

## Article

# Post-Disaster Recovery Effectiveness: Assessment and Prediction of Coordinated Development in the Wenchuan Earthquake-Stricken Areas

Liang Zhao, Chunmiao Zhang and Xia Zhou \*

School of Urban Economics and Management, Beijing University of Civil Engineering and Architecture, Beijing 102616, China

\* Correspondence: zhouxia@bucea.edu.cn

**Abstract:** Post-disaster rapid recovery and reconstruction, along with the evaluation of these efforts, are crucial for affected areas. They not only facilitate the swift repair of vulnerable systems but also reflect whether the recovery work has enhanced regional coordinated development. This is vital for achieving sustainable development post-reconstruction. This study addresses two main questions: (1) How effective were the recovery and reconstruction efforts in Mianyang, Deyang, and Guangyuan post-Wenchuan earthquake from a socio-economic–ecological system perspective? (2) What are the temporal and spatial changes in the Coordinated Development Index (CDI) of key affected counties? By constructing a framework to assess post-disaster coordinated development, this study utilized the entropy weight method and mean-variance method for the comprehensive weighting of evaluation indicators. The gray system prediction model G(1,1) was used to forecast the coordinated development levels of the three cities from 2019 to 2025. The findings reveal the following: (1) From 2005 to 2018, the CDI of Deyang, Guangyuan, and Mianyang showed a significant upward trend. Post-earthquake reconstruction measures like land planning and ecological restoration notably enhanced regional resilience and promoted coordinated development among social, economic, and ecological systems. (2) Despite overall success in reconstruction, disparities in development levels persist among Mianyang, Deyang, and Guangyuan. Predictions suggest that Deyang, Mianyang, and Guangyuan will achieve high-quality coordinated development in the next 5, 2, and 1 years, respectively. (3) Although significant achievements have been made through industrial restructuring, land reuse planning, and ecological restoration, more precise disaster prevention and mitigation strategies are needed to foster coordinated development among social, economic, and ecological systems. In summary, this study evaluates the post-disaster recovery effects in the hardest-hit areas of the Wenchuan earthquake and forecasts future development, providing a reference for similar post-disaster reconstruction areas in assessing and predicting coordinated development.

**Keywords:** ecological restoration; Wenchuan earthquake; coordinated development; assessment and prediction; gray model



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## 1. Introduction

Since the 21st century, under the influence of global climate change, earthquakes, floods, tsunamis, hurricanes, and other natural disasters have occurred frequently around the world [1], such as Japan's 9.0 magnitude earthquake [2], Zhengzhou's 7.20 floods [3], the U.S. Hurricane Katrina [4] and the Indian Ocean tsunami [5,6]. The occurrence of these

disasters has caused irreversible economic losses and negative impacts on the region. The effectiveness of post-disaster reconstruction in restoring the original buildings, land, arable land, and other ground cover damaged or abandoned due to the disaster is crucial. It is important to determine whether reconstruction efforts can return these areas to their pre-disaster conditions or improve them beyond that level. Additionally, post-disaster restoration should enhance the affected area's ability to balance the development of social, economic, and ecological factors. This balance is essential for the region to prevent ongoing damage from future disasters.

In the existing literature, scholars from both domestic and international contexts have assessed the effectiveness of post-disaster recovery and reconstruction from various perspectives. Some researchers have focused on the social dimension, considering social equity, community satisfaction, and risk reduction as the primary indicators for evaluating the effectiveness of reconstruction efforts [7]. Others have prioritized economic indicators, using the economic development of a city after recovery and reconstruction as the main criterion for measuring the effectiveness of post-disaster rebuilding [8]. However, different subsystems within a city are interdependent and mutually constraining. Focusing solely on rapid economic development in disaster-affected areas may accelerate reconstruction but can also exacerbate ecological degradation [9]. Conversely, overemphasizing ecological indicators may neglect the recovery of local livelihoods [10]. Specifically, the effectiveness of post-disaster recovery and reconstruction refers to the degree of success in achieving predetermined goals following natural disasters or other types of crises. Through the processes of recovery, reconstruction, and subsequent evaluation and forecasting, it is determined whether the overall objectives set by the Chinese government for disaster area reconstruction and development can be realized. This involves not only assessing whether the affected areas can return to their pre-disaster state or achieve further improvements but also considering the potential to optimize local social governance, industrial structure, and ecological frameworks during the reconstruction process. The ultimate aim is to realize more coordinated development across social, economic, and ecological dimensions.

