# Research on the Evaluation of Natural Disaster Recovery

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**Research Article**

**Keywords:** Post disaster recovery and reconstruction, Effect evaluation, ISM, AHP, fuzzy mathematics

**Posted Date:** April 15th, 2022

**DOI:** https://doi.org/10.21203/rs.3.rs-1558997/v1

# Research on the Evaluation of Natural Disaster Recovery

Shao-xiong Xu [1,3] · Zhuo-qun Du [2]

**Abstract:** Post-disaster restoration and reconstruction are important means to support and help areas where natural disasters occur to restore normal production and living order. Assessing the gap between the effects of restoration and reconstruction and the goals of reconstruction planning, as well as studying the expected demand gaps of different subjects, is the core objective of the evaluation of the effects of post-disaster restoration and reconstruction. Based on the summary and analysis of the practical experience of natural disaster recovery and reconstruction in China, a post-disaster recovery and reconstruction effect evaluation index system with 6 levels and 37 underlying indicators has been constructed, and based on the post-disaster recovery and reconstruction planning, two perspectives of coincidence and multi-subject demand evaluation have been achieved. An empirical analysis was made on the recovery and reconstruction of the "8.7 Zhouqu Debris Flow" disaster. Post-disaster reconstruction should be "people-oriented," starting from the actual situation of local cultural value restoration, focusing on the long-term goal of sustainable development of the ecological environment, grasping the short-term goal of restoring economic development, and focusing on key projects. Suggestions for the optimization of the economic stimulus of the project have also been put forward. Empirical research shows that the post-disaster recovery and reconstruction plan of the "8.7 Zhouqu debris flow" disaster achieves excellent consistency; the evaluation value of the post-disaster recovery and reconstruction effect based on the needs of multiple entities is good.

**Key words:** Post disaster recovery and reconstruction; Effect evaluation; ISM; AHP; fuzzy mathematics

## 1 Introduction

The post-disaster recovery and reconstruction of natural disasters are formulated following the "Emergency Response Law of the People's Republic of China" and the "Law of the People's Republic of China on Earthquake Prevention and Mitigation." The normal living, production and working conditions of the people promote the economic and social recovery and development of disaster-stricken areas. There are a few questions that need answering. Have the objectives of the post-disaster recovery and reconstruction plan been completed? How can the consistency of the reconstruction plan be calculated? Does the reconstruction effect meet the expected needs of different entities, and what is the gap? Appropriate evaluation indicators and methods are used to explore the effects of post-disaster recovery and reconstruction, and scientific guidance is provided for the evaluation of post-disaster recovery and reconstruction.

Post-project evaluation refers to a technical and economic activity that systematically and objectively analyzes and summarizes the purpose, execution process, role, and impact of the project after the project has been completed or after it has been operated for some time. An effect evaluation model was established in the United States in the 1830s. It was not until the 1970s that it was widely

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used by many countries and bilateral or multilateral aid organizations, such as the World Bank and the Asian Bank, to evaluate the results of funding activities around the world(Chen Yan,2007; Zhang Feilian,2004; Yang Yueqiao et al.,2014). In the literature, various studies have been conducted to e- -valuate the effect of post-disaster recovery and reconstruction. From the research object, Mojtaba Rafieian(Mojtaba Rafieian,2013). Limongelli studied the placement of sensors in post-earthquake reconstruction(M. P. Limongelli,2003; Jiuping Xu et al.,2013). From a management perspective, Du Jing made corresponding assessments from the development process and related impacts of the project(Du Jing,2009). Xu Jiuping and Wang He discussed the assistance and joint reconstruction of government organizations and nongovernmental organizations after the 2008 Wenchuan earthquake of magnitude 8.0 by applying the comprehensive integration model(Xu Jiuping et al.,2010). From the perspective of specific event evaluation, Chen Beibei evaluated the social impact of the reconstruction after the Wenchuan earthquake(Chen Beibei,2012); Xiao Lei and Li Shiming evaluated the ecological carrying capacity of the reconstruction area after the Wenchuan earthquake(Xiao Lei et al.,2009).

All kinds of natural disasters have the characteristics of strong suddenness, wide coverage, and great destructiveness, leading to the problems of tight time for post-disaster recovery and reconstruction, many projects to be reconstructed, scattered locations, and relatively high construction standards(Xu Jiuping et al.,2011; Xu Jiuping et al.,2010; Xu Jiuping et al.,2011; Shi Yingyi et al.,2017; Li Fugen et al.,2017).Although the research theory and application of effect evaluation are relatively mature, the theory of effect evaluation stays only at the stage of summary and feedback in the process of post-disaster recovery and reconstruction, and most post-disaster recovery and reconstruction research evaluates only earthquake disasters, which is natural in China and worldwide. There are a few evaluations of the scientific system of disaster recovery and reconstruction(Liu Yuqi,2017; Huang Jianwen et al.,2016; Chen Li et al.,2017; Chen Sheng et al.,2014; Wei Jianwen et al.,2015; Zhang Shu et al.,2016). Therefore, it is important to construct a reasonable and complete evaluation system for the recovery and reconstruction effects of natural disasters.

# 2 Model construction of post-disaster reconstruction effect evaluation

The objective of post-disaster recovery and reconstruction evaluation is to assess the loss and impact of the disaster, formulate the implementation plan of post-disaster recovery and reconstruction, and promote the economic and social recovery and development of the disaster area. As a complex all-round reconstruction process, it includes a material basis and spiritual culture. This process shows that the “central local” selects the existing urban areas as the geospatial carrier through the “application approval” process and takes the policy collection and derivative plan as the action guide, which will run through all levels of the country, province and city, departmental power, and civil power and act on the planning space within the geographical scope. There are clear guidelines and policy support for post-disaster recovery and reconstruction; that is, taking the national opinions on post-disaster recovery and reconstruction policies and measures as the starting point, the main policies are central overall planning, highlighting key points and giving priority to local governments, all parties’ support, tax and financial policies, and so on, so that the basic production and living conditions and economic and social development of the earthquake-stricken areas can be fully restored and exceed the pre-disaster level. This includes comprehensive consideration of social, economic, environmental, and other factors.

