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Disaster Insurance against Secondary Mountain Hazards in 32 Counties Severely Affected by the 2008 Wenchuan Earthquake

Yongshun Han[1], Shugang Peng[1], Chen Zhengchao[*2], Liu Xianzhao[1], Huang Peng[2], Dong Shaokun[1]

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Abstract China experiences the most frequent and serious mountain hazards in the world. Households, enterprises and local governments do not have the economic ability to recover and reconstruct following a catastrophic mountain hazard. Disaster insurance is an importantway to raise relief funds and share the risk and loss of mountain hazards in countries worldwide, although disaster insurance and loss rate calculations are still at an early stage. In this study, 32 counties severely affected by the 2008 Wenchuan Earthquake were selected as the study area with a township used as the basic unit of assessment. On the basis of extensive field investigations, the interpretation of remote sensing data and the results of previous studies, four methods were proposed to assess the risk of secondary mountain hazards and to calculate the premium rate for disaster insurance. Approaches for the regionalization and realization of disaster insurance were explored according to a risk assessment of secondary mountain hazards through the use of 3S techniques and established methods. The results were as follows: a) With 4154 collapses and landslides, over 1000 debris flows and 257 dammed lakes, secondary mountain hazards in the study area were controlled by active faults, seismic intensity, strata, lithology, slope and rainfall. Results showed they have become more frequent and serious; b) Disaster prevention and mitigation should be based on a vulnerability assessment. The study results allowed a classification into four zones: very high and high vulnerability zones, which accounted for 45.5% of the study area, moderate vulnerability zone (33.9% of the study area), and a low vulnerability zone (20.6% of the study area); c) Almost 80% of the study area was dominated by very high, high and moderate risk zones, accounting for 11.9%, 31.1% and 37.1% of the study area, respectively, and most of these zones were also categorized as very high, high, and moderate hazard and vulnerability zones. These zones are the key areas for secondary mountain hazard prevention and mitigation; d) Based on a quantitative risk assessment and the loss due to damages among affected entities, an insurance rate model was established and the average insurance rates in different risk zones was calculated and classified.This revealed large differences in average insurance rates among different risk zones. This is not favorable for the market operation and practice of mountain hazards insurance providers; and e) Based on townships as an administrative unit and an analysis of the ratio of contributions from different formation factors, the proposed methodologies solve such technical problems

[1] Hunan Province Engineering Laboratory of Geo-spatial Information, Hunan University of Science and Technology, Xiangtan 411201, China. E-mail first author: yongshunhan@126.com
[2] Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Beijing 100094, China.
* Corresponding author, e-mail: zcchen@ceode.ac.cn

as selecting an assessment unit and the major indices to be used, calculating the weight of each index and classifying the outcomes. The results fitted well with field investigation data, the socio-economic situation and the secondary mountain hazards in the study area. A partial post-earthquake reconstruction and disaster mitigation scheme proved to be feasible.

Key words Secondary mountain hazards; Risk assessment; Hazard insurance; Premium stipulation; Wenchuan Earthquake.

1. INTRODUCTION

China is one of countries that experience the most frequent and serious continental earthquakes and mountain hazards in the world. Over 1260 earthquakes with Ms≥7.0 have occurred in the world since the 1900s, 10% of which occurred in China. The Department of Land and Resources have confirmed the existence of over 0.23 million geo-hazards in China. Most of them are paroxysmal mountain hazards including collapses, landslides and debris flows, which seriously threaten the security of lives and properties leading to 1000 deaths and direct economic losses valued at 24.6 billion US$ every year(Jiang and Shen 2008). China has experienced a large peak of seismic activity and a remarkable degree of climate change since the 1990s. Secondary post-earthquake mountain hazards cause tremendous and lasting damage, which even exceeds those directly caused by the earthquake (Han et al. 2009). For example, on 12 May 2008,the Wenchuan Earthquake triggered 80 thousand collapses and landslides, thousands of debris flows and 257 dammed lakes with 0.15 million km^2 of destroyed land and an area of 0.5 million km^2 directly impacted. Secondary mountain hazards together with the earthquake resulted in 87 thousand deaths, including 20 thousand deaths attributed to secondary mountain hazards (Yin 2008). Moreover, the capital invested into earthquake relief and post-earthquake rehabilitation and recovery was in excess of US$ 6564.9 billion. The geo-environmental conditions of affected areas are changed substantially following strong shocks, allowing mountain hazards induced by heavy rainfall to become more frequent and serious, which results in heavy casualties and large economic losses. For example, 72 gully debris flows occurred in Beichuan County, Sichuan Province on 24 September 2008 resulting in 42 deaths and the burial of the old Beichuan County seat. An extraordinary flash flood and debris flow occurred in Zhouqu County town, Gansu Province on 8 August 2010 and resulted in 1765 deaths and direct economic losses valued at US$ 3.28 billion. There were also 30 gully debris flows, hundreds of slope debris flows and thousands of collapses and landslides along both sides of a 56 km long section of the Dujiangyan-Wenchuan Highway (Du-Wen Highway) from Yingxiu town to Weizhou town. Large scale secondary mountain hazards occurred once or twice each year after the earthquake, which severely damaged the roadbed, subgrade, bridge and tunnel of Du-Wen Highway and delayed traffic for an average of 15 days on each occasion (Table 1).

Table 1. Typical secondary mountain hazards in stricken areas following the 2008 Wenchuan earthquake.

Event	Date	Location or Scope	Secondary mountain hazards	Casualties	Economic losses or damage (billions US$)
Wenchuan Earthquake (Ms=8.0)	2008-5-12	0.5 millionkm2 area and 180 counties suffered	80 thousand landslides and collapses, thousands of debris flows, 257 dammed lakes	69,227 deaths, 17,923 missing	direct economic losses 1387.1; capital invested in recovery 6564.9
Beichuan	2008-	6 counties	72 gully debris flows,	42 deaths,	0.32

debris flow	9-24	around Beichuan, Sichuan Province	thousands of collapses and landslides	Beichuan town buried	
Yushu Earthquake (Ms=7.1)	2010-4-14	0.035 million km2 area affected	295 new mountain hazards in hidden sites	2698 deaths, 270 missing	5.2
Zhouqu debris flow	2010-8-8	Zhouqu county town, Gansu Province	extraordinary flash flood and debris flow, 1 dammed lake	1434 deaths, 331 missing	3.28
Yiliang Earthquake (Ms=5.7)	2012-9-7	Yiliang county, Yunnan Province. and Weining county, Guizhou Province	150 mountain hazards in hidden sites	80 deaths, 1.5 million affected	6.08
Lushan Earthquake (Ms=7.0)	2013-4-20	Lushan, Baoxing and Tianquan counties	355 landslides and collapses, 3 dammed lakes	217 deaths, 1.52 million affected	26.85
Du-wen highway debris flow	2013-7-10	A 56km long section of Du-Wen highway	hundreds of collapses and landslides, 46 debris flows, 24 dammed lakes		16 sites blocked, 9 bridges destroyed and faced with reconstruction

Secondary mountain hazards occur widely and cause great damage after earthquakes. Abrupt secondary mountain hazards hinder socio-economic development and post-earthquake rehabilitation in affected areas and also restrict disaster prevention and mitigation in mountainous areas. It is impossible to eliminate mountain hazards and the losses they cause, therefore it is essential to undertake economic compensation measures in the course of mountain hazard relief. In China, central and local governments at all levels undertake the contingency management of natural hazards and bear the responsibility for the risks associated with mountain hazards, while local residents rarely hold hazard insurance. Therefore, post-disaster economic compensation are mainly dependent on government subsidies and social donations. This not only adds to the financial burden of the government but also cannot fully compensate for the losses incurred because governments have limited financial resources. Governmental subsides and social donations only meet the immediate needs of daily life for local residents while for other long-term rehabilitation residents must rely on their own efforts (Mao 2006). However, a catastrophic mountain hazard often results in a large number of casualties and heavy economic losses, and many households, business enterprises and local governments do not have the economic ability to undertake long-term recovery and rehabilitation (Teng and Kato 2003; Wang 2006).

