# COMPREHENSIVE EVALUATION MODEL OF AGRICULTURAL DROUGHT DISASTER RISK /

# *农业干旱灾害风险综合评估模型*

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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 grey correlation, analytic hierarchy process (AHP), weighted synthesis method, natural hazards index method and Fisher optimal partitioning method in the case of Xiuwen, Rongjian, Yinjiang, Meitan,Nayong 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*

**摘要:** 以贵州省的修文、榕江、印江、湄潭、纳雍和兴仁为典型区，以气象学、农业学、灾害学、和自然灾害风险科学作为理论指导，综合考虑典型区自然、社会经济现状，从影响农业干旱灾害的风险四要素致灾因子危险性、承灾体的暴露性和脆弱性以及抗旱能力的方向出发，利用灰色关联度、层次分析法、加权综合法和自然灾害指数法、Fisher 最优分割法，构建了农业干旱灾害风险评估体系模型，建立干旱灾害风险评价概念框架及指标体系，确定了灾害风险阈值。根据农业灾情时序数据对作物产量损失进行估算并与干旱灾害风险指数进行相关性分析，以验证干旱综合风险模型的科学性。研究结果可为贵州及类似地区农业干旱灾害预警，以及相关部门的干旱灾害风险管理提供理论依据和指导。

**关键词:** 农业干旱灾害；风险评估；风险阈值；贵州省

## 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 [10]. The IPCC in its series assessment report pointed out that drought risk has a rising trend in the future [1]. 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 ℃. 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.

## 引言:

旱灾是全球最为常见的自然灾害。据测算，每年因干旱造成的全球经济损失高达 60-80 亿美元，远远超过了其它气象灾害[10]。IPCC 在其系列评估报告中指出，未来干旱风险有不断增加的趋势[1]。干旱灾害是贵州省主要的自然灾害之一。2009 年秋季以来，云贵川三省降水量与常年相比减少 30%~50%，平均气温也增长了 1℃以上。据最新资料统计，截至 2010 年初，中国已有受旱耕地面积 645 万公顷，比往年的受旱面积增加了近 180 万公顷，因干旱导致的饮水困难约有 2000 多万人，其中，西南地区就是干旱灾害严重地区。随着水库出现渗漏现象、河流开始干枯、农田灌溉无法满足、水井开始干涸，贵州省地区市遭遇了近年来最为严重的的特大干旱。旱情风险评价是认识风险的有效方法，是风险控制和风险管理的前提和基础，准确的灾害风险评价是风险管理的决策依据，是防治灾害的重要内容。因此，研究将自然灾害风险理论与风险量化、风险评价技术相结合研究贵州农业干旱风险对该地区旱情风险管理, 防灾抗灾工作具有重要意义。

## MATERIAL AND METHOD

### RESEARCH METHODS

The index system is selected based on the elements of drought risk (hazard, exposure, vulnerability and drought resistant ability) and analysis

## 研究方法和数据来源

### 研究方法

根据旱灾风险的组成要素（危险性、暴露性、脆弱性和抗旱能力），基于研究区的资料合理性、科学性和实用性

of rationality, scientific, practical utility of research data. The agricultural drought disaster risk values are calculated by synthesis analysis method formed from the grey correlation, analytic hierarchy process (AHP), weighted synthesis method, natural hazards index method and Fisher optimal partitioning 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.

选取适当的指标，通过由灰色关联度、层次分析法、加权综合法、自然灾害指数法、Fisher 最优分割法所组成的综合分析方法计算研究区农业干旱灾害的风险值。经过无量纲处理之后，典型区的农业干旱灾害的风险值都在某一区间之内。将该区间分成四级，分别对应不同的风险类型。同时通过这种等级划分，也可以分别得到危险性、暴露性、脆弱性和抗旱能力的相应风险类型。

### THE ANALYTIC HIERARCHY PROCESS (AHP)

The analytic hierarchy process (AHP) is a method system used to calculate weight coefficient of the complex multiple indexes [8]. 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.

### 层次分析法

层次分析法(AHP) [8]是一种用来计算复杂系统多元指标所对应权重系数的方法，这种方法可以对指标进行定量定性的分析。通过对研究体系的影响因素分析，并根据每个指标的紧密程度进行一对一的比较、分析和计算。本文通过九种判别等级来评价，通过量化分析每个指标，因为每指标对研究对象的影响轻重程度不同，所以每个指标对应的权重值也各不相同。

### THE GREY CORRELATION

The grey correlation is used to research the relation between two series increase speed. The correlation is indicated with the area in two series polygonal line.

