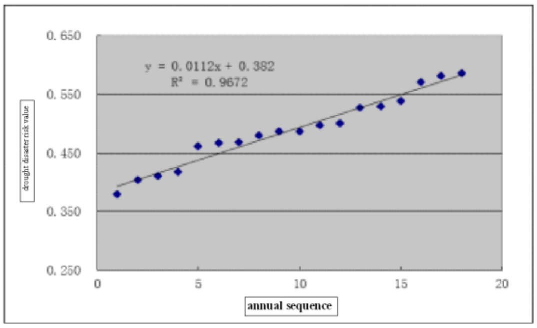

FIGURE 5 The scatter of agricultural drought disaster risk value in Xingren County

Drought disaster risk evaluation are classified four grades in order to synthesis analyze drought disaster risk based on data processing. Drought disaster risk threshold in typical areas are defined as Table 2.

TABLE 2 Threshold value and different risk types of agricultural drought disaster risk

Risk type	Light risk	Low risk	Medium risk	High risk
Threshold value	≤0.415	0.415~0.445	0.445~0.535	≥0.535

We found that 1990, 1992, 2001, 2002, 2003, etc are high-risk and middle-risk years by statistical comparison of risk values in three typical areas. The reasons for that are as follows:

1) From the aspect of disaster-causing factors, drought duration strength reflected by continuous no rain days is large, frequency of the drought reflected by wind speed and drought index is high, and incidence of drought reflected by drought frequency is high, all these accelerate drought disaster risk because these factors act "positive". So 1990 and 2003 are high risk years; 1992, 2001, 2002 are middle risk years.

2) From the aspect of vulnerability and exposure of hazard bearing body, agricultural crop sown area in 2000-2007 is much larger than that in 1990-1999 in three typical areas, the larger crop sown area is the more serious exposure is. Therefore, the larger yield loss is, the higher vulnerability is. Vulnerability risk values of crop yields in three typical areas locate high risk range in 1990, 1992, 2002. Vulnerability of crop is influenced essentially because crops in these years are suffered from severe summer drought. The districts that the population density is too large demand more water resources, which are bound to cause agricultural water relief, further to strengthen vulnerability of drought, and to lead to conflict with agriculture water and residents life water. So water resources should be allocated rationally [14].

3) From the aspect of drought resistant ability, which plays "positive" action based on the model because indexes of drought resistant are minimum optimal type. Some risk models define threshold values by the ratio of vulnerability, hazard, and exposure to drought resistant ability, drought resistant ability play "reverse" role. In this paper, drought-resistant ability is added in the model, so it should be "positive". Drought risks in some years lie in high risk range because weight value of drought-resistant ability in the model is low due to relatively difficulties of engineering and management in Guizhou.

Above all, the drought disaster risk is not defined by a single factor such as hazard of disaster-causing factors, exposure and vulnerability of hazard bearing body and drought resistance ability, but by complex multiple risk factors. We should improve agricultural technology and intensify drought resistance degree to relief drought influence on people’s production life in high risk years. We should improve engineering drought resistance and people's consciousness of water-saving in low risk years.

6 Inspection of agricultural drought disaster risk evaluation model

In order to test scientificity and applicability of risk model and drought disaster risk evaluation method, drought disaster risk indexes and crop yield losses estimated from agricultural disaster statistics are processed by correlation analysis in these typical areas. Crop yield losses are estimated in the case of areas of suffer drought, disaster, total crops failure and yield per Ha from statistics materials in GuiZhou [15]. The specific formula is as follows:

L=((T1-T2)*0.2+(T2-T3)*0.55+T3*0.9)W*10-3(6)

In Equation: L is the estimated value of crop yield losses; W is yield per Ha; T1 is the areas of suffer drought; T2 is disaster area; T3 is the area of total crops failure.

Crop yield losses are calculated from 1990 to 2007 year by year in Xiuwen, Meitan, Xingren, as shown Figure 6, Figure 7, and Figure 8.