It is necessary to invest large amounts of capital in the prevention and mitigation of mountain hazards, and post-disaster rehabilitation. In addition to the direct financial investment from central and local governments, hazard insurance is an important way to raise disaster-relief funds. Disaster relief funds can help compensate for the loss of property, can share the burden of mountain hazard risks. It typically provides prompt compensation, adequate redress and an extensive guarantee of damage repair. Therefore, hazard insurance has been paid attention to by researchers in the field of natural hazard mitigation and by governments worldwide. In America, flood control and management was initiated in 1803, and an earthquake insurance policy was placed on the market in 1916 with commercial earthquake insurances subsequently expanding worldwide as a significant measure to compensate for earthquake losses (Li and Xue 1997).In 1980, the Federal Emergency Management Agency was established and the National Flood Insurance Program was implemented. Compulsory liability insurance was put into effect at this time and disaster mitigation was socialized. In Germany, the first flood insurance organization was founded in 1845 and this was followed by flood insurance organizations and companies being established in neighbouring countries such as Austria and France. Germany's present natural disaster insurance provides cover for housing, household property and business risks (Wu, Wang and Jiang 1999) and an integrated system of compulsory liability insurance and financial guarantee has now been adopted. Following the 1964 Xinxie Earthquake, Japan began to establish earthquake insurance (Teng and Kato 2003). France and Britain currently carry out arbitrary liability insurances against mountain hazards (Sun and Wang 2008).

Western countries have a high level of economic development and the mountain hazard insurances policies offered by their companies mainly serve as a supplementary insurance against natural hazards, environmental liability, and fire (Sun and Wang 2008; Jiang and Shen 2008). In China, there is not yet an independent insurance body to regulate the insurance policies offered against mountain hazards. At present, the business of mountain hazard insurance is undertaken by several large insurance companies, and the insurance liabilities of mountain hazards including collapses, landslides, and debris flows etc. are covered and generally accepted in comprehensive property insurance policies with unified provisions and insurance rates throughout China (Wang 2006). However, China covers a vast territory and different regions are subject to a different probability and degree/ intensity of mountain hazards. Therefore the insurance premium for cover against a mountain hazard cannot be calculated according to a unified insurance rate, and it is necessary to make a risk assessment of mountain hazards in line with the national or provincial mountain hazard control program, and then to further regionalize the hazard and risk of mountain hazards in all quarters. This allows insurers to stipulate different insurance rates in the light of the different hazards or risks posed by mountain hazards in different regions.

The theoretical understanding of mountain hazard insurance is still at an early stage and still requires unified standards and methods for the risk assessment of secondary mountain hazards. Calculating the loss or loss rate due to hazard bearing bodies is of importance to hazard insurance but also to theoretical research (Wang 2006). In view of the above, risk-based disaster insurance against mountain hazards was considered in this study. Thirty two counties that were severely-affected by the 2008 Wenchuan Earthquake were used as the study area and a comprehensive database of secondary mountain hazards was established for the region on the basis of previous research results, an extensive field investigation, the interpretationof remote sensing data and other relevant data collection. The methodologies used for assessing the hazard, vulnerability and risk of secondary mountain hazards were reviewed to determine which was the most appropriate for calculating the rate of disaster insurance premiums. With townships as the unit of assessment, hazard, vulnerability and risk assessments and a regionalization of secondary mountain hazards in the study area were determined by means of 3S techniques and established methods.The loss rate of hazard bearing bodies and the insurance rate for cover against secondary mountain hazards were calculated in accordance with the related degree of hazard or risk associated with mountain hazards.

2. STUDY AREA AND DATA PROCESSING

2.1 Study area

2.1.1 Natural geo-environment

Thirty two counties were severely affected by the 2008 Wenchuan Earthquake including Wenxian

County in Gansu Province, Ningqiang County in Shaanxi Province and 30 other counties in Sichuan Province. The affected land area totalled 83645 km2. The region is located in the transition zone between the Tibetan Plateau and Sichuan Basin from 101°58 '05" to 106°29'54"E and N29°06'03" to 33°17'37". There is a complex topography, which consists of high mountains, plateaus, mid to low altitude mountains, hills, plains, and a basin. The whole terrain has a northwest to southeast trend, and can be divided into three typical geomorphologic zones: (1) The Longmen Mountains and the Western Plateau Mountain Zone in the northwest of the study area (marked as Zone 1) with high mountains, steep gullies, an altitude from 3000 to 5500 m and a difference in relative altitude of between 1500 and 3000 m, (2) The Longmen Piedmont Zone in the middle of the study area (marked as Zone 2), and (3) The Sichuan Basin Hilly Zone in the east of the study area (marked as Zone 3) where most of the altitude is no more than 1000 m and the difference in relative altitude is between 60 and 800 m (Figure 1).

This area is a large denudation region, with complicated geological structures and the development of many faults. The three active fault belts in the Longmen Mountains, are known as the Mao County-Wenchuan Fault, the Beichuan-Yingxiu Fault and the Anxian-Guanxian Fault, and all cut obliquely across the study area in a NE−SW direction with a length of 500 km and width of 80 km. Strong neotectonic activity causes frequent high-intensity earthquakes. For example, three strong earthquakes with an Ms over 7.0 have occurred in the study area in the past 80 years, including the 1933 Diexie Earthquake (Ms = 7.5), the 1976 Pingwu-Songpan Earthquake (Ms = 7.2), and the 2008 Wenchuan Earthquake (Ms = 8.0). The strata are well exposed and the igneous, sedimentary, and metamorphic rocks are all developed. This area is dominated by carbonate rocks, clastic rocks, and loose deposits of sedimentary rocks with an abundance of loose materials and is prone to secondary mountain hazards.

There is a large variation in the local climate with an unbalanced seasonal distribution of temperature, precipitation, and illumination. The eastern part of the study area is within the subtropical humid monsoon climate zone. The climate of the western part includes dry valley and moist monsoon zones and is affected by the presence of the mountains. Rainfall often occurs at night and the annual precipitation is mainly concentrated in the summer and autumn. The city of Yaan is a rainstorm centre with an annual maximum rainfall of 1732 mm and 10 rainstorm days, but the counties of Maoxian and Wenchuan in the arid valley zone have annual rainfalls of only 484 mm and 524 mm, respectively. The major rivers include the Minjiang River, Jialingjiang River, Fujiang River, Daduhe River and Bailong River. The dense river network, deeply-cut gullies and abundant water resources are all part of the Yangtze River hydrologic system.

