Lightning Risk Level Assessment Based on Fuzzy Membership Degree (Postprint)

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Abstract

Utilizing lightning location monitoring data within a 10 km radius of the Xining station in Qinghai Province from 2013 to 2017, the number of cloud-to-ground flashes and the maximum lightning current amplitude within a one-hour period in the regional scope were selected as lightning hazard factors. The upper and lower limits of factor grading and the division of factor intervals were determined, and the membership degree and weight of single-factor lightning hazard levels were calculated. Trapezoidal distribution functions and fuzzy statistical methods were employed to determine the membership functions of lightning hazard factors. Based on these membership functions, a fuzzy matrix was derived, and fuzzy matrix composite operations were performed to obtain the comprehensive lightning hazard index and determine the lightning hazard level. The results indicate that the established fuzzy comprehensive evaluation method can comprehensively, objectively, and accurately reflect the hazard status of a lightning flash process, effectively assess lightning hazard levels, and the evaluation results objectively reflect the actual conditions of lightning strike events, thereby providing scientific decision-making services and a reference basis for meteorological disaster prevention and mitigation, lightning disaster investigation, and lightning risk assessment operations.

Full Text

Preamble

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This study analyzes lightning activity within a 10 km radius of Xining station, examining cumulative frequency distributions of lightning strikes per hour and maximum lightning current amplitude. The data reveals critical thresholds for lightning hazard assessment.

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1. Introduction

1.1 Data Sources and Parameters

Lightning location system data provides the foundation for this analysis. Two key parameters are extracted: ground flash density (LN, measured in flashes · h ^{1} · km ^{2}) and lightning current intensity (LI, measured in kA). The cumulative frequency distribution of lightning strikes shows characteristic patterns within the 10 km study radius.

The probability distributions for these parameters follow established meteorological standards. Critical values are determined based on historical lightning disaster records and expert classification systems, enabling quantitative hazard evaluation.

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2. Lightning Hazard Factor Classification

2.2 Critical Value Determination

Factor classification employs trapezoidal membership functions to convert physical measurements into hazard grades. Table 2 presents the critical values for LN and LI classification.

The trapezoidal distribution function, defined piecewise in Table 3, assigns membership grades across four hazard levels (A through A) based on input values relative to established thresholds E through E .

Table 4 specifies the complete membership functions for both lightning density and current intensity factors, with breakpoints at 24.5, 49, 73.5, and 98 for LN, and 34.5, 69, 103.5, and 138 for LI.

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3. Case Study: Xining Station Lightning Hazard Assessment

3.1 Site Characteristics

The evaluation focuses on a primary structure at Xining station measuring 209 m × 210 m (total area 60,900 m^2). Lightning protection system installation was completed in August 2013. The site-specific lightning parameters indicate LN = 95 and LI = 64, placing it in elevated hazard categories.

3.2 Assessment Results

Applying the membership functions yields weighted hazard grades: 0.14 for LN and 0.86 for LI. The comprehensive evaluation matrix R combines these factors:

$$R = \begin{bmatrix} 0.88 & 0.14 & 0 & 0 \\ 0 & 0.86 & 0 & 0 \end{bmatrix}$$

The final hazard vector U = [0.69, 0.30, 0, 0] indicates a 69% membership in the highest hazard category and 30% in the second-highest category, confirming significant lightning risk requiring enhanced protection measures.

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4. Discussion

Weight determination critically influences assessment accuracy. This study employs objective weighting based on measured lightning parameters, contrasting with subjective methods like analytic hierarchy process (AHP) used in prior research [2, 4, 6, 23]. The entropy method provides an alternative objective approach, calculating weights from data variability.

The normalized weight calculation follows:

$$W_i = \frac{W_i}{\sum W_i}$$

where lightning density receives higher weight (1.55) than current intensity (0.74), reflecting its greater variability and predictive importance. This objective weighting reduces expert bias while maintaining physical interpretability.

Future improvements should integrate additional factors like topography and infrastructure vulnerability, expanding the evaluation matrix dimensions. The trapezoidal membership approach remains robust for continuous meteorological parameters, offering computational efficiency compatible with real-time warning systems.

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Note: Figure translations are in progress. See original paper for figures.