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Evaluation of the Economic Loss Caused by Zhouqu Debris Flow

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Abstract [**Objective**] The aim of this study was to evaluate the economic loss caused by Zhouqu debris flow. [**Method**] After the large debris flows happened on August 7, 2010 in Zhouqu, Gansu Province, we collected data at the first time after the disaster, and then built an assessment model to estimate the potential economic losses. [**Result**] The total loss reached 16.57×10^2 million Yuan, in which indirect economic loss was up to 2.42×10^2 million yaun while the actual direct economic loss was around 14.15×10^2 million Yuan. [**Conclusion**] The proportional coefficient method is a rapid and efficient method for evaluating the indirect loss caused by disasters.
Key words Debris flow; Indirect losses; Direct losses; Proportional coefficient method

The vast territory of China experiences frequent natural disasters, including floods, droughts, earthquakes, landslides, debris flows, marine disasters and *etc*. Debris flows are the most destructive of all water-related natural disasters. In the past few decades, China had been affected by severe debris flow, which caused considerable economic loss and serious damage to towns and farm. The total areal extent of debris flow has reached 4.30×10^6 km^2, occupying about 45% of China's total territory by 2004[1]. Estimates of losses caused by debris flows were up to 2 billion Yuan and 300–600 deaths annually[2]. Debris flow seriously affects people's lives and production.

Debris flow is a natural phenomenon widely occurred all over the world[3]. As a type of geomorphologic hazard, Beaty[4] fully recognized the importance of disaster reduction and appealed to geomorphologists to approach cataclysmic debris flow from the principle of catastrophism. After that, studies on debris flow have received more attention and a series of mechanisms have been carried out to prevent and control the disaster from its origin, driving force and some other factors influencing the environment and human life.

Big debris flows in China are mainly occurred in the mountain areas, which include Sichuan, Yunnan, Tibet, Shanxi and Gansu. In these areas, intense storms may cause flash floods with significant sediment transport. In steep torrents, the sediment discharge may increase so that the solid volumetric concentration often exceeds 40%–50%; that is what we call debris, and transport huge volumes of sediments that are then deposited on alluvial fans, where are often densely populated.

Generally, debris flows move at a great speed (*e.g.*, 0.8–28 m/s measured in the field)[5] and are able to carry metre-size boulders[6–7]. They have great destructive ability and can pose a significant hazard to people and infrastructure. In essences, debris flows consist of rock, earth, and other debris saturated with water[8]. They are caused by rapid accumulation of water in the ground, during heavy rainfall or rapid snowmelt, changing the earth into a owing river of mud. They can flow rapidly, striking with little warning at avalanche speeds. Debris flows also can travel several miles from their source, growing in size as they pick up trees, boulders and other materials. They can occur suddenly and inundate entire towns in a matter of minutes. Debris flows may also eventually become thinner muddy flooding waters as they deposit their heavier components. These debris flows generally occur during periods of intense rainfall. The occurrence of debris flow may be governed by the geologic characteristics of the watershed area[9].

Mechanism research has made significant progress; however, the economic effects and control technologies of debris flows are still poorly understood[10–12], and regional/local empirical research is still of vital importance. The disasters of debris flows are the outcome of natural processes interacting with human systems. Natural processes are complex, and reliable modification of debris flow processes requires a degree of understanding not yet available. The remote places at which debris flows normally happen are also a challenge for engineers and geographer preventing the natural processes fundamentally. The urgent need to reduce debris flow disasters is best met by modifying human systems, in particular, removing people and then assets from areas likely to be affected by debris flow[13]. Evacuating all of the people and assets from a hazard-prone area may be practically impossible owing to the limited terrestrial space, as well as social

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and legal difficulties. As a result, what we could do is to build a debris flow hazard assessment model to assess the potential effects of debris flow on economics and human life, and adjust the industrial structure and residential structure to minimize the loss of the hazards.

In this paper, we took Zhouqu as a case study area and developed a rational and quantitative approach, proportional coefficient method, to estimate the economic losses from debris ows, which was associated with land use or land cover change and ecological risk assessment.

Study Area and Methods

Physical settings of Zhouqu

Zhouqu County is located at the southeast of Gansu Province bordering the Tibetan Autonomous Region, which is a typical mountainous valley controlled by warm and wet climate conditions featured vertically. The altitude ranges between 1 173 and 4 504 m. The mean annual air temperature is around 14.1 ℃ while mean annual rainfall is at a range of 400–800 mm. These years, weak ecological environment has led to lower land productivity. The vulnerable ecological environment caused land degradation, and thus caused the land productivity declining. The weak ecological environment is the major factor that influencing the decline of land quality[14]. As to this disaster, the rainfall especially the flood is a direct factor leading to mudslides. We took the satellite remote sensing data before and after disaster to describe the trending with GIS technology. The serious disaster sites are shown in Fig.1 and Fig.2.

