Spatiotemporal Variation Characteristics of Rainstorm Flood Disasters at Different Grades in Xinjiang (Postprint)

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Abstract

Based on 3220 rainstorm and flood disaster events that occurred in 86 counties (cities) of Xinjiang from 1961 to 2019, a disaster loss index was constructed using five disaster elements: death toll, number of collapsed houses, number of collapsed sheds, number of livestock deaths, and affected crop area. The percentile method was applied to classify the disaster loss index into grades, and rainstorm and flood disaster events were quantitatively divided into four levels—general, relatively severe, severe, and extremely severe—to assess the spatiotemporal distribution and variation of rainstorm and flood disasters in Xinjiang. The Ili River Valley, Aksu Prefecture, and Kashgar Prefecture are the regions with the highest frequency of rainstorm and flood disasters in Xinjiang, and these three regions also experience the most severe disaster conditions. Areas with higher frequencies of less hazardous rainstorm and flood disasters (general and relatively severe levels) are primarily concentrated in northern Xinjiang. As the hazard level intensifies, the frequency of severe and extremely severe disasters in most areas of northern Xinjiang decreases rapidly. The average frequency in Aksu, Kashgar, and other areas of southern Xinjiang is significantly higher than in other regions of Xinjiang. The frequency of various hazard levels in the Ili River Valley ranges from medium to high compared with other regions, with the frequency of extremely severe rainstorm and flood disasters ranking among the top three in Xinjiang. Rainstorm and flood disasters in Xinjiang mainly occur in summer, with the highest frequency in June and July. An abrupt change in the frequency of rainstorm and flood disasters occurred in the mid-1980s. Since the mid-1980s, precipitation from March to October in Xinjiang has increased, extreme precipitation events have become more frequent, and the frequency of rainstorm and flood disasters at various hazard levels, annual frequency, and annual disaster loss index have increased by 3.8–5.6 times. Precipitation amount and the number of rainy days with heavy rain or above constitute the main disaster-causing factors for rainstorm and flood disasters in Xinjiang.

Full Text

Spatial and Temporal Variation Characteristics of Rainstorm Flood Disasters of Different Grades in Xinjiang

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Abstract

Based on 3,220 rainstorm flood disaster events recorded in 86 counties (cities) across Xinjiang from 1961 to 2019, this study constructs a disaster loss index using five disaster elements: number of deaths, collapsed houses, collapsed sheds, livestock deaths, and affected crop area. Using percentile methods to classify the disaster loss index, rainstorm flood disaster events are quantitatively divided into four grades—general, heavy, severe, and extreme—to evaluate the spatiotemporal distribution and variation of rainstorm flood disasters in Xinjiang. The regions with the highest frequency of rainstorm flood disasters are the Ili River Valley, Aksu Prefecture, and Kashgar Prefecture, which are also the areas experiencing the most severe disaster impacts. Areas with more frequent less-harmful events (general and heavy grades) are concentrated primarily in northern Xinjiang. As disaster severity increases, the frequency of severe and extreme grade events declines rapidly across most of northern Xinjiang. In contrast, southern Xinjiang regions such as Aksu and Kashgar show significantly higher average frequencies than other regions. The Ili River Valley exhibits moderate to high frequencies across all hazard grades, ranking among the top three in Xinjiang for extreme-grade events. Rainstorm flood disasters in Xinjiang occur predominantly in summer, with June and July showing the highest frequency. A regime shift in disaster occurrence emerged in the mid-1980s; since the mid-1990s, increased precipitation and more extreme precipitation events have produced 3.8–5.6 fold increases in the frequency of events across all hazard grades, annual occurrence frequency, and annual disaster loss index. Precipitation and the number of days with heavy-rainfall-or-greater events constitute the primary disaster-forming factors for rainstorm flood disasters in Xinjiang.

