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The vulnerability assessment method for Beijing agricultural drought

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Abstract. Drought is a major disaster which Beijing agricultural systems faced with, build drought warning mechanism we need in-depth analysis the causes and mechanism of the drought to provide a basis for scientific disaster reduction and prevention. VAM vulnerability assessment method, selected 15 factors represent drought exposure, sensitivity and adaptive capacity, based on improved analytic hierarchy process to determine the weight of each factors, use K-means clustering algorithm to generate the drought vulnerability index system of research district. Draw vulnerability zoning map based on ArcGIS.

Keywords: Vulnerability, Assessment, Index System, VAM, Agricultural Drought

1 Introduction

The risk of natural disasters is a result of natural disasters together with vulnerability, the level of loss risk is directly related with social vulnerability, to a great extent, decided by the vulnerability of hazard bearing [1]. Agricultural drought vulnerability means the property and status of agricultural production which is sensitive to drought and easily threatens by drought, as well as caused loss [2]. The impact factors of drought vulnerability are multifaceted [3].

Several scholars study on drought vulnerability in recent years, they focus on establishing drought vulnerability system based on a set of indicators. Liu Lanfang et al. [4] select nine indicators: precipitation, evaporation, the level of irrigation works and so on to evaluate vulnerability of agricultural drought in Hunan province. Wang Xiaohong et al.[5] develop a risk assessment model for agricultural drought, which includes the occurrence probability of drought, capacity of drought prevention, percentage of planting area, etc. Ni Shenghai et al. [6] select seven indicators to evaluate the Chinese agricultural drought vulnerability, according to the three elements, water resources characteristics, agriculture suffering drought and forming drought disaster circumstance and drought relief ability of water conservancies' facilities of the every locality, Wang Jingai et al.[7] obtains the distributional laws between the agricultural hazard- affected bodies and the centers of drought disaster in China based on regional combination of the hazard – formation factors with hazard - affected bodies. select three counties as typical hazard - affected bodies, i. e. the

rainfed field (Xinghe County) , the irrigated field (Xingtai County) & the paddy field (Dingcheng County) , set up a vulnerability diagnosis index system of agricultural drought disaster and put forward a regional assessment model of agricultural drought vulnerability, including the frangibility-adaptability model of the rainfed field , the production - living pressure model of the irrigated field and the water demand - supply model of the paddy field. Qiu Lin et al. [8] present threshold value of grade interval of estimation for vulnerability of agricultural drought in Hengyang city. According to variable fuzzy set theory, the variable fuzzy analysis method of multiple attribute and grades was proposed for quantitative estimation for vulnerability of agricultural drought disaster. Chen Ping, Chen Xiaoling, [9] select fourteen indicators representing exposure, sensitivity and adaptive capacity to droughts respectively. The weights of the indicators were calculated by analytic hierarchy process. Then using the composite index approach these indicators were combined into a drought vulnerability index of agricultural system by a linear aggregation. On the basis of the relationship between the drought vulnerability and exposure, sensitivity and adaptive capability, some suggestions for the drought hazard management in the future were proposed. Simelton et al. [10] identify socio-economic indicators associated with sensitivity and resilience to drought for each of China's main grain crops (rice, wheat and corn). Provincial harvest and rainfall data (1961–2001) are used to calculate an annual “crop-drought vulnerability index”. Leads us to propose a series of drought-vulnerability typologies based on the extent to which land, labor, capital, agricultural technology, and infrastructure buffer or exacerbate the effect of a drought event.