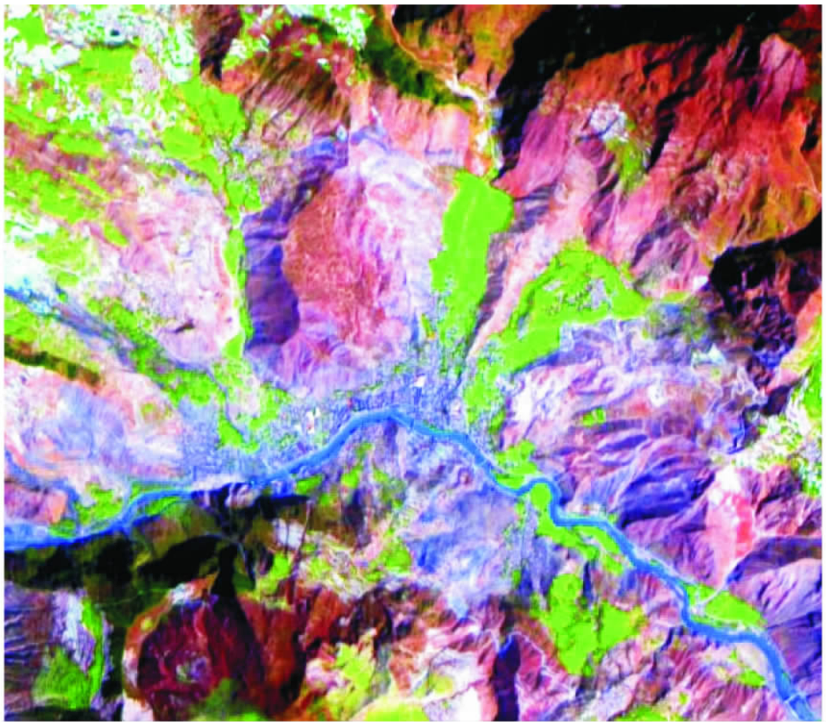


Fig.1 Remote sensing image before the debris flow

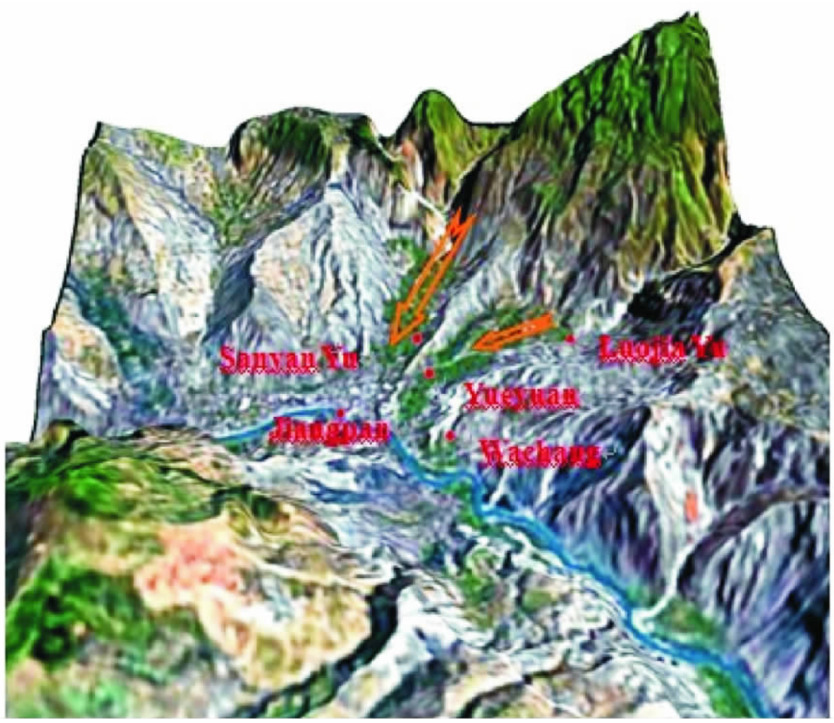


Fig.2 The overlying of remote sensing image and DEM Yellow arrows indicate the debris flow direction and submerged area

What's even worse, land use change and deforestation reflect their destruction in this disaster. To protect the ecological environment of Bailongjiang watershed, one of the most fragile and the largest valleys in Zhouqu County, the local government has speeded up the ecological construction projects including Grain for Green Project, Logging Ban Project, *etc*. Unfortunately, these projects have been carried out since late 1990s which does not exert effective effects on hindering the deforestation trend identified by the decoded land use maps (Fig.3 and Table 1).