The evaluation content of the effect of post-disaster recovery and reconstruction is to measure the coincidence degree of post-disaster recovery and reconstruction planning, that is, the completion degree of post-disaster recovery and reconstruction results and planning, as well as the expectation value of different subjects on the reconstruction effect. Based on the summary and analysis of the planning and practice of restoration and reconstruction in China and worldwide, this paper establishes an evaluation index system for the effect of restoration and reconstruction in disaster areas, which is people-oriented, considers regional sustainable development as the long-term goal, and regards economic development, social harmony, and emergency capacity as the core, including economic benefits, social benefits, humanistic value, ecological environment sustainability, and emergency capacity-building. Based on the summary and analysis of the practical experience of natural disaster recovery and reconstruction in China, this paper constructs an evaluation method for the effect of natural disaster recovery and reconstruction. This method uses an interpretive structure model to analyze the qualitative structure of the evaluation index system, establishes a multilayer hierarchical structure, and clarifies the relationship between the upper and lower levels of the index. The analytic hierarchy process (AHP) is used to rank the influence of the evaluation indexes of the reconstruction effect, and the weight set of the evaluation indexes is obtained.

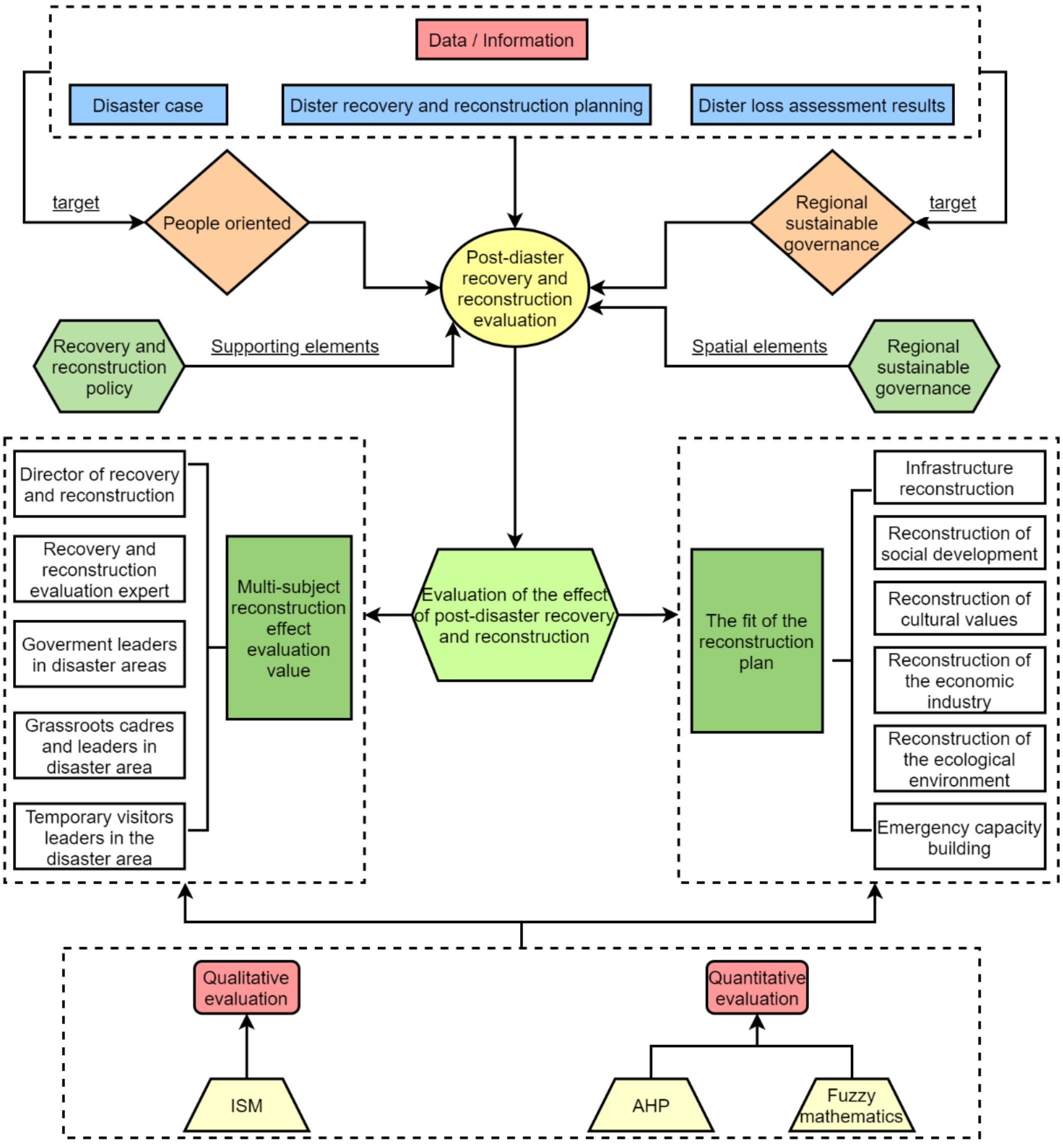


**Figure 1. Model construction of this article**

The quantitative statistical analysis of the planning objectives of the post-disaster recovery and reconstruction planning in the disaster area is carried out, and the realization coincidence degree of the reconstruction planning is calculated. Fuzzy mathematics is used to determine the membership matrix of the index system, and fuzzy comprehensive evaluation is used to quantitatively evaluate the recovery and reconstruction of the disaster area. The comprehensive evaluation results of multi-agent participation in the evaluation of the recovery and reconstruction of the disaster area are obtained. The construction of the model established in this paper is shown in Fig.1.

## 3 Evaluation index system for the effect of post-natural disaster recovery and reconstruction

Starting from the tasks and key content of post-disaster recovery and reconstruction, based on the objectives and relevant principles of post-disaster recovery and reconstruction of natural disasters, and considering the availability and validity of data, a post-disaster recovery and reconstruction effect evaluation index system is constructed,as shown in Fig.2 and Table1.

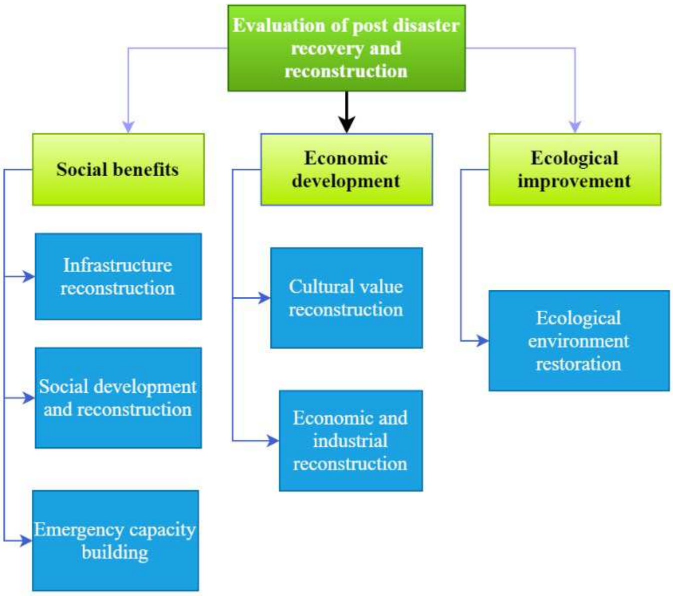


**Figure 2. Post-disaster recovery and reconstruction effect evaluation index system (first-level index)**

Based on the case analysis of reconstruction planning after major natural disasters, there are three aspects of the projects that are directly constructed after the disaster recovery and reconstruction: infrastructure reconstruction represented by housing and infrastructure construction, economic recovery focusing on improving residents' income and enterprise development in the disaster area, and ecological environmental protection. As "environmental protection" has increasingly become one of the most important dimensions in the development of urban and rural areas, it is listed as a primary indicator. The three aspects that are indirectly affected are society, residents' lives, and emergency response capabilities. The evaluation includes six first-level indicators: infrastructure, economic industry, ecological environment, social development, cultural value, and emergency response capabilities.