We commonly used drought index to indicate the degree of drought [11], however, it needs combine with drought vulnerability to accurately reflect drought risk. Yi Zhengjie et al.[12] built a farm soil moisture balance model together with simulation of soil moisture during crop's growth stages. In this way soil moisture simulation and drought degree evaluation are united to conduct dynamic evaluation of agricultural drought, which provides a handy and feasible method of real-time dynamic evaluation of agricultural drought through soil moisture simulation. Many scholars also have taken study on drought assessment of winter wheat in northern China. Wang Suyan et al.[13] based on understanding influence of water on the productive potentialities of winter wheat in semi-humid, semi-arid areas of northern China under natural climate condition, the “correction step by step” is used to calculate photosynthesis potential productivity, photo-temperature productivity and climate productive potentialities. Analysis the dynamic changes of winter wheat water and climate production potential in north China during the past 40 years. Sun Ning, Feng Liping et al.[14] Based on validation of two crop growth models (W heat SM and APSIM-W heat) for the winter wheat yield simulation of Beijing. Zhang Wenzong et al. [15] present a methodology for risk assessment and division of winter wheat drought hazard in Hebei Province, including the concept, calculation method and regional distribution of the disaster risk index. Also discussed the average decreasing rate, the disaster prevention and mitigation measures of dry year with different intensities and loses in different kind of risk areas.

During the growth period of winter wheat in northern winter wheat region, precipitation is mostly less than 250 millimeter. Along a gradient that sees increased aridity from south to north. In Beijing-Tianjin area, the precipitation has been less

than 150 millimeter. But the water demand for the growth period was about 350~500 millimeter and the demand for critical period was 200~250 millimeter, lack of 300 millimeter water [16]. The growth period of winter wheat in Beijing start from late September to mid-June [17], the rainfall of Beijing area is generally concentrated in the June to August, appear the phenomenon of precipitation and growth period of winter wheat water requirement dislocation, drought is a direct threat to stable and high yield of winter wheat, even has a serious impact on the socio-economic. It is urgent to carry out the study on Beijing drought vulnerability and reduce drought disasters.

The aim of this paper is to develop and apply a quantitative approach to agricultural drought vulnerability assessment within Beijing to identify which of the country's regions and districts are most vulnerable to drought. To achieve this aim, the study objectives are:

- a) To establish an index system for the assessment of agricultural drought based on the three elements of drought vulnerability;
- b) To select 15 factors represent drought exposure, sensitivity and adaptive capacity, based on improved analytic hierarchy process to evaluate the exposure, adaptive capacity and sensitivity of Beijing's eleven regions and the districts within the most vulnerable regions;

2 Materials and Methods

2.1 Study Area

Beijing is located in the longitude of 115° 20'to 117° 30' and the latitude of 39° 25'to 41°. About 150km distance to the west of Bohai, located in the northwest edge of the North China Plain, the city's total area is 16410.54 km², mountain area account for 62%, and about 38% of the areas are plains. Beijing is surrounded by the Taihang Mountains and Yanshan Mountains in its western and northern, its southeast is a plain. The terrain is higher in the west; north and northeast, while inclined to the south and southeast.

The populations of Beijing are about 20 million; multi-year average precipitation is 585mm, the city's total water resources are 2.308 billion m³, however, water resources per capita are only 107m³, water resources are very scarce. From the history of drought disasters in Beijing, Beijing's drought is divided into three categories: spring drought, the early summer drought, summer drought. In recent years, the drought frequent occurred in Beijing, except the lower droughts loss rate during the year 1990 to 1998, since 1999, the drought loss rates were at high value. The impact of drought on agriculture was very big, evaluating and predicting spatial distribution of a given period of the potential risks of agricultural systems in Beijing which affected by the drought is particularly important to provide the basis for scientific disaster prevention and mitigation.

2.2 Research Method

In this paper, using VAM vulnerability assessment methods [18], the three elements of vulnerability classified as exposure, sensitivity, and adaptive capacity. Exposure represent that system experience a degree of drought stress, it is related to the intensity, frequency and duration of the drought; sensitivity is the extent of agricultural system elements susceptible to the effects of drought; adaptive capacity is the behavior that stakeholders in the agricultural system taking to reduce the effects of drought in the pre-disaster and after disaster. The results of exposure, sensitivity, and adaptive capacity Co-expressed as drought vulnerability.

