



# A Risk Analysis-Based Assessment Method for Drinking Water Difficulty in Southwest China Due to Drought

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**Abstract.** Once a region experiences drinking water shortages, it poses a direct threat to the residents, particularly in rural and remote areas. Traditional methods mainly rely on manual statistical surveys, which are inefficient, highly subjective, and lack timeliness, making it difficult to take early countermeasures to mitigate the impact of drought disasters. Therefore, scientifically, efficiently, and reasonably analyzing the risk of drinking water difficulties caused by drought, improving drought monitoring and early warning capabilities, and planning countermeasures in advance are of great significance for safeguarding residents' livelihoods, maintaining social stability, and stabilizing economic development.

**Keywords:** Risk Assessment, Drinking water difficulty caused by drought, Southwest China

## 1 Introduction

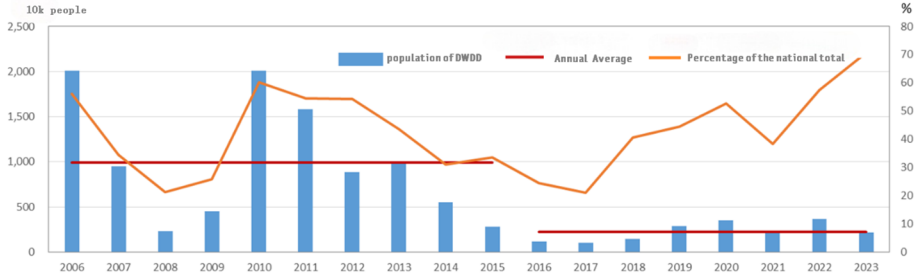
Drinking water difficulty caused by drought (DWDD) is a statistical indicator for drought disasters, defined as the shortage of water for urban and rural residents due to drought. According to *Classification of Regional Drought Severity* [1] that experience changes in water supply methods, water sources, water volume, water quality, water supply reliability, or convenience of water access due to drought, requiring emergency measures to ensure drinking water, and lasting for more than 15 consecutive days.

Southwest China, including Yunnan, Guizhou, Sichuan, and Chongqing, is a typical region characterized by uneven distribution of water resources and frequent droughts. In recent years, due to climate change and intensified human activities, the frequency and intensity of drought disasters have been increasing [2]. The karst landforms are widely distributed in Southwest China, resulting in poor surface water storage and retention conditions. Rainfall quickly infiltrates underground upon reaching the surface, creating an awkward situation where "rainwater cannot be stored," "surface water cannot be retained," and "groundwater is difficult to utilize." In rural and remote moun-

tainous areas, the population is sparsely distributed. Some residents live at high altitudes on the mountains, while rivers flow at low altitudes in the valleys, creating a regional characteristic of "people living uphill while water flows downhill." This makes it difficult to draw water from rivers. As a result, small-scale centralized or decentralized water supply systems, which rely on sources such as mountain streams or karst water, are commonly used. However, these systems are unstable in terms of water supply reliability and have weak disaster resilience. The issue of drinking water difficulties caused by drought is prominent, posing challenges to local economic and social development and the basic livelihood of residents.

## 2 Historical Disasters in Southwest China

Since 2006, the population facing drinking water difficulties due to drought in Southwest China has shown a trend of first increasing and then decreasing, with the severe drought in 2010 reaching the highest level in nearly two decades[3]. However, due to the advancement of the national rural drinking water safety project construction, the level of rural water supply security has significantly improved. The population of drinking water difficulties is 1–4 million, accounts for 20%–75% of the national total during the same period (Figure 1). It's obvious that drinking water difficulties caused by drought in rural areas remain a major impact of drought disasters in Southwest China, particularly in Yunnan Province.