### 灰色关联度

灰色相对关联度主要研究的是两序列增长速度之间的关系，用两条序列折线间所夹的面积大小来衡量两序列的关联性的大小。

### 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 [13]. Add the result that quantitative index multiply corresponding weighted index to donate the level of drought disaster risk. The formula is as follows:

### 加权综合法

加权综合评价法[13]是根据评价指标对于评价总目标所影响的重要程度的不同，分别对评价指标进行权重系数的分配。将量化后的指标与相应权重相乘后再相加，根据每个指标对干旱灾害风险值的正负相关程度不同利用加权综合的方式系统地加以集中，以表示干旱灾害风险的高低。用公式表示如下：

$$P=\sum_{i=1}^{n} A_i W_i \tag{1}$$

In equation (1): P is the overall evaluation value of the research object; Ai is the quantitative values of the i index; Wi 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.

式中：P 为研究对象所对应的总评价值；$A_i$ 为某系统第 i 项指标的量化值($0 \leq A \leq 1$)；$W_i$ 为某系统第 i 项指标的权重系数($W_i \geq 0, \sum_{i=1}^{n} W_i = 1$)；n 为评价体系指标的个数。

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 [9]:

每个指标对研究对象起到“正向”或是“反向”的作用，并且对应的单位也各不相同，为了计算方便，一般对数据进行归一化处理，具体方法如下[9]：

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

最大最优型：指标值越大，风险值越高，呈“正向”作用。

$$X_{ij}^{'} = \frac{X_{max} - X_{ij}}{X_{max} - X_{min}} \tag{2}$$

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

最小最优型：指标值越大，风险值越低，呈“反向”作用。

$$X_{ij}^{'} = \frac{X_{ij} - X_{min}}{X_{max} - X_{min}} \tag{3}$$

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

式中：$X_{ij}$ 为第 i 个对象的第 j 项指标；$X_{ij}^{'}$ 为无量纲化处理后第 i 个对象的第 j 项指标值；$X_{max}$ 和 $X_{min}$ 分别为该指标的最大值和最小值。通过上式可以看出，$X_{ij}^{'} \in$ [0，1]。

## 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 [12]. 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.

## FISHER OPTIMAL PARTITIONING METHOD

The optimal partitioning method was proposed by Fisher in 1958. The method make the segmentation deviation square sum in grades minimum, in the condition of no damage the ordering sample. The base idea is making n sample one class, then increasing classes in base of error function classified.

## RESEARCH MATERIAL

### 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.

### THE GENERAL SITURATION 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 16ºC, 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 14.9ºC, 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 15.2ºC, annual average rainfall of 1332.1 mm. Nayong county is located in the west north of Guizhou province with a total area of 2448 square kilometers, the annual average temperature 13.6ºC, annual average rainfall of 1243.5 mm. Yinjiang county is located in the east north of Guizhou province with a total area of 1969 square kilometers, the annual average temperature 16.8ºC, annual average rainfall of 1100 mm. Rongjiang county is located in the east south of Guizhou province with a total area of 3315.8 square kilometers, abundant plant resource. The coverage rate 68.8% is highest in Guizhou province.

Six 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.

## 自然灾害指数法

自然灾害风险指数法是通过研究未来若干年内可能达到的灾害程度及其发生的可能性而对旱情风险进行分析[12]。早先学者指出自然灾害风险主要由危险性、暴露性和脆弱性组成。但近几年研究发现随着人们对自然灾害的认识，抗旱能力对于自然灾害风险值的影响正在逐年增加，因此本次研究将抗旱能力也作为重要的因素之一加以考虑。干旱灾害的造成是致灾因子的危险性(H)、暴露性(E)、脆弱性(V)和抗旱能力(RE)综合作用的结果。

## Fisher 最优分割法

最优分割法是费舍尔（Fisher）在 1958 年提出的，主要是在不破坏有序样本的前提下，使其分割的级内离差平方和最小，而级间的离差平方和为极大的一种聚类分级方法。它的基本思想是先将 n 个样品看成一类，然后依据分类的误差函数逐渐增加分类。

## 研究资料

### 数据来源

本文所用气象和气候数据来自中国气象科学数据共享服务网，水文数据来自《贵州省水资源公报》和《贵州水利年报》，社会经济数据来自《贵州省统计年鉴》。

### 研究区概况

研究区主要包括贵阳市的修文县、遵义市的湄潭县和铜仁地区的兴仁县三个典型区。修文县地处黔中，总面积 1075.70 平方公里。境内平均海拔 1250 米，地势丘陵居多，年平均气温为 16℃，年降雨量达 1293 毫米。湄潭，位于贵州省北部，总面积 1864 平方公里，平均海拔 972.7 米，年平均气温 14.9℃，年均降雨量 1141 毫米。兴仁县位于贵州省黔西南州中部，国土面积 1785 平方公里，平均海拔 1253 米，年平均气温 15.2℃，年均降雨量 1332.1 毫米。纳雍县位于贵州省西北，总面积 2448 平方公里，年平均气温 13.6℃，年均降雨量 1243.5 毫米。印江县位于贵州省黔东北，总面积 1969 平方公里，年均气温 16.8℃，年降雨量 1100mm 左右。榕江县位于贵州省东南部，面积 3315.8 平方公里，榕江森林资源丰富，森林覆盖率达 68.8%，居全省之冠。