**Table.1 Calculation and explanation of the first-level and second-level indicators**

| First-level indicators | Secondary indicators | Calculation and interpretation |
|---|---|---|
| Infrastructure reconstruction | Housing supply restoration | Total urban and rural housing area |
| | Transportation facility restoration | Total mileage of roads at all levels |
| | Communication facility restoration | Number of base stations; length of cable and fiber; number of broadband access households |
| | Energy supply restoration | Energy supply facility (office) |
| | Restoration of power facilities | Transformer (number), power supply line (km) |

| First-level indicators | Secondary indicators | Calculation and interpretation |
|---|---|---|
| Economic and industrial reconstruction | Restoration of water conservancy facilities | Repair the mileage of ponds/reservoirs and main canals (km) |
| | Overall economic level | Gross regional product/permanent resident |
| | Growth | Gross domestic product (GDP) growth rate per capita |
| | Industrial structure | The proportion of secondary and tertiary industries in GDP |
| | GDP | GDP |
| Ecological environment restoration | Vegetation restoration | Increased area of vegetation restoration |
| | Biodiversity | Biodiversity Index |
| | Environmental quality | Environmental Quality Index |
| | Land degradation | Land degradation area |
| Social development and reconstruction | Population growth | Population growth rate |
| | Employment of urban and rural residents | Employment rate of urban and rural residents |
| | Urbanization | Urbanization rate |
| | Urban and rural medical resources | Number of medical beds/permanent population |
| Cultural value reconstruction | Educational resources | (Middle School*5 + Primary School*3 + Kindergarten*1)/ Built-up area |
| | Characteristic cultural protection | The guarantee mechanism of cultural inheritance |
| | Reconstruction of cultural facilities | Specific projects for restoration and reconstruction of cultural facilities |
| | Restoration of historical sites | Repair of damaged historical sites (office) |
| Emergency response capacity building | Monitoring and early warning | Monitoring and early warning points for hidden dangers of geological disasters; monitoring and early warning range |
| | Emergency response | Emergency response team construction; emergency response plan (number) |
| | Rescue | The number of emergency rescue teams (number); the number of emergency shelters (number) |
| | Relief supplies | Disaster relief material storage station (unit); disaster relief material storage (quilt, tent, etc.) |
| | Disaster management | Disaster management level and institution building |

The division and selection of secondary indicators are similar to the element layer. The second-level index is a further refinement of the first-level index. As the bottom-level index, the corresponding data acquisition and calculation issues must be considered—first, the calculation method of the indicator.

The first three indicators under the first-level indicator "economic and industrial reconstruction" focus on the overall situation of the restoration and reconstruction area to reflect the overall output level of the reconstruction effect. In addition, according to the ultimate goal of social development and reconstruction and development in the disaster-stricken areas, some secondary indicators select per capita quantity, such as "housing supply" and "medical resources." Second, the secondary indicators under "infrastructure restoration and reconstruction" are mostly based on the area of built-up areas, or the total planned area as the basis for calculation, so as to better reflect the differences and rationality of various indicators for post-disaster restoration and reconstruction. The detailed calculation and explanation of the secondary indicators are shown in Table.1.

# 4 Evaluation and analysis of the effect of post-natural disaster recovery and reconstruction

## 4.1 Evaluation of objects and data

### 4.1.1 Object selection and data acquisition

This article selects "8.7 Zhouqu debris flow" as the evaluation object. At around 22:00 on August 7, 2010, there was a sudden heavy rain in the mountainous area in the northeastern part of Zhouqu County, Gannan Tibetan Autonomous Prefecture. The rainfall reached 97 mm and lasted more than 40 min, causing a huge mountain torrent and geological disaster. The mud-rock flow was about 5 km long with an average width of 300 m, an average thickness of 5 m, and a total volume of 7.5 million $m^3$. The area flowing through was razed to the ground, and the infrastructure was seriously damaged. As of September 7, 2010, 1,557 people were killed, 284 were missing, and 2,315 were injured in the Zhouqu 8.7 landslide disaster. After the disaster, the state, based on the actual situation of the Zhouqu disaster area, formulated the "Zhouqu Post-disaster Recovery and Reconstruction Master Plan." Data acquisition basically comes from reconstruction plans, questionnaires, field survey statistics, bulletins, and government work reports.

## 4.2 Evaluation methods and analysis of evaluation results

### 4.2.1 Interpretation of structure method construction and qualitative analysis

Interpretative structural modeling (ISM), first proposed by Professor J. Warfield of the United States when analyzing the problems related to complex socioeconomic systems, is an important analysis method in systems engineering. This method is mainly used to divide a complex system into several subsystems. In the process of calculation, the constituent elements of the complex system are first proposed, information such as each element in the system and their mutual relations are processed, and the interaction between the various systems is sorted out by language. To determine the level and overall structure of the system, suppose post-disaster reconstruction effect evaluation is $S_0$, infrastructure reconstruction evaluation is $S_1$, economic industry reconstruction evaluation is $S_2$, social development reconstruction evaluation is $S_3$, cultural value restoration evaluation is $S_4$, ecological environment restoration evaluation is $S_5$, and emergency capacity building evaluation is $S_6$.

Modeling mainly has the following five steps:

(1) Identify key issues and influencing factors and establish a structural self-interaction matrix (SSIM) relationship table.

According to the unanimous opinion of the group discussion, a structural matrix of the interaction relationship among the evaluation elements of the impact of the post-disaster recovery and reconstruction effect listed in Table 3-1 is formed, where V indicates that the row element in the table directly affects the column element, A indicates that the column element has a direct impact on the row element, X indicates that the two elements of the row and column affect each other, and O indicates that the two elements of the row and column do not directly affect each other. The SSIM is shown in Table.2.