Using the formula [1]

$$V = f(E, S, A) \quad (1)$$

By the composite indicator method, the vulnerability results can be expressed as various indicators and the linear plus of their corresponding weights:

$$V = \sum_{i=1}^n I_i \times w_i + \sum_{l=1}^m I_l \times w_l + \sum_{r=1}^s I_r \times w_r \quad (2)$$

In the formula (1), V is drought vulnerability indicator of the evaluation unit; E is drought exposure indicator; S is drought sensitivity indicator; A is drought adaptability indicator. There are respectively multiplied by the evaluation indicator scores that belonging to the three elements and the corresponding weight of evaluation indicator. The I_i 、 I_l 、 I_r are the score of evaluation indicator i 、 l 、 r ; W_i 、 W_l 、 W_r are the weight value of the evaluation indicator i 、 l 、 r .

2.2.1 Establishment of the evaluation indicator system

Select representative sub-elements from the three elements: exposure, sensitivity and adaptive capacity in order to refine the three elements. this article focus on Beijing agricultural drought vulnerability, Beijing's high incidence of drought period was consistent with the growth of winter wheat, so the index system of this article mainly focus on considering the difference value between evaporation and rainfall in the winter wheat planting period and the proportion of winter wheat growth.

Table1. List of drought vulnerability indicators

Element	Evaluation indicators	The explain of evaluation indicators	Data sources	Time
Exposure (E)	Difference value between evaporation and rainfall/mm(+)	Reflects the degree of crop water demand is satisfied	China Meteorological Data Sharing Network	
	Average elevation/m(+)	Elevation is positively related to water abstraction difficulty during the drought period	International Scientific Database (90 meter resolution data)	2010
	Average slope/° (+)	The slope affect soil water retention capacity, increasing the severe drought period irrigation difficulty		

	The river network density/ (km/km ²) (-)	Lack of precipitation, surface runoff is a major water sources of production and living		
	Forest coverage /% (-)	Influence the climate of the area and the conservation of rainfall		
	The irrigation index (-)	The proportion of effective irrigation area in the total area of cultivated land		
	Winter wheat planting ratio (+)	The proportion of winter wheat acreage in the total cultivated area		
Sensitivity (S)	Proportion of agricultural population(+)	The agricultural population groups are most sensitive to drought	Regional Statistical Yearbook of Beijing	2010
	Facilities agricultural area ratio(-)	The proportion of facilities agricultural area in the total cultivated area		
	Multiple cropping indicator (+)	Indicator of the degree of cultivated land use		
	Grain yield per unit area/ (t/hm ²)(-)	The lower, the more serious the impact of drought decrease yields, the more sensitive to drought		
	Rural electricity consumption/10 ⁴ kwh(-)	Reflect the level of the rural economy, as well as the time and the frequency use of agricultural machinery		
	Net income of rural residents/Yuan(-)	Income determines the drought disaster recovery capabilities		
Adaptive capacity (A)	Arable land per capita/hm ² (-)	The performance of the population effect and the pressure of land	Regional Statistical Yearbook of Beijing	2010
	Agricultural power in unit of arable land / (w/hm ²) (-)	Manifest the level of mechanization of agricultural production, but also reflect the size of the irrigation mechanical power during drought period		

Note: The table "+" and "-" represent the various evaluation and drought vulnerability positive or negative correlation (partial indicators refer to Chen Ping [29] indicator system)

2.2.2 The processing of indicator data

1) Difference value between evaporation and rainfall

Study area's main agricultural drought duration was the growth period of winter wheat from October to the second year of June. Firstly, reference crop evapotranspiration ET_0 use Penman formula recommended by Food and Agriculture Organization of the United Nations. Calculating the difference value between evaporation and rainfall in 16 meteorological stations of the study area, secondly, use ArcGIS regression kriging spatial interpolation to deal with the data to get the 90meter \times 90meter raster map of difference value between evaporation and rainfall in the whole study area. Thirdly, count the average value of the difference value between evaporation and rainfall in each evaluation unit.