Damages caused by debris flow in Zhouqu

The debris flow, which occurred in the Zhouqu County was about 5 000 m long, 300 m wide on average and 750 million m^3 in volume. Heavy rainfall accompanying it reached more than 97 mm and lasted 40 min, and mudslides rushed into the town and formed the barrier lakes. About 1 478 people were killed and 294 were missed due to this natural disaster. It is a dramatic loss to all the three industries (Fig.4 and Table 2).

Methods

Direct and indirect losses were caused by the disaster. In addition, there is a close linkage between indirect and direct economic losses. The

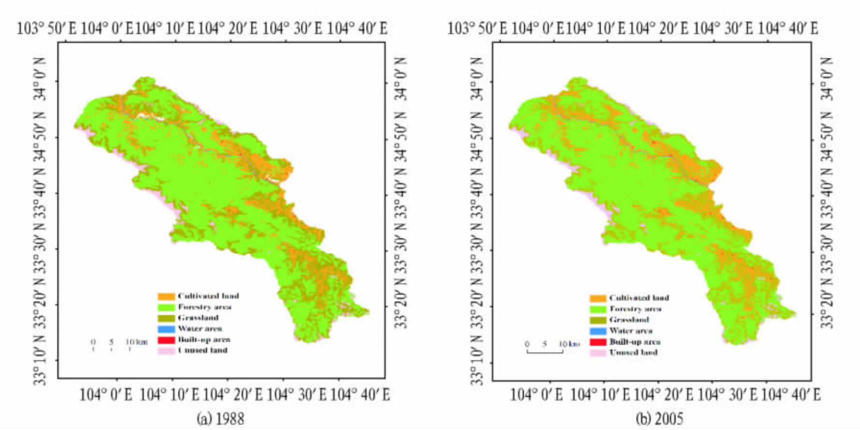
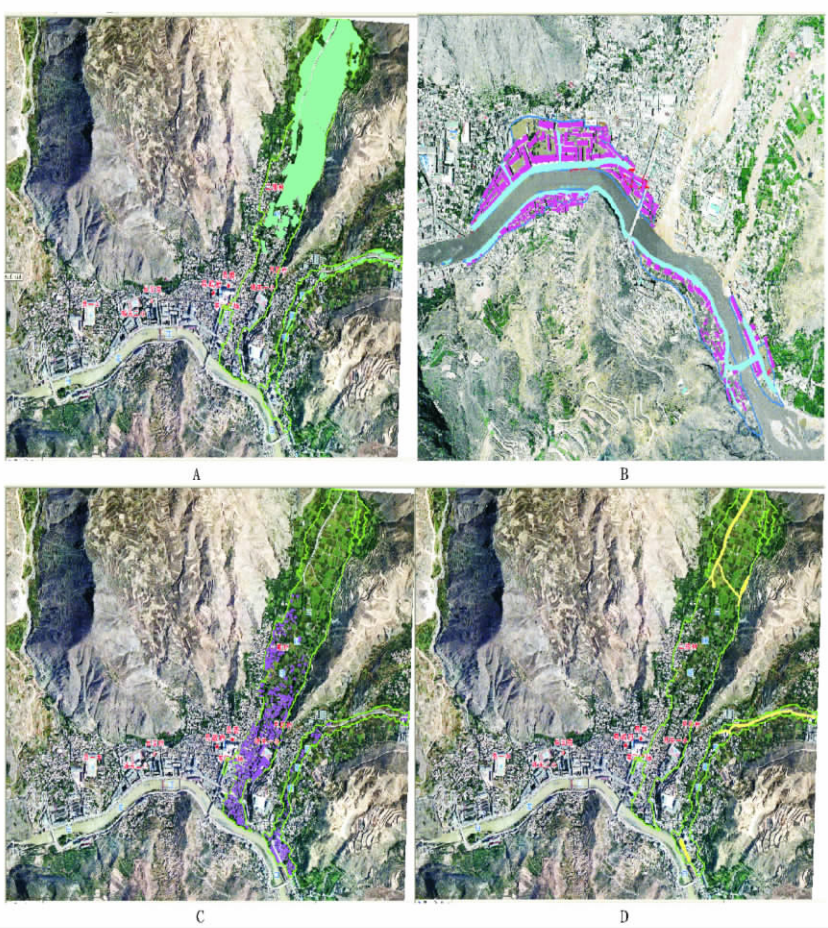