**Table.2 Structural self-interaction matrix(SSIM)**

| Element | S6 | S5 | S4 | S3 | S2 | S1 | S0 |
|---|---|---|---|---|---|---|---|
| S0 | A | A | A | A | A | A | |
| S1 | O | O | O | V | V | | |
| S2 | V | O | A | V | | | |
| S3 | V | V | O | | | | |
| S4 | O | O | | | | | |
| S5 | O | | | | | | |
| S6 | | | | | | | |

(2) Generate adjacency matrix.

If $S_i$ and $S_j$ in SSIM are V, then $a_{ij}$ is recorded as 1 in the reachable matrix and $a_{ji}$ is recorded as O; if $S_i$ and $S_j$ in SSIM are A, then $a_{ij}$ is recorded as 0 in the reachable matrix and $a_{ji}$ is recorded as 1; if $S_i$ and $S_j$ in SSIM are X, then $a_{ij}$ is recorded as 1 in the reachable matrix and $a_{ji}$ is recorded as 1; if $S_i$ and $S_j$ in SSIM are O, then $a_{ij}$ is recorded as 0 in the reachable matrix and $a_{ji}$ is recorded as 0. The adjacency matrix A of the evaluation elements of the post-disaster recovery and reconstruction effect listed in Table.3.

**Table.3 djacency matrix (A)**

| Element | S0 | S1 | S2 | S3 | S4 | S5 | S6 |
|---|---|---|---|---|---|---|---|
| S0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S1 | 1 | O | 1 | 1 | 0 | 0 | 0 |
| S2 | 1 | O | 0 | 1 | 0 | 0 | 1 |
| S3 | 1 | 0 | O | 0 | 0 | 1 | 1 |
| S4 | 1 | O | 1 | 0 | 0 | 0 | 0 |
| S5 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| S6 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |

(3) Generate reachable matrix.

It can be seen from formula (2) that the elements of A are 1 and 0, which belong to a Boolean matrix. According to the Boolean algorithm, $M = (A + I)_k = (A + I)_{k-1} \neq (A + I)_{k-2} \neq \ldots \neq (A + I)(k \leq n - 1)$. Determine the reachable matrix M: adjacency matrix + identity matrix = initial reachable matrix ,as is show Table.4.

**Table.4 nitial reachable matrix (A)**

| Element | S0 | S1 | S2 | S3 | S4 | S5 | S6 |
|---|---|---|---|---|---|---|---|
| S0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| S1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| S2 | 1 | O | 1 | 1 | 0 | 0 | 1 |
| S3 | 1 | 0 | O | 1 | 0 | 1 | 1 |
| S4 | 1 | O | 1 | 0 | 1 | 0 | 0 |
| S5 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| S6 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |

(4) Level allocation of each element, establish a hierarchical structure diagram, and find the reachable set $R(S_i)$ (starting from $S_i$, the set of all elements that may be reached) and the preceding set $A(S_i)$ (all the possible $S_i$). Let $C(S_i) = R(S_i) \cap A(S_i)$ (all elements that can affect both $S_i$ and $S_i$) ,as is show Table.5.

**Table 5 The reachable set M, antecedent set, and common set table A of the matrix**

| Element | $R(S_i)$ | $A(S_i)$ | $C(S_i)$ |
|---|---|---|---|
| $S_0$ | 0 | 0,1,2,3,4,5,6 | 0 |
| $S_1$ | 0,1,6 | 1,2,4,5 | 1 |
| $S_2$ | 0,1,2,6 | 2,4,5 | 2 |
| $S_3$ | 1,3 | 3,4,5 | 3 |
| $S_4$ | 0,1,2,3,4,5,6 | 4 | 4 |
| $S_5$ | 0,1,2,3,5 | 4,5 | 5 |
| $S_6$ | 0,6 | 1,2,6 | 6 |

If $R(S_i) = C(S_i)$, then $R(S_i)$ is the highest-level feature set. After finding the highest-level feature set, you can cross out the corresponding rows and columns from the reachability matrix and then continue to search for new highest-level features from the remaining reachability matrix. By analogy, the highest set of elements contained in each level can be found. Find the new superlative element from the remaining reachable matrix. By analogy, find the set of the highest-level elements contained in each level. If $L_1, L_2, ..., L_k$ are used to represent the levels from top to bottom, then there are k levels of the system. The following formula is used to express the division between levels L(n): $L_n = [L_1, L_2, ..., L_k]$.

(5) Generate a hierarchical structure diagram.

The interpretation structure model evaluated after reconstruction is obtained through modeling, as shown in Figure.3.

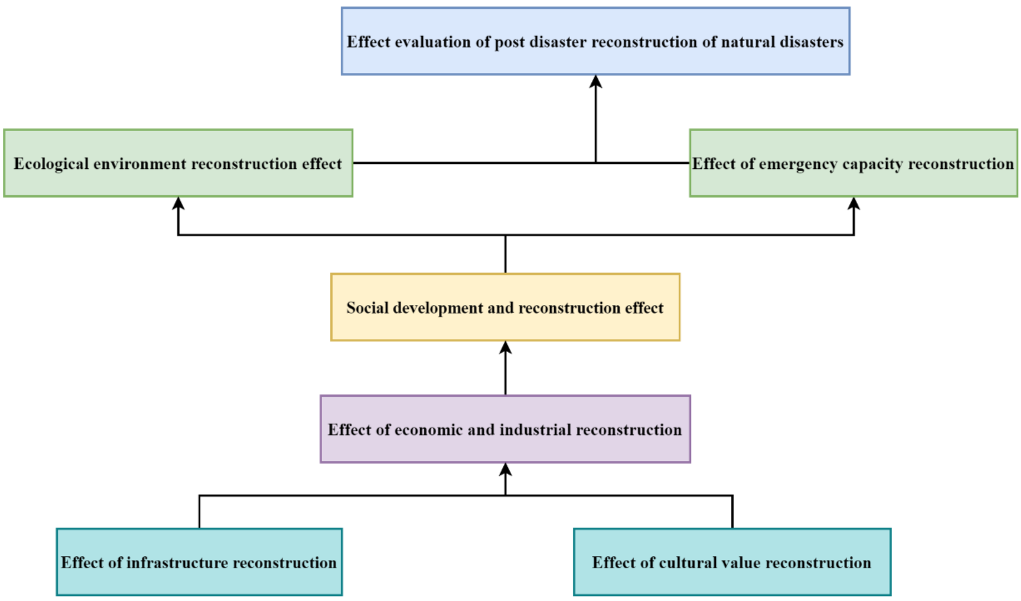


**Figure 3. Comprehensive weight of first-level indicators**

It can be seen from the constructed first-level indicator system that post-disaster recovery and reconstruction are not a simple material reconstruction, but a holistic reconstruction. In the process of recovery and reconstruction, infrastructure projects, economic and industrial development, social effects, and human values, eco-environment restoration and emergency response capacity building are related to each other, and the evaluation content involved is intricate. Post-disaster reconstruction evaluation should be “people-oriented,” starting from the local cultural value and infrastructure reconstruction, to drive social development and economic and industrial reconstruction, which is conducive to the long-term goal of sustainable development of the ecological environment. Through the implementation of key infrastructure projects, the pulling effect of the economy and the final reconstruction effect are reflected in two aspects: (i) to promote the restoration of social order to normal so that the lives of the affected residents and the ecological environment are gradually restored to the pre-disaster level and (ii) to exceed and improve the disaster-affected area's emergency response ability.

