Social Vulnerability Assessment and Comprehensive Zoning of Natural Disasters in Gansu Province (Postprint)

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Abstract

Reducing social vulnerability is of significant importance for natural disaster risk prevention. At the county/district unit scale, this study selected three disaster-bearing bodies—population, economy, and crop farming—to construct a social vulnerability assessment indicator system suitable for the region, and evaluated the social vulnerability to natural disasters in Gansu Province, including exposure, sensitivity, adaptability, and comprehensive social vulnerability. Subsequently, based on the physical geography zoning paradigm, a systematic compilation of the comprehensive zoning scheme for natural disaster social vulnerability at the county/district unit scale in Gansu Province was conducted. The results indicate: (1) The comprehensive social vulnerability index in Gansu Province generally exhibits a macro-scale pattern of high in the east and low in the west, and high in the south and low in the north. High-vulnerability areas are mainly concentrated in the Longdong, Longzhong, and Longnan regions, demonstrating clustering characteristics in densely populated disaster-bearing areas such as cities and their adjacent counties/districts. (2) The comprehensive zoning scheme consists of two levels: the first-level zones comprise four dominant natural disaster type zones, including the western Hexi Corridor sand-dust storm dominant disaster zone, the Lanzhou drought dominant disaster zone, the Longnan rainstorm-flood landslide/debris flow dominant disaster zone, and the multiple disaster types zone covering the Hexi Corridor and Longdong-Longzhong-Gannan regions. The second-level zones consist of 14 comprehensive vulnerability grade zones with different structures. This scheme systematically expresses the macro-scale spatial differentiation patterns of social vulnerability structures under regional dominant natural disaster types, and can serve the diverse regional differences and needs in reducing natural disaster social vulnerability.

Full Text

Introduction

Under global change, the risk of losses from natural disasters to human society is increasing [ ]. Vulnerability serves as a crucial bridge linking hazard to disaster situations and risk [ ]. The losses and risks from natural disasters depend not only on the quantitative response relationship of structural damage to disaster-bearing bodies under natural disaster impact, but also on the interrelated effects of environmental, demographic, social structural, and industrial factors within a region. Social vulnerability analyzes vulnerability from a socioeconomic perspective, arguing that differences in the internal structure of social systems lead to varying system vulnerabilities that cannot be fully mitigated by structural measures alone [ ]. Understanding and quantitatively assessing the social influencing factors of disaster-bearing bodies within a region, and revealing the macro-scale patterns of their spatial differentiation, can help reduce natural disaster risks, adapt to future climate change, and allocate disaster relief resources at the macro level [ ].

Current research on social vulnerability to natural disasters primarily employs comprehensive indicator system approaches. There are significant differences in how these indicator systems are constructed, which can be divided into two categories. One uses statistical methods to form evaluation indicator systems through bottom-up aggregation. This method requires large amounts of data and is susceptible to data completeness limitations. Typical studies include local social vulnerability models that, through comprehensive community-scale indicators, reveal uneven distribution of social vulnerability across different social groups and regions [ ]. The other category is based on theoretical deduction of impact factors, constructing evaluation indicator systems through top-down approaches. Most current research on social vulnerability to natural disasters at the regional scale in China adopts this method [ ]. Additionally, studies from a resilience perspective can be viewed as social vulnerability research from the opposite angle, assessing the capacity of systems to maintain key characteristics, structures, and functions after external disturbances [ ].

The ecological environment in China's northwest arid and semi-arid regions is fragile, with highly unique distributions of population, economy, and other factors, drawing significant attention to social vulnerability patterns and driving factors [ ]. Current research on social vulnerability in northwest China and Gansu Province has focused mainly on rural regional systems, natural-social systems, and social-ecological systems [ ], with vulnerability studies targeting natural disasters primarily addressing agricultural drought [ ]. These assessment results express spatial differentiation in vulnerability levels, but relatively little analysis has been conducted on the systematic structural differences underlying comprehensive vulnerability, failing to meet practical application needs for vulnerability reduction. Therefore, this study constructs a social vulnerability evaluation indicator system for natural disasters in Gansu Province adapted to

the county/district scale, selects data from 87 counties and districts to comprehensively assess social vulnerability to natural disasters, and then systematically conducts regionalization research on the macro-scale differentiation patterns of social vulnerability to natural disasters in this region using the natural geographic regionalization paradigm. This approach expresses not only vulnerability level differences but also the regional differentiation of factor structure characteristics that form these vulnerability levels. The regionalization results can serve diverse regional differences and needs in disaster relief, adaptation enhancement, and social vulnerability reduction.

