

Postprint of Provincial-Level Assessment of Agricultural Risk from Meteorological Disasters Based on Mixed Loss Exceedance Curves

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Abstract

In recent years, the global strategy for disaster risk reduction's recognition of extensive disaster risks and the effectiveness of continuously prioritizing the management of intensive disaster risks at local scales have sparked controversies among academics and emergency management stakeholders regarding disaster risk management theory and practice. By analyzing the characteristics of historical meteorological disasters in Shanxi Province from 1983 to 2019, this study proposes using the Hybrid Loss Exceedance Curve (HLEC) to estimate the Average Annual Agricultural Economic Loss (AAL) and the Maximum Agricultural Economic Loss under typical return period scenarios (OEP) for meteorological disasters at the provincial level in China, thereby comprehensively and accurately reflecting the agricultural risk level of meteorological disasters. The results show that: (1) The AAL of meteorological disasters in Shanxi Province reaches 22.22×10^8 yuan, with the OEP of a single disaster event exceeding 0.15×10^8 yuan, meaning that there serves for a yuan, respectively. (2) HLEC is effective for disaster risk assessment at the provincial scale, with its applicability and efficiency at the prefecture-level city and county/district scales approaching 60%. (3) Over 97% of historical meteorological disasters in Shanxi Province are extensive disasters, causing more than 95% of agricultural affected area and agricultural economic losses, with the corresponding proportions of AAL and OEP both exceeding 85%. Extensive disaster risk is the focus of provincial disaster risk reduction and disaster risk management. Based on this, this study preliminarily confirms the necessity for local or grassroots levels to reduce extensive disaster risk (why manage), discusses the reasons for the inadequacy of traditional emergency management in controlling extensive disaster risk (dare not manage, cannot manage, and unwilling to manage), and proposes the significance of timely responding to extensive disaster risks and avoiding their cumulative socioeconomic impacts (such as permanent poverty alleviation, high-quality

urbanization, and sustainable development), aiming to provide correct direction for governments and emergency management departments at all levels in formulating disaster risk reduction and disaster risk management strategies, and to offer decision-making references for improving disaster resilience in cities, communities, and households.

Full Text

Agricultural Risk Assessment of Meteorological Disasters at Provincial Level Based on Hybrid Loss Exceedance Curve

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Abstract: In recent years, the global disaster risk reduction (DRR) strategy's recognition of extensive disaster risk and questioning of the effectiveness of continuously prioritizing intensive disaster risk management at local scales have sparked academic and stakeholder debates on disaster risk management (DRM) theory and practice. By analyzing the historical characteristics of meteorological disasters in Shanxi Province, this study proposes using the hybrid loss exceedance curve (HLEC) to estimate China's provincial-level average annual agricultural economic loss (AAL) and maximum agricultural economic loss under typical return period scenarios (OEP), thereby accurately reflecting agricultural risk levels from meteorological disasters. The results indicate: (1) The AAL from meteorological disasters in Shanxi Province is 2.222×10^9 Yuan, with single-event losses exceeding 1.5×10^7 Yuan. This means the province's annual reserve for "disaster prevention and emergency management expenditure" should be no less than 2.222×10^9 Yuan, while damaged counties should maintain reserves of at least 1.5×10^7 Yuan per disaster event. (2) The HLEC model proves effective for disaster risk assessment at the provincial scale, with applicability and efficiency approaching 60% at prefecture and county scales. (3) Over 97% of historical meteorological disasters in Shanxi Province are extensive disasters, causing more than 95% of agricultural disaster area and economic losses, with corresponding AAL and OEP accounting for over 85%. Extensive disaster risk represents the true and cumulative risk at the provincial level, and its consequences—including poverty, welfare reduction, infectious diseases, and health deterioration—warrant serious attention in DRR and DRM. This study preliminarily confirms the necessity of local or grassroots extensive risk reduction (why to manage), discusses reasons for insufficient traditional emergency management of extensive risk (dare not manage, cannot manage,

and unwilling to manage), and proposes the significance of timely extensive risk response to avoid cumulative socioeconomic impacts (such as permanent poverty alleviation, high-quality urbanization, and sustainable development). These findings aim to provide correct direction for governments and emergency management departments at all levels to formulate DRR and DRM strategies and offer decision-making references for improving disaster resilience in cities, communities, and households.