2.1.2 Socio-economic conditions

At the end of 2007, the study area had a total population of 11.997 million, with 11.325 million residents living in agricultural areas and 0.672 million urban residents. The number of employed people was 8.689 million. However, the population distribution was extremely uneven. The population density and number of towns was high in Zone 2 with 600 to 800 persons/km2 moderate in Zone 3 with 400 to 600 persons/km2 and low in Zone 1 with 150 to 300 persons/km2in its western area and 50 to 150 persons/km2in the arid valley along the Minjiang River.

There were large differences in the level of economic development in the study area. The level of economic development of the seven counties in Zone 2 was higher than the other two zones with a GDP of 125.3 billion US $, GDP per capita of 3055.3 US $, economic density of 1.26 million US $/ km2 and a rural per capita net income of 813.7 US $. The level of economic development of the 14 counties in Zone 3 was relatively high with a GDP of 15.3 billion US $, GDP per capita of 1,940 US $, economic density of 730 US $ / km2 and a rural per capita net income of 610 US $. The 11 counties in Zone 1 had the lowest level of economic development with a GDP of 2.2 billion US $, GDP per capita of 1,735 US $, economic density of 46 thousand US $ / km2 and a rural per capita net income of 431 US $. The 2008 Wenchuan Earthquake resulted in direct economic losses of 1,129 billion US $ in the study area.

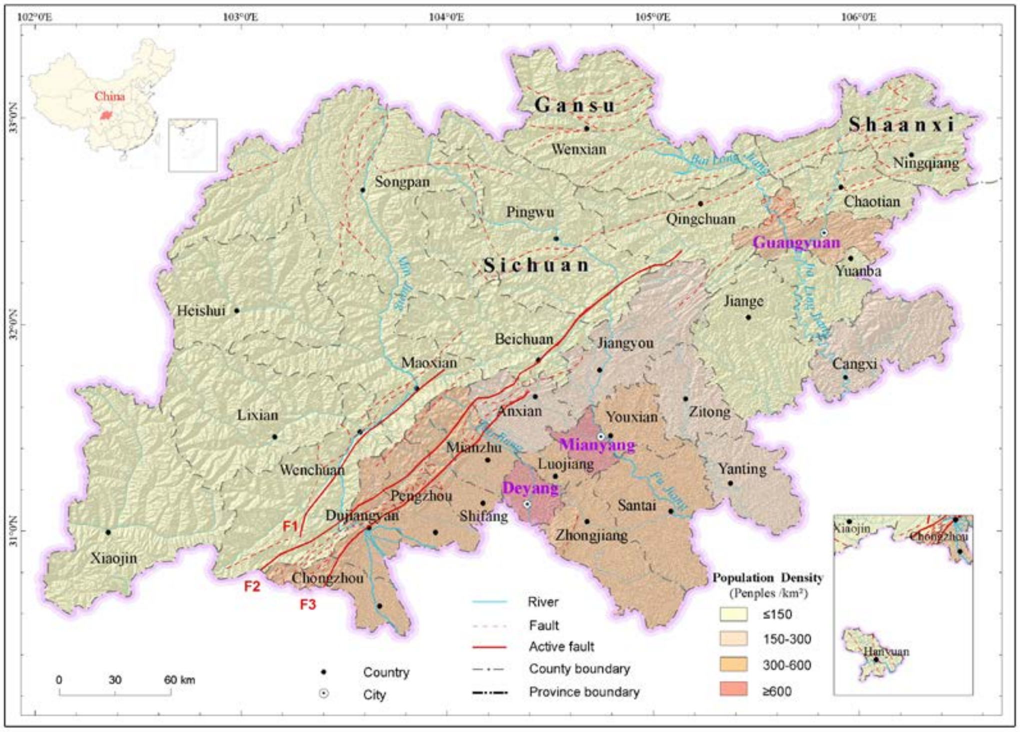

Figure 1. Distribution of population and mountain hazards in the study area

2.1.3 Mountain hazards

As a result of the specific geo-environment and socio-economic conditions, frequent heavy rainstorms and strong earthquakes as well as increasingly violent human activities, the study area has the most serious mountain hazards in China. Before the earthquake, there were 2675 sites subject to mountain hazards in this area, most of which were due to collapses, landslides and debris flows. After the earthquake, there were 8093 new mountain hazard sites including 4154 collapses and landslides, over 1000 debris flows and 257 dammed lakes. The secondary mountain hazards are distributed along active fault belts and rivers. These mountain hazards are characterized by their abrupt occurrence, a chain of disasters, concealment, an obvious hysteresis effect, and large amounts of physical destruction, and their distribution is affected by the geological structure, earthquake intensity, strata lithology, slope, and elevation. With the increasing enhancement of post-earthquake restoration and human activities, secondary mountain hazards in the study are likely to be triggered by heavy rainfall and will become more frequent and serious. A higher incidence of secondary mountain hazards is expected in this area in the 5 to 10 year period after the earthquake. It is therefore necessary to conduct risk management and ensure adequate disaster insurance against secondary mountain hazards.

2.2 Data sources and processing

Mountain hazards have a close relationship both with internal factors such as topography, geomorphology, lithology, and geological structure and with external geo-environmental factors including hydrology, vegetation cover, and soil conditions. They are induced by rainfall, earthquakes, and human activity and can cause great harm to life and property. Therefore, all of these factors should be taken into account when undertaking a risk assessment of secondary mountain hazards. These factors can be made assessment from large amounts of heterogeneous and multi-source data, including spatial data, attribute data, socio-economic data, statistics, multi-media data, thematic data, and disaster data (Han et al. 2009). It is necessary to adopt the use of some appropriate data models, processing methods, data standards, and database management systems for processing, organizing, storing, and managing this data. From the perspective of disaster management systems and the risk assessment of secondary mountain hazards, the required data sources can be classified into five types as follows.

2.2.1 Basic spatial data

Basic spatial data consists of topographic, geomorphologic, geologic, hydrologic, meteorological, land-use, seismic and human activity data, and materials, which reflect the formation of and conditions that induce mountain hazards and are the basis of a risk analysis and the cartography of mountain hazards. Topographic and geomorphologic data mainly comprise digital linear and raster graphs with 1 to 50 thousand and 1 to 100 thousand scales as well as GeoDEM images with a resolution of 30 m. These data were used here to generate elevation, slope, aspect, cutting density, and surface undulations by means of spatial analysis models. Geological data include stratigraphy, lithology, geological structure, and geological rock group, and were mainly acquired from 1:200 thousand geological maps and the Chinese Geological Atlas. Vegetation and land-use data contain the type and distribution of pre and post-earthquake land coverage and was mainly obtained from 1:100 thousand vegetation and land-use maps made in 2000. Meteorological data includes precipitation, temperature and evaporation, which were collected from meteorological departments, related thematic atlases and the China Meteorological Data Sharing Service System. Hydrologic data includes the extent of river systems, runoff, and groundwater, which were collected from 1:500 thousand hydro-geological maps and other thematic atlases. Seismic data includes records of historical earthquakes and seismic intensity or acceleration maps, which were obtained from earthquake departments, published literature, and related atlases.

A series of unified geospatial references and coordinate systems were established. Then all of the basic spatial data was processed into vector or raster digital data and managed in the form of hierarchical spatial layers using ArcGIS9.3 software. By means of vector editing and processing, spatial analysis, and data format conversion, a basic spatial database with corresponding attribute information was established and managed using ArcSDE.

