Chen, M., Hu, G., Chen, N., Zhao, C., Zhao, S., & Han, D. (2016). Valuation of debris flow mitigation measures in tourist towns: a case study on Hongchun gully in southwest China. *Journal of Mountain Science*, *13*(10), 1867-1879. https://doi.org/10.1007/s11629-015-3759-4

Valuation of debris flow mitigation measures in tourist towns: a case study on Hongchun gully in southwest China

Ming-li Chen(1), Gui-sheng Hu (2), Ning-sheng Chen (2), Cun-yao Zhao (3), Song-jiang Zhao (4), Da-wei Han (5)

1. State Key Laboratory of Hydraulics and Mountain River Engineering, Sichuan University, Chengdu, China
2. Key Lab of Mountain Hazards and Surface Processes, Institute of Mountain Hazards and Environment Chinese Academy of Sciences, Chengdu, China, chennsh@imde.ac.cn
3. Chengdu University of Technology, Chengdu, China
4. Sichuan Huadi Geological Engineering Company, Chengdu, China
5. Department of Civil Engineering, University of Bristol, Bristol, United Kingdom

Abstract

Tourist towns have dual functions of tourism and local community living. However, a vast number of these towns are located in the mountain areas, which are constantly threatened by natural hazards such as debris flows. If a huge investment is spent on the hazard control engineering, the value on the engineering project should be estimated properly. However, such valuations at tourist towns are usually very challenging and controversial. In this study, an attempt has been made to evaluate the economic value of the debris flow control engineering in tourist towns by integrating both welfare and disaster economics. The total value of debris flow prevention and control engineering in tourist towns (VDFE) includes investment cost (IC), disaster mitigation benefit (DMB), and loss of brand value (LBV). Here DMB is assessed by the cost-benefit method. The LBV is estimated by incorporating brand equity and cost-benefit methods. The engineering for debris flow control in the Hongchun Gully of southwest China was built to protect Yingxiu tourist town and was assessed as an example. The IC for the engineering is 180 million RMB, however, the VDFE reaches as high as 3,401 million RMB, of which the LBV is 169 million RMB, and the input-output ratio is 1:18. Thus, the LBV cannot be neglected in case of VDFE estimation process. The more developed the tourism in one town or city is, the greater the LBV and the higher the VDFE are.

Key words: Tourist towns; Economic value of the debris flow control engineering; Disaster mitigation benefit; Tourism brand value; Brand equity; Yingxiu

Introduction

Tourist towns have at least dual functions, i.e., tourism and township. Numerous tourist towns and cities lie in the mountain areas worldwide. A lot of them are affected by debris flow hazards, for example, Beijing (Wu 2001), Jiuzhaigou (You et al. 2003; Cui et al.. 2003), Dali (Parnell 2009) and Yingxiu (Cui et al. 2012) in China, Almaty in Kazakhstan (Wei and Chen 2006), Caracas in Venezuela (Wei et al. 2000), Aguas Calientes in Peru (Carreño and Kalafatovich 2006), and Obudu in Nigeria (Igwe 2015). The debris flow hazards would not only produce an unrecoverable impact on the tourism scenes and landscape (Cutter et al. 2015; McCoy 2015), but also cause serious injuries and deaths also. Over ten times of debris flows occurred in Jiuzhaigou World Natural Heritage between 1956 and 984, and killed 45 people (You et al. 2003). The deaths of 71 persons were caused by a debris flow occurred in Hong Kong in 1972 (Zhang and Liu 2006). An extra example is that a vast debris flow in Caracas, Venezuela led to more than 30, 000 people dead or missed on December 15 and 16, 1999 (Chen et al. 2010; Cui et al. 2011).

Debris flow happened in tourism towns is hazardous to the residents and tourists, and takes an extensively and intensively adverse impact on these towns. As a result, governments usually spend a great deal of money to build the mitigating engineering measures to protect the town. For examples, a total of 300 million RMB had been successively spent to control over 20 sites of debris flows in Beijing, China (Wu 2001), while an investment of 16 million and 100 million US$ was used to control the debris flow hazards in the Medeu Valley in Almaty, Kazakhstan (Wei and Chen 2006) and in Caracas, Venezuela (Wei et al. 2000). Furthermore, after the Wenchuan Earthquake (8.3 Mw) occurred in May 12, 2008, a vast fund was invested to control debris flow hazards in towns of Yingxiu, Jiuzhaigou, Wolong and

Qingping, etc., of which 400 million RMB was spent in 11 debris flow control sites in the Wenjiagou Gully in Qingping while 180 million RMB was used for debris flow control engineering in the Hongchun Gully in Yingxiu (Cui et al. 2012).

It is noticeable that massive investment has been used to control the debris flow hazards in tourist towns, and the doubt is that could the cost produce sufficient economic benefit? And how to evaluate the benefit value? The answers to those issues will help us in decision-making on hazards control. Here, the basic concept about the benefit evaluation of disaster control is addressed as follows. Commonly the brand value (BV) for each tourist town increases with advertising. The VDFE is the total value of debris flow prevention and control engineering, which includes the investment cost (IC) and disaster mitigation benefit (DMB) (Liu and Zhao 2008; Zhong and Lin 2003; Wang and Huang 1997; Blahut et al. 2014). Quantitatively the IC can be expressed as the investment cost in debris flow prevention and control engineering. The disaster mitigation benefit (DMB) refers to the utmost disaster loss reduced possibly within the lifespan of the prevention and control projects. Particularly, negative DMB refers to the high investment with low benefit return. Here, the loss of brand value(LBV) of a tourist town stands for that of the total lost value of the tourist town in the disasters processes according to the views of consumers and tourists, which may depend on the levels of the quality, culture, availability, security, publicity, etc. In a special situation, negative LBV indicates the brand value increases under the effect of the aforementioned factors. Traditionally LBV is not included in VDFE, but for the tourist town the BV exists and grows with the town development (Huan et al. 2004; Zimmermann 2004; Coe et al. 2014; Wu and Hayashi 2014). Therefore, it is reasonable to estimate the VDFE considering the LBV.

In this study, taking the debris flow engineering control in the Hongchun Gully in Yingxiu as example, we attempted to establish a VDFE evaluation method. The objectives of this study are: (1) to identify the factors of VDFE in tourist towns; and (2) quantitatively estimate VDFE and the factors of IC, DMB and LBV.

1 The VDFE model and approaches

1.1 The VDFE model

Formula (1) (Marx 1867) for expressing the worth of commodities is:

$$W = C + V + M \tag{1}$$

C stands for the currency value used to buy the means of production, and V for the currency value for employing labor force.

C+V is the invested capital, and M is surplus value, or profit, which is the increase in the value of the invested capital. The M values of commodities can only come into existence in circulation. The prevention and control of debris flow is a non-profit project invested by the government. It will not be in circulation so there would be no increased value in the invested capital, which is the main reason why many economists consider it as a way to safeguard our heritage. But, as a matter of fact, the investment in this kind of projects is sure to yield great “profits” (the property saved because of the prevention of the disasters, etc.).