Keywords: hybrid loss exceedance curve (HLEC); meteorological disasters; extensive disaster risk; agricultural economic losses; Shanxi Province

Introduction

Meteorological disasters are the most frequent and severe type of natural disasters. China is among the few countries with the most diverse natural disasters and the most serious losses. In 2020, various natural disasters nationwide affected 1.76×10^8 person-times, damaged 2.54×10^4 houses, and caused direct economic losses of 3.702×10^{11} Yuan. According to the China Climate Bulletin 2020, meteorological disasters caused 1.99577×10^{11} Yuan in direct economic losses, accounting for 93.40% of total disaster impacts. Meteorological disasters are widely distributed and recurrent, causing substantial and continuously accumulating impacts, particularly agricultural losses. Identifying, assessing, and managing meteorological disaster risk constitutes a primary component of DRR strategy implementation and a key driver for achieving the “Making Cities Resilient” goal of the UN Office for Disaster Risk Reduction.

Disaster risk assessment primarily employs probability distribution models for loss exceedance curves to quantitatively evaluate disaster risk magnitude and levels by calculating annual expected losses. Loss exceedance curves include maximum loss exceedance probability curves and cumulative loss exceedance probability curves. The former assesses the maximum single event occurring annually, while the latter shares the same meaning as retrospective loss exceedance curves (RLEC) and prospective loss exceedance curves (PLEC). RLEC estimates losses from extensive disasters based on historical disaster data, whereas PLEC uses mathematical probability distribution models to estimate losses from intensive disasters. Velásquez et al. further proposed the hybrid loss exceedance curve (HLEC), which involves small to medium loss risks and extreme loss risk estimation, and conducted empirical tests in South America.

Empirical studies include Zhang et al., who used historical disaster data to estimate agricultural disaster indices (disaster area and sown area) and assess agricultural meteorological disaster risk in Jilin Province across different regions and return periods. Liu et al. applied disaster-yield assessment models to quantitatively calculate meteorological disaster losses to regional grain production in Northeast China’s three provinces for risk prevention and control. Huang et al. used agricultural meteorological disaster indices to measure im-

pacts of extreme precipitation, drought, and freezing damage on rapeseed yield in Jiangsu Province to reduce agricultural meteorological disaster sensitivity. Xu et al. proposed an agricultural flood disaster vulnerability evaluation index system to quantitatively assess vulnerability levels and spatiotemporal distribution of agricultural flood disasters in Baoji City through weighted models. Wang et al. simulated drought stress response mechanisms of dryland spring wheat yield in the Loess Plateau region of central Gansu through agricultural production system simulation models.

Limited by interdisciplinary integration, risk attribution, and frontier tracking, existing research has not applied HLEC to assess provincial-level meteorological disaster agricultural risk in China, lacking empirical cases specifically discussing disaster risk scenarios or types. To clarify differences between extensive and intensive disaster risk scenarios and prioritize local-scale DRR, this study uses Shanxi Province to appropriately and comprehensively assess agricultural risk from meteorological disasters. We estimate annual agricultural economic loss expectations, examine HLEC applicability differences across provincial, prefecture, and county scales, and provide decision support for regional governments and emergency management departments to formulate disaster prevention and reduction policies, offering countermeasures for local farmers to mitigate and transfer meteorological disaster agricultural risk.

1 Study Area Overview

To comprehensively and accurately identify and assess natural disaster risk scenarios and levels at China's provincial scale, this study selected Shanxi Province as the research area due to its complete historical disaster records, resource-based economic transformation, and medium-level urbanization development. Located in the middle reaches of the Yellow River basin, Shanxi Province features higher terrain in the northeast and lower terrain in the southwest, with mountains and hills covering 80.1% of its total area. The province has a temperate continental monsoon climate, with average annual temperatures of 4.2–14.2°C and annual precipitation of 358–621 mm. At the end of 2021, the permanent population was 3.48048×10^7 , with a gross regional product of 2.259016×10^{12} Yuan, per capita disposable income of 2.749×10^4 Yuan, and per capita consumption expenditure of 1.867×10^4 Yuan.