六个典型区都属于亚热带季风气候，冬无严寒，夏无酷暑。但由于贵州独特的喀斯特地形地貌，以及土壤石漠化严重，导致干旱灾害严重，给当地的生产生活造成影响和损失。

## RESULT

### 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).

## 结果

### 农业干旱灾害风险指标选取

干旱灾害是在承灾体的脆弱性下发生的具有危险性的干旱事件，在人类进行抗旱减灾的努力下，产生的不利结果。其中，承灾体的暴露性是致灾因子危险性和承灾体脆弱性的接触面，是脆弱性的先决条件。危险性和脆弱性则是旱灾发生的根本原因。危险性、脆弱性、暴露性越大、干旱灾害风险越大，反之，三者越小则干旱灾害风险越小。抗旱能力则是人们为了抵抗干旱灾害所付出的努力和行动，抗旱能力对干旱灾害风险呈“反向”作用。一个典型区的农业干旱灾害风险主要由这风险四要素组成（如图1）。

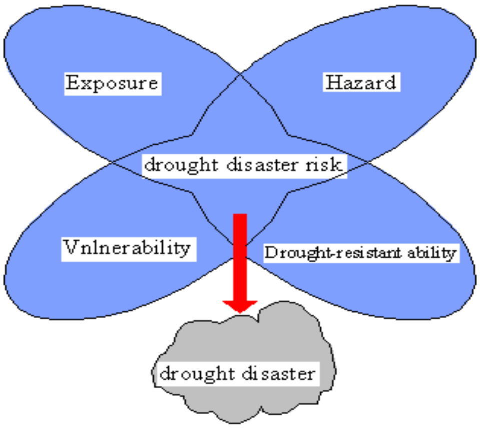


**Fig.1-**The formation factors of agricultural drought disaster risk

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 [5]. These principles that include purposiveness, systematicness, scientificity, comparability and operability are considered to select indexes, combining with physical circumstances at the same time [2]. 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. At the same time, the correlation degree between indexes and crop yield loss. In the paper, 15 indexes are selected as evaluation indexes totally. The result of correlation degree analysis are shown in table 1, which show selecting the indexes being reasonable.

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 and density of population , the larger sown area and density of population are, and the greater the exposure for crops is [6]. 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 [4]. Drought-resistant ability is denoted by yields rates of drought or waterlogging and water saving rate in technology

农业干旱灾害风险是多因素共同作用的结果，它涉及到气候、大气、耕种作物[5]以及人类对资源所造成的积极和消极的影响等各方面因素。所以农业干旱是一种极其复杂的自然灾害，它不仅是一种物理过程，同时也与气候变化、自然资源、社会经济相关。由于农业干旱的复杂性和多变性，指标的选取就成为农业干旱风险评价的前提和关键。综合考虑指标体系的目的性、系统性、科学性、可比性和可操作性原则，结合实际操作情况和资料获取的难易程度选取指标[2]。根据指标选取的原则，基于干旱灾害风险组成四要素（危险性、脆弱性、暴露性和抗旱能力）对农业干旱灾害风险的影响，同时考虑贵州地区的农业干旱不同于一般的农业干旱，其典型的喀斯特地形地貌形成地下以及山体内部岩溶地形，降水或形成地表径流直接流走或渗入地下不能很好地储存和利用，土壤的石漠化速度快，土层浅薄，水土流失较为严重，以及通过分析各指标同作为损失状况的相关性，共选取 16 个指标作为评价指标。所选取的各项指标与作物的损失状况进行灰色关联度分析，结果如表 1 所示，说明选择这些指标是合理的。

危险性主要根据气象资料中 2～9 月降水量表示粮食作物生长期内降水的多少，2～9 月连续无雨日数表示降雨的均匀程度或者干旱持续时间；干旱频率反映了干旱发生的可能性。暴露性主要表现在农作物的播种面积[6] 和人口密度，对于农作物来说，播种面积越大，人口密度越大，暴露性越大；选用因旱粮食损失、受旱面积和农作物单位面积产量[4]作为脆弱性指标，来表征研究区的易损程度；抗旱能力在技术层面上选取旱涝保收率和节水率为指标，在

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.