According to the welfare economics, the value lies in people’s understanding of, attitude towards and beliefs in things. It’s the outcome of people’s subjective perception of objective things. Therefore, all things’ value is a reflection of people’s attitude, preference and behavior (Tang 2011). People’s willingness to pay (WTP) shows their preference to things. WTP has actually become a value indicator, and thus the value of all things and service can be shown in Formula (2) (Tang 2011):

$$Z = Y \tag{2}$$

Z is the value of things and service, and Y is people’s willingness to pay for the things and service and their increased value.

From the perspective of the welfare economics, to reduce environmental disasters and their damage, the government has the willingness to pay, so funds are allocated to debris flow prevention and control engineering. The investment in the engineering projects actually refers to the government’s willingness to pay. The profit from reducing environmental disasters and the reduced tourist LBV are mainly brought by the investment in the engineering. When combining Formulas 1 and 2, we have Formula 3:

$$VDFE = IC + F \tag{3}$$

VDFE refers to the value of debris flow prevention and control engineering. It’s W in Formula 1 and Z in Formula 2; IC is the cost of the engineering which equals C and V in Formula 1; F, which is M in Formula 1, is the total yield of the engineering when they reach the end of their lifespan. IC and F equal Y in Formula 2.

The total yield of the engineering when they reach the end of their lifespan, marked as F, includes the profit from reducing debris flow disasters and the reduced LBV, namely:

$$F = LBVz + DMBz \tag{4}$$

LBV_Z refers to the reduced tourism brand value loss and DMB_Z refers to the profit from reducing debris flow disasters when the prevention and control engineering reach the end of their lifespan.

Here is another form of Formula 3:

$$VDFE = IC + LBVz + DMBz \quad (5)$$

VDFE consists of the investment cost (IC), reduced loss of brand value (LBV_Z) and the disaster mitigation benefits (DMB_Z). In order to derive VDFE, we should first know IC, LBVz and DMBz.

IC and DMB_Z have been discussed and studied by many researchers, and the evaluation methods are comprehensive. This paper draws upon the common methods to evaluate IC and DMBz. However, the LBVz caused by debris flow disasters has never been touched, so in this study we will explore new evaluation methods regarding the LBVz.

1.2 LBV methods

When debris flow hit tourist towns, tourists will feel unsafe. As a result, tourists would step away from travelling for a while or even a long time. This kind of negative information would cause tourists to lose faith in the tourism brand (Dawar and Lei 2008). In order to build a high recognition of the brand, tourist towns often need to invest a huge amount of capital in promotion, for the reason that the brand value is fundamentally decided by its performance in the market (Fan and Leng 2000). As a result, debris flow would cause losses of the brand value (Huang and Min 2002; Yang et al. 2008), and the construction of hazard prevention and control projects would to some extent reduce the damage which should be considered as part of the value contributed by the projects.

Cost approach, market approach, and yield approach are the three main brand value evaluation methods. Cost approach attaches greater importance to the investment in the setting up of the brand, market approach the outcome of the brand, and yield approach the profits in the long term. Nevertheless all of the three approaches don’t take the consumers into consideration, thus fail to reflect the real source of the brand value. As a matter of fact, consumers’ recognition is the key factor in realizing the brand value. Brand equity reflects brand value, and the two are positively correlated (Keller 1993). For this reason, the band value evaluation method brought up by Hu (2005) suggests the max brand equity approach can reflect the source of the brand value, emphasizing tourists’ contribution to tourist attractions’ brand value, and the calculating formula is:

$$BV = \sum_{i=1}^{n} \{ Max(RI)_i \times Q_i \times T_i \times K_i \} \quad (6)$$

BV stands for Brand Equity, n stands for the number of tourist types defined by tourists’ characteristics, Max$(RI)_i$ stands for the tourist attraction owner’s maximum interests in accordance to Type i tourists, Q_i stands for the number of years in which the tourist attraction’s brand sustains attraction on Type i tourists, T_i refers to the theoretical target tourist sources, and K_i stands for discount rate.

The main flaw in this formula is its over-emphasis on tourists’ loyalty to the brand. Although the data of tourists’ loyalty is objective, it is very limited and the measuring is not easy to operate because it requires relatively greater cost; there’s also limitation in the correctness of the judgment for future situation, and it’s very hard to distinguish who actually change their choice of the brand; it’s hard to gather statistics about the highly scattered individual customers’ times of buying various brands and the level of fondness; it’s rather subjective and random to decide the time span of the continued influence of a certain brand and the corresponding theoretical source of customers; what’s more, this approach mainly calculates the interests made by consumption in which customers recognize a certain product when and after buying it, but tourism product, especially tourist towns are rarely attracting multiple consumption, and therefore fall into the category of one-off expenditure.

Take the base of the above-mentioned formula, and modify it by combining it with the yield approach to deal with the flaws, we come up with this tourist town geographical-disaster-caused band value loss evaluation formula:

$$LBV_j = \frac{(Tr_{j-1} + Tr_j + Tr_{j+1})}{3 \times 365} \times T_j \times (1+i)_j \quad (7)$$

LBV_j stands for the brand value loss within j years. Tr_{j-1} stands for tourism revenue a year ahead of the disaster. Tr_j stands for tourism revenue of the disaster year. Tr_{j+1} stands for tourism revenue of the year after the disaster year. All the data can be obtained from the local tourist administration. T_j stands for j year disaster recovering period, mainly using transportation and landscape recovering time as a frame of reference and take the maximum number. i stands for annual interest rate, taking the disaster year’s bank benchmark interest rate.

The advantages of Formula (7) are: it can directly and comprehensively evaluate the tourist brand value loss caused by debris flow, and the data is easy to collect, analyze, and calculate. It also embodies the idea that one should view the situation from the perspective of customers, change tourism products in the market according to tourism revenue's change, thus reflecting the dynamic change of customers' withdrawing from the market because of negative influences such as disasters (Dawar and Lei 2008). At the same time, this formula emphasizes the characteristic of tourism towns' "one-time" expenditure, i.e. tourists normally don't repeat their expenditure. It also evaluates the brand value in accordance with consumers' tourist preference and purchase will (Keller 1993).

Moreover, in Formula (7), LBV_j stands for the brand value loss in different years. The total loss of brand value（LBV_Z）saved by prevention and control projects cannot be calculated by simply adding up the retrieved brand value loss of each year within the life cycle; In Formula (8) (Smith 1996 and Asian Disaster Reduction Center 2005) the risk of disaster is in a positive relation to the disaster's probability and the loss of disaster. Therefore, in the actual calculation, one should take into consideration of the disaster's probability of occurrence in the calculation of debris flow mitigation benefits and loss of brand value.

$$R = P \times L \tag{8}$$

where R stands for the risk of disaster. P stands for the disaster's probability and L stands for the loss due to the disaster.

$$LBV = \frac{\sum_{j=1}^{X} LBV_j}{X} \tag{9}$$

$$LBVz = \frac{LBV \times P}{n} \times \frac{(1+i)^n - 1}{i} \tag{10}$$

LBV stands for tourism brand mean value loss caused by debris flow, X stands for debris flow's number of occurrence since the founding of tourism towns. P stands for the probability of occurrence within the debris flow engineering's life cycle, n stands for the life cycle of the debris flow engineering, and i stands for the benchmark interest rate.