Study Area and Data

1.1 Study Area Overview

Gansu Province is located at the geographic center of China's land territory, extending from northwest to southeast (1655 km long, 32°11 ~42°57 N, 92°13 ~108°46 E), with an average north-south width of about 530 km. It lies at the intersection of the Tibetan Plateau, Loess Plateau, and Inner Mongolia Plateau, belongs to the Yangtze River, Yellow River, and inland river systems, and spans three climate zones: the eastern monsoon region, northwest arid and semi-arid region, and Tibetan Plateau cold region. The diversity and complexity of the natural environment are prominent, resulting in significant spatial and temporal differentiation in disaster-forming environments, hazard factors, and disaster-bearing body elements. The province has a total population of approximately 7 people and an area of 4.258$×10^{2}$ km^2, representing a typical sparsely populated region with more people in the southeast and fewer in the northwest. Moreover, population, economy, and other elements in the northwestern part of the province are heavily concentrated in oases, creating severe distribution imbalances [ ]. These factors collectively make the regional differentiation of natural disaster vulnerability in Gansu Province particularly significant. Conducting comprehensive social vulnerability regionalization can systematically reveal these differentiation patterns and provide scientific foundations for regionally tailored vulnerability reduction strategies at the macro-strategic level.

Considering the complex and diverse natural disaster systems and significant disaster chain phenomena in Gansu Province [ ], this study categorizes multiple natural disasters according to disaster chain types. Based on the China Natural Disaster Newspaper Database, which records disaster occurrences from years with actual disaster records showing significant losses, drought and arid disasters are consolidated into a single arid disaster category. In this region, landslides and debris flows are primarily triggered by rainstorms, so they are consolidated into rainstorm-flood disasters. The final regionalization includes five disaster (chain) types: earthquake, arid disaster, rainstorm-flood-landslide-debris flow, and sandstorm, which account for occurrence records, representing approximately of total disaster records. The selected disaster-bearing bodies are population, economy, and planting industry, which are most affected by these

disaster types.

1.2 Data Sources

The basic research units are 87 counties and districts in Gansu Province. Population data are derived from the seventh national population census 公报 [ ]. Economic and planting industry-related data primarily come from the Gansu Statistical Yearbook and China County Statistical Yearbook, with missing data supplemented by prefecture-level city statistical yearbooks and county government 公报 data. Since 2020 data were heavily impacted by the pandemic, 2019 data were used as substitutes. Regional disaster data come from the China Provincial Newspaper Disaster Database provided by Beijing Normal University's Regional Geography Laboratory. This database was established by reviewing provincial newspaper sources, extracting disaster-related news reports, and classifying and summarizing information including disaster timing, type, and severity, covering natural disaster types. As the database records actual disasters, it reflects regional natural disaster exposure levels. Land use data are from the GlobeLand30 global land cover data released by the Ministry of Natural Resources (Table 1).

1.3 Methods

1.3.1 Natural Disaster Social Vulnerability Assessment Indicator System Construction. Referencing existing research results and data availability [5-8,10-27], an evaluation indicator system for social vulnerability to natural disasters at the county/district scale in Gansu Province was established based on three core dimensions: exposure, sensitivity, and adaptability (Table 2). Exposure includes population exposure, economic exposure, planting industry exposure, and historical disaster exposure. Sensitivity and adaptability are divided into population, economic, and planting industry dimensions. Specific indicators and their descriptions are shown in Table 2.

Weight Calculation. This study uses the entropy method to calculate indicator weights. As an objective weighting method, the entropy method uses information entropy contained in data as the evaluation standard for weight magnitude, eliminating evaluator subjectivity. The general steps are: first, standardize data to eliminate differences in measurement units and dimensional scales between raw data (positive indicators use formula , negative indicators use formula); second, calculate the proportion of each county/district's indicator value to the total for each indicator (formula); third, calculate each indicator's information entropy value (formula); and finally, calculate each indicator's weight (formula).

Comprehensive Vulnerability Calculation Model. Based on the aforementioned assessment framework, this study uses formula to calculate natural disaster social vulnerability and various dimensions at the county/district scale in Gansu Province [ ]. The formulas calculate exposure index, sensitivity index,

and adaptability index respectively. Exposure and sensitivity together express potential social vulnerability, while adaptability has an offsetting effect on social vulnerability. The three components collectively constitute the regional natural disaster social vulnerability index at the county unit scale. Indicators used to calculate the adaptability index are normalized as negative indicators; when expressing adaptability alone, corresponding negative values should be taken.