经济层面上选取人均收入和抗旱投入资金为指标，在政策与管理层面上选取抗旱灌溉面积和解决临时饮水人口为指标。

**ESTABLISHMENT OF AGRICULTURAL DROUGHT DISASTER RISK MODEL**

According to the mechanism of agricultural drought disaster risk [7], considering four risk factors and indexes in the typical areas, drought disaster risk evaluation system is established by using the analytic hierarchy process (AHP) and weighted synthesis methods (Table 1).

根据农业干旱灾害风险形成机制[7]，综合考虑典型区的风险要素 4 个因子及其指标，利用层次分析法和加权综合法，建立如下贵州典型区农业干旱灾害风险评价体系（表 1）。

Table 1

**Index system and weights of agricultural drought disaster risk assessment**

| | Factor | Index system | Weight | Correlation degree to crop yield loss |
|---|---|---|---|---|
| Index system of agricultural drought disaster risk assessment | Hazard(H) 0.387 | Precipitation （mm） | 0.417 | 0.661 |
| | | Evaporation （mm） | 0.241 | 0.663 |
| | | Drought index | 0.097 | 0.698 |
| | | Drought frequency （%） | 0.089 | 0.646 |
| | | Soil type | 0.157 | 0.679 |
| | Exposure（E） 0.155 | Agricultural crop sown area （ha） | 0.750 | 0.715 |
| | | Density of population (number/km$^2$) | 0.250 | 0.613 |
| | Vulnerability（V） 0.265 | The drought area ratio （%） | 0.443 | 0.723 |
| | | Crop yield loss because of drought | 0.387 | 0.735 |
| | | Drop yields （kg/ha） | 0.170 | 0.810 |
| | Drought resistant ability （RE） 0.193 | The drought and flood insurance yield （%） | 0.192 | 0.677 |
| | | Per capital net income （Yuan/person ） | 0.087 | 0.592 |
| | | Water-saving percentage（%） | 0.073 | 0.611 |
| | | Irrigation area （10$^3$ha） | 0.183 | 0.800 |
| | | Drought relief funds （Yuan/ha） | 0.108 | 0.622 |
| | | Irrigation rate （%） | 0.357 | 0.712 |

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 [3]. Formula as follow:

干旱灾害风险反映了自然灾害对承灾体的潜在危险和直接危害，依据灾害风险评估技术理论体系，综合考虑了致灾因子危险性、承灾体的暴露性和脆弱性以及抗旱减灾能力[3]，公式如下：

$$Risk=\left(H^{WH}\right)+\left(E^{WE}\right)+\left(V^{WV}\right)+\left(RE^{WR}\right) \tag{4}$$

$$H=\sum_{i=1}^{n=5} X_{hi}W_{hi} \tag{5}$$

$$E=\sum_{i=1}^{n=1} X_{ei}W_{ei} \tag{6}$$

$$V=\sum_{i=1}^{n=3} X_{vi}W_{vi} \tag{7}$$

$$RE=\sum_{i=1}^{n=6} X_{ri}W_{ri} \tag{8}$$

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;

上式中，Risk 是农业干旱灾害风险值，用于表示干旱灾害风险程度；H、E、V、RE 的值相应的表示危险性、暴露性、脆弱性和抗旱能力因子的值；Wh、We、Wv、Wr 表示危险性、暴露性、脆弱性和抗旱能力的权重；Xi 为各评价指标的量化值，Wi 为各评价指标的权重系数[14]。通

$X_i$ is the quantitative value of each index; $W_i$ is weight coefficient of each evaluation index [14].The comprehensive drought risk value is calculated by those equations in these typical areas, which reflect drought risk level directly.

过上式得到兴仁、修文、湄潭三个典型区的旱灾综合风险值，风险值的大小直接体现了该地区的旱灾风险高低。

## 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 typical areas based on the indexes selected and the model built. The risk values show the risk state.

The risk class and threshold are ascertained by using optimal partitioning method. The scatter diagram of error function and classification grade is drawn in order to decided optimal class. As shown in figure 2. The inflection point is located 4 partitions. The error function doesn't increase obviously with classification numbers increasing. So, the optimal classification grade is 4, low risk, middle risk, high risk, very high risk. The threshold values are shown in figure 2.

## 农业干旱灾害风险评估与风险阈值确定

对研究区进行农业干旱灾害风险评价的过程中，选取1990-2007 年为时间尺度进行分析研究，根据前文选取的指标和构建的模型，得出典型区的农业干旱灾害综合风险值，风险值的大小直接体现了该地区的旱灾风险高低。

运用最优分割法来确定干旱灾害风险的最优划分等级和阈值。为确定最优分割等级，做出误差函数与分类等级的散点图如图 2 所示。从图中可以看出拐点在 4 分割处，如果分类数继续增加，误差函数的变化也不大，因此最优分割等级为 4 等级，依次是低风险、中风险、高风险、极高风险。由最优分割法确定的具体界限值如表 2 所示。