1.3 Calculation of the benefits from reducing the disasters

Disaster loss is divided into direct loss (S1) and indirect loss (S2), which are assessed separately. The benefits from reducing the disasters are a sum of direct loss and indirect loss.

$$DMB_j = S_{1j} + S_{2j} \tag{11}$$

DMBj is the benefits from reducing the disasters in Year j, S_{1j} is the direct loss in Year j and S_{2j} is the indirect loss in Year j.

The direct loss caused by debris flow normally includes road loss (Sa), building loss (Sb), casualties (Sc), loss of the landscape environment (Sd) (Table 1). Indirect loss generally includes lifeline loss (Ts), traffic disruption (Ps), and the decrease of business turnover (Bs) (Table 2).

To calculate the benefits from reducing the disasters within the lifespan of the prevention and control projects involves considering the value of time and money and the probability that the disaster will happen, which is in accordance with the calculation of LBVz, and DMBz can be expressed in the following formula:

$$DMBz = \frac{DMB \times P}{n} \times \frac{(1+i)^n - 1}{i} \tag{12}$$

$$DMB = \frac{\sum_{j=1}^{X} DMB_j}{X} \tag{13}$$

DMB indicates the benefits from alleviating the disasters, and X refers to the return period of debris flow in tourist towns after their construction.

1.4 The calculation of the investment cost

The investment in the debris flow prevention and control engineering normally includes the construction fund and maintenance fund, which is allocated by the government, and calculated according to the actual cost. The data can be obtained from Ministry of Land and Resources.

1.5 The estimation of VDFE

As is mentioned previously, VDFE includes investment cost (IC), disaster mitigation benefits (DMB_Z), and loss of brand value (LBV_Z) (Figure 1).

The methods and formula to calculate IC, LBVz and DMBz are summed up in Table 3.

VDFE can be expressed in the following formula:

$$VDFE = IC + \frac{LBV \times P}{n} \times \frac{(1+i)^n - 1}{i} + \frac{DMB \times P}{n} \times \frac{(1+i)^n - 1}{i} \quad (14)$$

Its short form is:

$$VDFE = IC + \frac{(LBV + DMB) \times P}{n} \times \frac{(1+i)^n - 1}{i} \quad (15)$$

2 Application of the model: the debris flow control engineering in Hongchun

2.1 Study area

The Hongchun Gully is located in Northeast of Yingxiu, Sichuan Province, southwest China, on the left side of Minjiang River. The gully is situated in N31°04′01.1″ and E103°29′32.7″, with a total area of 5.35km^2. The highest point of the watershed is 2168.4m, the relative height difference of the watershed is 1288.4m, the length of mainly gully is around 3.6km and the sectional shapes are V-shaped. The average of the main gully bed gradients is 358‰, and the mountain slope is 35°-45° (Figure 2). The Hongchun Gully consists of Ganxipu, Dashui, Xindianzi tributary, and it is the only one in Yingxiu that may break the main river.

Yingxiu is about 78km away from Chengdu, and is situated at the edge of Sichuan Basin with subtropical humid monsoon climate. The average annual rainfall is between 1000~1600mm and the maximum daily precipitation is 269.8mm.

The weak rocks of Hongchun Gully were affected by the Yingxiu-Beichuan fault. Yingxiu is the epicenter of the 2008 Wenchuan Earthquake (Mw8.3). The powerful earthquake leads to vulnerable geological environment, and increases the risk of debris flow, landslide and other hazards.

It has been reported that the government planned to rehabilitate Yingxiu as a tourist town with an estimated investment of RMB 2 billion after the 2008 Wenchuan Earthquake (Xinhuanet 2009). Yingxiu has received 4 million visitors in 2014 and became a tourist town (China Economic Net 2015).

2.2 The debris flow hazard of Yingxiu tourist town

On August 14, 2010 in Yingxiu, the Hongchun Gully received a heavy rainfall with daily precipitation of 163mm. This was the largest and most destructive debris flow in the recent hundreds of years, and was triggered in the gully. The debris flow carried lots of loose sediments and the total amount is about 8.05 × 10^{5}m^3. Around 4.0×10^{5}m^3 of the debris rushed into and blocked the Minjiang River (Figure 3A). This led to serious disasters (Figure 3B): 400m-highway of the No.213 National Highway was interrupted, 17 people died, 59 people were missing and 8000 people were forced to evacuate (Table 4).

Abundant loose materials were triggered by large quantities of precipitation to form the Hongchun Gully debris flow. According to the survey, there was a total volume of 3.7314×10^{6}m^3 loose materials at 52 sites on the watershed after the 2008 Wenchuan Earthquake. The debris flow sources in the watershed include collapse landslide, channel deposits and surface erosion (Figure 4). Separately, there were the volume of 1.83×10^{6}m^3 loose materials from the collapse and landslide source at 37 sites, 1.84×10^{6}m^3 from channel source and 5.9×10^{4}m^3 from surface erosion source in the watershed.

2.3 The dynamic parameters of the debris flow on August 14, 2010

The bulk density of the debris flow was obtained by the Weighting Method from Code for Investigation of Debris flow in China. The velocity of the debris flow was obtained by Manning's formula. The torrent discharge of different frequency was obtained by calculating with Code for Hydrology in Sichuan, and the discharge of the debris flow was obtained based on the bulk density and the torrent discharge. The volume of the debris flow was obtained based on the discharge and movement time. According to the survey, the disaster on August 14 is a large scale viscous debris flow: the density is 1.8t/m^3, the maximum discharge is 291m^3/s, the total of slurry volume is 2.7×10^{5}m^3, and the volume of the total debris is 8.05×10^{5}m^3 (Sichuan Huadi Geological Engineering Company 2011).

2.4 Mitigating Engineering

The debris flow control engineering combines block dams and drainage channel building (Figure 5). The block dams had been built to stabilize the vulnerable debris flow sources on the upstream. The structures include 4 Grid dams (2 High dams among them) and many check dams to stabilize debris in the upstream. There is a 600m channel to transport debris flow into Minjiang River. The engineering structures are built to satisfy 50-year return period debris flow. Investment on the engineering is 150.01 million RMB (Table 5), the cost of engineering maintenance is 30 million RMB, and the total investment on the engineering is 180 million RMB.

