J. Agric. Meteorol, （農業気象）60 (5): 921-924, 2005

Risk Assessment and Regionalization of Agro-meteorological Hazards in Jilin Province, China

Jiquan ZHANG[*], Seiji HAYAKAWA[**], Daowei ZHOU[***], and Hui ZHANG[*]
[*] College of Urban and Environmental Science, Northeast Normal University, Changchun, 130024 China
[**] Department of Biological and Environmental Sciences, Faculty of Agriculture, Yamaguchi University Yamaguchi, 753-8515 Japan
[***] Institute of Grassland, Northeast Normal University, Changchun, 130024 China

Abstract

Jilin province is one of the major maize-growing regions of China and is also one of the major contributors to the Maize Belt of the world's Temperate Zone. Agro-meteorological hazards such as drought, waterlogging and cool summer occur with very high frequency and affect grain production and social-economic development in Jilin province. Moreover, both the frequency of these hazards and losses from them are considered to be increasing with global warming. This study presents a methodology for risk analysis and assessment of meteorological hazards to agricultural production in Jilin province, China, based on Geographical Information System (GIS) from the viewpoints of climatology, geography, disaster science, disaster risk analysis, environmental science, and so on. This study can be expected to provide the basis for developing strategies to mitigate agro-meteorological hazards and reducing the losses from them, and adjust the medium and long-term distribution of agricultural activities so as to adapt to environmental changes and to ensure agricultural sustainable development.

Key words: Agro-meteorological hazards, Cool summer, Drought, Risk assessment, Waterlogging

1. Introduction

Jilin province, located in the Songliao Plain, is one of the major maize-growing regions of China. Agro-meteorological hazards, which account for 80% of the total natural hazards, are characterized by their high frequency, broad range and increasing tendency, due to the unstable monsoon climate and the peculiar natural environmental factors in the area. These agro-meteorological hazards cause a large reduction in maize yield, of which 80% results from drought, waterlogging and cool summer (Zhang, 2004). Consequently it is important to comprehensively estimate the potential threat and the direct losses attributable to these phenomena on maize production. These studies form the basis for making strategies to reduce the losses in maize yield caused by drought, waterlogging and cool summer and to adjust the medium and long-term distribution of agricultural activities so as to adapt to environmental change. Therefore, this study presents a methodology for risk analysis and assessment of agro-meteorological hazards to agricultural production in the maize-growing area of Jilin province, China, based on Geographical Information System (GIS).

2. Materials and Methods

2.1 Climatic indices of the main agro-meteorological hazards

Climatic indices of agro-meteorological hazards can provide an objective way to define the hazards and assess the current extent and severity of the hazards over a region. Since it is based on rainfall over the crop-growing season (May-September), it is considered to be crucial to crop growth, and a criterion is fairly suitable for the determination of drought and waterlogging of crops. In this context, the criterion as shown in Table 1 is used to identify and evaluate drought and waterlogging of crop adapted in Jilin province from considerations of the agro-meteorological features and stage of crop growth (Zhang *et al*, 2004). Cool summer is a condition of low temperature (more than 0ºC) sufficient to have an adverse effect to crops during the growing season. In this study, the temperature during the crop-growing season and its

Table 1. Criterion of drought and waterlogging according the Rainfall Anomaly Ratio (%) (*RAR*).

	Drought	Waterlogging
Spring	$RAR_{April\text{-}May} < -30\%$	
Summer	$RAR_{June\text{-}August} < -30\%$	RAR_{June} or RAR_{July} or $RAR_{August} \geq 100\%$
Autumn	$RAR_{September\text{-}October} < -50\%$	

$RAR = (R - R_m)/R_m$ where R is the rainfall during a defined period, and R_m is the mean rainfall during that period.

Table 2. The standards of cool summer at the various $\bar{T}_{5-9}$.

$\bar{T}_{5-9}$ (°C)		80.0	85.0	90.0	95.0	100.0	105.0
ΔT_{5-9} (°C)	Moderate cool summer	-1.1	-1.4	-1.7	-2.0	-2.2	-2.3
	Severe cool summer	-1.7	-2.4	-3.1	-3.7	-4.1	-4.4

$\bar{T}_{5-9}$: the long-term (i.e., over years) mean temperature during the growing season (May to September), ΔT_{5-9}: the departure of temperature during the growing season (May to September) from the long-term (i.e., over years) mean temperature during the same period.

departure from temperature average over some time period (as shown in Table 2) were used to define cool summer year (Zhang, 2004).