2.2.2 Thematic data

Thematic data relating to secondary mountain hazards includes the distribution, development, and mode of action of mountain hazards, as well as disaster prevention and control information. These data are important for the risk assessment of mountain hazards and represent the characteristics of the development of a mountain hazard and the resulting disaster, being a function of structural engineering. Mountain hazard data contains the type, distribution, scale, frequency, magnitude, and mode of action of pre- and post-earthquake mountain hazards. Disaster prevention and control data include information relating to structural engineering and the effectiveness, investment required, and type of countermeasures needed for disaster prevention and control, as well as the capacity building required to manage mountain hazards. All of this information was acquired mainly from a field investigation, interpretation of remote sensing data, the existing literature including published reports and atlases, and the Department of Land and Resources and the Chinese Academy of Sciences(CAS). As with the basic spatial data, the thematic data was processed through ArcGIS9.3 software and a thematic database was established.

2.2.3 Socio-economic data

Socio-economic data includes the population, key industries and their output, levels of wealth from assets and resources, as well as the losses and damage caused by mountain hazards. These data reflect the pre-earthquake socio-economic conditions and post-earthquake socio-economic losses and are the basis of a vulnerability assessment and disaster insurance against mountain hazards. They were collected from a field investigation, administrative statistics, and existing literature including published reports and related atlases. This data was standardized and presented in the form of two-dimensional tables. As an object-oriented relational database management system, SQL Server-2008 was used to process, organize, store, and manage these data, leading to the establishment of a socio-economic thematic database.

2.2.4 Remote sensing data

Remote sensing images were mainly used to update related basic and thematic data for risk analysis and to survey and monitor secondary mountain hazards, levels of disaster damage and losses, land cover, and construction activities. These images included ADS40(0.5m with and 0.5m resolution), IKNOS(1m), ALOS(1m), FormoSat-2(2m), Spot(5m and 10m), ETM(15m) and Modis (250m) images with phases from May, 2008 to May, 2013. ADS40 images were obtained from the Institute of Remote Sensing and Digital Earth. CAS, ETM and Modis images were downloaded free of charge from various websites and the other images were obtained by purchasing them from the relevant companies. The data were processed and analysed by means of Erdas9.1, ENVI4.7, ArcGIS9.3, and Google Earth software. For interpretation, remote sensing data was combined with large scale digital topographic maps, field investigation materials, and experimental data, and information relating to pre and post-earthquake land cover, mountain hazards, disaster losses, and damage was extracted.

2.2.5 Hypermedia data

Hypermedia data mainly included pictures, records, videos, maps, literature, reports, models, and methods. The information obtained included a large number of valuable first-hand data collected from the field investigation, theoretical analysis, numerical computation, and the compilation of relevant materials. Most of these data were processed and stored using SQL Server-2008 software and a hypermedia database was established including data sourced from multi-media, literature, models, methodology, and existing knowledge.

3. METHODOLOGIES

Calculating the premium rate is crucial for disaster insurance against mountain hazards. Based on the hazard and vulnerability assessments, a risk assessment of specific mountain hazards can be made and regionalized, so as to determine the probability of occurrence, endangerment, degree of risk, and scope of the mountain hazard. The outcomes of a risk assessment of mountain hazards can then provide a basis or reference for calculating the insurance premium and preventing losses for different hazard classifications and regions.

3.1 Hazard assessment model

Hazard assessment is a precondition for the risk assessment of mountain hazards. It focuses on the natural attributes of mountain hazards and is used to determine the probability of occurrence, degree of hazard and scope, of the mountain hazard. The factors used to assess a hazard can be divided into topographic, geologic, meteorological and hydrologic, land cover, and a human activity indexes, and each index can be divided into sub-indexes. All of the related factors and indexes form a hierarchy index system for hazard assessment and an analytic hierarchy process (AHP) model can then be used to process the assessment of indexes and calculate their weightings. The related procedures and methods used to determine secondary mountain hazards in the study area were previously reported and their corresponding outcomes were considered in this study (Han et al. 2009).

To determine the hazard probability and value of mountain hazards in a certain area, the "hazard degree index" was introduced and can be defined as the value or magnitude of a hazard, such as a mountain hazard. It can be expressed as a function of the weighting of each major index and its corresponding weighting (Formula 1):

$$H_i = \sum_{j=1}^{m} w_{1j} \cdot X_j \quad (i=1,2,\ldots,n;\ j=1,2,\ldots,m) \tag{1}$$

where n is the number of assessment units, i is the ith assessment unit; m is the number of assessing indexes, j is the jth assessing index; H_i is the hazard degree index of the ith assessment unit; X_j is the value of the jth assessing index in the ith assessment unit, which can be determined from normalized data; and w_{1j} is the weight of the jth assessing index (X_j), which can be determined by correlation analysis and expert judgment.

3.2 Vulnerability assessment model

Vulnerability assessment is the basis of the risk assessment of mountain hazards. It focuses on the socio-economic attributes of mountain hazards and is used to determine the probability and value of casualties and economic losses caused by mountain hazards. Factors influencing a vulnerability assessment include population, key industries and their output, levels of wealth from assets and resources, and the countermeasures employed for disaster prevention and control. A comprehensive vulnerability assessment of mountain hazards can be divided into social vulnerability and economic vulnerability and can be calculated by means of an integrated analysis of the two single vulnerabilities. Large amounts of heterogeneous data and materials related to the vulnerability assessment are located in different governmental departments, research institutions, and with key personnel. It is difficult to collect some of this primary data and the information acquired is often incomplete.

As a nonlinear mathematical model, the grey system is based on the principle of non-complete information. Considering the fuzziness, greyness, randomness, and uncertainty of the assessment data, index, and criteria, a grey system can make full use of limited system information. Only by processing part of the available data or information can this system make a dynamic description and evaluation of the possible outcomes, thus largely overcoming the subjective error of weightings within a vulnerability assessment index (Song et al. 2002). The main procedure is as follows:

Step 1.Select the reference and comparative sequences.

The most important index for assessing the vulnerability of mountain hazards is selected as the reference sequence, marked as Y_0. Then comparative sequences are selected successively as Y_j.

$$\begin{cases} Y_0 = (Y_0(1), Y_0(2), \ldots, Y_0(i), \ldots, Y_0(n)) \\ Y_j = (Y_j(1), Y_j(2), \ldots, Y_j(i), \ldots, Y_j(n)) \end{cases} \quad (i = 1,2,..,n;\ j = 1,2,\ldots,m) \tag{2}$$

Where i, n, j, m are the same as in Formula 1; Y_0 is the reference sequence; and Y_j is the jth comparative sequence.

Step 2.Normalize the assessing indexes.

Different assessing indexes and the related data have different types of data, precision, and dimensions.

Therefore, these data must be normalized to dimensionless values between 0 and 1 (Formula 3).

$$\mathrm{Y}_i^{'}(k) = \frac{\mathrm{Y}_i(k) - \min \mathrm{Y}_i(k)}{\max \mathrm{Y}_i(k) - \min \mathrm{Y}_i(k)} \qquad (k = 1,2,...,n; i = 1,2,...,m) \tag{3}$$

where m and n are the same as in Formula 1; k is the k^{th} assessment unit; i is the i^{th} assessing index; $Y_i(k)$ is the true value of the i^{th} assessing index in the k^{th} assessment unit; Y_i'(k) is the normalized value of $Y_i(k)$; and max Y_i (k) and min $Y_i(k)$ are the maximum and minimum values of $Y_i(k)$ in all assessment units.