The engineering system is composed of five zones. The Ganxipu zone is the largest part in the branch of the right bank, with a plan that combines stabilizing slope with check dams and 2 grid dams. The investment arrived at 28.13 million RMB. In the Dashui zone there were 2 grid dams with an investment of 26.26 million RMB. In the Xindianzi zone there were 2 groups of check dams and a channel with an investment of 18.23 million RMB. In the Middle mainstream zone, there were 4 grid dams with an investment 24 million RMB. In the downstream zone, there were 600 drainage channels with an investment of 53.39 million RMB to build 4 segments D to guide the debris flow into the river.

2.5 Valuation of debris flow control engineering

2.5.1 Valuation of DMB

On the method of direct economic loss assessment (Table 1), it is estimated that the direct economic loss reached 459.85 million RMB for the debris flow hazards on August 14, 2010 (Table 6). With respect to only one debris flow hazard occurrence (i.e., j=1) since the tourist town (Yingxiu) has been built, the DMB equals to DMB_j, and is 459.85 million RMB.

2.5.2 Valuation of LBV

The debris flow occurred in the Hongchun Gully could destroy the Dujiangyan-Wenchuan Highway and No G213 National Road via Yingxiu. Nevertheless the hazards directly threaten the Yingxiu tourist town. Here Formulas (7) and (9) are used for estimating LBV.

As the town was completely rebuilt at the end of 2011, the tourism was beginning to develop in 2012. The tourism income of 24 million RMB (Sina Net, 2013) in 2012 is set as Tr_j value of Formula (7). The recovery time (T) from the geohazard is assigned as 1 year. Subsequently the mean annual LBV_j is:

$2,400\times365\div365\times(1+6.4\%)= 2,554$ ($\times10^4$ RMB)

This is equivalent to the DMB calculation, because of j=1, then LBV equals to LBVj, and is 2,554 ($\times10^4$ RMB).

2.5.3 Valuation of debris flow control engineering

Employing Formulas (10), (12) and (14), the VDFE reaches 3,401,040 thousand RMB, of which the IC, DMBz, and LBVz are 180,000 thousand RMB, 3,051,560 thousand RMB, and 169,480 thousand RMB, respectively (Table 7).

As a result, the LBV is much higher than the IC for the engineering (Table 6). Accordingly the LBV cannot be neglected in case of the VDFE approach (Figure 6). Actually the input-output ratio (IC/F or IC/(DMBz+LBVz)) is 1:18.

3 Discussion and Conclusions

The disaster mitigation benefit (DMB) refers to the utmost disaster loss reduced possibly within the lifespan of the prevention and control projects. Strictly, it should be evaluated by comparison of the disaster loss with/without mitigation engineering projects. The disaster loss caused by debris flow is complicated, which includes economic loss, environment loss, resource loss and human casualty. It is difficult to precisely assess the disaster loss without mitigation engineering at present. In addition, how to assess the disaster loss without mitigation engineering is an issue that should be studied by the research community in the future. On the other hand, the DMB of the Hongchun Gully was obtained by estimating disaster loss of the debris flow on August 14,2010 in Yingxiu town. The DMB of the Hongchun Gully is obtained based on the disaster accident on August 14, 2010 in Yingxiu. The model of VDFE estimation had been checked in the case of the debris flow control engineering in the Hongchun Gully, and the results show that the effectiveness of the model is fine and it has the certain practical application value. The model of VDFE is built up on the input-output based disaster loss, which is the upmost potential loss for a disaster and will provide appropriate risk management information for the government to make a decision about the debris flow control measurement. The disaster loss based on the input-output model is superior for application to that on the general equilibrium model. The former is clear to understand, easy to follow and acceptable for the government to apply for its upmost loss result. The later is non-liner and may be used to obtain the lower limit of the disaster loss.

In conclusion，The proposed VDFE model is applicable and effective in evaluating the value of debris flow prevention and structural control work in tourist towns. It depends on investment cost (IC), disaster mitigation benefit (DMB), and loss of brand value (LBV). The model had been checked in the case of the debris flow structural control work in the Hongchun Gully in Yingxiu, Sichuan, southwest China, and the results show that the structural control work is valuable for disaster alleviation. The analysis indicates that the loss of brand value (LBV) resulting from the debris flow hazard cannot be neglected in the case of VDFE. The loss of brand value (LBV) is much higher than the investment cost (IC) for the engineering projects, and the greater the LBV, the higher the VDFE are. The VDFE model is used to assess the utmost disaster loss reduced possibly with the linear input-output method, because the input-output ratio is the topmost effects of disaster loss assessment. Consequently, compared with the common equilibrium model, the VDFE model is useful in providing appropriate risk management information for the government to assess disaster mitigation projects and make an informed decision.

Acknowledgement: The study is supported by the program of Increasing resilience to natural hazards in earthquake prone regions in China: The National Natural Science Foundation of China (No：4151101234) and Newton Fund via Natural Environment Research Council (NERC) and Natural Environment Research Council (ESRC) (NE/N012143/1). We are grateful to the three reviewers for providing the constructive comments and valuable suggestions in improving the manuscript.

References

Blahut J, Glade T, Sterlacchini S (2014) Debris flows risk analysis and direct loss estimation: the case study of Valtellina di Tirano, Italy. Journal of Mountain Science 11: 288-307. DOI: 10.1007/s11629-013-2806-2

Carreño R, Kalafatovich S (2006) The Alcamayo and Cedrobamba catastrophic debris flow (January, March and April 2004) in Machupicchu area—Peru. Landslides 3: 79-83. DOI: 10.1007/s10346-005-0009-9

Chen NS, Zhou W, Yang CL, et al. (2010) The processes and mechanism of failure and debris flow initiation for gravel soil with different clay content. Geomorphology 121: 222-230. DOI: 10.1016/j.geomorph.2010.04.017

China Economic Net (2015) Culture and tourism: Transformation and upgrading for Post-Wenchuan Earthquake industries at Dong Village in Yingxiu. http://www.ce.cn/culture/gd/201508/24/t20150824_6302152.shtml. Accessed 24 August 2015. (in Chinese)

Coe JA, Kean JW, Godt JW, et al. (2014) New insights into debris-flow hazards from an extraordinary event in the Colorado Front Range. GSA Today 24(10): 4-10. Doi:10.1130/GSATG214A.1

Cui P, Liu SQ, Tang BX, et al. (2003) Debris flow prevention pattern in national parks—Taking the world natural heritage Jiuzhaigou as an example. Science in China Ser. E Technological Sciences 46(S): 1-11. DOI: 10.1360/03ez0004

Cui P, Hu KH, Zhuang JQ, et al. (2011) Prediction of debris-flow danger area by combining hydrological and inundation simulation methods. Journal of Mountain Science 8: 1-9. DOI: 10.1007/s11629-011-2040-8

Cui P, Lin YM, Chen C (2012) Destruction of vegetation due to geo-hazards and its environmental impacts in the Wenchuan earthquake areas. Ecological Engineering 44: 61-69. DOI: 10.1016/j.ecoleng.2012.03.012

Cutter SL, Ismail-Zadeh A, Alcántara-ayala I, et al. (2015) Pool knowledge to stem losses from disasters. Nature 522: 277-279. DOI: 10.1038/522277a

Dawar N, Lei J (2008) Brand crises: The roles of brand familiarity and crisis relevance in determining the impact on brand evaluations. Journal of Business Research 62: 509-516. DOI: 10.1016/j.jbusres.2008.02.001

Fan XC, Leng Y (2000) Brand valuation using Consumer's Loyalty Degree. Scientific Management Research 18(5): 50-56.