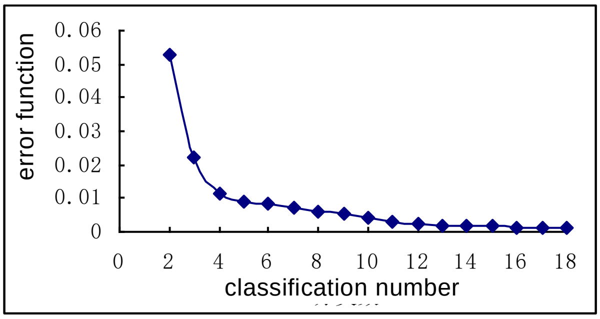


**Fig 2-** The scatter diagram of error function and classification grade

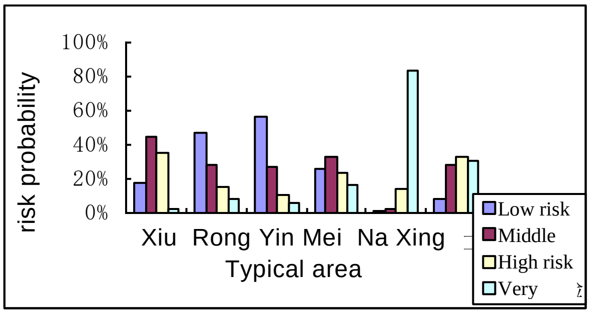


**Fig 3 -**The drought disaster risk probability in typical areas

**Table 2**

**Threshold value and different risk types of agricultural drought disaster risk**

| Risk type | Low risk | Medium risk | High risk | Very high risk |
|---|---|---|---|---|
| Threshold value | ≤0.385 | 0.385~0.452 | 0.452~0.510 | ≥0.510 |

## DROUGHT DISASTER COMPREHENSIVE RISK PROBABILITY ANALYSIS IN AREAS

The risk degrees are divided of sample years in typical areas in case of comprehensive risk threshold value. The risk probability can be drawn based of risk class and information diffuse theory, as shown in figure 3.

We can know from figure 3 that different degree drought risk probabilities are different in typical areas. The numbers of middle risk years is most in Xiuwen, but least very high risk. Yinjiang has most low risk years, and Rongjiang takes second place. But Yinjiang has least high risk. Meitan has much middle risk. Nayong has most years of very high risk, but least years of low and middle risk. Xinren has least years of low risk, differs little in middle risk, high risk and very high risk. The probability of high risk is next to Xiuwen, and the probability of very high risk is next to Nayong.

## 典型区各等级旱灾综合风险发生的概率分析

根据综合风险阈值对典型区样本年进行风险程度的划分，根据信息扩散理论模型和划分的风险等级，可以得到研究区各等级旱灾综合风险发生的概率，如图 3 所示。

从图 3 中可以得出：典型区各县处于不同程度干旱风险的概率不同。对于修文，处于中风险的年份最多，在各典型县中也是最多的；但是处于极高风险的年份却是各个典型县最少的。榕江处于低风险的年份最多，在各个典型县中仅次于印江，比其他典型县大。印江处于低风险的年份最多，在各典型县中也是最多的；但是处于高风险的年份却是各个典型县最少的。湄潭处于中风险的年份较多，在各个典型县中仅次于修文，比其他典型县大。纳雍处于极高风险的年份最多，在各典型县中也是最多的；但是处于低、中风险的年份却是各个典型县最少的。兴仁处于低风险的年份最少，在各典型县中也是最少的；处于中、高、极高风险的概率相差不大，处于高风险的概率仅次于修文，比其他典型县大；处于极高风险的概率仅次于纳雍，比其他典型县大。

## DROUGHT DISASTER COMPREHENSIVE RISK ANALYSIS IN AREAS

The average comprehensive risk value can be got by caculating average value of comprehensive risk value from 1990 to 2007 in typital areas. As shown in table 3 and figure 4.

We can know from the result that Yinjiang has low risk; Xiuwen, Rongjiang and Meitan have midle risk; Xinren has high risk; Nayong has very high risk. West north and west south are hightest, middle and north are next, and east is lowest. Nayong has biggest risk value with biggest exposure and vulnerability; Rongjiang has less risk value because other factors' risk values are low level but hazard. So drought disk is the result of four factors comprehensive doing not single factor doing. In very high risk year, we should improve agricultural produce level and increase drought resistance strength to resist effectively disaster influence to crops, in order to insure food security. In middle risk years, the disaster-causing factors have lower risk in typical areas, the vulnerability of disaster bodies should be strengthened to resist natural disaster.