Step 3.Calculate the absolute differences between the reference sequence and comparing sequences.

$$\Delta_i(k) = \left| \mathrm{Y}_i^{'}(k) - \mathrm{Y}_i^{'}(0) \right| \tag{4}$$

where i, k and Y_i'(k) are the same as in Formula 3; and $\Delta_i(k)$ is the absolute value of the difference between Y_i'(k) and Y_i'(0).

Step 4. Calculate the maximum and minimum values of the above absolute differences.

$$\begin{cases} \Delta\min = \min(\min \Delta_i(k)) \\ \Delta\max = \max(\max \Delta_i(k)) \end{cases} \tag{5}$$

where $\Delta_i(k)$ is the same as in Formula 4; $\min \Delta_i(k)$ is the minimum value of the ith of $\Delta_i(k)$ in the kth assessment unit and Δ min is the minimum value of the ith of $\Delta_i(k)$ in all assessment units; and $\max \Delta_i(k)$ and Δ max are similar to $\min \Delta_i(k)$ and $\min(\min \Delta_i(k))$.

Step 5. Calculate the correlation coefficient.

$$\varphi_{\mathrm{i}}(k) = \frac{\Delta\min + \partial \cdot \Delta\max}{\Delta_i(\mathrm{k}) + \partial \cdot \Delta\max} \tag{6}$$

where $\Delta_i(k)$, Δ min and Δ max are the same as in Formulas 4 and 5; ∂ is a proportionality constant between 0 and 1, generally taken as 0.5; and $\varphi_{\mathrm{i}}(k)$ is the correlation coefficient of $\Delta_i(k)$.

Step 6. Calculate the correlation value.

$$\mathrm{R}_{\mathrm{i}}(Y_0, Y_{\mathrm{i}}) = \frac{1}{n}\sum_{i=1}^{n} \varphi_{\mathrm{i}}(k) \tag{7}$$

where i, k, n, Y_0 and Y_i are the same as in Formula 2; $\varphi_{\mathrm{i}}(k)$ is the same as in Formula 6; and $\mathrm{R}_{\mathrm{i}}(Y_0, Y_{\mathrm{i}})$ is the i^{th} correlation value between the reference sequence and the i^{th} comparative sequence.

Step 7. Calculate the weighting of each assessing index.

$$w_{2i} = M_i / \sum_{i=1}^{n} M_i \tag{8}$$

Where i is the same as in Formula 2; M_i is the corresponding value of $R_i(Y_0, Y_i)$; and W_{2i} is the weighting of the i^{th} assessing index.

Step 8. Calculate the vulnerability degree index.

To determine the degree and value of mountain hazard vulnerability in a certain area, the "vulnerability degree index" was introduced to calculate the vulnerability value or the magnitude of a mountain hazard. It reflects the degree of vulnerability for a specific socio-economic situation in each assessment unit, i.e., the larger its value the more vulnerable is the socio-economic situation of a certain unit. It can be expressed as a function of the weighting of each vulnerability index and its corresponding weighting (Formula 9):

$$V_i = \sum_{j=1}^{m} w_{2j} \cdot Y_j \quad (i=1,2,\ldots,n;\ j=1,2,\ldots,m) \tag{9}$$

where i, j, m and n are the same as in Formula 2; Y_j is the value of the j^{th} assessing index in the i^{th} assessment unit; w_{2j} is the same as in Formula 8; and V_i is the vulnerability degree index of the i^{th} assessment unit.

3.3 Risk assessment model

According the definition of risk given by the Department of Humanitarian Affairs of the United Nations and other researchers(Hollingsworth and Kovacs 1981; Varnes1984; Maskrey1989; Tobin 1997; Delye et al. 1998), risk is dependent on the hazard and the vulnerability and there is a positive correlation between the risk and both the hazard and vulnerability. Therefore the risk can be expressed as the product of the hazard and the vulnerability and a "risk degree index" can be introduced to determine the risk probability and to evaluate the mountain hazards in a certain area as follows(Formula 10):

$$R_i = H_i \times V_i \qquad (i = 1,2,...,n) \tag{10}$$

where H_i and V_i are the same as in Formulas 1 and 9; and R_i is the value of the degree of risk of mountain hazards in the i^{th} assessment unit.

3.4 Disaster insurance rate model

The insurance premium rate includes the pure premium rate and the additional premium rate. The insurance premium rate is related to the costs, profit, and risk of the insurer and the insured (Harrington and Niehaus 2005).An analysis of the expected utility and insurance premium was undertaken in our preliminary study (Han 2008). Previous studies of disaster insurance against earthquakes and floods were referred to in the paper (Qin 2004; Zheng 2012). The insurance premium rate can be calculated on the basis of a risk assessment of secondary mountain hazards as follows:

$$P_{Ir} = P_{cr} + P_{ar} \tag{11}$$

Where P_{ir} is the insurance premium; P_{cr} is the pure premium rate; and P_{ar} is the additional premium rate

The pure premium rate is the rate used to pay indemnities or reparations and can be calculated as follows (Formula 12):

$$\mathrm{P_{cr}} = \overline{\rho} \cdot (1 + k) \tag{12}$$

Where $\mathrm{P_{cr}}$ is the same as in Formula 11; $\overline{\rho}$ is the ratio of payment to the total amount insured in a certain period, i.e., the average loss rate; and k is an additional risk coefficient.

The additional rate (Par) is the rate required to maintain the normal operation of an insurance company, which includes operating costs, safety and amortization, and profit from ordinary activities. It is usually expressed as a percentage of the pure premium rate and the ratio is denoted as γ.

Therefore, the insurance premium rate can be calculated as follows (Formula 13):

$$\begin{cases} \mathrm{P_{Ir}} = \overline{\rho} \cdot (1+k) \cdot (1+\gamma) = \rho_T \cdot \pi \cdot (1+k) \cdot (1+\gamma) \\ \rho_T = \dfrac{A_L}{A_I} \end{cases} \tag{13}$$

where $\mathrm{P_{Ir}}$, $\overline{\rho}$, k and γ are the same as in Formulas 11 and 12; ρ_T is the comprehensive rate of property losses; A_L is the total loss of assets; A_I is the total value of assets; and π is the probability of occurrence of mountain hazards, which is used instead of the structural engineering standards, (e.g., if the probability of occurrence is once in a century π is 1%).

Under the principle of rate fairness and for security requirements, γ is taken as 20% and k as 10%, which means the annual surplus is equivalent to 10% of the compensation funds as a risk surcharge (Han 2008).

4. CASE STUDIES

4.1 Assessment unit

The selection of an adequate assessment unit is the basis of the risk analysis, regionalization, and cartography of secondary mountain hazards. It has a direct influence on the reliability, accuracy, and application of risk assessment results. However, it is necessary to maintain interior similarity in a unit while having a large dissimilarity between different units. Common assessment units include grid cells, geomorphic units, topographic units, small watersheds, and units with homogeneous conditions such as administrative divisions. Grid cells have the advantage of rapid element subdivision and overlap operation in the form of a matrix, and are therefore easy to operate. However, they separate the natural geo-conditions and related information and cannot reflect the actual situation of a mountain disaster. Geomorphic units, topographic units, and small watersheds represent the actual situation and the formation of mountain hazards, but it is difficult to collect, process, and analyse socio-economic data when using these units. A county-level administrative divisional unit is more suited to socio-economic investigation and analysis, and is favoured by governments at all levels when making disaster prevention and mitigation decisions and to undertake disaster prevention planning and risk management. However, this unit is typically of a larger scope and has a lower assessment accuracy, and it still fails to reflect the geo-environment and the formation of mountain hazards.