Hu BZ (2005) Tourist-based brand valuation for tourism spots. Journal of Jiangxi University of Finance and Economics 38(2): 59-61.

Huan TC, Beaman J, Shelby L (2004) No-escape natural disaster: Mitigating Impacts on Tourism. Annals of Tourism Research 31: 255-273. DOI: 10.1016/j.annals.2003.10.003

Huang JH, Min JCH (2002) Earthquake devastation and recovery in tourism: The Taiwan Case. Tourism Management 23: 145-154. DOI: 10.1016/S0261-5177(01)00051-6

Igwe O (2015) Analyses of the October 2013 fatal slope failures on the metamorphic terrains of Obudu tourist area, South-Southeast Nigeria. Arabian Journal of Geosciences 8: 7425-7434. DOI 10.1007/s12517-014-1659-5

Keller KL (1993) Conceptualizing, measuring and managing customer-based brand equity. Journal of Marketing 57: 1-22. DOI: 10.2307/1252054

Li DH et al., (2013) Engineering management and its effect of large debris flow at Hongchun Valley in Yingxiu town, Wenchuan. Journal of Engineering Geology 21(2):260-268(in Chinese)

Liu XL, Zhao Y (2008) Estimation on Indirect Economic Losses of Geomorphic Hazards-Taking debris

flow as an example. Progress in Geography 27(3): 7-13.
Marx KH (1867) Capital: A Critique of Political Economy (Volume I). Hamburg: Verlag von Otto Meisner.
Mccoy SB (2015) Infrequent, large-magnitude debris flows are important agents of landscape change. Geology 43: 463-464. DOI: 10.1130/focus052015.1
Parnell J (2009) Global mass wasting at continental margins during Ordovician high meteorite influx. Nature Geoscience 2: 57-61. DOI: 10.1038/ngeo386
Sina Net (2013) Perplexity of Yingxiu reconstruction. http://news.sina.com.cn/c/2013 -05-09/100027071526.shtml. Accessed 9 May 2013. (In Chinese)
Sichuan Huadi Geological Engineering Company (2011) Survey Report of the Hongchun Gully Debris Flow. (In Chinese)
Tang YD (2011) The Economics of Disasters. Beijing: Tsinghua University Press. (In Chinese)
Wang HZ, Huang YX (1997) A discussion on the basic concepts and classification of indirect economic losses of seismic disaster. Journal of Natural Disasters 6(21): 11-16.
Wei XL, Chen NS (2006) Catastrophic debris flow characteristics of Alamaty, Kazakhstan on March 14th, 2004. Mountain Research 24(B10): 209-216.
Wei FQ, Xie H, Lopez JL, et al. (2000) Extraordinarily serious debris flow disasters in Venezuela in 1999. Mountain Research 18(6): 580-582.
Wu LH, Hayashi H (2014) The impact of disasters on Japan's inbound tourism demand. Journal of Disaster Research 9(S): 699-708.
Wu ZH (2001) The mud-rock flow disaster and their touch off condition by rainfall in Beijing Area. Research of Soil and Water Conservation 8(1): 67-72.
Xinhuanet (2009) The Overall Planning of Yingxiu for Post-Wenchuan Earthquake Restoration and Reconstruction has been approved. http://news.xinhuanet.com/ newscenter/2009-05/08/content_11338690.htm. Accessed 8 May 2009. (In Chinese)
Yang WQ, Chen GJ, Wang DJ (2008) Impact of the Wenchuan earthquake on tourism in Sichuan, China. Journal of Mountain Science 5: 194-208. DOI: 10.1007/s11629-008-0205-x
You Y, Ou GQ, Lv J, et al. (2003) Debris flow disaster and its control in Guanmiao gully in Sichuan Province. Journal of Disaster Prevention and Mitigation Engineering 23(4): 50-55.
Zhang YF, Liu H (2006) Landslide and its preventive/mitigation system in HongKong. Journal of Guangzhou University (Natural Science Edition) 5(1): 45-50.
Zhao Y, Liu XL (2005) Economic benefit evaluation of the prevention and project for debris flow. The Chinese Journal of Geological Hazard and Control 16(3): 42-53.
Zhong JR, Lin JQ (2003) Study on seismic indirect economic loss. Journal of Natural Disasters 12(4): 88-92.
Zimmermann M (2004) Managing Debris Flow Risks. Mountain Research and Development 24: 19-23. DOI: 10.1659/0276-4741(2004)024[0019:MDFR] 2.0.CO;2