Fig.3 Land use patterns in Zhouqu County of Gansu Province, China in (A) 1988 and (B) 2005

Table 1 Changes of land uses and GDP of Zhouqu County in Gansu Province

Years	Cultivated land	Forestry area	Grassland	Water area	Built-up area	Unused land	GDP
1988	1 584.16	611.27	7.13	3.55	82.9	321.69	105.61
2005	1 598.21	601.14	6.03	3.91	100.9	300.42	1 598.21

Land is measured in square kilometers; GDP is measured in million Yuan at the price of year 2000.



(A) buildings, in the purple area; (B) roads, in the yellow area; (C) land, in the green area; (D) flooded and destroyed road and houses, in the blue and red areas respectively.

Fig.4 Distribution of damages caused by Zhouqu debris flow on August 11, 2010, China

direct economic losses contain the fixed assets losses, the current assets losses, the property losses and other economic losses. Indirect economic losses include the associated socio-economic losses, disaster losses and resource losses. The direct economic losses are more serious, and indirect economic loss is even worse which is always lasting for a long period.

In this paper, we choose and use a proportional coefficient method to assess the total economic losses caused by debris flow which occurred in the Zhouqu County. Considering from the disaster prevention and mitigation level, this method is still a practical valuable assessment approach. A certain proportion between indirect economic loss and direct economic losses can be estimated using the following equation:

$$IEL=\lambda\times DEL \quad (1)$$

Where, *IEL* represents the indirect economic loss; *DEL* represents the direct economic loss; λ is a ratio that defined by a statistical analysis for the typical case or by experience according to situation. Usually, the ratios of direct economic losses to indirect economic losses of several geological disasters adopted by the departments of land and resources are fixed as: 1:10 is taken for collapse and slide; 1:5 is taken for debris flow; and 1:3 is taken for ground subsidence.

Given the data coming from the subjective experience of the related professionals, it bears important reference meaning; but from the decision-makers' review, its scientific objective basis is far from enough. In this paper, we took the ratio of 1:5. In order to keep away from the influence of subjectivity when choosing the ratios and the estimation error, we chose to assign and convert λ by using the following equation:

$$IEL=\lambda'\times DEL \quad (2)$$

The indirect economic loss caused by debris flows was considered from two aspects: the influence from both internal and external factors, and the holding of external interference. We chose five basic factors to analyze the indirect economic losses (Table 3), including population density (*P*) (people/km^2), GDP (*G*) (×10^4 Yuan/km^2), disasters area (*A*) (km^2), disasters influence time (*T*) (year) and relief funds (*F*) (×10^4 Yuan). From the internal factors to assess, the level of wealth density is higher when the population density and GDP are larger, and then the indirect economic loss was also quite large under the same scale of disaster. From the external factors to assess, under the equal economic situations, the indirect losses are greater when the disaster occurs at a larger area and lasts for a longer time. Conversely, if the relief funds get improved, the indirect economic loss will decrease accordingly.

Equation of λ' is formulated as following:

$$\lambda' = P' \times G' \times A' \times T' / F' \quad (3)$$

To assure the accuracy of the estimation of the economic loss for various sectors, the coefficient was calculated based on the losses affiliated with each sector, and then used to calculate the indirect economic loss from all the statistical agencies to get the total indirect economic loss. The formula is as follows:

$$IEL = \sum_{i=1}^{n} \lambda_i \cdot DEL_i \quad (4)$$

Where, *IEL* represents the indirect economic loss; n represents the number of objects affected by disasters; λ_i is a ratio; DEL_i represents the direct economic loss. Different receptors of disaster are more complex, and need to be measured repeatedly based on the disaster data.

Currently, the methods to calculate the indirect losses is far from mature, so we selected a percentage of direct losses to evaluate the economic losses. Chen[16] put forward a set of ratios of indirect loss to direct losses by sectors, which were 0.15, 034, 0.10, 0.45, 0.37, 0.10, 0.25 and 0.23 for residential buildings, public property, public undertakings, industry, business, agriculture, highway and railway, respectively.