## 典型区旱灾综合风险分析

将各典型区 1990-2007 年的旱灾综合风险值求均值，得到多年的平均风险值如表 3 和图 4 所示。

根据各地多年综合风险均值可知，印江处于低风险；修文、榕江、湄潭处于中风险；兴仁处于高风险；纳雍处于极高风险。从整体来看，西北、西南最高，中部和北部次之，东部最低。其中，纳雍的暴露性、脆弱性因子值最大，其他因子值也处于较高值，故其风险值最大；榕江虽危险性风险值最大，但其他因子风险均处于较低水平，故风险值较低。故典型区的干旱灾害风险并不是由单一因素如致灾因子危险性、承灾体暴露性和脆弱性以及抗旱减灾能力决定的，而是四个方面因素的综合作用影响的结果，因此在极高风险年份除去客观因素的影响下，应当考虑提高农业生产水平、加大抗旱减灾力度以便能够有效地抵御灾害对农业的产生的影响，保证区域粮食安全。而对于中风险的年份来说，典型区表现出较低的致灾因子风险性，同样在去除客观因素的影响下，建议从承灾体脆弱性方面加强，对抵抗自然灾害起到加强保护作用。

Tabel 3

**Comprehentive risk value of many years in typical**

| Typical area | Xiuwen | Rongjiang | Yinjiang | Meitan | Nayong | Xinren |
|---|---|---|---|---|---|---|
| Comprehensive risk value | 0.433 | 0.394 | 0.383 | 0.436 | 0.567 | 0.481 |

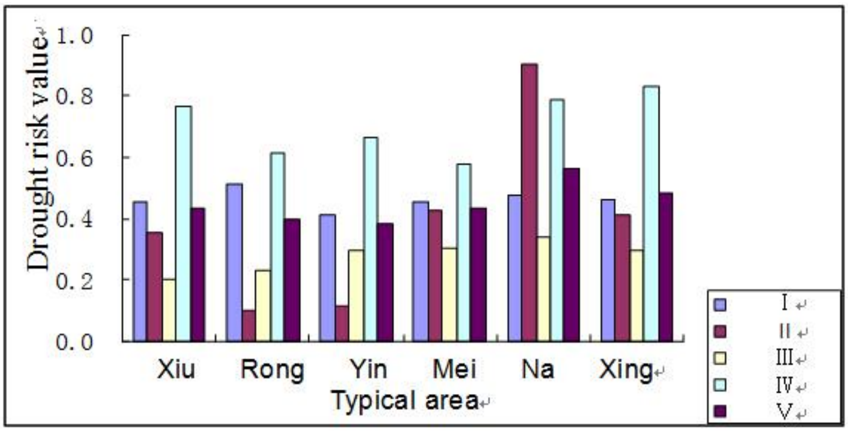


**Fig 4- Comprehentive risk value of many years in typical**

*Ⅰ—Hazard Ⅱ—Exposure Ⅲ—Vulnerability Ⅳ—Drought resistant ability Ⅴ—Comprehensive risk value*

## CORRELATION OF DROUGHT RISK INDEXES AND DISASTER LOSS

Drought disaster risk indexes can be got based on indexes factors quantized value by using natural disaster risk index method, but crop loss that is core factor of agricultural system. So, we research the correlation of drought risk indexes and history disaster loss data of drought disaster occurred. Crop loss rate due to drought is used to represent disaster loss according to agricultural disaster data which are given by statistic department of Guizhou province [11, 15].

Fomular as follow:

## 典型区旱灾风险指数与灾害损失相关性分析

根据各指标因子的量化值，运用自然灾害风险指数法得到典型区的干旱灾害风险指数，但是没有考虑到农业系统的核心因子——作物的损失状况。进行自然风险评估的目的就是为了研究灾害损失，因此，依据各典型区干旱灾害风险指数和已发生干旱灾害的历史灾情损失资料，对两者间的相关性进行研究。根据贵州统计部门提供的农业灾情统计数据，选择因旱粮食损失率来表述灾害损失[14,15]，具体公式如下。

$$F = \Delta Y / Y \tag{9}$$

$$\mathrm{L} = (\mathrm{D}_1 - \mathrm{D}_2) \times 0.2 + (\mathrm{D}_2 - \mathrm{D}_3) \times 0.55 + \mathrm{D}_3 \times 0.9 \tag{10}$$

In equations, $F$ is crop loss rate due to drought; $\Delta Y$ is crop loss yield due to drought; $Y$ is normal crop yield. $L$ is comprehensive coefficient of crop loss; $D_1$ is the ratio of crop afflicted area to plant area; $D_2$ is the ratio of crop disaster area to plant area; $D_3$ is the ratio of crop no any output area to plant area.