Consistency of time Matching is good between crop yield losses and agricultural drought disaster risk value in typical areas. The results have no significant difference by a=0.05 t test, which denote drought disk evaluation value has a certain objectivity. In Xiuwen, the relationship between crop yield losses and drought disk value has no significant difference (p=0.86>0.05); In Meitan, the relationship between crop yield losses and drought disk value has no significant difference (p=0.94>0.05); In Xingren, the relationship between crop yield losses and drought disk value has no significant difference (p=0.21>0.05).

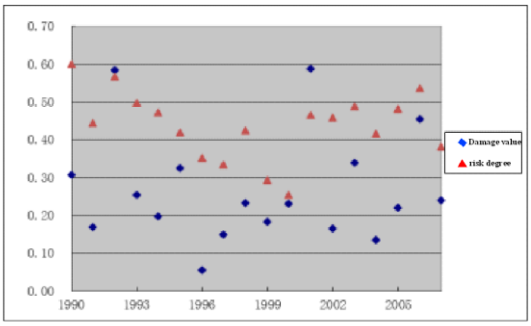

FIGURE 6 The scatter chart of drought disaster risk value and crop yield losses in Xiuwen

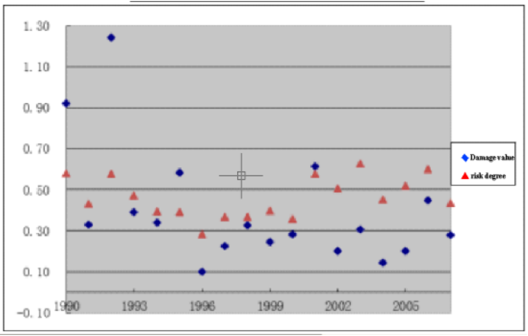

FIGURE 7 The scatter chart of drought disaster risk value and crop yield losses in Meitan

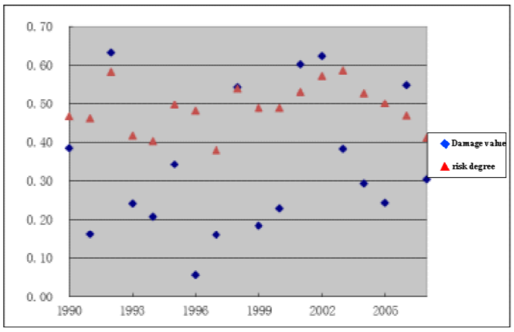

FIGURE 8 The scatter chart of drought disaster risk value and crop yield losses in Xingren

7 Conclusions

In the paper agricultural drought disaster risks are evaluated using the method of natural disaster index, which provide reference for the relevant departments to formulate the drought early warning and risk management. Select drought time intensity and frequency of drought as disaster-causing factors, crop sown area and agricultural production level as hazard bearing body, those are research subject. Hazard of disaster-causing factors, exposure and vulnerability of hazard bearing body, and drought resistance ability are selected as evaluation indexes. Natural and social factors are considered in selecting indexes, materials of precipitation, disaster statistics and social economic are used fully. Analytic hierarchy process (AHP) is used to analyze the factor indexes weights, which make agricultural drought risk assessment results have rationality and reference. High risks are mainly concentrated in the 1990, 1992, 2001, 2003, 2006 from the point of drought disaster risk evaluation values. Guizhou province totally presents a higher drought situation in corresponding years from (statistics materials of drought levels of serious drought 20 years and region distribution in Guizhou). Therefore, the model established in the paper can adapt to different agricultural drought disaster risk evaluation in districts similar with Guizhou province. Through the research we recognize that drought disaster risk is high in Guizhou province, although average annual rainfall is nearly 1200 mm, severe drought disasters influence and damage to the local production and life due to the unique karst topography and serious soil desertification in Guizhou. So strengthen the construction of water storage projects and water-saving irrigation projects are an important work, at the same time people's consciousness of water-saving should be raised.

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