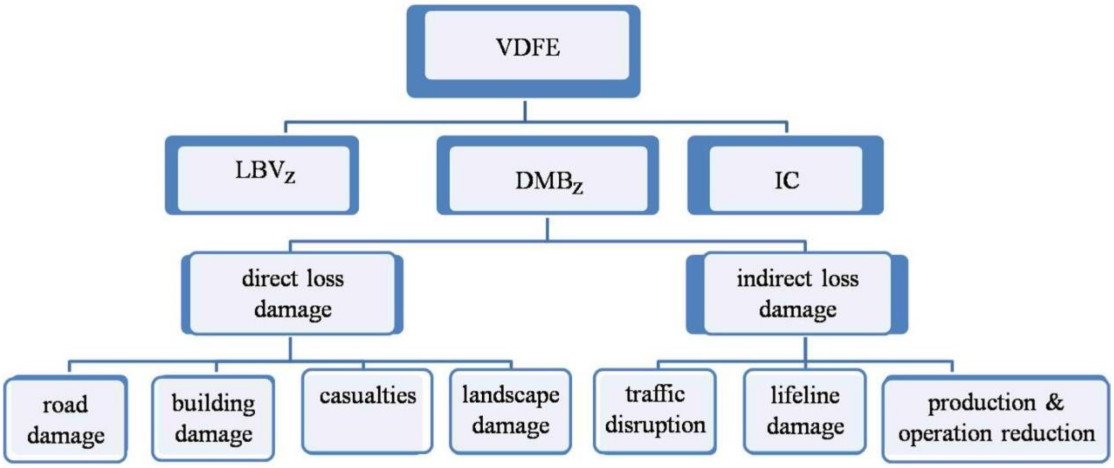

Figure 1 Framework for the economic valuation on the project of debris control

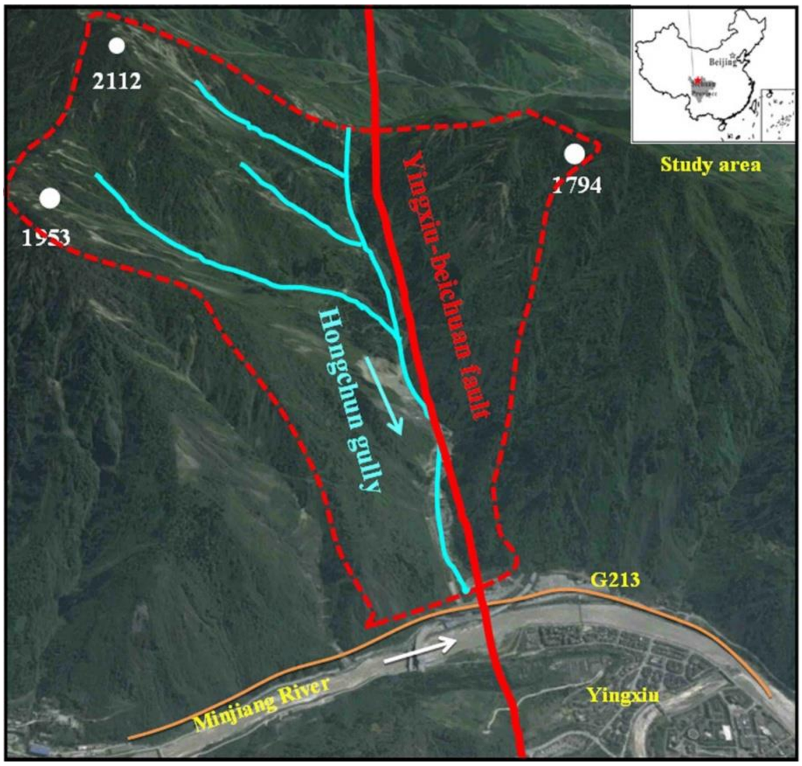

Figure 2 The landscape of the Hongchun Gully

(A) (B)

Figure 3 The debris flow blocked Minjiang River (A) and Yingxiu town was flooded (B)

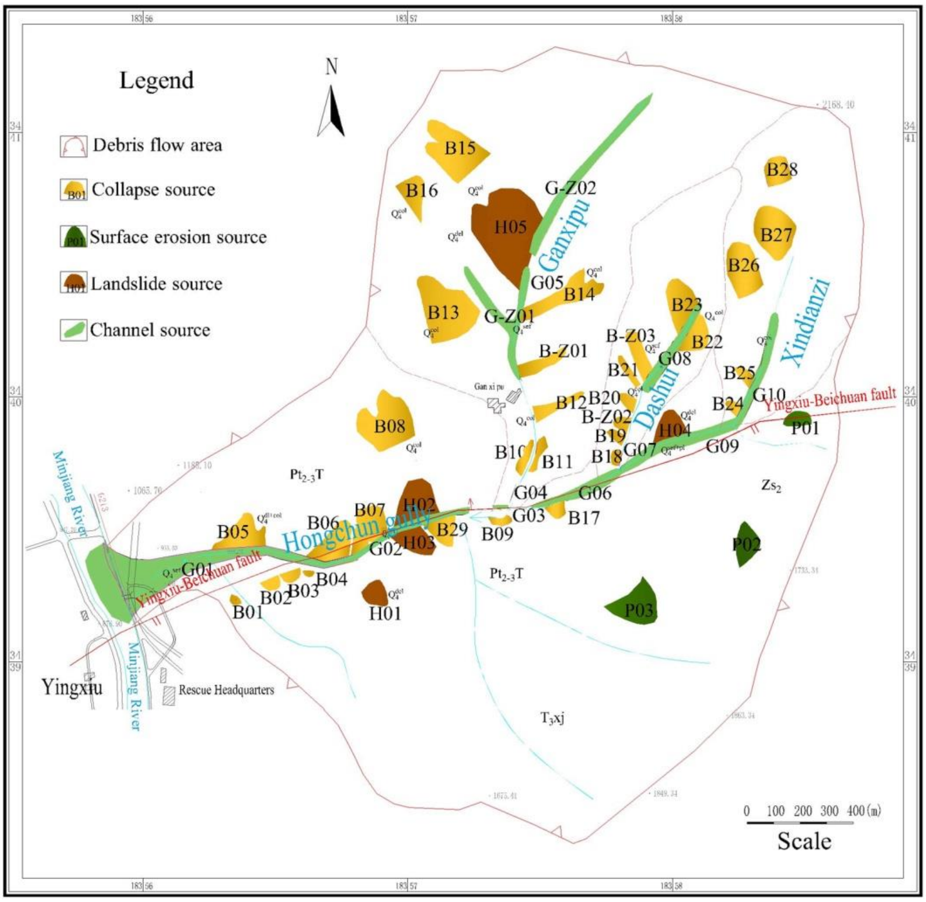

Figure 4 The debris flow source distribution map of the Hongchun Gully((revised from Li et al.,

2013)

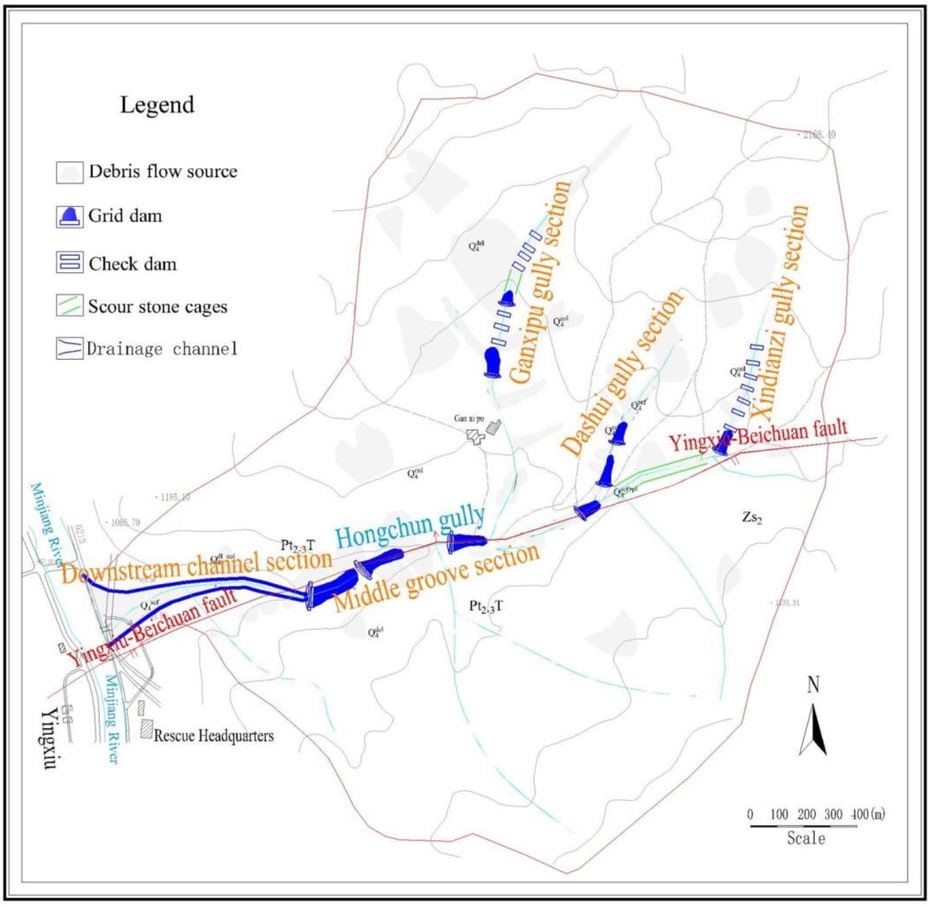

Figure 5 The engineering layout plans of the Hongchun Gully(revised from Li et al., 2013)