After the Wenchuan earthquake, the government of China put forward the overall goal of recovery reconstruction and development of the disaster area, which is 'three years of basic recovery, five years of development and revitalization, and ten years of overall well-being' [11,12]. Post-disaster recovery, development and revitalization, and overall well-being are three closely linked stages, and the development status of the disaster area after recovery and reconstruction directly reflects the effectiveness of recovery and reconstruction to a certain extent [13,14]. To expedite the achievement of the United Nations Sustainable Development Goals (SDGs) and facilitate post-disaster restoration and reconstruction, China has implemented a disaster relief strategy known as 'one province, one rescue, and counterpart assistance' [15]. This initiative helps regions recover from disasters, revitalize their industries, and achieve sustainable social and economic post-disaster reconstruction and repair work. Combined with the development needs of the disaster area, Sichuan Province has further formulated the 'Wenchuan Earthquake Stricken Areas Development and Revitalisation Plan (2011-2015)' and 'Sichuan National Economic and Social Development' Twelfth Five-Year Plan, which became policies and development requirements to support the development of the affected areas [16]. Mianyang Municipality has promulgated the Outline of the Twelfth Five-Year Plan for National Economic and Social Development of Mianyang City and the Development Plan of Mianyang Science and Technology City (2011-2015), focusing on social, economic, and ecological deployment. Post-disaster recovery and reconstruction allow us to evaluate whether these efforts have achieved the anticipated goals of regional coordinated development [17-19]. This assess-

ment is crucial for promoting social, economic, and ecological recovery in the region and ensuring the sustainability of its development [20,21].

As a complex system, the earthquake-affected area, based on the post-disaster recovery perspective, utilizes socio-economic and other panel data to comprehensively evaluate the level of coordinated development in each year and systematically analyzes the status of the development differences in different regions in both the temporal and spatial dimensions [22,23]. On the time scale, this study sets the evaluation period as 2005–2018, to compare and analyze the level of coordinated development in different periods before and after the disaster and the restoration and reconstruction [24,25]; this study also sets the prediction time as 2019–2025, to predict and analyze the next six years based on the evaluation results of the coordinated development level in the disaster area. To compare the differences in the coordinated development of composite systems across various disaster areas, this study focuses on three regions: Mianyang, Deyang, and Guangyuan. All counties and cities within these areas have been impacted by disasters.

The two primary issues of this study are as follows: (1) How effective have the recovery and reconstruction efforts been in these regions from a socio-economic and ecological perspective? (2) What temporal and spatial changes have occurred in the Coordinated Development Index (CDI) of the key affected areas? By visualizing the spatiotemporal differences in the coordination development index during the disaster area reconstruction process, this study assesses the outcomes of post-disaster recovery and reconstruction in the three regions, clarifying whether the social, economic, and ecological systems have a strong level of coordinated development during post-disaster reconstruction [26]. Additionally, this study predicts the future coordinated development status of the region based on the coordination development index from 2005 to 2018, conducts a comparative analysis of the differentiated coordinated development, and makes predictions on how long it will take to achieve a high-quality coordinated development level. The significance of this study lies in its ability to effectively evaluate the coordinated development level of the social-economic–ecological composite system in three severely affected disaster areas when the post-Wenchuan earthquake reconstruction tasks are essentially completed. This has reference significance for continuously improving the content of post-disaster recovery and reconstruction plans and for the post-disaster recovery and prediction of similar regions and cities affected by natural disasters.