Keywords: rainstorm flood disaster; disaster loss index; classification; spatiotemporal differences

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1 Introduction

Rainstorm flood disasters are natural hazards caused by prolonged heavy rainfall or accumulated precipitation that inundates low-lying areas, resulting in population and economic losses. Although Xinjiang is located in an arid and semi-arid region of northwestern China, rainstorm flood disasters occur with high frequency and cause severe damage, ranking first among all meteorological disasters in terms of direct economic losses according to disaster statistics. From 1961 to 2019, 3,220 rainstorm flood events occurred in 86 counties (cities) across Xinjiang, causing 376 deaths, collapsing over 156,300 houses and 51,700 sheds, killing 169,000 livestock, and affecting 160,000 hectares of crops. These disasters involve multiple damage categories including human casualties, crops, agricultural facilities, livestock, houses, and sheds. Using economic loss alone for comprehensive assessment proves insufficient and yields low credibility. Therefore, constructing a disaster loss index that comprehensively reflects rainstorm flood disaster information is essential.

Recent risk assessments based on GIS technology have attracted attention, yet numerous scholars continue using statistical methods to analyze disaster loss indices and hazard levels. Studies evaluating disaster severity through multiple loss elements have employed grey relational analysis on three evaluation factors (rainstorm frequency, affected crop area, and comparable economic loss) to classify disasters into severe, heavy, moderate, and light grades. Other research has constructed disaster grade indices and disaster magnitude indices to assess temporal and spatial hazards, while some have established relative disaster indices through affected area proportions or used dimensionless and normalization methods to build comprehensive meteorological disaster loss indices. Current assessments of rainstorm flood hazards in Xinjiang primarily use single indicators like direct economic loss or fatalities for spatiotemporal analysis without establishing hazard grades, making it urgent to identify the spatial distribution and variation of hazard intensity across the entire region.

This study constructs a disaster loss index based on disaster elements to quantitatively classify rainstorm flood events and analyze their spatiotemporal distribution patterns. The results provide technical support for hazard assessment and natural disaster risk zoning of rainstorm flood disasters in Xinjiang.

2 Data and Methods

2.1 Data Sources Based on rainstorm flood disaster records from the Xinjiang Civil Affairs Department, we compiled 3,220 disaster records from 86 counties (cities) between 1961 and 2019. Each record includes occurrence date (year-month-day), affected area (county/city), and five disaster elements: deaths, collapsed houses, collapsed sheds, livestock deaths, and affected crop area. For rainstorm events occurring on the same day, data were integrated by county (city) and counted as one disaster event per county (city).

Xinjiang’ s complex terrain features three major mountain ranges—Altai, Tianshan, and Kunlun—whose snow and glacier melt feed over 570 rivers across basins north and south of the Tianshan Mountains. The region’ s inland location and unique topography create a strongly continental temperate arid climate, with average annual precipitation of approximately 160 mm distributed unevenly in space and time, concentrated in mountainous areas and along mountain slopes, with minimal precipitation in desert basins. Based on geographic and climatic precipitation characteristics, Xinjiang is divided into 12 regions: Altay Prefecture, Tacheng-Emin Basin, Bortala Prefecture, Ili River Valley, northern Xinjiang along the Tianshan Mountains, Kashgar Prefecture, Hotan Prefecture, Kizilsu Prefecture, Aksu Prefecture, Bayingolin Prefecture, Turpan City, and Hami City (Figure 1).

[Figure 1: see original paper]

2.2 Disaster Loss Index and Classification Thresholds For the 3,220 rainstorm flood events, we first calculated the mean and maximum values for each of the five disaster elements. Each element value was divided by its maximum for dimensionless processing. The dimensionless cumulative value for a given disaster element was then divided by the number of events to obtain its weight, denoted as a (Table 1).