Mountainous areas account for 90.9% of the study area, with 65.1%of the area being classed as a middle-high altitude mountainous area. The boundaries of towns in mountainous areas are determined by rivers and the ridgelines of watersheds. As a result, these town boundaries contain most of the relatively

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complete small watersheds and topographic and geomorphic units and to a certain extent reflect the geo-environment of mountain hazards. The town boundary unit is the basic unit used for disaster prevention and mitigation, the management of society, and is also used in socio-economic surveys. The town-level administrative unit was therefore selected as the basic unit in the risk assessment and analysis of disaster insurance against secondary mountain hazards.

4.2 Hazard assessment of secondary mountain hazards

The results of previous hazard assessments of secondary mountain hazards in the study area were adopted and applied to undertake the risk assessment and disaster insurance analysis. By considering the formation, development, and factors that trigger secondary mountain hazards, eleven assessment indexes were selected to establish a system for assessing hazards. The AHP model and Formula 1 were used to calculate the weighting and hazard degree index, and the hazard assessment outcomes were classified into four zones: very high, high, moderate, and low hazard zones (Han et al. 2009)(Table 2, Figure 2).

Figure 2. Hazard regionalization map of secondary mountain hazards in the study area

Table 2. Hazard assessment statistics for secondary mountain hazards in the study area

Hazard zone	Hazard index	Affected counties	Number of towns	Zonal area/km2	Ratio /%
Low	< 0.5	An, Jingyang, Dujiangyan, Heishui, Luojiang, Mianzhu, Ningqiang, Pengzhou, Santai, Shifang, Yanting, Zhongjiang	113	6920.76	9.4
Moder-ate	0.5~0.6	An, Beichuan, Cangxi, Chongzhou, Jingyang, Dujiangyan, Lizhou, Yuanba, Hanyuan, Heishui, Jiange, Jiangyou, Li, Luojiang, Mao, Fucheng, You, Mianzhu,	431	38570.06	52.4

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		Pengzhou, Qingchuan, Santai, Songpan, Wen, Wenchuan, Yanting, Zhongjiang, Zitong			
High	0.6~0.7	An, Beichuan, Chongzhou, Dujiangyan, Lizhou, Chaotian, Hanyuan, Jiange, Jiangyou, Li, Mao, Mianzhu, Pengzhou, Pingwu, Qingchuan, Shifang, Songpan, Wen, Wenchuan, Xiaojin	205	20385.24	27.7
Very high	> 0.7	An, Beichuan, Chongzhou, Dujiangyan, Lizhou, Chaotian, Hanyuan, Hei, Jiange, Jiangyou, Mao, Mianzhu, Pengzhou, Pingwu, Qingchuan, Shifang, Songpan, Wen, Wenchuan, Xiaojin	90	7691.63	10.5

4.3 Vulnerability assessment of secondary mountain hazards

The vulnerability assessment of secondary mountain hazards was comprised of a social vulnerability assessment and an economic vulnerability assessment and its value was dependent on the amount, quality, structure and disaster resilience of the population and local economy. Through the collection of relevant materials, field investigation, sampling, literature retrieval, and statistical processing, a large amount of pre and post-earthquake socio-economic data was acquired, including population, industrial output, fixed assets and related investments, various regional resources, housing, construction, transportation, health care, education, ethnicity, and disaster losses. By combining the direct index with an indirect index, these data were compiled, processed and piloted to establish a socio-economic database. Based on an analysis of the degree of contribution to each factor, ten assessment indexes were selected to undertake the social vulnerability assessment of secondary mountain hazards: total population (Y_1), residential population (Y_2), natural population growth rate (Y_3), sex ratio (Y_4), age structure (Y_5), ethnic structure (Y_6), education (Y_7), disaster prevention and mitigation capabilities (Y_8), medical care (Y_9), and road network structure and strength (Y_{10}). Seven assessment indexes were selected to undertake the economic vulnerability assessment: economic output (Y_{11}), economic growth rate (Y_{12}), value of fixed assets (Y_{13}), value of resources (Y_{14}), industrial structure (Y_{15}), disaster prevention and resilience (Y_{16}) and environmental conditions (Y_{17}). An index system for the vulnerability assessment of secondary mountain hazards was then established as shown in Table 3.

Table 3. The index system for the vulnerability assessment of secondary mountain hazards

Assessment types	Factor type	Index	Remarks
Social vulnera-bility	Population size	Y_1	The total household population by the end of a certain year /10 thousand persons
		Y_2	Current population excluding migrant workers and employment/10 thousand persons
		Y_3	The difference between birth rate and mortality / %
	Population structure	Y_4	The ratio of the male and female population / %
		Y_5	The proportion of the population under 15 and over 65 / %
		Y_6	The proportion of the minority population / %

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		Y_7	The proportion of the population of primary school age and lower / %
	Disaster prevention & mitigation	Y_8	Measures and capacity building for disaster prevention and mitigation
		Y_9	The total number of hospital beds
		Y_{10}	The number, quality, structure and strength of roads
Economic vulnera - bility	Economic activity	Y_{11}	The annual total output of the primary, secondary and tertiary industries /10 thousand US$
		Y_{12}	The annual growth rate of total industrial output / %
		Y_{13}	The cumulative total investment in fixed assets in a decade / billion US $
		Y_{14}	The value of land resources / 10 thousand US $
	Economic structure	Y_{15}	The proportion of secondary and tertiary industries / %
	Disaster resilience	Y_{16}	Industry aggregation and its disaster resilience
		Y_{17}	The geo-environment in which major economic entities are located

Because of the large differences in the values and dimensions of different data, these assessment indices were normalized to a value between 0 and 1, so as to avoid concealing the characteristics of the data. Then the 17 normalized assessment indices were input into Formulas 2 to 9 to calculate the social vulnerability degree index and the degree of economic vulnerability index for each assessment unit. As a result, a comprehensive vulnerability degree index was calculated by means of the square root model, and the results were graded and classified into four vulnerability zones (very high, high, moderate and low vulnerability) according to an arithmetic sequencing method(Table 4, Figure 3).