**4.3 Analytic hierarchy process and weight determination analysis**

The AHP provides a method that can synthesize people's different subjective judgments, can give the results of quantitative analysis, and can ultimately simplify the very complex system into pairwise comparisons and simple calculations between various factors. By analyzing the factors and interrelationships contained in complex problems, the problem is decomposed into different elements, and these elements are merged into different levels to form a multilevel structure. At each level, according to a certain rule, the elements of the level can be compared pairwise to establish a judgment matrix. By calculating the maximum eigenvalue of the judgment matrix and the corresponding orthogonalized eigenvector, the weight of the element at this level for the criterion is obtained. On this basis, the combined weight of the elements at each level for the overall goal is calculated to obtain different scenarios.

The basic steps of the AHP are as follows:

(1) Establish a multilevel hierarchical structure.

Based on the understanding and preliminary analysis of the problem, the various elements involved in the evaluation system are arranged hierarchically according to their nature. This article establishes a multilevel hierarchical structure based on the interpretation structure method.

(2) Establish a judgment matrix.

An element of the upper level of the judgment matrix is used as an evaluation criterion, and the element value of the matrix is determined by comparing the elements of this level. The element values of the judgment matrix reflect people's understanding of the relative importance (or pros and cons, preferences, attitudes, etc.) of a certain factor (indicator). Generally, a scale method of 1–9 or its reciprocal is adopted, as shown in Table 6. When the importance of the mutual comparison factors can be explained by the ratio with practical significance, the corresponding element value of the judgment matrix can take the corresponding standard value.

**Table 6 Judgment matrix scale and its meaning**

| Standard value | Definition | Description |
|---|---|---|
| 1 | Equal importance | Compared with the factors $X_i$ and $X_j$, the two factors are of equal importance |
| 3 | Slightly important | Compared with $X_j$, factor $X_i$ is slightly more important than $X_j$ |
| 5 | Obviously important | Compared with $X_j$, factor $X_i$ is significantly more important than $X_j$ |
| 7 | Strongly important | Compared with $X_j$, factor $X_i$ is more important than $X_j$ |
| 9 | Extremely important | Compared with $X_j$, factor $X_i$ is extremely more important than $X_j$ |
| 2,4,6,8 | | The median value between the above two adjacent judgments |

(3) Calculate the relative importance.

Find the maximum eigenvalue $\lambda_{max}$ of the judgment matrix and then find the corresponding eigenvector W, that is, $A*W = \lambda W$. Among them, the components of W ($W_1$, $W_2$, ..., $W_n$) correspond to the relative importance of n elements, that is, the weight coefficient.

(4) Consistency inspection.

Check the consistency of the judgment matrix to determine whether the weight distribution is reasonable. The test formula is $C_R = C_I/R_I$, $C_I = (\lambda_{max} - n)/(n - 1)$, where $C_I$ is the consistency test index, n is the order of the judgment matrix, and $R_I$ is the average random consistency index, the values of which are shown in Table 7. When $C_R < 0.10$, it is considered that the judgment matrix has acceptable inconsistency. Otherwise, it is considered that the initially established judgment matrix is unsatisfactory and needs to be re-assigned and carefully corrected until the consistency check is passed.

**Table 7 Average random consistency index $R_I$**

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| $R_I$ | 0 | 0 | 0.5149 | 0.8931 | 1.1185 | 1.2494 | 1.345 |

(5) Comprehensive importance calculation.

After calculating the relative importance of the elements at all levels, the overall importance of the elements at all levels to the overall system (also known as the overall weight of the system) can be obtained from the top level from top to bottom; that is, the overall hierarchical ranking is performed.

This paper is based on the AHP to determine the weight of each indicator. On the basis of expert scoring, using Yaahp10.2 software, select judgment matrix aggregation and arithmetic average as the group decision-making method and calculate the comprehensive weight result of the index. Among the first-level indicators, the comprehensive weight of “infrastructure reconstruction effect” is 0.3424, “social development reconstruction effect” is 0.1136, “ecological environment reconstruction effect” is 0.2152, “emergency capacity reconstruction effect” is 0.1005, “economic industry reconstruction effect” is 0.1687, and “cultural value reconstruction effect” is 0.0596. The results of secondary index weights are shown in Figures.4 and Figures.5.