式中：$F$ 为因旱粮食损失率；$\Delta Y$ 为因旱粮食损失产量；$Y$ 为正常状况下粮食产量。

式中: L 为综合减产系数；$D_1$ 为作物受灾面积占播种面积的比例；$D_2$ 为作物成灾面积占播种面积的比例；$D_3$ 为作物绝收面积占播种面积的比例。

## CORRELATION ANALYSIS OF DROUGHT RISK INDEXES AND CROP LOSS RATIO DUE TO DROUGHT

In the base of computing crop loss ratio due to drought from 1990-2007 in each typical area, analyzing the correlation of drought disaster risk index and crop loss ratio due to drought, the result is shown in figure 5 to figure 10. The correlation equation of drought risk index and crop loss ratio due to drought can be got in each typical area.

## 旱灾风险指数与因旱粮食损失率相关性分析

逐年计算 1990-2007 年各典型区因旱粮食损失率，并与之前得到的各典型区的干旱灾害风险指数进行相关性分析，如图 5 到 10 所示，得到各典型区旱灾风险指数与因旱粮食损失率的相关方程。

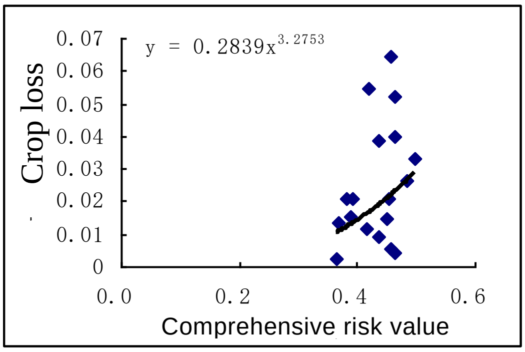


**Fig.5 -** Correlation of crop loss due to drought and risk index in Xiuwen

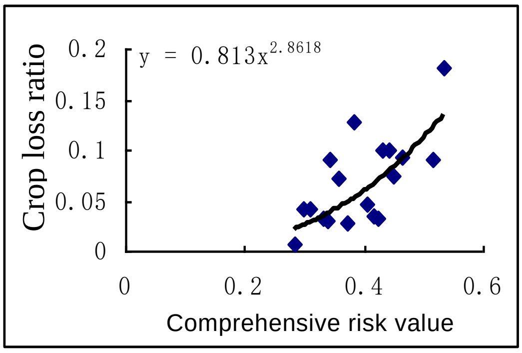


**Fig.6 -** Correlation of crop loss due to drought and risk index in Rongjiang

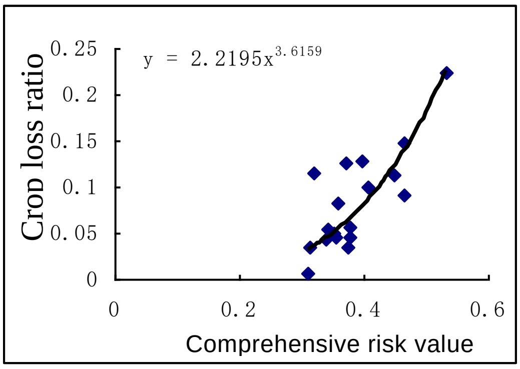


**Fig.7 -** Correlation of crop loss due to drought and risk index in Yinjiang

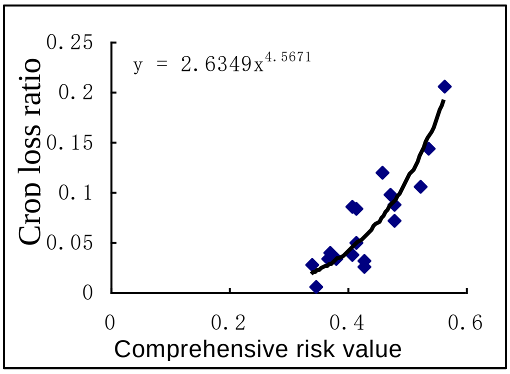


**Fig.8** - Correlation of crop loss due to drought and risk index in Meitan

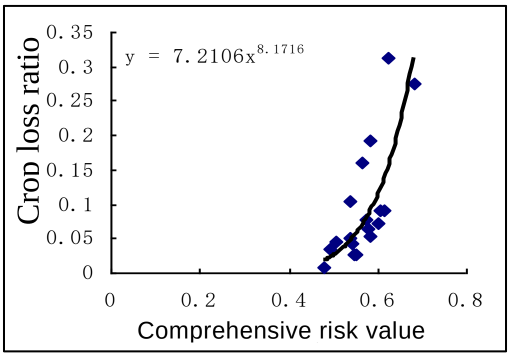


**Fig.9** - Correlation of crop loss due to drought and risk index in Nayong

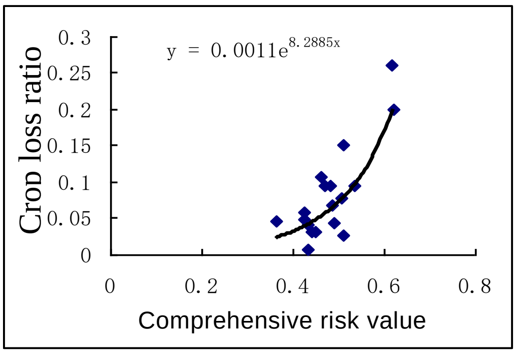


**Fig.10 -** Correlation of crop loss due to drought and risk index in Xinren

From the figure 5 to figure 10, we can know that drought disaster risk index is positive correlation with crop loss ratio due to drought, the correlation coefficient are 0.341、0.678、0.693、0.821、0.787、0.651 in Xiuwen, Rongjiang, Yinjiang, Meitan, Nayong, Xinren. The results indicate the evaluation model is reasonable that is builded by using the grey correlation, analytic hierarchy process (AHP), weighted synthesis method, natural hazards index method and Fisher optimal partitioning method. The evaluation result is objective. The model can be used to evaluate agricultural drought disaster risk in certain area. The relation of risk index and crop loss ratio is builded by correlation equation, and the crop loss yield can be predicted by drought disaster risk index in certain area in the future.