**Fig. 1.** Annual changes in the population of drinking water difficulties due to drought in Southwest China from 2006 to 2023

## 3 Main Mechanisms of Drought Formation

### (I) Regional Water Vapor Imbalance

Over the past 50 years, regional surface temperature has risen by approximately  $0.8^{\circ}\text{C}$ , and potential evapotranspiration has increased at a rate of 1.0 mm per decade, accelerating soil moisture loss during dry periods[4–6]. Frequent El Niño events strengthen and stabilize the subtropical high, blocking water vapor transport to Southwest China (e.g., the extreme drought during 2009–2010). Meanwhile, enhanced thermal forcing over the Qinghai-Tibet Plateau weakens the South Asian monsoon, resulting in insufficient water vapor supply from the Indian Ocean.

### (II) Precipitation Deficiency

Complex landforms such as the Hengduan Mountains and Yunnan-Guizhou Plateau block water vapor transport from the Indian Ocean and Pacific Ocean, leading to significantly reduced precipitation on leeward slopes (e.g., central Yunnan, southern Sichuan). In dry-hot valleys, annual evaporation can be 5–10 times the precipitation; the strong foehn effect (hot, dry downdrafts) further intensifies drought conditions[7].

### (III) Poor Water Storage and Regulation Capacity

Karst landforms are widely distributed in Southwest China, covering about 40% of the regional area. This landscape features well-developed surface fissures, causing rapid rainwater infiltration and loss (e.g., about 70% of rainfall is unavailable for use in the Stone Forest area of Yunnan). The shallow soil layer (generally <30 cm) has weak water retention capacity, and deep groundwater burial (usually >50 m) makes exploitation difficult. This creates a dilemma: atmospheric water hard to store, surface water hard to retain, groundwater hard to use.

### (IV) Inadequate Infrastructure

Population distribution is scattered in mountainous areas, and the common problem of people living high while water lies low leads to high water supply costs and low security rates. Farmland is fragmented (“cultivated from mountain tops to river banks”), making irrigation difficult and costly (e.g., 3.3 million mu of farmland in Sichuan lack small and micro water sources and irrigation facilities). The coverage of emergency backup water sources is low (only 8% of township water supply stations in Sichuan have emergency water sources). Large and medium-sized water storage projects are scarce (more than 30 counties in Yunnan lack medium or large reservoirs), resulting in severely inadequate water storage and regulation capacity.

## 4 Risk Assessment Method and Case Study

The evaluation system is established by selecting appropriate indicators from three dimensions—hazard(H), exposure(E), and vulnerability(V)—while considering the principles of scientific validity, comparability, operability, and data accessibility[8]. This system operates at three levels: target, factor, and indicator. Fuzzy mathematics is applied to calculate the risk of drought-induced drinking water shortages, thereby assessing the risk of such shortages in the region. The weight of each index in the evaluation system is determined by the analytic hierarchy process. Based on the regional disaster theory, the risk degree of drinking water shortage is calculated.

### 4.1 Indicators and Classification Criteria

#### **Hazard Indicator.**

##### *Average Annual Precipitation.*

This index is the average of the total precipitation of a certain place divided by the number of years, which is the most intuitive and simple index to characterize the cli-

mate condition of a certain area. The precipitation data in this paper are from the National Qinghai-Tibet Plateau Data Center, with a spatial resolution of 1 km grid data from 1954 to 2023. The index grades considered regional precipitation characteristics and typical climate zoning, as shown in Table 1.

**Table 1.** Classification Standard of Average Annual Precipitation

Classification Standard	Risk level assignment			
	Extremely Low	Low	Medium	High
Average Annual Precipitation(P)	[1600,2000)	[1200,1600)	[800,1200)	[400,800)
Index Assignment(h <sub>1</sub> )	1/2	1	2	4

### *Elevation.*

The elevation can distinguish the highland and plain, which objectively reflects the convenience of the region to obtain water resources. The DEM digital elevation data used in this paper is the spatial resolution of 90 meters grid data from the geospatial data cloud. The indicator levels are classified according to the regional topography characteristics, as shown in Table 2.