## 2. Data and Methods

### 2.1. Overview of the Study Area

On 12 May 2008, an earthquake measuring 8.0 on the Richter scale occurred in Wenchuan County, Sichuan Province, China, at a depth of 19 km, severely damaging an area of more than 100,000 square kilometers and causing more than 69,000 people to lose their lives, more than 370,000 people to be injured, and direct economic losses of about CNY 845.1 billion, as of 21 November 2008 [27]. The Wenchuan earthquake-hit area is located in the transition zone between the eastern part of the Tibetan Plateau and the Sichuan Basin, with a large elevation span, topographic relief, and a variety of landforms. In addition, the earthquakes triggered more than thousands of secondary geologic hazards, such as mudslides, landslides, and so on [28], which not only caused serious damage to the local land use and ground cover but also brought great threats to the lives and properties of the residents. This study is based on indicator assessment data primarily published in statistical yearbooks at the county and city levels. To ensure the completeness and accuracy of the data, as well as the scientific and comprehensive nature of the post-disaster reconstruction assessment, we selected all the disaster-stricken counties, cities, and districts

within Mianyang, Deyang, and Guangyuan as the study area. This selection included a total of 22 counties, cities, and districts (Figure 1).

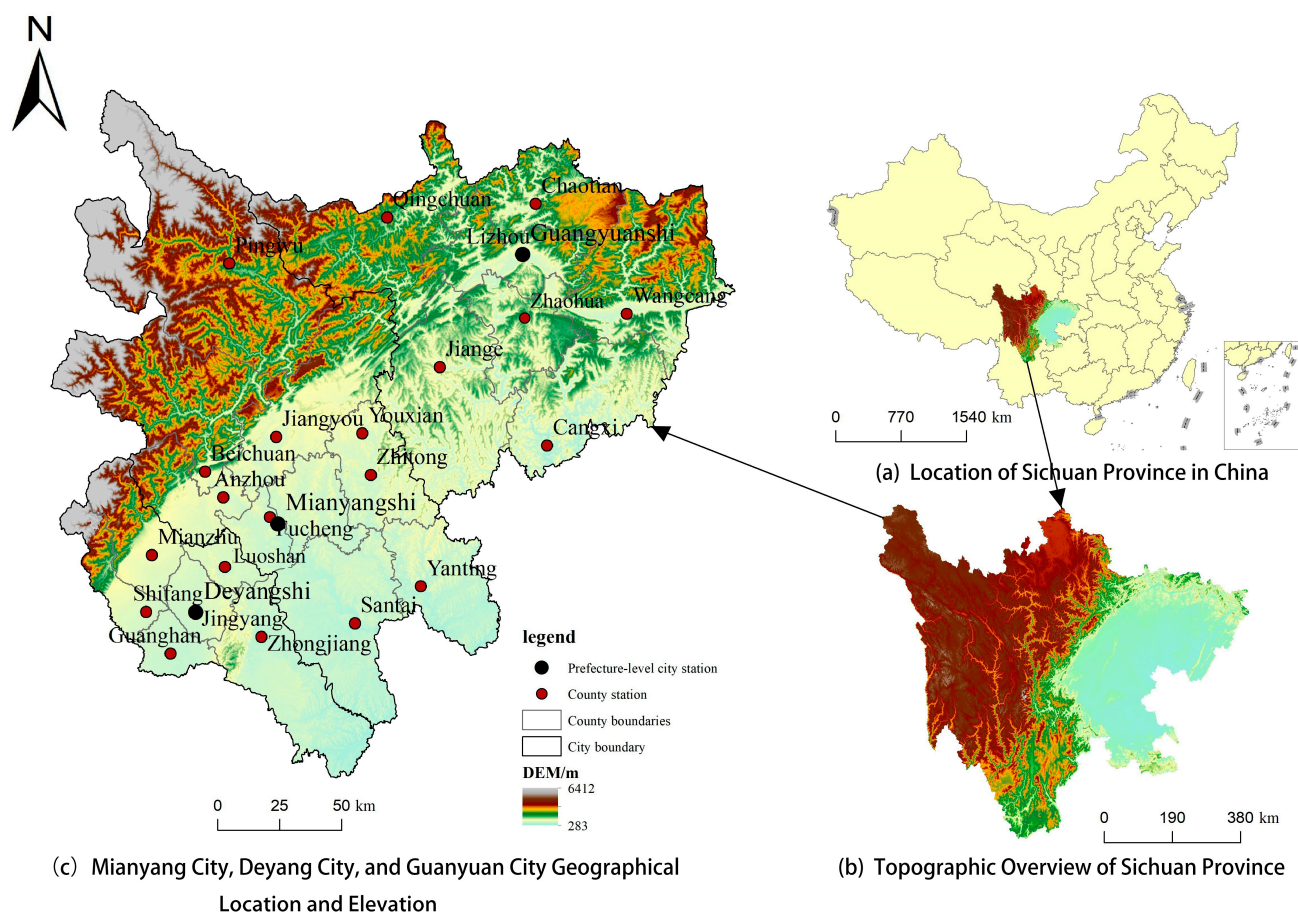


**Figure 1.** Location and topography of Mianyang, Deyang, and Guangyuan in the Wenchuan earthquake-affected areas.

## 2.2. Data Sources

This study treats the disaster area as a complex vulnerability system, analyzing it from social, economic, and ecological perspectives. An indicator system was developed around key aspects such as social well-being, emergency response, economic levels, industrial structure, resource utilization, and environmental protection [22,29]. The data for these indicators mainly come from the Mianyang Statistical Yearbook (2005–2018), Mianyang Annual Report (2005–2018), Deyang Statistical Yearbook (2005–2018), Deyang Annual Report (2005–2018), Guangyuan Statistical Yearbook (2005–2018), Guangyuan Annual Report (2005–2018), as well as the Sichuan Statistical Yearbook (2005–2018), China County Statistical Yearbook, Sichuan Environmental Yearbook, Land and Resources Yearbook, and other relevant yearbooks, social statistical bulletins, and survey reports. In addition, some missing data were found during the data organization process. Since the indicators selected in this study are mainly statistical data of the socio-economic ecosystem, which have strong time-series characteristics, and the missing data are random and not numerous, the common linear interpolation method is adopted to fill in the missing values in this study. Given the extensive time span of this study (2005–2025), the use of interpolation to address partial missing data not only ensures the continuity and consistency of the time-series data but also allows us to retain a larger and more representative dataset, thereby enhancing the robustness of the statistical analysis.