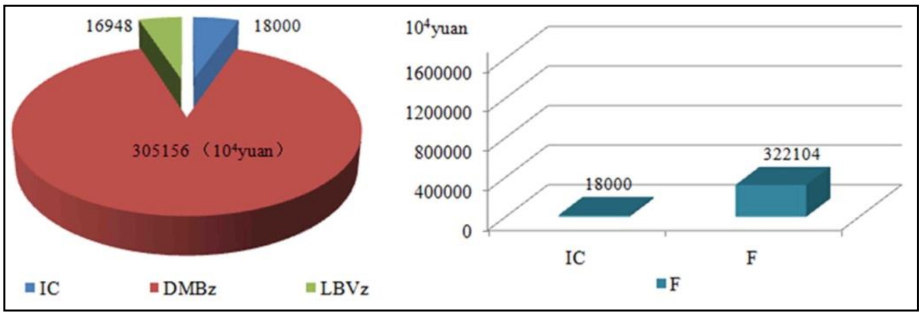

Figure 6 Pie Chart of VDFE in the Hongchun Gully, Yingxiu

Table 1 Evaluation methods of the direct damage caused by mudslides

Direct loss	Evaluation methods	Evaluation formula	Data range
Road loss	restoration cost approach (Tang 2011)	$S_a = S_{a1} + S_{a2}$ $S_{a1} = L_{a1} \times P_{a1}$ $S_{a2} = L_{a2} \times D_{a2} \times H_{a2} \times P_{a2}$	1. S_{a1} stands for the road damage caused by the rushing of the debris flow. La1 is the length of the damaged road. 2. S_{a2} is the road loss caused by the mud submerging the road. L_{a2} is the length of the road submerged. D_{a2} is the width of the road submerged. H_{a2} is the thickness of the mud. P_{a2} is unit cost of construction.
Building loss	Replacement cost approach and restoration cost approach (Tang 2011)	$S_b = A \times P_b$	A is the area of the building of the same kind. P_b is unit price of replacement or restoration.
Casualties	Human capital approach (Zhao and Liu 2005)	$S_c = 30 \times Y \times P_1 + Y \times P_2$	Y—average GDP of local people that year (10 thousand RMB per capita). P_1— the sum of the death toll and the number of people unaccounted for (person). P_2—the sum of the injured (person).
Landscape environment loss	restoration cost approach (Tang 2011)	$S_d = V_d \times f$	V_d is the value of landscape environment loss, and f is the coefficient of estimated loss.
The sum of direct loss		$S_1 = S_a + S_b + S_c + S_d$	

Table 2 Evaluation methods of the indirect damage caused by mudslides

Indirect loss	Evaluation methods	Evaluation formula	Data range
Traffic disruption	Traffic flow approach (Liu and Zhao 2008)	$TS = TS_1 + TS_2$ $TS1 = (C_2 - C_0) \times (V_0 - V_1) \times L \times t + (C_1 - C_0) \times V_1 \times L \times t$ $TS_2 = V_0 \times P \times t$	TS_1: indirect loss caused by the disaster damaging the road; TS_2: indirect loss caused by the disaster damaging the road; C_0: average cost of each vehicle before the road is damaged (Unit: RMB/vehicle/km); C_1: average cost of each vehicle after the road is damaged (Unit: RMB/vehicle/km); C_2: average cost of each vehicle making a detour to reach the destination after the disaster (Unit: RMB/vehicle/km); The three values are estimated according to the types of vehicle that mainly go through this section of the road (such as off-roaders, truck, etc.) and the distribution of the road network; V。: the traffic flow before the road is damaged in the disaster (Unit: vehicle/hour), which can be determined by the road grade and the development of the local economy; V1: the traffic flow after the road is damaged in the disaster (Unit: vehicle/hour), which can be determined during field investigation; L is the length of the road damaged (Unit: km); t: time needed for traffic restoration (Unit: hour), which depends on how the road repair goes.
Lifeline loss	(Liu and Zhao 2008)	$PS = \sum_{i=1}^{n} P_i \times t_i$	i: lifeline types; p: everyday average turnover (Unit: yuan/d); t: time for restoration (Unit: d), p and t can be obtained from local related authority; n stands for the mudslide project's life span.
The decrease of production and operations management	Investigation approach (Liu and Zhao 2008)	$BS = \sum_{i=1}^{n} \sum_{j=1}^{n} P_{ij} \times (Q_{ij} - Q'_{ij}) \times t_{ij}$	i: disaster-stricken businesses; j: the type of disaster-stricken products; n: the number of disaster-stricken businesses and the types of disaster-stricken products; Pij: the price of a certain product of a business (Unit: yuan/measurement unit); Qij: output before the disaster (Unit: measurement unit/d); Q'ij: output after the disaster (Unit: measurement unit/d); tij: time for reduction of output or production halt (Unit: d); n stands for the mudslide project's life span. Ask the business for more information.
The sum of indirect loss (S_2)		$S_2 = TS + PS + BS$	

Table 3 Calculation and assumption of tourist town debris flow engineering value constitution

Formula	Constitution of project value
IC	Input cost decided by calculating the project construction total cost and maintenance cost from government's prevention and control project appropriation;
$LBVz = \frac{LBV \times P}{n} \times \frac{(1+i)^n - 1}{i}$ $LBV = \frac{\sum_{j=1}^{X} LBV_j}{X}$ $LBV_j = \frac{(Tr_{j-1} + Tr_j + Tr_{j+1})}{3 \times 365} \times T_j \times (1+i)_j$	LBV_z refers to the tourism brand's total loss (unit: ten thousand RMB) when the debris flow engineering life cycle comes to an end (normally 50 years); LBV refers to the brand's mean loss value (unit: ten thousand RMB per time) caused by debris flow since the setting-up of the tourist town; LBV_j refers to the brand value loss for j years (unit: ten thousand RMB).
$DMBz = \frac{DMB \times P}{n} \times \frac{(1+i)^n - 1}{i}$ $DMB = \frac{\sum_{j=1}^{X} DMB_j}{X}$ $DMB_j = S_{1j} + S_{2j}$	DMB_z refers to the disaster reduction gross earnings when the life cycle of the debris flow engineering comes to an end (normally 50 years). DMB refers to the disaster mean loss value (unit: ten thousand RMB per time) caused by debris flow since the setting up of the tourist town. DMB_j refers to the disaster reduction gross earnings (unit: ten thousand RMB) for j years, which is the sum of the direct (S_1) and indirect (S_2) loss caused by debris flow.