2) Natural element indicators

The average elevation and average slope value in the evaluation unit were calculated by DEM image and slope map through ArcGIS. The drainage density values in evaluation unit was the intersection of the river vector layers and administrative boundaries vector layers in the study area by ArcGIS, then open the property sheet to sum its rivers' total length in each evaluation unit, latter, divided by the evaluation unit area.

2.2.3 Indicators quantify and weight calculations

Analytic Hierarchy Process (AHP) is a method of evaluation and decision-making which is a combination of qualitative and quantitative analysis, quantitative analysis of the person's qualitative subjective judgment, making variety of heterogeneous data integration, it is a currently widely used to determine the weight. However, using AHP to build a judgment matrix will be a certain degree of subjectivity because the experts' judgment of the relative importance of the indicators varies different, while insufficient application of existing quantitative information is also an obvious inadequacy. Therefore, we can use the improved analytic hierarchy process method to calculate the weight of drought vulnerability indicators. Firstly, divide the evaluation behavior into three levels. Target layer is evaluation of vulnerabilities; criterion level is three drought vulnerability factors (exposure, sensitivity, adaptive capacity); lowest level is index layer which belonged to the upper evaluation indicators.

Assume that there are n number indicators involved in the evaluation, $N = \{1, 2, \dots, n\}$, P is an indicator of vulnerability standard evaluation set, according to study of this article, P have 5 elements, that is any indicator divided as the five clustering by the standard. The X_{ab} is the maximum membership grade of an indicator, according to the principle of maximum membership grade; the indicator is belonging to b clustering. The clustering level of X_{ab} which is maximum membership grade of an indicator belonging worse, the indicator of vulnerability is worse, the greater it caused vulnerability impact on the criterion level.

When two indicators are at the same level in criteria layer, the vulnerability impact on criteria layer are of equal importance; when the index i is at worse vulnerability clustering level when compared with index j , then consider that index i cause greater vulnerability impact on the criterion level than the index j . So:

- $d_{ij} =$ {
- 9 The degree of vulnerability of the index i is four levels lower than the index j
 - 7 The degree of vulnerability of the index i is three levels lower than the index j
 - 5 The degree of vulnerability of the index i is two levels lower than the index j
 - 3 The degree of vulnerability of the index i is one level lower than the index j
 - 1 The degree of vulnerability of the index i is the same as the index j
- {
- (1/3) The degree of vulnerability of the index j is one level lower than the index i
 - (1/5) The degree of vulnerability of the index j is two levels lower than index i
 - (1/7) The degree of vulnerability of index j is three levels lower than the index i
 - (1/9) The degree of vulnerability of index j is four levels lower than the index i

Finally, use the K-means algorithm for the discretization of each index data indicators. The data is divided into five levels, making assignments for each indicator positive correlation with vulnerability assigned as 2,4,6,8,10; negatively correlated with vulnerability assigned as 10,8,6,4,2.

3 Results and Analysis

Making the weight of exposure, sensitivity and adaptive capacity in the criterion level equal. Using improved analytic hierarchy process to calculate the weight of the drought vulnerability indicators, and vulnerability evaluation results of all districts and counties in Beijing are shown in Table 2 and Table 3. View from the comprehensive weight of each indicator, Agricultural power in unit of arable land, the river network density, difference value between evaporation and rainfall, the three indicators have more important impact on target layer in drought vulnerability.

Table2. Hierarchical structure and indicator weights of vulnerability evaluation

(Consistency has passed the examination)