1.3.2 Natural Disaster Social Vulnerability Comprehensive Regionalization Regionalization Purpose and Principles. The main purpose of this regionalization is to systematically divide regions to reveal macro-scale regional differentiation patterns of natural disaster social vulnerability at the county/district unit scale in Gansu Province, providing scientific foundations for decision-making in natural disaster risk prevention management, insurance business market geographic layout, pricing, and risk control. Based on natural disaster regionalization research practices [9,28-31,36-37] and combined with social vulnerability regional differentiation mechanisms, the following principles are established: (1) Highlight multi-dimensional characteristics of regional natural disaster social vulnerability, expressing not only comprehensive vulnerability index level differentiation but also regional differentiation patterns of multi-dimensional elements constituting social vulnerability; (2) Maintain integrity of county/district administrative units, following regional conjugacy principles to facilitate unified application of regionalization results within the same administrative region; (3) Use bottom-up merging as the main method, combined with top-down division. With support from high-resolution spatial data, comprehensively apply multiple methods to construct regionalization comprehensive quantitative models, improving the quantitative degree of regionalization boundaries [ ]; (4) Adjust and merge enclaves and scattered patches based on spatial proximity, natural similarity of regional units, and highlighting high-level regions.

Regionalization Levels and Indicator System. Considering the spatial-temporal scale, element dynamics, regional characteristics, regionalization indicator data, and result expression of Gansu Province's natural disaster system, this study adopts a two-level regionalization system. The first level is dominant natural disaster type zones. Regionalization indicators are historical natural disaster occurrence frequencies, reflecting macro-scale spatial differentiation patterns of specific disaster types in Gansu Province's counties and districts. The second level is comprehensive social vulnerability level zones. Regionalization indicators are components of the comprehensive social vulnerability index, including exposure, sensitivity, and adaptability, reflecting macro-scale spatial differentiation patterns of social vulnerability structure differences under specific dominant disaster type backgrounds.

Regionalization Process and Methods. First, specify regionalization basis by concretizing general principles according to regional and data characteristics. Second, determine preliminary regionalization schemes using zoned classification, multi-indicator spatial clustering, and k-means clustering meth-

ods for bottom-up merging to obtain reasonable preliminary zone numbers and ranges. Finally, determine comprehensive regionalization boundaries by overlaying first-level and second-level zones, supplemented by systematic top-down spatial division. Fine adjustments are made according to regionalization principles and geographic similarities, referencing regional geographic characteristics, mainly including enclave patch and scattered patch merging, zone naming, and statistical analysis of characteristic parameters to obtain final regionalization schemes.

Results

2.1 Social Vulnerability Index Differentiation Patterns

Exposure, sensitivity, adaptability, and regional comprehensive vulnerability indices were calculated for 87 county/district units. Using natural breaks classification, evaluation results are shown in Figure 1.

2.1.1 Differentiation Patterns The exposure index generally shows a macro-scale differentiation pattern of high in the east and low in the west, high in the south and low in the north. The highest exposure areas are concentrated in prefecture-level city urban areas within Gansu, with secondary high areas concentrated in surrounding counties. This is because in northwest arid and semi-arid regions, disaster-bearing bodies such as population, economy, and planting industry are concentrated in cities and surrounding areas with better natural conditions. Medium exposure areas are mainly concentrated in counties surrounding urban areas and along the Hexi Corridor. Although western Gansu is sparsely populated, disaster-bearing bodies are concentrated in oases, resulting in medium exposure levels. Low exposure areas are concentrated on the northern edge of the Qaidam Basin and western Tibetan Plateau region, where population, economy, and planting industry volumes are all relatively small.

The sensitivity index also shows a macro-scale pattern of high in the east and low in the west, high in the south and low in the north. High-sensitivity areas are mainly concentrated in northern Tianshui City, the region with the largest population and planting industry proportion in Gansu. Secondary high areas are distributed contiguously in Longnan City and scattered in central and Hexi Corridor regions. This is because Longnan City has relatively good natural conditions, with relatively large population and planting industry proportions. Medium-sensitivity areas are distributed along the Hexi Corridor and in central Gansu, directly related to their medium-level population and planting industry proportions. Low-sensitivity areas are mainly distributed along the Qilian Mountains and Gannan Plateau region, where population, economy, and planting industry scales are relatively small.