2.2 Data collection and processing

In this paper, the data consisting of statistical data on the agricultural economy (annual crop sown area and yield etc.), climate (monthly rainfall, temperature and humidity etc.) and main damage conditions caused by agro-meteorological hazards (annual covered area, affected area and crop losses etc.) for each site of the Jilin province (1949-1990) and geographical data (illustrated by a meteorological factor distribution map, land-use zonation map, maize yield distribution map, landform zonation map, soil zonation map, and so on) are collected from the Meteorological Bureau, Agricultural Bureau and Statistical Bureau of Jilin province. Due to the large amount of available data, Geographical Information System (GIS) is an essential tool to gather, store, handle, update, output and display spatial data. In this study, the Agro-meteorological Disasters Data Base (ADDBASE) was constructed as a GIS database. The flow chart in Fig. 1 summarizes the procedure used to assess the risk of agro-meteorological hazards to maize.

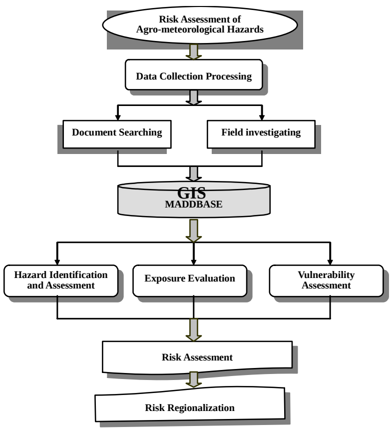

Fig.1 Flow chat showing the procedure used to make risk assessment of agro-meteorological hazards.

2.3 Analysis methods

2.3.1 Weight Comprehensive Analysis (*WCA*)

This method assumes that the degree of the influence of each factor *j* on a particular object *i* to be assessed is discriminated as the quantification value of the indicator *j* is different, the total of the influences on this object can be expressed by Eq.(1)(Zhang, 2004; Zhang *et al*, 2004).

$$CV_i = \sum_{i}^{m} QV_{ij} WC_j \tag{1}$$

where CV_i is the comprehensive value of the assessment object *i*, QV_{ij} is the quantification value of the indicator *j* with respect to the assessment object *i* ($QV_{ij} \geq 0$), WC_j is a weight on the indicator *j* ($0 \leq WC_j \leq 1$) and is computed using *AHP*, and *m* is the number of assessment indicators.

2.3.2 *AHP* (Analytic Hierarchy Process)

The Analytic Hierarchy Process (*AHP*) is a decision analysis method, which combines both quantitative and qualitative criteria in decision problems. Briefly, it follows five basic steps in applying the *AHP* in practice: (1) structure the decision hierarchy; (2) collect data by pairwise comparisons; (3) check consistency of material judgments; (4) apply the eigenvector method to compute weights; and (5) aggregate the weights to determine a ranking of decision alternatives (Zhang *et al*, 2004).

3. Results and Discussion

3.1 Agro-meteorological hazards assessment

Drought, waterlogging and cool summer are related not only to climatic factors such as precipitation, temperature and aridity, but also to conditions of the earth's surface such as landform, soil type and so on. Moreover, since drought, waterlogging and cool summer is an essential prerequisite to drought, waterlogging and cool summer, and the greater the frequency of drought, waterlogging and cool summer disaster, the greater the probability of drought, waterlogging and cool summer occurrence, the frequency of drought occurrence can reflect the probability of drought disaster occurrence (Zhang, 2004; Zhang *et al*, 2004). Therefore, in this study, Potential Danger Index of Agro-meteorological Hazards (*PDAH*) and Frequency of Agro-meteorological Hazards Occurrence (*FAHO*) are used to identify and assess agro-meteorological hazards. The following model is used to calculate *PDAH* by using *WCA* and *AHP*:

$$PDAH = PDAH_d + PADH_w + PDAH_c$$
$$= \sum_{i}^{3} \sum_{j}^{m} QV_{ij} WC_j \tag{2}$$

where $PDAH_d$, $PADH_w$ and $PADH_c$ denotes potential danger index of drought, waterlogging and cool summer, respectively, QV_{ij} is the quantification value of the indicator j with respect to the hazard i ($QV_{ij} \geq 0$) and is quantified in consideration of the maximum and the minimum value of the raw data of each assessment indictors by using the method of scaling value and point scoring method (*SVPS*) (Zhang *et al*, 2004), WC_j is a weight on the indicator j ($0 \leq WC_j \leq 1$) and is computed using *AHP*, and m is the number of assessment indicators i representing agro-meteorological hazard (drought, waterlogging and cool summer). *PDAH* comprehensively corresponds to the degree of the potential danger of agro-meteorological hazards, that is, the higher *PDAH*, the higher the potential danger degree of agro-meteorological hazards. Figure 2 shows the indicators and weights of potential danger of drought, waterlogging and cool summer. The degree of potential danger of drought, waterlogging and cool summer is comprehensively assessed and zoned based on *PDAH* values calculated by Formula (2) in districts of Jilin province using GIS (Fig. 3).