Target layer	Criterion level		Index layer		Comprehensive weight
	Element	Single-layer weight	Element	Single-layer weight	
Drought vulnerability	Exposure (E)	1/3	Difference value between evaporation and rainfall/mm(+)	0.3 534	0.1178
			Average elevation/m(+)	0.1 176	0.0392
			Average slope/° (+)	0.1 755	0.0585
			The river network density/(km/km ²) (-)	0.3 534	0.1178
			Forest coverage /% (-)	0.0 92	0.0307
	Sensitivity (S)	1/3	The irrigation Index (-)	0.1 495	0.0498
			Winter wheat	0.1	0.0374

		planting ratio (+)	123	
		Proportion of agricultural population(+)	0.2 803	0.0934
		Facilities agricultural area ratio(-)	0.1 061	0.0354
		Multiple cropping index (+)	0.1 061	0.0354
		Grain yield per unit area/ (t/hm ²)(-)	0.1 538	0.0513
Adaptive capacity (A)	1/3	Rural electricity consumption/10 ⁴ kwh(-)	0.1 14	0.038
		Net income of rural residents/Yuan(-)	0.1 701	0.0567
		Arable land per capita/hm ² (-)	0.2 537	0.0846
		Agricultural power in unit of arable land / (w/hm ²) (-)	0.4 623	0.1541

Table3. Vulnerability assessment of districts and counties in Beijing (Exposure element index assessment result)

Evaluation index	Difference value between evaporation and rainfall	Average elevation	Average slope	The river network density	Element index result
Daxing	1.178	0.0784	0.117	0.4712	1.8446
Miyun	0.7068	0.2352	0.585	0.9424	2.4694
Pinggu	0.7068	0.0784	0.585	0.9424	2.3126
Yanqing	0.2356	0.392	0.468	1.178	2.2736
Huairou	0.7068	0.392	0.351	0.9424	2.3922
Tongzhou	1.178	0.0784	0.351	0.7068	2.3142
Changping	0.4712	0.1568	0.117	0.9424	1.6874
Shunyi	0.7068	0.0784	0.468	0.9424	2.1956
Mengtougou	0.2356	0.3136	0.234	0.4712	1.2544
Fengtai	0.9424	0.0784	0.468	0.2356	1.7244
Fangshan	0.2356	0.1568	0.234	0.9424	1.5688

(Sensitivity element index assessment result)

Evaluation index	Forest coverage	The irrigation Index	Winter wheat planting ratio	Proportion of agricultural population	Facilities agricultural area ratio	Multiple cropping index	Grain yield per unit area	Element index result
Daxing	0.307	0.0996	0.0748	0.5604	0.1416	0.354	0.1026	1.64
Miyun	0.0614	0.3984	0.2992	0.1868	0.354	0.2124	0.3078	1.82
Pinggu	0.0614	0.0996	0.2244	0.5604	0.354	0.354	0.1026	1.7564
Yanqing	0.1228	0.2988	0.374	0.3736	0.354	0.1416	0.4104	2.0752
Huairou	0.1842	0.1992	0.374	0.3736	0.2832	0.2124	0.2052	1.8318
Tongzhou	0.307	0.0996	0.1496	0.7472	0.1416	0.2832	0.2052	1.9334
Changping	0.1842	0.1992	0.2244	0.3736	0.0708	0.0708	0.513	1.636
Shunyi	0.307	0.0996	0.0748	0.934	0.1416	0.354	0.1026	2.0136
Mengtougou	0.2456	0.498	0.2992	0.1868	0.0708	0.354	0.513	2.1674
Fengtai	0.2456	0.2988	0.1496	0.1868	0.0708	0.0708	0.513	1.5354
Fangshan	0.2456	0.1992	0.2992	0.3736	0.2124	0.2124	0.3078	1.8502

(Adaptive capacity element index assessment result)

Evaluation index	Rural electricity consumption	Net income of rural residents	Arable land per capita	Agricultural power in unit of arable land	Element index result
Daxing	0.152	0.3402	0.6768	0.9246	2.0936
Miyun	0.38	0.567	0.3384	1.2328	2.5182
Pinggu	0.228	0.4536	0.6768	0.3082	1.6666
Yanqing	0.38	0.567	0.1692	1.541	2.6572
Huairou	0.304	0.4536	0.6768	0.3082	1.7426
Tongzhou	0.076	0.2268	0.6768	1.541	2.5206
Changping	0.076	0.3402	0.846	1.541	2.8032
Shunyi	0.152	0.1134	0.5076	0.9246	1.6976
Mengtougou	0.38	0.2268	0.846	1.2328	2.6856
Fengtai	0.076	0.1134	0.846	0.6164	1.6518
Fangshan	0.152	0.3402	0.6768	0.6164	1.7854