Table 4.Vulnerability assessment statistics for secondary mountain hazards in the study area

Vulnerability zone	Vulnerability degree index	Number of affected counties	Number of affected towns	Zonal area / km2	Ratio of zonal area to the study area
Low	< 0.26	5	118	17213.41	20.58
Moderate	0.26~0.30	9	217	28390.71	33.94
High	0.30~0.34	14	421	29904.25	35.75
Very high	>= 0.34	4	163	8129.85	9.72

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Figure 3.Regionalized vulnerability map of secondary mountain hazards in the study area

The results of the vulnerability assessment show that:

a) The study area is dominated by moderate, high and very high vulnerability zones, which account for 79.4% of the total area, and most of the high and very high zones are located in the Longmen Piedmont Zone (Zone2), which has a high population density and high levels of economic activity. The low vulnerability zone accounts for 20.6% of the study area and most of this zone is situated in the northwest high mountain area (Zone1) with a high degree of hazard.

b) The very high vulnerability zone is mainly located in Zones 2 and 3, with an area of 8129.85 km2 and comprises 9.7% of the study area. This zone contains four county-level cities and 163 towns with a relatively flat terrain, a concentrated population, a higher carrying capacity of environmental resources, and well developed socio-economic conditions. For example, its total assets account for 20% of the total assets of the whole study area and its annual economic output accounts for 30% of the total for the whole study area. From the results of the hazard assessment, 72.3% of the area of this zone has a moderate degree of hazard, while 24.9% of the area of the zone has a very high and high degree of hazard. Therefore, it is inadvisable to undertake construction and development in the very high and high hazard areas in this zone, while it is advisable to rationally exploit the moderate and low hazard areas in this zone while limiting the population of the land to within the carrying capacity according to available resources and environmental conditions.

c) The high vulnerability zone contains 14 county-level cities and 421 towns. It extends for an area of29904.25 km2, which accounts for 35.75% of the study area. Over two-thirds of this zone is located in Zone3 with a relatively large population and a high population density of 350 persons/km2, but the other third is located in Zone2 with a lower population density of less than 30 persons/km2. The socio-economic conditions of this zone are relatively well developed and its annual gross domestic product accounts for more than 50% of the total for the whole study area. The combined annual gross domestic product (2012) of Jingyang, Pengzhou, Ningqiang, and Dujiangyan county-level divisions is more than 3.28 billion US $. When considering the hazard assessment results, 48.3% of the area had a very high or high degree of hazard while 51.7% of the area had a moderate or low degree of hazard. This zone was severely affected by the 2008 Wenchuan earthquake and the active Longmenshan faults and is subjected

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to medium-large secondary mountain hazards. Almost half of this zone is also a very high or high hazard zone, which are the key areas where attention should be focused on the prevention and mitigation of secondary mountain hazards.

d) The moderate vulnerability zone contains nine county-level cities and 217 towns. It extends for an area of28390.71km2, which accounts for 33.94% of the study area. Most of this zone is located in Zone1 with a relatively small population and the population density of 75% of the zone is less than 150 persons/ km2. Its economy is underdeveloped with lower total assets than the other zones. When considering the hazard assessment results, 37.4% of this zone had a very high or high degree of hazard, 60.1% had a moderate degree of hazard and only 2.5% had a low degree of hazard. Although most of this zone is prone to secondary mountain hazards, it is considered to be only a moderate vulnerability zone due to its relatively lower socio-economic conditions.

e) The low vulnerability zone contains five county-level cities and 118 towns. It extends for an area of17213.41 km2, which accounts for 20.58% of the study area, most of which is located in Zone1. It is a mid-high altitude mountain area that was affected by the 2008 Wenchuan earthquake and the active Longmenshan faults and is subjected to secondary mountain hazards. However, this zone has poor socio-economic conditions with a sparse population, very scarce and barren farmlands and very low levels of environmental resources. Its cumulative total investment in fixed assets in a decade was less than 10% of the total for the whole study area. When considering the hazard assessment results, 45.9% of this zone had a very high or high degree of hazard and the remaining 54.1% had a moderate degree of hazard. This zone is extremely vulnerable to secondary mountain hazards and it is inadvisable to only conduct small scale construction and development in the hazard areas of this zone.

4.4 Risk assessment of secondary mountain hazards

Considering the danger from secondary mountain hazards and the socio-economic conditions, the results of previous risk assessments were reviewed and the weightings of the hazard degree index and the vulnerability degree index were valued as 0.64 and 0.35, respectively. The hazard degree index and the vulnerability degree index of each assessment unit were input into Formula 10 and the corresponding risk degree index was calculated. Then the results were graded and classified into four risk zones (very high, high, moderate, and low risk) according to the Fisher-Jenks algorithm method (Table 5, Figure 4).

Table 5.Risk assessment statistics for secondary mountain hazards in the study area

Risk zone	Number of affected counties	Number of affected counties	Zonal area / km2	Ratio of zonal area to the study area/ %
Low	14	150	16703.56	19.97
Moderate	29	379	31012.66	37.08
High	24	307	26001.50	31.09
Very high	14	83	9927.89	11.87

Figure 4. Regionalized risk map of secondary mountain hazards in the study area

The results of the risk assessment show that:

a) The study area is dominated by moderate, high and very high risk zones, which account for 80% of the study area, and most of very high risk zones are located in Zone2, along the three active faults which triggered the 2008 Wenchuan Earthquake. High and moderate risk zones account for 68.2% of the study area and 77.4% of the high and moderate risk zones are also very high and high hazard areas.

b) The very high risk zone is mainly located in Zone2 with an area of 9927.89km^2, accounting for 11.87% of the study area. This zone contains 14 county-level cities and 83 towns and is mainly located in Zone2. The zone is near to three active faults, and it was severely affected by the 2008 Wenchuan Earthquake and is subjected to large-scale mountain hazards. When considering the results of the hazard and vulnerability assessment, all of the zone had a very high or high degree of hazard and 44.7% of the zone also had a very high or high degree of vulnerability. Therefore, this zone is a key area where attention should be focused on the prevention and mitigation of secondary mountain hazards and it is inadvisable to undertake construction and development in this zone.

c) The high risk zone contains 44 county-level cities and 307 towns. It extends for an area of 26001.50 km^2, which accounts for 31.09% of the study area. The percentage of the zone that also had a very high or high degree of hazard was 77.4, and 64% of the zone also had a high degree of vulnerability. Therefore, most of this zone incurs three threats from secondary mountain hazards. It is advisable to take comprehensive disaster prevention and mitigation measures throughout the zone.

d) The moderate risk zone contains 29 county-level cities and 379 towns. It extends for an area of 31012.66 km^2, which accounts for 37.08% of the study area. This zone is located across the study area. The percentage of this zone that also had a moderate or high degree of hazard with medium scale secondary mountain hazards was 99.3. Thirty four percent of this zone had a high degree of vulnerability. These areas were concentrated on Zones 2 and 3, which have relatively well developed socio-economic conditions. In this zone, the risk from secondary mountain hazards is mainly located in Zones 2 and 3.

e) The low risk zone contains 11 county-level cities and 150 towns. It extends for an area of 16703.56 km^2, accounting for 19.97% of the study area, most of which is located in Zones 1 and 2. The percentage

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of this zone that also had a high degree of vulnerability was 90.4, but all of this zone had a moderate or low degree of hazard. Therefore, the risk is mainly dependent on the vulnerability of secondary mountain hazards in this zone.

4.5 Disaster insurance against secondary mountain hazards

The value loss rate is a key parameter for determining insurance rates. The value loss rate of a disaster-bearing entity is the ratio of the value of losses caused by the disaster to the pre-disaster value, and it is positively correlated with the degree of destruction experienced by the entity and the hazard value of different mountain hazards. This rate is often obtained from large sample statistics or experimental analysis (Zhang, Zhang and Luo 1998; Luo 2000; Ji 2005). However, there are lots of people and economic entities that are affected by secondary mountain hazards and it is difficult to obtain overall and reliable population, economic, and disaster loss data. Using the results of the hazard assessment, 53 towns with different degrees of hazard and easy access to data were selected as samples to calculate the average loss rate of economic entities. Building collapse rates in the 53 towns were acquired and were considered to represent the value loss rate of disaster-bearing entities in the study area (Table 6). The average value loss rate of affected buildings in the different hazard zones was calculated and revised in comparison to the earthquake intensity and field investigation data. As a result, a dependency relationship could be determined between the value loss rate of the affected entity and the degree of hazard (or risk) of secondary mountain hazards(Table 7).