The adaptability index shows an overall pattern of high in the west and low in the east, high in the north and low in the south. High-value areas are

concentrated in the central-western Hexi Corridor and urban areas of Baiyin City. The central-western Hexi Corridor has much smaller population, agriculture, and economic scales compared to other regions, resulting in the highest per capita resources for improving adaptability. Urban areas of Lanzhou and Baiyin City have higher urbanization levels, and under the strong provincial capital development model, they have greater resource investment for improving adaptability. Medium adaptability areas are concentrated in Dingxi City, southern Tianshui City, and Longnan City region, which have large population and economic scales and agriculture dominated by planting industry, resulting in fewer per capita adaptability resources compared to high-level areas. Low adaptability areas are mainly distributed in Gannan Tibetan Autonomous Prefecture, eastern Dingxi City, and northern Qingyang City, where population and economic development are relatively backward and per capita adaptability resource investment is smaller.

The comprehensive vulnerability index shows a pattern of high in the east and low in the west, high in the south and low in the north. High-vulnerability areas are mainly concentrated in eastern, central, and southern Gansu, clustering around densely populated disaster-prone areas such as cities. This is because these areas have high exposure and sensitivity, but due to large population and economic scales, per capita adaptability resources are relatively insufficient, resulting in the highest comprehensive vulnerability. Medium-vulnerability areas are mainly concentrated in counties along the Hexi Corridor, Linxia Hui Autonomous Prefecture, and northern Lanzhou City, directly related to their medium exposure and medium-high adaptability. Low-vulnerability areas are concentrated along the Qilian Mountains and Gannan Plateau region, where disaster-bearing bodies are small in scale, exposure and sensitivity levels are relatively low, and adaptability is relatively high.

2.1.2 Regional Differentiation Characteristics Gansu Province's regional natural disaster social vulnerability shows obvious regional differentiation characteristics. First, counties in western Gansu with vast land and sparse population have small population and economic scales with relatively concentrated distribution patterns, creating significant regional differences from central and eastern areas. Statistics on the proportion of county area at different levels of exposure, sensitivity, adaptability, and comprehensive vulnerability index show that western counties contribute to larger proportions of low exposure, low sensitivity, high adaptability, and low vulnerability areas. Combined with distribution maps, this indicates that for western Gansu's vast and sparsely populated counties, directly using county area for average indicators is inappropriate.

Second, structural differences form comprehensive vulnerability levels, meaning the high-low characteristics of exposure, sensitivity, and adaptability show clear regional differentiation. Gansu Province's comprehensive vulnerability element composition differences can be roughly divided into four regions: the Hexi Corri-

dor shows medium exposure, high sensitivity, and high adaptability; the central Loess Plateau shows high exposure and high sensitivity; the Gannan Plateau shows low exposure, low sensitivity, and low adaptability; and the southeastern mountainous region shows high exposure, high sensitivity, and low adaptability.

2.2 Comprehensive Regionalization Scheme

2.2.1 First-level Zoning Scheme The first-level zoning represents dominant natural disaster type zones. Disaster occurrence frequencies were statistically analyzed by county/district, and k-means clustering was applied for spatial clustering analysis. Based on preliminary research results, the cluster number was set to 4. After preliminary clustering and comprehensive adjustment of fragmented patches according to regionalization principles and disaster diversity indices, the first-level zoning was obtained (Figure 2). The western Hexi Corridor sandstorm-leading disaster zone (I) accounts for 40.98% of Gansu's total area. This region is deep inland with extensive deserts and gobi, where sandstorm disaster impacts far exceed those of earthquakes and rainstorm-flood disasters. The Lanzhou drought-leading disaster zone (II) accounts for 3.04% of the area, with disaster-bearing bodies such as population, economy, and planting industry highly concentrated and affected by multiple disasters, though drought impacts are relatively prominent. The Longnan rainstorm-flood-landslide-debris flow-leading disaster zone (III) accounts for 7.54% of the area. This region belongs to the Yangtze River basin, affected by the southeast monsoon and mountainous terrain, with rainstorm-flood and secondary landslide-debris flow disasters significantly higher than other natural disaster types. The central-eastern Hexi Corridor and east, central, and southern Gansan multihazard disaster zone (IV) accounts for 48.43% of the area, affected by diverse natural disasters including earthquakes, sandstorms, drought, rainstorm-flood, and secondary landslide-debris flow, with no dominant disaster type. Due to its large area, earthquake disaster frequencies are slightly higher than in other regions.