Table 2 Basic information on the occurrence of Zhouqu debris flow

Items		Total
General situation	Population//$\times 10^4$ persons	13.47
	Population density//persons/km^2	44.75
	Land area//$\times 10^2$ km^2	30.10
	Cultivated land //km^2	109.6
Damages to local people	Death toll//individuals	1 478
	Households affected//households	4496
	Population affected//individuals	20 227
	Percentage of affected people to the total people//%	15
Damages to the buildings	Numbers of damaged buildings	568
	Total damaged area//$\times 10^2$ m^2	606.39
	Flooded and destroyed buildings// buildings	250
	Flooded and destroyed built-up area//$\times 10^2$ m^2	616.9
	Flooded buildings//buildings	4189
	Flooded built-up area//$\times 10^2$ m^2	209.5
	Flooded and destroyed office buildings of the local government//buildings	21
Loss of corps and livestock	Cropland area damaged//hm^2	200
	Monetary value of crop damaged//million Yuan	10.56
	Flooded cropland area//hm^2	23.37
	Percentage of flooded cropland//%	0.88
	Deaths of livestock//$\times 10^4$	1.00
	Loss of livestock sector//$\times 10^2$ million	1.62
Damages to road and bridges	Flooded road area by debris flows//hm^2	1.74
	Flooded road area by floods//hm^2	3.22

Data was from the Centre for Earth Observation and Digital Earth, Chinese Academy of Sciences.

Results and Analysis

Firstly, the equation (1) was adapted to calculate the *IEL*, in which, λ equals to 5 and DEL is up to14.15× 10^2 million Yuan, so *IEL* =70.75 ×10^2 million yuan. The total GDP of Zhouqu County was about 4.63 ×10^2 million Yuan in 2008, which is in sharp contrast to 84.90 ×10^2 million Yuan economic losses released by the local government. Given to the large gap between the estimated economic losses and the released GDP by the local government, we then concluded that the total economic losses estimated were unbelievable.

According to the equation (2), five factors, population density, GDP, disaster area, disaster influence time and relief funds, need to be considered. After calculating λ' =1 ×1 ×2 ×2/2 =2, then we got another result of *IEL* (*IEL*= 28.30×10^2 million Yuan), and we concluded that the total loss was up to 42.45×10^2 million Yuan. Compared to the first method, the second was reduced with errors obviously. Although we synthesized the indirect economic loss to five influencing factors, the accuracy was still subject to the experience.

Each kind of natural disaster has its own features, therefore, it is almost impossible to formulate a unitary set of coefficients and use them to evaluate all kinds of economic losses. In this study, a well-thought formula was introduced that corresponds to each

Table 3 Mapping table used to transform values of proportional coefficient for evaluating the indirect economic losses

Factors	P//people/km^2		G//$\times 10^4$/km^2		A//km^2		T//year		F//$\times 10^4$ Yuan	
Value range of the factor	<50	≥50	<20	≥20	<1	≥1	≤1	>1	<200	≥200
Assigned value	1	2	1	2	1	2	1	2	1	2
Actual value of Zhouqu County	44.75		12.56		1 010		2		20 800	
Assigned value for evaluating the economic loss of Zhouqu debris flows	1		1		2		2		2	

The data was from the study by Liu and Zhao[15].

Table 4 Estimated economic loss caused by Zhouqu debris flow ×10^2 million

Items	Estimated values	Items	Estimated values
Loss of business sector	1.12	Loss of agricultural sector	5.00
Residential loss	0.33	Direct loss of highway	1.50
Loss of public property	0.66	Direct loss of railway	2.78
Loss of public facility	0.84	Direct economic loss	14.15
Loss of industrial sector	0.30	Indirect economic loss	2.42
		Total economic loss	16.57

Data was from Chinese Academy of Sciences.

kind of receptors of disaster:

$IEL=\sum_{i=1}^{n}\lambda_i \cdot DEL_i$, ($\lambda_i$ is referred to the study by Chen[17]), then we got the last indirect loss as much as 2.42×10^2 million Yuan, which was more reasonable. In the end, together with the actual direct losses 14.15 ×10^2 million Yuan, we defined the total economic loss was around 16.57 ×10^2 million Yuan. Although the estimated loss by using this method might be unscientific or inaccurate due to the data limitation, the proportional coefficient method would still be regarded as a rapid and quantitative method for evaluating the indirect loss of disasters.