Table 1 Weight, average, and maximum values for disaster loss index calculation

Disaster Element	Weight	Average	Maximum
Deaths	0.20	0.12	36
Collapsed Houses	0.20	48.61	3,000
Collapsed Sheds	0.20	16.05	1,000
Livestock Deaths	0.20	52.48	3,270
Affected Crop Area	0.20	497.52	31,000

The disaster loss index Z is calculated as:

$$Z_i = \sum_{j=1}^{5} a_j \frac{X_{ij}}{X_{j\max}} - \sum_{j=1}^{5} a_j \frac{\bar{X}_j}{X_{j\max}}$$

where i = 1, 2, ···, 3220 represents each rainstorm flood event; j = 1, 2, ···, 5 represents the five disaster elements; *a_j* is the weight of each element; *X_{ij}* represents the value of the *j*-th disaster element for the *i*-th event; *X_{jmax}* is the maximum value of the *j*-th element; and *X̄_j* is the average value of the *j*-th element.

After calculating the disaster loss index, values were sorted in ascending order. Using the percentile method, thresholds at the 25th, 75th, and 95th percentiles were applied to classify events into four grades (Table 2).

Table 2 Classification standard for rainstorm flood disasters

Percentile (r)	Disaster Loss Index (Z)	Hazard Grade
r $\leq$ 25%	Z $\leq$ 0.21963	General (Grade 1)
25% < r $\leq$ 75%	0.21963 < Z $\leq$ 0.90931	Heavy (Grade 2)
75% < r $\leq$ 95%	0.90931 < Z $\leq$ 2.33651	Severe (Grade 3)
r > 95%	Z > 2.33651	Extreme (Grade 4)

2.3 Statistical Methods Linear trend estimation was applied to analyze temporal variation trends. The cumulative anomaly method was used for abrupt change detection in time series. Annual disaster loss index is defined as the sum of disaster loss indices for all events in a given year, while average annual disaster loss index represents the mean value across the study period.

3 Results

3.1 Spatial Distribution of Rainstorm Flood Disasters The regions with highest average annual occurrence frequency are Bortala Prefecture, Altay Prefecture, and Hami City for Grade 1 events; Kashgar Prefecture, Kizilsu Prefecture, and Aksu Prefecture for Grade 2; and Aksu Prefecture, Kashgar Prefecture, and Ili River Valley for Grade 3 (Figure 2). For Grade 4 events, the top three regions are Ili River Valley, Aksu Prefecture, and Kashgar Prefecture. The regions with highest annual disaster loss index are also Ili River Valley, Aksu Prefecture, and Kashgar Prefecture, consistent with the annual occurrence frequency pattern.

Areas with more frequent less-harmful events (Grades 1-2) are concentrated in northern Xinjiang. As hazard level increases, severe and extreme grade events decrease rapidly across most of northern Xinjiang, while southern regions like Aksu and Kashgar show significantly higher frequencies than other regions. The Ili River Valley maintains moderate to high frequencies across all hazard grades, ranking among the top three for extreme-grade events.

Analysis of maximum occurrence frequencies reveals that Bortala Prefecture' s maxima concentrate in lower hazard grades, Ili River Valley' s maxima concentrate in higher hazard grades, while Aksu Prefecture shows high maxima across all hazard grades. The top three regions for maximum annual disaster loss index are Ili River Valley, Aksu Prefecture, and Kashgar Prefecture, consistent with average intensity analysis and demonstrating that our disaster loss index and classification accurately reflect actual disaster intensity.

[Figure 2: see original paper]

3.2 Monthly Variation From 1961-2019, Xinjiang experienced 3,220 rainstorm flood events. Seasonally, summer accounts for the absolute majority across all grades: Grade 1-4 summer occurrences represent 70.6%, 73.8%, 66.7%, and 63.6% of annual totals, respectively. As hazard grade increases, the summer proportion decreases slightly but remains dominant.

Monthly analysis shows Grade 1 events peak in July, June, and August; Grade 2 events in July, June, and May; Grade 3 events in July, June, and August; and Grade 4 events in July, June, and August (Figure 3). June and July are the top two months for all hazard grades, coinciding with peak months for precipitation, heavy-rain days, and rainstorm days. Precipitation serves as the direct material condition for these disasters, and the peak timing of heavy-rain days aligns perfectly with disaster occurrence peaks.