In 2021, Shanxi Province experienced 27 meteorological disaster events, with hail (30.34%), rainstorm and flood (27.76%), and drought (14.32%) being the most frequent local disaster types. These disasters caused 4 casualties, damaged or destroyed 1.08×10^4 houses, and resulted in direct economic losses of 7.9813×10^9 Yuan, including 3.9131×10^9 Yuan in agricultural economic losses and 2.06595×10^4 hectares of affected crop area. According to the extensive and intensive disaster risk scenarios proposed by the UN Office for Disaster Risk Reduction, over 97% of meteorological disasters in Shanxi Province are “extensive disasters” (defined as disasters causing <30 deaths and <600 damaged houses), resulting in 70.52% of casualties, 49.36% of direct eco-

conomic losses, 96.23% of house collapses, 90.92% of affected agricultural area, and 95.75% of agricultural economic losses. This study uses agricultural economic loss indicators to characterize meteorological disaster agricultural risk, applying HLEC to quantitatively estimate combined risks from extensive and intensive disaster scenarios, providing decision support for Shanxi's disaster loss reduction and urban resilience improvement.

2.1 Data Sources and Processing

Historical disaster records for Shanxi Province from 2009–2021 were obtained from Shanxi Provincial Meteorological Bureau and local meteorological departments, covering disaster types including hail, rainstorm and flood, drought, strong wind, continuous rain, low temperature damage, snow disaster, forest and grassland fire, and lightning. Disaster records include casualties, house damage, economic losses, and agricultural impacts (affected area and agricultural economic loss). This study selected “agricultural economic loss” to characterize meteorological disaster agricultural risk. According to the National Meteorological Disaster Collection and Reporting Technical Specification (2018), agricultural economic loss refers to direct economic losses to agricultural production (excluding animal husbandry, forestry, and fishery losses).

Original data were corrected (duplicate records identified and removed), then aggregated by year and region (province, prefecture, county) to compile disaster frequency, annual cumulative agricultural economic loss, and single-event agricultural economic loss for HLEC estimation. Given relatively stable crop types, disaster resistance, agricultural production, and socioeconomic development levels within the limited time span, as well as stable loss assessment methods, price levels, and currency values, using long-term accumulated and complete agricultural economic loss data for disaster risk assessment is credible. Errors from process-based loss estimation are acceptable compared to those from incomplete data.

2.2 Research Methods

The HLEC curve fitting involves three steps: (1) For the “agricultural economic loss” series, use SPSS software’s “regression curve estimation” to fit the optimal function (logarithmic function) for RLEC. The logarithmic function expression is: $y = a + b \times \ln(x)$, where y is the estimated agricultural economic loss (Yuan) and x is the annual exceedance probability. (2) Use the Data Processing System’s “hydrometeorological frequency analysis—Pearson III distribution” to fit PLEC. (3) Calculate the weighted average of RLEC and PLEC to obtain HLEC.

For multiple disasters within one year, calculate annual cumulative agricultural economic loss (AEP) to estimate AAL for both risk scenarios. For single-event maximum agricultural economic loss (OEP), calculate only the loss estimate for the corresponding annual exceedance probability to assess different return period scenarios. The specific calculation process is: (1) Apply Pearson III

distribution to the “agricultural cumulative economic loss” historical series, back-calculate forward-looking sequences for annual exceedance probabilities of 10.00%, 5.00%, 3.33%, 2.50%, 1.25%, 1.00%, 0.67%, 0.50%, 0.33%, 0.25%, 0.20%, 0.14%, 0.11%, 0.10%, 0.07%, 0.05%, 0.03%, 0.02%, and 0.01%, then use logarithmic functions to calculate AAL for extensive disaster risk scenarios. (2) Replace the series with “single-event maximum agricultural economic loss,” repeat step (1) to calculate AAL for intensive disaster risk scenarios. (3) Weighted average AAL from both scenarios to obtain HLEC’s AAL.

The Pearson III distribution function is:

$$f(x) = \frac{\beta^\alpha}{\Gamma(\alpha)} (x - \alpha_0)^{\alpha-1} e^{-\beta(x-\alpha_0)}$$

where x is the estimated agricultural economic loss (Yuan), α , β , and α_0 are shape, scale, and location parameters, and $\Gamma(\alpha)$ is the gamma function.