Conclusions and Discussion

During this study, the debris flow hazards are referred to the indirect economic loss coefficient method, the maximum ratio is 16 and the minimum value is 1/2[15]. When only a single kind of disaster occurs and leads to loss, the ratio of direct economic loss to indirect economic loss, λ ranges from 0.1 to1.99, which means the bigger coefficient is 19.9 times of the smaller. With the further research, we need to determine the proportion of different coefficients according to the different types and difference of the disaster carriers. Just to know any combination of disasters, we can get the direct economic losses by a corresponding quantitative evaluation to the ratio of the disaster indirect losses.

Disaster to human society eventually causes a different degree of damage. Due to the field investigation and analysis can not be finalized in a short-term, so the proportional coefficient method is still an effective approach that could be recommended. According to the proportional coefficients estimated by the method, we get the ratio of the direct economic loss over the indirect economic loss. Although there is experience in evaluation of direct economic losses, and indirect economic loss is not simply linear with relationship, the present research level still can be regarded as a kind of fast feasible evaluation method. But considering the proportional coefficient can lead to larger arbitrariness, we choose various kinds of ratio in terms of the disaster carriers to assess the economic loss [17], so as to control the error and get the accurate estimation of the economic losses caused by the Zhouqu Debris Flow.

The geographical environment of Zhouqu County is rather complex, together with its ecological environment and special climate conditions. All these conditions contribute to the occurrence of the natural disaster, such as landslides, mudslides and earthquakes. We collected data on the first time after the disaster and then estimated the economic loss by using proportional coefficient method. The results of economic losses are surprisingly high, which could be used as a reference for completing the post–disaster reconstruction in future.

A comprehensive analysis on the debris flow disaster indicates that human had played a major role to drive the occurrence of this disaster. First, the expansion of urban built-up area, the aggravation of the land use intensity increase the risk of occurrence of natural disaster. More human activities, urban expansion, shrinkage of cultivated land have led to land storage capacity dropping and soil softening, which are easy to cause disaster. Secondly, the local ecological environment of Zhouqu is fragile. Every year about 100 000 m^3 of forest in Zhouqu has been lost due to the logging and the land reclamation in the steep land of farmers. In recent years, part of land also lost for soil erosion. Deforestation is also an important reason that has caused tectonic soft lithology, landslides and debris flow disaster especially when the flood coming. Moreover, the management agency and planners did not pay enough attention to frequently occurred debris flow. For a long time they neglected the rational utilization of land and paid attention to the immediate interests of human activities, then caused the soil vulnerable to fragile so that in the current times human´s tiny disturbance may cause disaster.

The hazards of large mudslide have attracted more and more attention. From a nationwide range, landslide and debris flow and drought, flood geology disasters occurred frequently and have risen to national emergency. It has caused ten thousands of billion of direct economic losses and inestimable indirect economic loss, and made great impact on people's lives. From the long-term perspective, indirect losses may sustain for a long period, so the economic loss may be more severe than estimated.

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作物生长模型同化 SAR 数据模拟作物生物量时域变化特征

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摘 要 生物量是监测作物长势的一个重要指标，可以反映作物的生长状况，和作物产量有密切关系。遥感获取生物量的方法之一是通过基于矢量辐射传输方程的微波冠层散射模型反演，但多数模型反演方法并未考虑作物生物量在不同阶段的变化特征。运用数据同化方法，将 SAR 数据提取的生物量信息和作物生长模型结合，描述作物生物量与时间变化的关系，提高生物量估测精度。通过分析生物量和 SAR 数据提取的后向散射系数的时域变化关系建立反演模型估算生物量。在构建代价函数的基础上，采用共轭梯度法对生长模型参数进行优化，使模型估算的生物量和 SAR 数据反演的生物量差值最小。结果表明，引入 SAR 数据修正后的作物生长模型模拟生物量和实测值的时间分布基本吻合，且比未引入 SAR 数据的结果精度有明显提高。因此采用 SAR 数据提取的作物实时生长信息可以修正作物生长模型关键参数以提高模拟生物量的精度。

关键词 数据同化；生物量；SAR；作物生长模型

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舟曲泥石流经济损失评估

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摘 要 [目的]对舟曲泥石流造成的直接和间接经济损失进行评估。[方法] 在 2010 年 8 月 7 日舟曲发特大泥石流发生的后第一时间收集了相关数据，建立评估模型，采用比例系数法估计潜在的经济损失。[结果]评估结果表明，此次灾害共造成经济损失 16.57 亿元人民币，其中间接经济损失高达 2.42 亿，直接经济损失 14.15 亿。[结论] 至目前为止，比例系数法仍是一种快速有效的评估间接经济损失的方法。

关键词 泥石流，间接经济损失，直接经济损失，比例系数法

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