2.2.2 Second-level Zoning Scheme The second-level zoning represents social vulnerability level zones. First, for application convenience and reasonable zone numbers, the comprehensive vulnerability index was divided into high, medium, and low categories using natural breaks classification at the county/district unit scale. Then, exposure, sensitivity, and adaptability indices were used as indicators for spatial clustering analysis to obtain preliminary zones. Finally, fine adjustments were made under vulnerability level constraints to form high, medium, and low-level zones with different structural types. After adjustment, the second-level zoning can be roughly divided into 14 regions (Figure 3): 4 high-vulnerability sub-regions including Lanzhou (urban area), Wuwei City, Qingyang City, and the area from Dingxi City to Longnan City; 6 medium-vulnerability sub-regions mainly including central and eastern Hexi Corridor, Pingliang City, and eastern Longnan City; and 4 low-vulnerability sub-regions including the western Qilian Mountains and Gannan Tibetan Autonomous Prefecture region.

2.2.3 Comprehensive Regionalization Scheme Overlaying first-level and second-level zones and applying fine comprehensive adjustments according to regionalization principles and geographic similarities, including enclave and fragmented patch merging, the final comprehensive vulnerability regionalization scheme was obtained (Figure 4). The naming principle uses place names (counties/districts, geographic units) + dominant natural disaster type for first-level zones, and place names (counties/districts, geographic units) + vulnerability level for second-level zones. Zone codes adopt a structure of first-level zone type (I-IV) + second-level comprehensive vulnerability level (1-3 representing low, medium, high) (Table 4). Key original data from county/district units or raster units were averaged by new zone units to form zone characteristic parameter tables.

For practical application convenience in guiding actual social vulnerability reduction, the social vulnerability and its three elements for each county/district unit in the zones were averaged and expressed using bar charts to intuitively show systematic element differentiation patterns of natural disaster social vulnerability in Gansu Province (Figure 5). The regionalization scheme expresses not only comprehensive social vulnerability level differences but also structural differences in constituent elements, revealing that vulnerability reduction priorities should differ by zone and providing scientific foundations for zone-specific vulnerability reduction strategies.

Discussion

Regional Inappropriateness of Area-based Indicators. In this study, 耕地 and artificial land were used as benchmarks for some area-based indicators to avoid errors from large areas without disaster-bearing bodies in western Gansu's vast and sparsely populated regions. However, for densely populated eastern Gansu, disaster-bearing body distribution is not limited to 耕地 and artificial land, so this calculation method may introduce some errors. Future research should consider dividing eastern, central, and western regions and calculating area-based indicators separately according to disaster-bearing body distribution characteristics in each region to better reflect actual conditions.

Inability to Distinguish Potential vs. Actual Exposure. Exposure can be divided into potential exposure and actual exposure. Potential exposure mainly refers to the scale of disaster-bearing bodies that could be impacted by natural disasters. Actual exposure refers to the scale of disaster-bearing bodies within potential exposure that are not protected by protective measures and would truly be impacted. This study considers multiple natural disasters in the region, but data on protective measures are difficult to obtain. Additionally, the provincial newspaper disaster database mainly comes from news reports, providing insufficient specific disaster data to express the scale of disaster-bearing systems truly exposed to natural disaster impacts after removing protective measures. For example, in planting industry, irrigated areas do not suffer major impacts from drought. Therefore, exposure in this study represents potential

exposure, and future research should further distinguish actual exposure within potential exposure as data and methods improve.

Conclusions

1) Natural disaster social vulnerability in Gansu Province shows a macro-scale differentiation pattern of high in the east and low in the west, high in the south and low in the north. High-vulnerability areas are mainly concentrated in eastern, central, and southern Gansu, clustering around densely populated areas such as cities. This is because these areas have high exposure and sensitivity levels, but large population and economic scales result in relatively insufficient per capita resources for adaptability. Low-vulnerability areas are mainly distributed along the Qilian Mountains and in Gannan Tibetan Autonomous Prefecture counties, where small disaster-bearing body scales result in low exposure and sensitivity but relatively high per capita adaptability resources.

2) Spatial differentiation of dominant natural disasters is significant across different regions of Gansu Province. The first-level zoning of the comprehensive regionalization scheme shows that Gansu can be divided into four dominant natural disaster type zones, including the western Hexi Corridor sandstorm-leading disaster zone, Lanzhou drought-leading disaster zone, Longnan rainstorm-flood-landslide-debris flow-leading disaster zone, and the central-eastern Hexi Corridor and east, central, and southern Gansu multihazard disaster zone.

3) Different zones should have different priorities for reducing regional social vulnerability and improving comprehensive risk prevention levels. The 14 second-level zones in the comprehensive regionalization scheme indicate differentiation in vulnerability index levels and element structures: the western Hexi Corridor shows low exposure and high adaptability, with vulnerability mainly determined by sensitivity; the central-eastern Hexi Corridor and Lanzhou surrounding areas show medium vulnerability with high sensitivity; and eastern and southern Gansu show high vulnerability formed by high sensitivity and low adaptability.

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