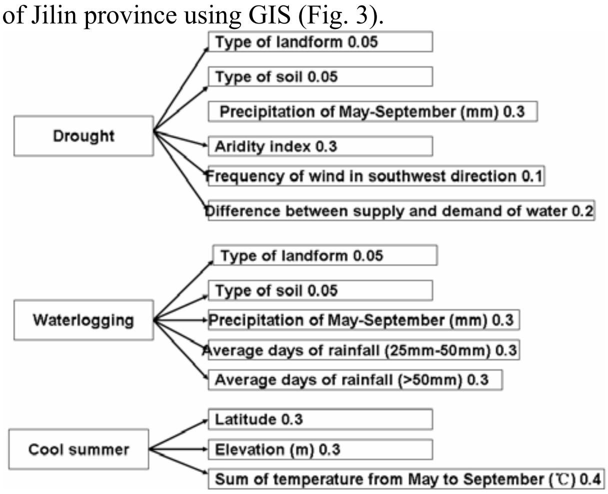

Fig. 2. Assessment indicators of potential danger of drought, waterlogging and cool summer
(The numbers are the weights of each indicator).

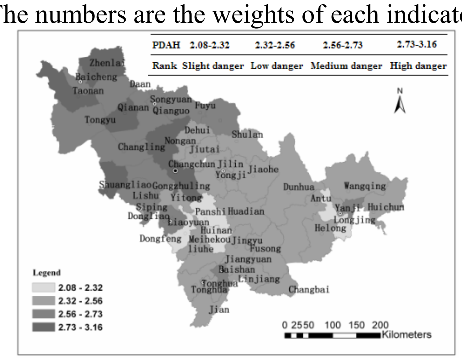

Fig. 3. Regional classification of the degree of potential danger of agro-meteorological hazards.

3.2 Exposure evaluation of agro-meteorological hazards

Exposure refers to the spatial distribution or frequency of an involved object exposed to the hazard. For field crop, average yield of crop per unit area can indicate both production level of crops and disaster combating capability in various regions. In general, a region with high production level of maize crop has high disaster combating capability and low potential loss of maize yield (Zhang, 2004). In this study, the average yield of crop per unit area was selected as an index evaluating exposure of maize production to the hazards, which contributes to disaster combating capability and the risk potential of agro-meteorological hazards to maize production in the different regions. Spatial distribution map of average yield of maize per unit area is drawn by GIS(Fig. 4).

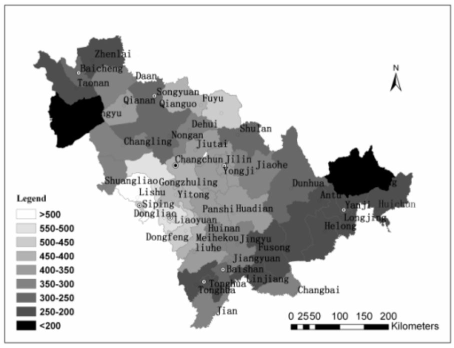

Fig. 4. Spatial distribution map of average yield of maize per unit area (kg/ha)

3.3 Vulnerability assessment of agro-meteorological hazards

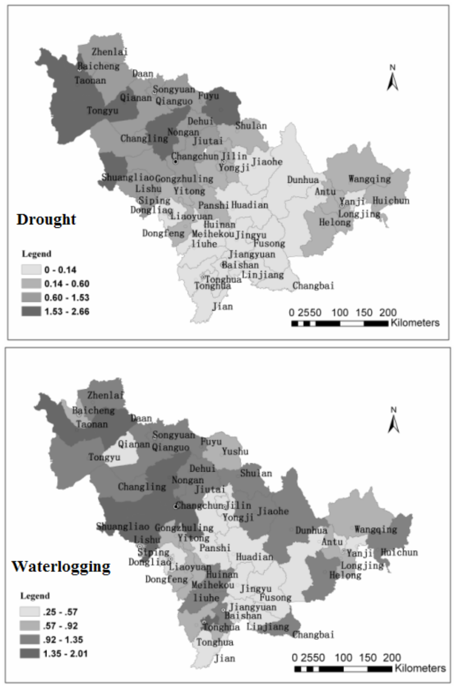

Fig. 5. Spatial distribution of vulnerability of drought and waterlogging.