从图中可知，典型区修文、榕江、印江、湄潭、纳雍、兴仁的旱灾风险指数与因旱粮食损失率之间存在明显的正相关关系，它们的相关系数分别达到 0.341、0.678、0.693、0.821、0.787、0.651。这说明本研究通过指标选取,利用灰色关联度分析、自然灾害风险指数法、层次分析法、加权综合评价法、Fisher 最优分割法等方法建立模型进行农业干旱灾害风险评价是合理的，其评价结果也具有一定的客观性，可以依据此模型来评价不同区域农业生产受到干旱灾害影响的风险大小。同时，通过各典型区旱灾风险指数与因旱粮食损失率的相关方程，建立起旱灾风险指数与因旱粮食损失率的联系，可以通过得到的旱灾风险指数来预估典型区的粮食损失状况。

## 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. The risk class and threshold are ascertained by using optimal partitioning method. Analytic hierarchy process (AHP) is used to analyze the factor indexes weights, which make agricultural drought risk assessment results have rationality and reference. The relation of risk index and crop loss ratio is built by correlation equation, and the crop loss yield can be predicted by drought disaster risk index in certain area in the future.

We can know from the result that Yinjiang has low risk; Xiuwen, Rongjiang and Meitan have midle risk; Xinren has high risk; Nayong has very high risk. Drought disk is the result of four factors comprehensive doing not single factor doing. In very high risk year, we should improve agricultural produce level and increase drought resistance strength to resist effectively disaster influence to crops, in order to insure food security. In middle risk years, the disaster-causing factors have lower risk in typical areas, the vulnerability of disaster bodies should be strengthened to resist natural disaster. In a world, the model builded is reasonable, that can be used evaluate agriculture drought disaster risk in Guizhou province.

## 结论

利用自然灾害指数法对农业干旱灾害风险进行评价,为相关部门制定干旱预警、风险管理等方面提供借鉴作用。本文以贵州干旱时间强度和干旱频率为致灾因子,以作物播种面积和主要粮食作物生产水平为承灾体作为研究区农业干旱灾害风险评评价的研究对象,选取致灾因子危险性、承灾体暴露性和脆弱性以及抗旱能力作为评价因子，从指标的选取方面考虑了以自然因素和社会因素相结合的角度来研究农业干旱风险的问题较为全面。充分利用了降水资料、灾害统计资料和社会经济背景资料等。利用最有分割法确定风险等级和阈值。利用层次分析法对各因子指标进行权重分析,使得农业气象干旱风险评估结果具有合理性和参考性。通过各典型区旱灾风险指数与因旱粮食损失率的相关方程，建立起旱灾风险指数与因旱粮食损失率的联系，可以通过得到的旱灾风险指数来预估典型区的粮食损失状况。

根据各地多年综合风险均值可知，印江处于低风险；修文、榕江、湄潭处于中风险；兴仁处于高风险；纳雍处于极高风险。典型区的干旱灾害风险并不是由单一因素如致灾因子危险性、承灾体暴露性和脆弱性以及抗旱减灾能力决定的，而是四个方面因素的综合作用影响的结果。因此在极高风险年份除去客观因素的影响下，应当考虑提高农业生产水平、加大抗旱减灾力度以便能够有效地抵御灾害对农业的产生的影响，保证区域粮食安全。而对于中风险的年份来说，典型区表现出较低的致灾因子风险性，同样在去除客观因素的影响下，建议从承灾体脆弱性方面加强，对抵抗自然灾害起到加强保护作用。总之，本文所建立的干旱评估模型是合理的，可以据此对贵州的农业干旱灾害风险进行评估。.

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