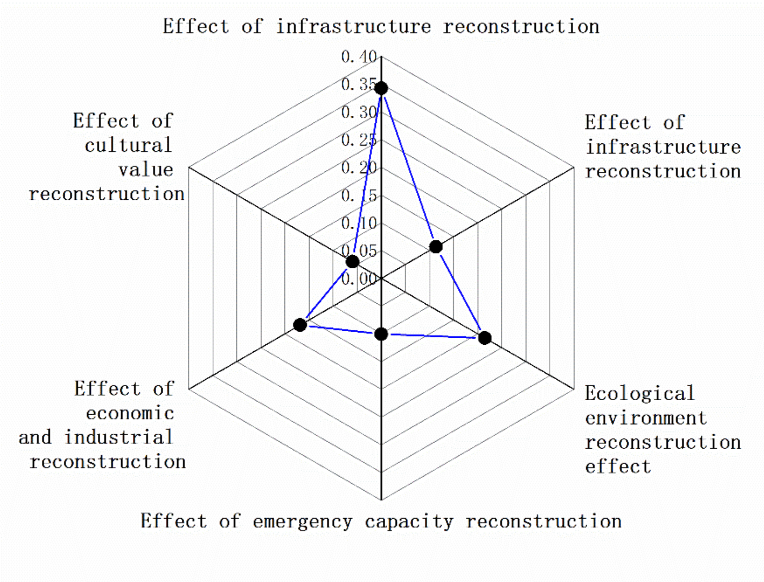


**Figure 4 Comprehensive weight of primary indicators**

Perform quantitative statistical analysis of the planning objectives of the post-disaster recovery and reconstruction plan in the disaster area, and construct the evaluation method of the fit degree of the reconstruction plan. According to the reconstruction plan of biodiversity, overall economic level, energy supply restoration, housing supply restoration, vegetation restoration, transportation facility restoration, disaster management, GDP growth rate, communication facility restoration, water conservancy facility restoration, urbanization, education resources, reconstruction of cultural facilities, protection of characteristic culture, urban and rural medical resources, restoration and reconstruction of power facilities, land degradation, monitoring and early warning, employment of urban and rural residents, environmental quality, emergency response, disaster relief supplies, rescue and relief, gross domestic product, industrial structure, and population are considered. The percentages of growth and historical site restoration completion are $T_1$, $T_2$, $T_3$, $T_4$, $T_5$, $T_6$, $T_7$, $T_8$, $T_9$, $T_{10}$, $T_{11}$, $T_{12}$, $T_{13}$, $T_{14}$, $T_{15}$, $T_{16}$, $T_{17}$, $T_{18}$, $T_{19}$, $T_{20}$, $T_{21}$, $T_{22}$, $T_{23}$, $T_{24}$, $T_{25}$, $T_{26}$, and $T_{27}$, multiplied by the sum of their respective weights, that is, to achieve consistency in the post-disaster recovery and reconstruction plan:

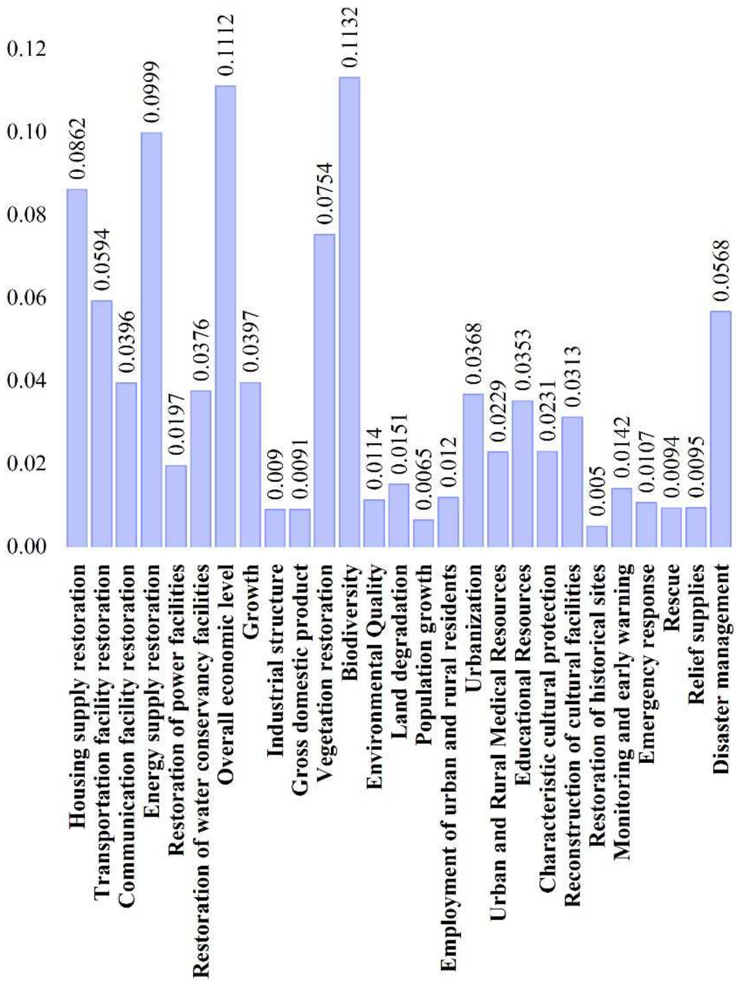


**Figure 5. Evaluation index ISM for the effect of post-disaster recovery and reconstruction**

$T_0 = T_1*0.1132 + T_2*0.1112 + T_3*0.0999 + T_4*0.0862 + T_5*0.0754 + T_6*0.0594 + T_7*0.0568 + T_8*0.0397 + T_9*0.0396 + T_{10}*0.0376 + T_{11}*0.0368 + T_{12}*0.0353 + T_{13}*0.0313 + T_{14}*0.0231 + T_{15}*0.0229 + T_{16}*0.0197 + T_{17}*0.0151 + T_{18}*0.0142 + T_{19}*0.0120 + T_{20}*0.0114 + T_{21}*0.0107 + T_{22}*0.0095 + T_{23}*0.0094 + T_{24}*0.0091 + T_{25}* 0.009 + T_{26}*0.0065 + T_{27}*0.005.$

According to the set of comments that $T_0$ belongs to, determine the completion of the post-disaster recovery and reconstruction plan and implement quantitative evaluation of the post-disaster recovery and reconstruction plan. Based on the corresponding weight data of the evaluation indicators, the evaluation factor set, comment set, value set, and weight set are established. According to the value of $T_0$, the consistency of the after-effect evaluation of post-disaster recovery and reconstruction is determined, as shown in Table 8.

**Table 8 Comment set**

| Assessed value | Comments |
|---|---|
| >90 | Excellent |
| 80–90 | Good |

| | |
|---|---|
| 60–79 | Medium |
| <60 | Poor |

According to the Zhouqu debris flow reconstruction plan and the progress of the Zhouqu debris flow disaster recovery and reconstruction project, statistical analysis of the completion of the secondary indicators is shown in Table 9.

**Table 9 Cmpletion of evaluation indicators for post-disaster restoration and reconstruction effects**

| Evaluation index | Degree of completion | Evaluation index | Degree of completion | Evaluation index | Degree of completion |
|---|---|---|---|---|---|
| $T_1$ | 100% | $T_2$ | 100% | $T_3$ | 100% |
| $T_4$ | 100% | $T_5$ | 70% | $T_6$ | 100% |
| $T_7$ | 100% | $T_8$ | 100% | $T_9$ | 100% |
| $T_{10}$ | 100% | $T_{11}$ | 85% | $T_{12}$ | 100% |
| $T_{13}$ | 82% | $T_{14}$ | 75 | $T_{15}$ | 100% |
| $T_{16}$ | 100% | $T_{17}$ | 70 | $T_{18}$ | 100% |
| $T_{19}$ | 93% | $T_{20}$ | 85% | $T_{21}$ | 100% |
| $T_{22}$ | 100% | $T_{23}$ | 100% | $T_{24}$ | 100% |
| $T_{25}$ | 100% | $T_{26}$ | 95% | $T_{27}$ | 70% |

$T_0 = T_1*0.1132 + T_2*0.1112 + T_3*0.0999 + T_4*0.0862 + T_5*0.0754 + T_6*0.0396 + T_7*0.0594 + T_8*0.0397 + T_9*0.0396 + T_{10}*0.0376 + T_{11}*0.0368 + T_{12}*0.0353 + T_{13}*0.0313 + T_{14}*0.0231 + T_{15}*0.0229 + T_{16}*0.0197 + T_{17}*0.0151 + T_{18}*0.0142 + T_{19}*0.0120 + T_{20}*0.0114 + T_{21}*0.0107 + T_{22}*0.0095 + T_{23}*0.0094 + T_{24}*0.0091 + T_{25}* 0.0090 + T_{26}*0.0065 + T_{27}*0.005 = 88.9\%$. According to the establishment of the evaluation factor set, comment set, value set, and weight set, the comment level corresponding to the consistency of the Zhouqu debris flow recovery and reconstruction plan is excellent.