(Vulnerability assessment result)

Name of district	Daxing	Miyun	Pinggu	Yanqing	Huairou	Tongzhou
Vulnerability assessment result	5.5782	6.8076	5.7356	7.006	5.9666	6.7682
Name of district	Changping	Shunyi	Mengtougou	Fengtai	Fangshan	
Vulnerability assessment result	6.1266	5.9068	6.1074	4.9116	5.2044	

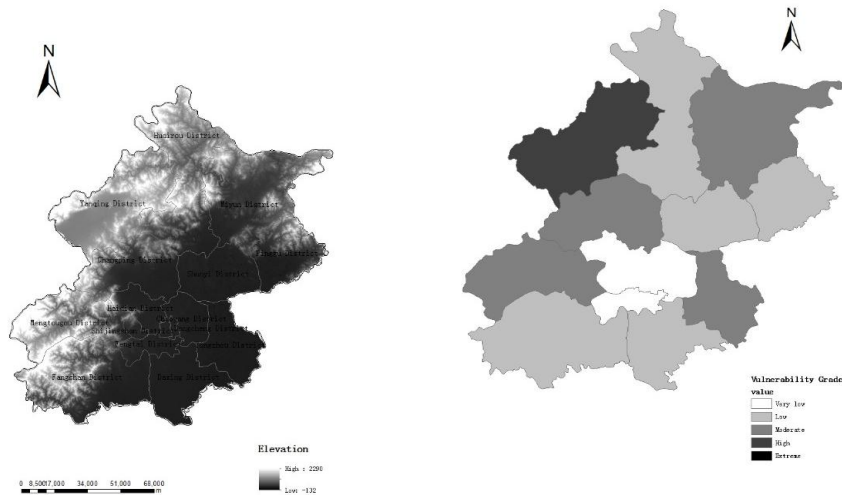


Fig.1. Topography and administrative divisions of Beijing

Fig.2. The distribution of vulnerability grade

Beijing's topography and administrative divisions are shown in Figure 1. The level of vulnerability distribution is shown in Figure 2.

4 Conclusions

In this study, use the drought vulnerability assessment which considers three main factors. First, VAM is an effective method for analyze vulnerability of the various elements, VAM assessment methods is better at determining the impact factors of drought vulnerability, in order to analyze the area which may frequently occur drought. Prevent or reduce disaster losses before the drought had occurred.

However, using AHP to build a judgment matrix will be a certain degree of subjectivity because the experts' judgment of the relative importance of the indicators varies different, while insufficient application of existing quantitative information is also an obvious inadequacy. When using the improved analytic hierarchy process method to calculate the weight of drought vulnerability indicators, can avoid judgment matrix randomness which varies from person to person. This method is more objectivity, very stability, simple and easy to calculate. Using K-means algorithm to making index data discretization, can avoid the disadvantages of equal-width interval method which is too simple and easily influenced by the amount of data. Index data discretization has directly impact on the assignment of the index data and the accuracy of the final vulnerability assessment. Therefore, a suitable discretization method is particularly important.

Look at the result of index system for drought vulnerability assessment, the exposure index of Miyun, Pinggu, Huairou, Tongzhou are higher, indicating that the four districts experienced larger degree of drought stress. The sensitivity index of Mentougou, Shunyi, Yanqing are higher, suggesting that in the three districts, the extent of agricultural system elements susceptible to the effects of drought are larger. Adaptive capacity index of Changping, Yanqing, Mentougou, Miyun are higher, showing that when these four districts occurred drought, the capability of stakeholders

in the agricultural system taking measures to reduce the effects of drought in the pre-disaster and after disaster are poor. Integrate the three elements, the greater drought vulnerability districts are Yanqing, Miyun, Tongzhou, Mentougou and Changping.

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