[Figure 3: see original paper]

3.3 Interannual Variation From 1961–2019, annual occurrence frequencies for all hazard grades show increasing trends with varying rates. Grade 1–4 increase rates are 1.4, 1.2, 0.8, and 0.4 occurrences per decade, respectively. The overall annual occurrence frequency increases at 3.8 events per decade, while the annual disaster loss index grows at 4.5 per decade. All decadal growth rates pass significance tests at the 95% confidence level.

Abrupt changes detected using cumulative anomaly and *t*-test analysis show Grade 1 events shifted in 1985, Grade 2 in 1986, Grade 3 in 1993, and Grade 4 in 1995. Post-shift increases range from 2.2–9.0 times pre-shift averages. Annual occurrence frequency and annual disaster loss index both shifted in 1995, with post-shift increases of 4.4 and 4.5 times, respectively. The most pronounced post-shift increase occurs for Grade 4 events.

Strong correlations exist between annual occurrence frequency, annual disaster loss index, and precipitation variables. Annual occurrence frequency correlates with March–October precipitation ($r = 0.68$), heavy-rain days ($r = 0.72$), and rainstorm days ($r = 0.62$). Annual disaster loss index shows similar correlation patterns, all significant at the 95% confidence level (Table 3).

Table 3 Correlation between annual occurrence frequency, annual disaster loss index and precipitation variables

Variable	Precipitation	Heavy-rain Days	Rainstorm Days
Annual Occurrence (Y)	0.68	0.72	0.62
Annual Loss Index (Z_y)	0.71	0.75	0.64

Linear regression equations show that for every 10 mm increase in precipitation, 0.05 increase in heavy-rain days, or 0.20 increase in rainstorm days, annual occurrence frequency and disaster loss index increase correspondingly. Heavy-rain days show the strongest correlation, indicating that precipitation at or above heavy-rain thresholds can generate rainstorm flood disasters.

Cumulative anomaly analysis of precipitation, heavy-rain days, and rainstorm days all reveal a regime shift in 1995. Precipitation and heavy-rain days transitioned from a low-value to high-value climate state, while rainstorm days showed increased interannual variability after 1995, maintaining an upward trend but with slower increase rates compared to precipitation and heavy-rain days (Figure 5).

[Figure 5: see original paper]

4 Conclusions

Using five major disaster elements, we constructed a disaster loss index that comprehensively reflects multi-dimensional losses from rainstorm flood disasters. The index quantitatively classifies events into general (Grade 1), heavy (Grade 2), severe (Grade 3), and extreme (Grade 4) grades to evaluate rainstorm flood disasters of varying intensity in Xinjiang from 1961–2019. This disaster loss index effectively captures both average and extreme conditions of rainstorm flood disasters in Xinjiang.

1. **Spatial patterns**: The Ili River Valley, Aksu Prefecture, and Kashgar Prefecture experience the highest frequency and most severe rainstorm flood disasters. Less-harmful events concentrate in northern Xinjiang, while severe and extreme events decrease rapidly there with increasing hazard level. Southern Xinjiang regions like Aksu and Kashgar show significantly higher frequencies than other areas. The Ili River Valley maintains moderate to high frequencies across all grades, ranking top three for extreme events. The Ili River Valley receives Xinjiang' s highest annual precipitation, while Aksu and Kashgar experience high frequencies of short-duration heavy precipitation, providing the material basis for these disasters.

2. **Temporal patterns**: Rainstorm flood disasters occur mainly in summer, peaking in June and July—coinciding with peak months for precipitation, heavy-rain days, and rainstorm days.

3. **Regime shift**: A abrupt change occurred in the mid-1980s, with the mid-1990s marking a clear shift to increased March–October precipitation and more extreme precipitation events. This produced 3.8–5.6 fold increases in event frequency across all grades, annual occurrence frequency, and annual disaster loss index. Precipitation and days with heavy-rain-or-greater events are the primary disaster-forming factors.

This study provides a technical basis for hazard assessment and natural disaster risk zoning of rainstorm flood disasters in Xinjiang. Future research should focus on the disaster mechanisms of extreme precipitation events to further understand rainstorm flood disaster formation processes in Xinjiang.

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