**4.4 Fuzzy comprehensive evaluation method**

The fuzzy comprehensive evaluation method applies the principle of fuzzy transformation and the principle of maximum membership degree and considers various relevant factors of the evaluation system. It mainly involves four factors: factor set X, plan set A, membership matrix R, and weight distribution vector W. The specific steps of the application are as follows:

(1) Establish factor set X and plan set A.

Assuming factor set $X = \{X_1, X_2, ..., X_m\}$, alternative plan set $A = \{A_1, A_2, ..., A_n\}$ for the given alternative $A_j$ (j = 1,2, ..., n), which can be expressed as an m-dimensional “vector” form: $A_j = \{X_{j1}, X_{j2}, ..., X_{jm}\}$, where $X_{jk}$ (k = 1, 2, ..., m) is the plan. The reflection of $A_j$ is on factor $X_k$. $X_{jk}$ can be a quantity (when $X_k$ is a quantitative index) or a qualitative description in natural language (when $X_k$ is a qualitative index), and $A_j$ is a scheme in the set and a fuzzy subset of X.

(2) Establish the weight set W of the factor set X.

In this paper, the above-mentioned AHP is used to determine the weight set W of the factors. The factor weight set $W = (W_1, W_2, ..., W_m)$ refers to the importance and degree of influence of each factor on the method to be selected and satisfies

$$0<W_k<1, \quad \sum_{k=1}^{m} W_k = 1$$

(3) Determine the membership matrix.

The membership degree of the quantitative index is determined by the membership function, and the nonquantitative index is determined by the binary contrast weighting method. This article mainly introduces the membership matrix for determining nonquantitative indicators. Assuming that the target factor set to be compared in importance in the system is $X = \{X_1, X_2, ..., X_m\}$, the importance of the factors in the target factor set X is qualitatively arranged in a binary comparison. If the targets are concentrated, make a binary comparison between the targets $X_k$ and $X_l$: if $X_k$ is more important than $X_l$, set the ranking scale $e_{kl} = 1$, $e_{lk} = 0$; if $X_k$ and $X_l$ are equally important, set $e_{kl} = 0.5$ and $e_{lk} = 0.5$. If $X_l$ is more important than $X_k$, set the sorting scale $e_{kl} = 0$, $e_{lk} = 1$ (k, l = 1, 2, ..., m). According to the comparison result, establish the target factor set binary comparison importance qualitative ranking matrix E:

$$E = \begin{bmatrix} e_{11} & e_{12} & \cdots & e_{1n} \\ \cdots & \cdots & \cdots & \cdots \\ e_{m1} & e_{m2} & \cdots & e_{mn} \end{bmatrix}$$

Index importance ranking consistency theorem: When $0 \le e_{ij} \le 1$, $e_{ij} + e_{ji} = 1$, and $e_{ij} = e_{ji} = 0.5$ (i = j), call matrix E an ordered binary comparison matrix about importance. When objective i makes a binary comparison with respect to the importance of j, $e_{ij}$ is the fuzzy scale of the importance of objective i to j; $e_{ji}$ is the fuzzy scale of importance of objective j to i. Arrange the rows and numbers of the ranking consistency scale matrix E from large to small, then $\beta_i = \sum_{j=1}^{m} \beta ij$ $(i \neq j,\ i = 1, 2, \cdots, m)$, according to sorting and checking the relation table of relative membership degree between mood operator and quantitative scale (Table 10), and the relative membership degree of nonquantitative index can be obtained.

**Table 10 Relative membership degree relationship between mood operator and quantitative scale**

| Tone operator | Confusion scale value | Relative membership |
|---|---|---|
| Same | 0.500–0.525 | 1.000–0.905 |
| Trifle | 0.550–0.575 | 0.818–0.739 |
| Slightly | 0.600–0.625 | 0.667–0.600 |
| Relatively | 0.650–0.675 | 0.538–0.481 |
| Obvious | 0.700–0.725 | 0.429–0.379 |
| Significant | 0.750–0.775 | 0.333–0.290 |
| Fully | 0.800–0.825 | 0.250–0.212 |
| Most | 0.850–0.875 | 0.176–0.143 |
| Extremely | 0.900–0.925 | 0.111–0.081 |
| Exceeding | 0.950–0.975 | 0.053–0.026 |
| Unparalleled | 1.000 | 0 |

(4) Comprehensive evaluation.

From the evaluation matrix R (subscription matrix) and the factor weight set W, the comprehensive evaluation of scheme set A can be obtained as

$$B = WR = (W_1, W_2, \cdots, W_m) \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} = (b_1, b_2, \cdots, b_n)$$

In the formula, $b_j = \sum_{k=1}^{m} W_k r_{kj}$, which represents the comprehensive satisfaction or comprehensive superiority of the plan set $A_j$.

**4.5 Build a comment collection data set**

According to the excellent, good, medium, and poor levels, the comment set V is composed, V = {V1, V2, V3, V4} = {excellent, good, medium, poor}, and the corresponding value set of the comment set is {N1, N2, N3, N4}T = {>90, 80–90, 60–79, <60}.

Based on the post-disaster restoration and reconstruction demonstration of the "8.7 Zhouqu debris flow," the evaluation of the effect of post-disaster restoration and reconstruction involving multi-agent participation was completed in terms of the completion of the social–economic–ecological environment–emergency capability. A questionnaire survey is used, and the scope of the survey is the post-disaster recovery and reconstruction leaders, post-disaster recovery evaluation experts, local leaders, residents in the disaster area, and tourists. The fuzzy comprehensive evaluation method is used for evaluation, the comprehensive evaluation vector for the evaluation of the post-disaster restoration and reconstruction effect to be evaluated is obtained, and the actual situation of the evaluation of the post-disaster restoration and reconstruction effect is determined.