**Table 2.** Classification Standard of Elevation

Classification Standard	Risk level assignment			
	Extremely Low	Low	Medium	High
Elevation(E)	[0,500)	[500,1000)	[1000,2000)	[2000,6000)
Index Assignment(h <sub>2</sub> )	1/2	1	2	4

### *Geological Structure.*

The extensive karst landforms in southwest China reduce the storage capacity of regional water resources. The regional water storage capacity is characterized by regional geological structure and lithology. The index is graded by regional permeability, as shown in Table 3.

**Table 3.** Classification Standard of Geological Structure

Classification Standard	Risk level assignment		
	Low	Medium	High
Geological Structure(G)	Tight	with certain porosity and permeability	Dissolvable
Index Assignment(h <sub>3</sub> )	1	2	4

### **Exposure Indicator.**

Exposure assessment is to study the types, scope, quantity and density of disaster-bearing bodies in drought-affected areas. Generally, the greater population, the greater risk. The population density was divided into high, middle, low and very low risk areas. The spatial distribution data of population were obtained from the 2019 data of the resource and environment science data registration and publishing system with a spatial resolution of 1 km. The indicator is graded by regional population density, as shown in Table 4.

**Table 4.** Classification Standard of Population

Classification Standard	Risk level assignment			
	Extremely Low	Low	Medium	High
Population of Grid( $P_o$ )	[10,100)	[100,300)	[300,1000)	[1000,500000)
Index Assignment( $e$ )	1/2	1	2	4

**Vulnerability Indicator.**

Vulnerability is the sensitivity of regional water supply security to drought events. The ability to resist disasters is characterized by two indicators: the level of water supply engineering and the level of regional economic support.

*Distribution of Water Supply Project.*

Due to the differences in natural environment, infrastructure, and engineering operation and maintenance management, regions have different resistance to drinking water shortage. With the construction of water supply projects, the rural water supply network has been continuously improved, the scale of water supply has been significantly increased, and the possibility of drinking water difficulties due to drought in the region has been reduced. The indicator is graded by regional project density, as shown in Table 5.

**Table 5.** Classification Standard of Water Supply Project

Classification Standard	Risk level assignment			
	Significantly reduce risk	Effectively reduce risk	reduce risk	No effect
The number of Projects in a Grid( $Pr$ )	[100, $\infty$ )	[50,100)	[10,50)	[0,10)
Index Assignment( $v_1$ )	1/2	3/5	4/5	1

*Gross Domestic Product.*

GDP is a comprehensive index that reflects the scale of regional economic development and the operation of regional national economy. The higher the regional GDP, the more developed the social economy, the more complete the drought resistance measures, the more economic conditions for drought resistance projects, the stronger the ability to resist drought disasters, the higher the per capita income of residents, the better the economic ability, the more affordable the water cost, and the lower the possibility of drinking water affected by drought. The spatial data of GDP used were sourced from the 2019 dataset with a spatial resolution of 1 kilometer, obtained from the Resource and Environmental Science Data Registration and Publication System. The index measurement is shown in Table 6.

**Table 6.** Classification Standard of GDP

Classification Standard	Risk level assignment			
	Extremely Low	Low	Medium	High
GDP of Grid( $G$ )	[10,100)	[100,300)	[300,1000)	[1000,50000)
Index Assignment( $V_2$ )	1/2	1	2	4

## 4.2 Indicator Weight Assignment

Once the values of each indicator are determined, changes in weights will directly alter the evaluation results. The Analytic Hierarchy Process (AHP)[9] is a multi-objective decision analysis technique that combines qualitative and quantitative approaches. Due to its systematic, flexible, and practical characteristics, it is particularly suitable for analyzing and making decisions in complex systems involving multiple objectives, levels, factors, and alternatives[10]. This paper adopts the Analytic Hierarchy Process to determine the indicator weights.