Table 6. Building collapse rate statistics for 53 towns in the study area

Town	collapse ratio /%	Degree of hazard	Town	collapse ratio /%	Degree of hazard	Town	collapse ratio /%	Degree of hazard
Feishui	20	Very high	Dongxing	28	high	Hebian	22	Moderate
Jushui	24	Very high	Xuankou	78	high	Xinqiao	24	Moderate
Xiaoba	62	Very high	Bajiao	72	high	Louqiao	49	Moderate
Tianchi	97	Very high	Doukou	48	high	Zhongxin	38	Moderate
Guanzhuang	73	Very high	Pingtong	77	high	Heqing	25	Low
Qianjin	53	Very high	Xiangyan	46	high	Xinshi	31	Low
Qingxi	18	Very high	Tashui	19	Moderate	Lichun	31	Low
Yinghua	74	Very high	Huangtu	23	Moderate	Junle	30	Low

Hongbai	94	Very high	Badi	28	Moderate	Aoping	5	Low
Nanba	88	Very high	Macao	35	Moderate	Lingjie	3	Low
Shuiguan	40	Very high	Baishen	34	Moderate	Yunxi	23	Low
Anchang	47	high	Qinglian	29	Moderate	Juyuan	37	Low
Sangzao	29	high	Xiping	37	Moderate	Xujia	21	Low
Qingping	73	high	Xinchun	21	Moderate	Danian	7	Low
Bayi	25	high	Zagunao	30	Moderate	Lixian	10	Low
Hanzeng	16	high	Nanxin	24	Moderate	Fanjia	18	Low
Xiameng	22	high	Tangxun	30	Moderate	Tumen	13	Low
Ganbao	13	high	Qingyi	25	Moderate			

Table 7. The relationship between the value loss rate of the affected entity with the degree of hazard for mountain hazards

Items	Value			
Level of destruction of affected entities	Low	Moderate	High	Very High
Hazard zone	Low	Moderate	High	Very high
Average value loss rate of different hazard zones /%	19.45	29.25	44.15	58.45
Average value loss rate of different risk zones /%	21.67	31.11	39.47	53.80

In the last century, there were three strong earthquakes ($Ms \geq 7.0$), which occurred in the study area, therefore the frequency of secondary mountain hazards triggered by strong earthquakes may be assumed to have a 30-year return (i.e., once in 30 years). Post-earthquake secondary mountain hazards in the study area are induced and controlled by locally heavy rainfall. For example, the Zhouqu debris flow was induced by a strong rainfall event with π=1%; In Beichuan, Dujiangyan, Wenchuan, Mianzhou, and Shifang where heavy rainfall is common and loose materials are abundant, large-scale secondary mountain hazards were triggered by rainstorms with π=5% and they caused substantial damage and tremendous losses. Therefore, the frequency of rainfall with π=5% can be taken as the probability of occurrence of a secondary mountain hazard. This frequency and the data in Table 7 was input into Formula 13. As a result, the different average insurance rates for cover against secondary mountain hazards in different hazard zones could be determined. The results were graded and classified into four insurance rate zones using an arithmetic sequence method, including very high, high, moderate, and low insurance rate zones (Table 8).

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Table 8. Rate classification statistics for disaster insurance against secondary mountain hazards in the study area

Insurance rate zone	Average rate / %	Zonal area / km2	Ratio of zonal area to the study area/%
Low	1.43	16703.56	19.97
Moderate	2.05	31012.66	37.07
High	2.61	26001.50	31.09
Very high	3.55	9927.89	11.87

The results of this calculation of disaster insurance rates for cover against secondary mountain hazards show that:

a) The area within the four insurance rate zones is normally distributed with small areas at the two ends but a large area in the middle, and the average insurance rates in these insurance zones also follow a normal distribution. Such areas can be used to conduct further research and to implement disaster insurance.

b) The average insurance rate for cover against secondary mountain hazards in the study area was 2.41%, which was much higher than the basic rate (0.1-0.28%) of property insurance, in which geo-hazard insurance requires an additional insurance cover. It was also higher than the basic rate of cover in low and moderate insurance rate zones of the study area. However, in the very high and high insurance rate zones the basic rate of cover was above the average insurance rate for cover against mountain hazards in the study area. These higher premiums or rates are beyond the affordability of ordinary households and insurance companies, thus limiting or affecting the development of disaster insurance against secondary mountain hazards in China.

c) The low insurance rate zone accounts for 19.97% of the study area, and it has a low degree of hazard or risk. Therefore, local residents or enterprises do not need to insure in theory or they are unwilling to insure in practice. The average insurance rate for cover against mountain hazards in this zone is 1.43%, which violates the principle of fairness in economics.

d) The very high insurance rate zone accounts for 11.87% of study area with an average insurance rate of 3.55%, which is related to the very high degree of hazard or risk. This insurance rate is about 1.5 times greater than the average in the study area, and the high insurance premium prevents local residents and enterprises from obtaining security of life and property.

e) The moderate and high insurance rate zone accounts for 68.16% of the study area with average insurance rates of 2.05% and 2.61%, respectively, which are related to the moderate or high degree of hazard or risk. The average insurance rates in the two zones were similar to that for the whole study area. Therefore, it is advisable to adjust the insurance rate in these two zones according to the actual demand and the market situation, and it is easy to achieve an optimal balance between insurers and insurance companies in moderate and high rate zones.

5. CONCLUSIONSAND SUGGESTIONS

a) The 2008Wenchuan Earthquake and its aftershocks, the special geo-environment, and heavy rainstorms all contributed to the formation and development of secondary mountain hazards, which have become more frequent and serious in the post-earthquake period. It is imperative to provide disaster insurance on the basis of a quantitative risk analysis or on a regionalized basis so as to share or compensate for disaster losses, because the recovery and rehabilitation from losses caused by catastrophic secondary mountain hazards are often beyond the ability of many households, business enterprises and local governments to undertake on their own.

b) The key to any risk assessment lies in selecting appropriate units of assessment, establishing a scientific indexing system, adopting feasible models and undertaking a reasonable analysis and classification of results. Considering both the precision of assessment and the access to the collection and processing of data, an administrative boundary at town level was selected as the basic analytical unit of the risk assessment for disaster insurance. The assessment indexes and their related weightings can be objectively acquired by means of the formation contribution analysed model and the adoption of a grey system. It is convenient to make a quantitative calculation and analysis of secondary mountain hazards by introducing models to determine the degree of hazard, vulnerability and risk.

c) The vulnerability assessment was divided into social and economic vulnerability categories, and the factors and indexes of disaster prevention, mitigation and resilience were taken into account. The risk was defined as the product of the hazard and vulnerability of secondary mountain hazards using the 10 formulas presented in this paper. The results and regionalization maps of the hazard, vulnerability, and risk assessments fit well with the actual distribution of and damage caused by secondary mountain hazards in the study area.

d) The insurance rate was determined on the basis of a risk assessment of secondary mountain hazards. Its value reflected the specific characteristics of mountain hazards in the region and embodies the principle of fairness. However, this methodology of stipulating insurance rate often results in a large difference in insurance rates for cover against disasters among different risk zones, which is not favourable for the operation of the mountain hazard insurance market.

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