AAL is the weighted average of all reasonable loss values, reflecting the expected annual average loss over a future period. Its function expression is:

$$AAL = \int_0^1 x \cdot p(x) dx$$

where x is the annual exceedance probability and $p(x)$ is the loss estimate under the corresponding annual exceedance probability condition.

3.1 Comparison of HLEC Assessment Results Across Different Spatial Scales

The HLEC-estimated meteorological disaster agricultural risk across different spatial scales in Shanxi Province shows that provincial and Jincheng city curves fit well. HLEC-calculated AAL for Shanxi Province meteorological disasters is 2.222×10^9 Yuan, RLEC calculates 1.057×10^9 Yuan, and PLEC calculates 2.268×10^9 Yuan, with HLEC falling between them. HLEC comprehensively considers both extensive and intensive disaster risks through historical empirical fitting and probability model prediction, yielding more reasonable and accurate results.

Compared with Velásquez et al.’s national-scale results for Bolivia, Costa Rica, Ecuador, El Salvador, Guatemala, Honduras, Nepal, Peru, and Venezuela (all with $AAL < 2.222 \times 10^9$ Yuan), only Mexico exceeds this value. This confirms that national-scale disaster records focus on intensive disasters, while provincial-scale records encompass extensive disasters. HLEC mixes both risk components, revealing the complete provincial-scale disaster risk profile.

To examine HLEC applicability at prefecture and county levels, this study calculated AAL for 11 prefecture-level cities and 11 counties with the most severe agricultural economic losses. Results show: 7 samples (Shanxi Province, Taiyuan, Yuncheng, Jincheng, Changzhi, Jinzhong, Yuanping, Yanhu District, Fenyang,

Yanggao, Xi, Datong County, Changzi County) show HLEC between RLEC and PLEC, indicating improved assessment accuracy. For 4 samples (Xinzhou, Linfen, Lüliang, Baode County, Xiaoyi City), HLEC exceeds both, while for 3 samples (Datong, Yangquan, Shuozhou, Xiangfen County), HLEC is lower than both, indicating limited applicability. The overall effective rate is 59.09%, with higher efficiency at smaller spatial scales (70.00% at prefecture level, 45.45% at county level), demonstrating HLEC's good applicability at sub-national scales.

[Figure 1: see original paper]

3.2 Agricultural Risk of Meteorological Disasters Under Typical Return Period Scenarios

HLEC-estimated agricultural economic losses under typical return period scenarios (inverse of annual exceedance probability) in Shanxi Province show that at 84.86% exceedance probability (1000-year return period), extensive disaster risk accounts for 90.28% of total risk, while intensive disaster risk accounts for 9.72%. At 50-year return period (2% exceedance probability), the single-event maximum agricultural economic loss is 2.61×10^8 Yuan. At 100-year return period (1% exceedance probability), the single-event maximum agricultural economic loss is 9.25×10^8 Yuan.

Furthermore, the proportion of extensive disaster risk exceeds 85% across all annual exceedance probability conditions, increasing with higher exceedance probability. For example, at 0.1% exceedance probability (1000-year return period), extensive disaster risk accounts for 96.52%. This demonstrates that extensive disaster risk is the priority for disaster risk reduction at China's provincial scale. The maximum agricultural economic loss from a single meteorological disaster ranges from 0.85×10^8 to 22.22×10^8 Yuan, representing 12.49% to 13.62% of total losses. Over the past 1–7 years, the annual cumulative agricultural economic loss has been 10.57×10^8 Yuan, equivalent to the average annual loss from meteorological disasters with 3.4-year return period.

4 Discussion

This study confirms the scientific validity and applicability of HLEC in provincial-level meteorological disaster agricultural risk assessment in China. Key evidence and perspectives include:

- (1) HLEC appropriately and completely reflects local meteorological disaster risk profiles, providing scientific basis for accurate risk assessment and response. The calculated AAL (2.222×10^9 Yuan) and typical return period agricultural economic loss values offer important references for developing “financial reserve plans for meteorological disaster agricultural risk.” For instance, at least 8.5×10^7 Yuan should be reserved annually to address near 100-year return period agricultural economic losses; an average annual reserve of 2.222×10^9 Yuan addresses various ex-

ceedance probability scenarios; and 6.6×10^8 Yuan should be prepared within 10 years for 50-year return period (2% exceedance probability) scenarios. Shanxi Province's 2021 disaster prevention and emergency management expenditure was 4.477×10^8 Yuan (0.93% of general public budget expenditure), approximately 2 times the funds needed for meteorological disaster agricultural risk. Further estimation of geological and biological disaster risks is recommended to determine reasonable reserve amounts and adjust fund allocation structures across disaster prevention sectors.