The judgment matrix is determined using empirical scoring methods. According to empirical analysis, the regional rainfall indicator is the most important, followed by geological structure conditions, which are slightly more important than regional altitude. The judgment matrix is presented accordingly, and based on this, the weight coefficients are calculated, as detailed in Tables 7-9.

**Table 7.** Weight Values of Risk Indicator

Indicator	Hazard	Exposure	Vulnerability
weight value	0.60	0.25	0.15

**Table 8.** Weight Values of Hazard

Indicator	Average Annual Precipitation	Elevation	Geological Structure
weight value	0.54	0.16	0.30

**Table 9.** Weight Values of Vulnerability

Indicator	Water Supply Project	GDP
weight value	0.67	0.33

Based on the established indicator system, using AHP to determine the weights of each risk indicator. The risk value for drinking water difficulties caused by drought is calculated for each unit by summing the products of the indicator weights and their corresponding risk values.

## 4.3 Risk Assessment and Classification

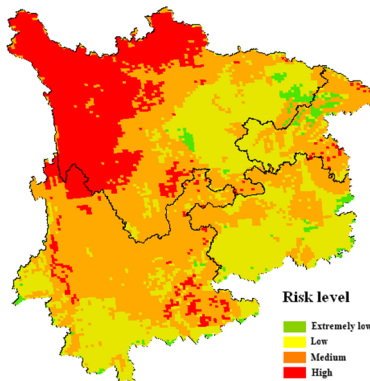
Based on the degree of membership, the risk level of drinking water difficulty caused by drought is determined. The classification basis is shown in Table 10, and the distribution of drinking water difficulty risk caused by drought in the four provinces and regions of Southwest China is illustrated in Figure 2.

$$R = A \cdot H + B \cdot E + C \cdot V$$

Where: R is the risk degree value; H is the hazard assessment value; E is the exposure assessment value; V is the vulnerability assessment value; A is the hazard weight assignment; B is the exposure weight assignment; C is the vulnerability weight assignment.

**Table 10.** Risk classification standard for drinking water difficulty caused by drought based on membership degree

Risk Grade	Risk degree range	Risk level	Definition
1	[0.0,1.0)	Extremely Low	The possibility of being affected by drinking water difficulties caused by drought is extremely low
2	[1.0,1.4)	Low	There is a possibility of being affected by drinking water difficulties caused by drought, but the likelihood is low.
3	[1.4,2.2)	Medium	It's relatively high being affected by drinking water difficulties caused by drought
4	[2.2,4.0]	High	The possibility of being affected by drinking water difficulties caused by drought is high



**Fig. 2.** Distribution of drinking water difficulty levels caused by drought in Southwest China

## 5 Conclusion

As shown in the figure 2, the four provinces in Southwest China are predominantly characterized by low and medium risks. The northwestern and western parts of Sichuan, due to factors such as high altitude, low regional GDP output, and limited water supply projects, exhibit high regional hazard and vulnerability, making them high-risk areas for drinking water difficulties caused by drought. The northeastern and southeastern parts of Chongqing, southeastern and southwestern parts of Yunnan, and southern Sichuan, due to poor geological conditions and limited water supply projects, also show high regional hazard and vulnerability, resulting in a relatively high risk of drinking water difficulties caused by drought. In contrast, areas such as eastern Sichuan, central and western Chongqing, southern Guizhou, and southern Yunnan have a relatively low likelihood of experiencing drinking water difficulties caused by drought.

Based on survey data and the statistical reporting of drinking water difficulties caused by the winter-spring continuous drought and summer drought in Southwest China in 2024, the multi-dimensional scope of drinking water difficulties proposed in this chapter largely covers the areas where actual drinking water difficulties occurred.

Furthermore, the northeastern and southern parts of Sichuan, most parts of Yunnan, and northern and western Guizhou have a relatively high likelihood of being affected by drinking water difficulties caused by drought, which aligns with the main areas affected by actual drought conditions in the relevant provinces.

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