Vulnerability means the extent the object is vulnerable to the forces of the hazard and the degree of exposure. Since the Percentage of the Agro-meteorological Hazards Affected Area to Maize Sown Area(*PAHAA*) has a strong positive correlation with the negative values of fluctuation of crop yields caused by natural hazards obviously showing both the degree of damage and the regional differences, *PAHAA* is used in this study to evaluate the regional degree of damage they caused to maize as an indicator of vulnerability assessment (Zhang, 2004; Zhang *et al*, 2004). Vulnerability of drought, waterlogging and cool summer is assessed and zoned using GIS, respectively(e.g. Fig 5).

3.4 Risk assessment and regionalization of agro-meteorological hazards

What is called the risk of agro-meteorological hazards to maize indicates the potential threat and direct endangerment of agro-meteorological hazards to maize-production. Based on the standard formulation of disaster risk shown as: disaster risk = hazard + vulnerability (Wilhite, 2000, Zhang *et al*, 2002) and the above-mentioned conceptual framework, the risk assessment model of agro-meteorological hazards to maize production can be described by Formula (3) to make the comprehensive and objective assessment on their risk extent to maize.

$$AHRI_i = PDAH_i + \sum_{i}^{3} FAHO_{ij} WC_j + \sum_{i}^{3} PAHAA_{ij} WC_j \qquad (3)$$

where $AHRI_i$ is the agro-meteorological hazards risk index to maize in district i, $PDAH_i$ is potential danger index of three agro-meteorological hazards shown in Formula (2) in the district i, $FAHO_{ij}$ is the occurrence frequency of the hazard j in district i, $PAHAA_{ij}$ is the percentage of the hazard j affected area to maize sown area in district i, WC_j is a weight on the hazard j ($0 \le WC_j \le 1$) and is computed using *AHP and* according to the regional differences of occurring situation of agro-meteorological hazards, and j represents agro-meteorological hazards (drought, waterlogging and cool summer). The higher *AHRI* , the greater the risk of agro-meteorological hazards.

Based on the above study, the values of $AHRI_i$ are used as the criteria for making a comprehensive assessment and regional classification as to the risk degree of drought, waterlogging and cool summer to maize. In order to assess the risk degree of agro-meteorological hazards to maize, a criterion of risk assessment is created according to the four-grade system based on the computed results of $AHRI_i$ by using the data in Jilin province from 1949 to 1990, and then, based on the criterion, the risk degree caused by agro-meteorological hazards are assessed and zoned (Fig. 6).

4. Conclusion

This paper presents a risk assessment framework for the characterization and quantification of the agronomic impacts of agro-meteorological hazards crop damaged area and crop loss data. Application of the proposed methods to maize-growing region of Jilin based on historical climate, crop yield, crop sown area,

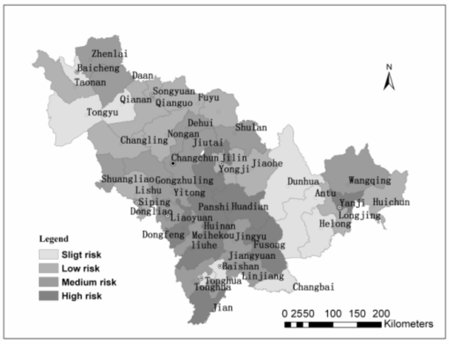

Fig. 6 Risk regionalization of agro-meteorological hazards to maize in Jilin province.

province, China, has shown that they are useful in performing the impact and risk assessment associated with those hazards, and that the resulting hazard risk map may be used by different district authorities to develop disaster risk protection plans. The methods have certain advantages, such as having simple processes and easily available data, and providing quantitative, comparative, synthetic, objective and analysis results. The methodology employed in this study can be applied to the study of other agro-meteorological disasters. The information from this study is potentially useful reference in decision making of disaster prevention and agricultural sustainable development planning.

Acknowledgment

This study is supported by the Scientific Research Foundation for the Returned Overseas Chinese Scholars, State Education Ministry and Key Laboratory of Ecological Restoration and Ecosystem Management of Jilin province.

References

Zhang, J. Q., 2004: Risk assessment of drought disaster in the maize-growing region of Songliao Plain, China. *Agriculture Ecosystems & Environment*, **102** (2), 133-153.

Zhang, J. Q., Okada, N., Tatano, H. and Hayakawa, S. J., 2004: Damage evaluation and regionalization of agro-meteorological disasters in the maize-growing region of Songliao Plain, China: Case study area of Lishu area of Jilin Province, *Natural Hazards*, **31** (1), 209-232.

Wilhite, D. A., 2000: Drought as a natural hazard: Concepts and definitions, Chapter 1. In *Drought: A Global Assessment, Natural Hazards and Disasters Series* (ed. by Wilhite, D. A.). Routledge Publishers, U.K., 3-188PP