- (2) Main concerns preventing HLEC application in provincial meteorological disaster agricultural risk assessment include: socioeconomic development factors affecting agricultural economic loss and agricultural system resilience stability under different spatiotemporal scales, potentially causing unreliable risk assessment results. However, in Shanxi Province, socioeconomic resilience has significantly improved during 2009–2021, with agricultural system exposure to meteorological disasters not increasing. Crop variety updates, farmers' disposable income growth, and agricultural mechanization development have reduced agricultural system vulnerability to some extent, while other risk management strategies' effectiveness (such as low agricultural insurance willingness) remains to be confirmed. Therefore, result randomness and volatility from HLEC estimation need not be considered.
- (3) Historical disaster series, intensive disaster frequency, and HLEC fitting methods all affect fitting accuracy. Further discussion on long time spans (>30 years) and high-precision fitting methods is recommended. Differences in HLEC can also identify disaster risk scenario types across countries or regions: Bolivia (1.0986×10^6 km²), Costa Rica (5.11×10^4 km²), and Mexico (1.9644×10^6 km²) are intensive disaster risk regions, while China's Shanxi Province (1.567×10^5 km²) is an extensive disaster risk region. Datong County (0.15×10^4 km²) and Yanggao County (0.46×10^4 km²) can be considered Shanxi's "disaster risk hotspots."

To effectively manage extensive disaster risk at provincial and local scales, this study recommends: (1) Emergency management system reform and local government decentralization can improve DRR performance and socioeconomic effects. Traditional top-down emergency management models somewhat neglect risk-exposed residents' needs and willingness, while insufficient grassroots fiscal autonomy affects community risk mutual aid capacity and immediate extensive disaster response, resulting in "dare not manage, cannot manage" outcomes that exacerbate extensive risk accumulation, causing poverty relapse, health deterioration, welfare damage, and even triggering intensive disaster risks that constrain sustainable development. (2) Free market capital operation and accelerating economic globalization have created local governments' "governance limited by financing" inertia. (3) China's provincial meteorological disaster agri-

cultural risk reality shows: extensive disasters (deaths <30 and damaged houses <600) absolutely dominate, accounting for 21.89×10^9 Yuan (95.75% of losses). As the saying goes, “for every major catastrophe, thousands of smaller events occur”—extensive disaster risk is the truly significant risk type requiring attention and reduction.

5 Conclusion

To overcome risk bias from loss exceedance curve fitting that underestimates extensive disaster scenarios while overestimating intensive disaster scenarios, this study employs HLEC as an innovative approach to map China’s provincial meteorological disaster agricultural risk panorama. Main conclusions are:

- (1) HLEC appropriately and completely reflects local meteorological disaster risk profiles, providing decision-making basis for scientific and accurate meteorological disaster agricultural risk assessment and response. The calculated Shanxi Province AAL (2.222×10^9 Yuan) and typical return period agricultural economic loss values offer important references for developing financial reserve plans. For example, prepare at least 8.5×10^7 Yuan annually for near 100-year return period losses; maintain average annual reserves of 2.222×10^9 Yuan for various exceedance probability scenarios; and prepare 6.6×10^8 Yuan within 10 years for 50-year return period (2% exceedance probability) scenarios.
- (2) HLEC demonstrates good applicability at provincial, prefecture, and county scales. Shanxi’s extensive meteorological disasters (deaths <30 and damaged houses <600) account for 70.52% of casualties, 49.36% of direct economic losses, 96.23% of house collapses, 90.92% of affected agricultural area, and 95.75% of agricultural economic losses. Extensive disaster risk is the truly significant risk type requiring attention. Compared to global and national DRR focus on intensive disaster hotspots, local scales (prefecture, county, township, community) should prioritize extensive disaster risk management. Shanxi’s over 97% extensive meteorological disasters represent the real and cumulative risk that DRR and DRM should address.

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