**Table 11 Results of evaluation indicators for the post-disaster restoration and reconstruction of the Zhouqu debris flow**

| Evaluation index | Evaluation value | Evaluation results |
|---|---|---|
| Infrastructure reconstruction effect | 0.903429 | Excellent |
| Economic and industrial reconstruction effect | 0.9736 | Excellent |
| Ecological environment reconstruction effect | 0.5911541 | Poor |
| Social development and reconstruction effect | 0.7504 | Medium |
| Cultural value reconstruction effect | 0.70032 | Medium |
| Emergency response capability reconstruction effect | 0.9350 | Excellent |
| Comprehensive results | 0.7689 | Medium |

Through the calculation of weights and membership degrees, and based on the principle of maximum membership, the results obtained can directly see the evaluation results based on the classification of the first-level indicators of Zhouqu debris flow recovery and reconstruction. The results are shown in Table 11. From the statistical results in the table, it can be seen that in the first-level indicators of the after-effect evaluation system for the restoration and reconstruction of the Zhouqu debris flow disaster, the evaluation results range from “excellent” to “poor.” The evaluation results of housing construction and infrastructure, economic industry, and emergency response capacity are “excellent,” meaning that the main goals of post-disaster recovery and reconstruction are housing construction and infrastructure, with the restoration of economic industries and the improvement of emergency energy levels as the main goals. In terms of social development and cultural facility restoration value indicators, the evaluation result is “medium,” indicating that post-disaster restoration and reconstruction of social development and cultural facility restoration value need to continue to improve and increase resource tilt. However, the evaluation result in the restoration of the ecological environment is poor, indicating that the restoration and reconstruction of the ecological environment is relatively low, the task of disaster restoration and reconstruction planning has not been completed, and the degree of reconstruction is in line with the expectations of the public.

## 5 Discussion

The evaluation model method of post disaster recovery and reconstruction effect of major natural disasters proposed in this paper provides a qualitative and quantitative evaluation model method for the evaluation of post disaster recovery and reconstruction effect. However, due to the subjective initiative of experts, evaluation index system, questionnaire design and questionnaire distribution in the model method, the evaluation process is random. At the same time, due to insufficient personal ability and short time, There are still the following problems in this study, which need to be further studied and improved:

(1) In this paper, the explanatory structure model (ISM) is used to determine whether the evaluation index is directly or indirectly related to the evaluation of post disaster recovery and reconstruction effect. The randomness of determining the reachability matrix is large. In the future research, we need to find a new method to determine the relationship between index levels more accurately.

(2) In the process of quantitative evaluation of some indicators in the questionnaire design, there are differences in statistical caliber, and the filling personnel are more subjective in the process of filling in the questionnaire method. Therefore, how to improve the quality of questionnaire filling personnel and how to supervise questionnaire filling need to explore new methods. Due to the first mock exam of the effect of the time and the reason for the reconstruction of the major natural disasters, the improvement of this model method is the focus of future research.

## 6 Conclusion

(1) An evaluation index system for the effect of restoration and reconstruction in disaster areas has been established, which is people-oriented and considers regional sustainable development as the long-term goal, with economic development, social harmony, and emergency response capabilities as the core, including economic benefits, social benefits, human values, and ecological environmental sustainability. The first index and 37 second index systems in six areas, including emergency response capacity building, provide an evaluation basis for the evaluation of post-disaster recovery and reconstruction effects. The accuracy of the index value determines the reliability of the model results. How to construct a more reasonable and scientific index system requires further exploration and research.

(2) A post-disaster recovery and reconstruction effect evaluation model from both qualitative and quantitative aspects has been constructed. ① The post-disaster recovery and reconstruction effect evaluation indicators are selected. ②ISM is used to conduct qualitative research on evaluation indicators. ③AHP is used to calculate the index weights for the primary and secondary indicators, the quantitative calculation method for the after-effect evaluation of the overall plan for the restoration and reconstruction of the disaster area is constructed, and the evaluation of the coincidence of the plan is completed. ④ Based on the multi-agent participation questionnaire of economic–social–ecological restoration and reconstruction in the disaster area, the fuzzy mathematics method is used to construct a quantitative comprehensive evaluation method of multi-agent participation in the evaluation of the post-disaster rehabilitation and reconstruction effect in the disaster area. ⑤The results of the "certainty and two quantitative" evaluation model are analyzed, and a comprehensive evaluation of the results of post-disaster recovery and reconstruction is performed. The evaluation model provides practical and feasible methods for scientifically and rationally assessing the effects of natural disaster recovery and reconstruction from both qualitative and quantitative aspects.

(3) Through the example verification of the post-disaster recovery and reconstruction effect evaluation model, the post-disaster recovery and reconstruction effect evaluation of the "8.7 Zhouqu debris flow" was carried out. Through qualitative analysis, the post-disaster recovery and reconstruction evaluation should be based on the humanities' construction as the starting point. The ecological environment is a long-term goal. The economic growth of the disaster-stricken areas is stimulated through the construction of industrial housing and infrastructure investment. The direct performance of the reconstruction effect is only in two aspects: social development and emergency response capabilities. According to the quantitative analysis of the completion degree model of the post-disaster recovery and reconstruction plan, the coincidence degree of the Zhouqu debris flow recovery and reconstruction plan is 88.9%, and the evaluation effect is excellent.

(4) From the four aspects of society–economy–ecological environment–emergency capability to complete the evaluation of the recovery and reconstruction effect with multi-agent participation, it can be seen that in the first-level indicators of the "Zhouqu debris flow" post-disaster recovery and reconstruction evaluation system, the evaluation results are "excellent" to "poor," among which the evaluation results of housing construction and infrastructure, economic industry, and emergency response capability are "excellent," indicating that the main objectives of post-disaster recovery and reconstruction are housing construction and infrastructure, restoring economic industries, and upgrading emergency energy levels. In terms of social development and cultural facility restoration value indicators, the evaluation result is "medium," indicating that post-disaster restoration and reconstruction of social development and cultural facility restoration value need to continue to improve and increase resource tilt.

*Data availability.* According to the notice of the State Council of China on printing and distributing the overall plan for post disaster recovery and reconstruction in Zhouqu, determine the implementation status, distribute and recover questionnaire I and Questionnaire II for statistical analysis.

*Supplement.*The supplement related to this article is available online at: 10.27205/d.cnki.gltec.2020.000932

*Author contributions.* SX and ZD conceived and designed the experiments. XS performed the experiments. SX analyzed the results. SX wrote the original paper, with input from all the co-authors.

*Competing interests.* The authors declare that they have no conflict of interest.

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*Financial support.* No

*Fund Project Funding.* No

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