Note: P refers to debris flow's probability of occurrence. The probability within the engineering's life cycle is represented as P(y, n), i.e. the probable number of occurrences of debris flow that happen only once in y years happen in n years within the engineering life cycle; n stands for the debris flow engineering's life span, which is normally designed as 50 years; X refers to the return period when the tourist town is hit by debris flow since the setting-up of it, the data of which is obtained by calculating the tourism loss caused by disaster according to the local tourism administration and disaster occurrence times counted by the land ministry; i refers to benchmark interest rate.

Table 4 Disaster induced by the Hongchun Gully debris flow

Type	Damage
Infrastructure	400m-highway of No.213 National Highway buried by debris flow deposits
Casualty	17 people died, and 59 people were missing
Town	Yingxiu district was flooded
Environment	$4.0\times10^5 m^3$ debris flow rushed into and blocked the Minjing river
Transportation	Traffic interrupted the No.213 National Highway

Table 5 The statistics of design features and investment of the engineering

Zone	Treatment Engineering		Structure Size	Function	Volume of the engineering	Investment
Ganxipu	Grid dam	1#	High 9m Length 37.9m	Capacity 10301m^3 Stabilize 5943m^3	Earthwork 11381m^3 Stone excavation 3211 m^3 Capacity 2339 m^3 Soil transport 6988 m^3 Drill 64m C25 Concrete 10644 m^3 Masonry 1390 m^3 Rebar 20T Form clamp 5263m^2 Scaffold 5818 m^2 Bitumen and board 36 m^2	28.13 million RMB
		2#	High 8m Length 24m	Capacity 5760m^3 Stabilize 3600m^3		
	Check dam	1#	Built 3 Dams High 5m Length 14.5-16.7m	Capacity 3860m^3， Stabilize 15100m^3		
		2#	Built 4 Dams High 5m Length 16.4-19m	Capacity 5730m^3 Stabilize 19201m^3		
	Toe wall		High 3.5m Length 84m	Stabilize 12000m^3		
Dashui	Grid dam	1#	High 7m Length 19.7m	Capacity 5714m^3 Stabilize 517 m^3	Earthwork 2511m^3 Stone excavation 534 m^3 Capacity 502 m^3 Soil transport 2010 m^3 C25 Concrete 1675 m^3 Bitumen and board 1455 m^2	26.26 million RMB
		2#	High 7m Length 25.8m	Capacity 5789m^3 Stabilize 9000m^3		
Xindianzi	Grid dam		High 7m Length 30.35m	Capacity 6682m^3 Stabilize 5012m^3	Earthwork 5088m^3 Stone excavation 1570 m^3 Capacity 2977 m^3 Soil transport 6657.8m^3 Drill 48m C25 Concrete 6276 m^3 Rebar 8T Form clamp 6739m^2 Scaffold 1641 m^2 Bitumen and board 187 m^2	18.23 million RMB
	Check dam		Built 7 Dams High 5m Length 11-26.5m	Stabilize 21000 m^3		
	Scour stone cages		High 2.5m Width 4m Length 364m	Stabilize 25000 m^3		
Middle mainsream	Grid dam	1#	High 20m Length 114.4m Width of Grid 1m Built 68 Pile foundation Length of pile 7-21m	Capacity 156302m^3 Stabilize 110000m^3	Earthwork 49210m^3 Stone excavation 9159 m^3 Capacity 13505 m^3 Soil transport 54669 m^3 Drill 1938.6m C25 Concrete 62603 m^3 Masonry 4981 m^3 Rebar 391T Form clamp 26715m^2 Scaffold 18715 m^2 Bitumen and board 36 m^2 Rubber strip 1940m^2	24.00 million RMB
		2#	High 18m Length 95m Width of Grid 1.2m Built 40 Pile foundation Length of pile 6-18m	Capacity 84088m^3 Stabilize 70000m^3		
		3#	High 10m Length 42m Width of Grid 1.2m Built 6 Pile foundation Length of pile 3-6m	Capacity 13652m^3 Stabilize 488m^3		
		4#	High 8m Length 42m Width of Grid 1.2m	Capacity 8308m^3 Stabilize 11000m^3		

			Built 8 Pile foundation Length of pile 8m			
Downstream	Drainage channel	A	Length 165m Width 19-25m Gradient 160‰	Bed reinforce 165m Discharge 200.9m^3/s	Earthwork 163349m^3 Stone excavation 40838 m^3 Capacity 32638 m^3 Soil transport177092 m^3 Scaffold 1681m^3 C25 Concrete 13724m^3 Rebar 20T Form clamp 1989m^2 Bitumen and board 8860 m^2	53.39 million RMB
		B	Length 435m Width 30m Gradient 129‰	Bed reinforce 435m Discharge160.14m^3/s		
		C	Length 105m Width 32m Gradient 207‰	Bed reinforce 105m Discharge 238m^3/s		
		D	Length 100m Width 35m Gradient 90‰	Bed reinforce 100m Discharge 171.8m^3/s		
Engineering maintenance						30.00 million RMB

Table 6 Evaluation of direct economic loss induced by the debris flow hazards

Direct economic loss	Valuation method	Calculation model	Value ($\times10^4$ RMB)
40×10^4 m^3 of the debris flow materials entered into the Minjiang River, and blocked the channel while No G213 National Road was destroyed： 400 m road had been buried.	Recovery cost method	$S_a=S_{a1}+S_{a2}=La_1\times P_{a1}+La_2\times D_{a2}\times H_{a2}\times Pa_2$	1,236
Reported toll： 17 people death, 59 people missed.	Human capital method	$S_c=30\times Y\times P_1+\times Y\times P_2$	4,749
The new district of the town was buried by debris flow.	Replacement cost met hod	$S_d=V_d\times f$	40,000
DMB_j		$DMB_j=S_a+S_c+S_d$	45,985

Table 7 The total value of the engineering for debris flow control in the Hongchun Gully in Yingxiu, Sichuan, southwest China

Parameters	Model	Boundary condition	Value ($\times 10^4$ RMB)
IC		Costs for the engineering construction and maintenance.	18,000
DMBz	$DMBz = \frac{DMB \times P}{n} \times \frac{(1+i)^n - 1}{i}$	$DMBz = \frac{45985 \times P(50,50)}{50} \times \frac{(1+6.4\%)^{50} - 1}{6.4\%}$	305,156
LBVz	$LBVz = \frac{LBV \times P}{n} \times \frac{(1+i)^n - 1}{i}$	$LBVz = \frac{2554 \times P(50,50)}{50} \times \frac{(1+6.4\%)^{50} - 1}{6.4\%}$	16,948
VDFE	$VDFE = IC + LBVz + DMBz$		340,104