### 2.3. Research Methods

The earthquake imposes external disturbances on the normal development of the disaster area, causing deviations from its usual development trajectory. Post-disaster recovery and reconstruction further influence this development process [30,31]. Therefore, segmented regression was used to better understand the changes in the coordinated development of the complex system in the disaster area. Segmented regression involves fitting regression relationships with different slopes for different ranges of explanatory variables, and the segment points are the points that separate these ranges [32]. The segmented package in R was used for conducting segmented analysis on linear regression to identify the segment points. In this process, the results of the linear regression were input into the segmented package, and the initial segment point was set to 2008, the year of the earthquake. The segmented package uses an iterative algorithm to find reasonable segment points based on the provided regression results and the initial segment point. Based on the regression equation slopes and segment points, this study can analyze in detail the changes in the development degree, coordination, and Coordinated Development Index of each disaster area and its various subsystems [33,34].

However, the coordinated development model for the disaster-affected areas' social, economic, and ecological systems is a static method of analysis that assesses the current state based on existing indicators. To gain a better understanding of the future development trends of these areas, this study utilizes a more advanced gray forecasting method to further predict the regional development trajectory. Gray system theory deals with uncertain systems that have "partially known and partially unknown information", commonly referred to as systems with "small samples" and "poor information". Within these methods, gray forecasting is a significant component of gray system theory. The GM(1,1) model, known for its simplicity, minimal data requirements, and quick computation time, has been extensively applied in both natural and social fields [35]. In this study, we will utilize the GM(1,1) model to forecast the future coordinated development levels of the three disaster areas: Deyang, Guangyuan, and Mianyang.

## 3. Post-Disaster Coordinated Development Indicator System and Calculation

### 3.1. Framework for the Construction of the Indicator System

This study first establishes a framework for the coordinated development of the composite system in the disaster area, provides a high-level overview of the area to be evaluated, and defines the composition, structure, and boundaries of the composite ecosystem in the disaster area [36,37]. The conceptual framework of socio-economic-ecological complex system theory was developed, and 22 factors were identified in three dimensions: social, economic, and ecological [38,39]. By analyzing the composition and mechanism of these sub-systems, it is beneficial to understand the coordinated development level of the disaster area by constructing indicators to evaluate the development of each system in the disaster area from different levels. The theoretical framework of the coordinated development indicator system for the disaster area has been constructed by combining the analysis of the composite system's composition in the disaster area and relevant theoretical research. This framework is formed through a top-down refinement of content and is oriented by the evaluation objectives. The selection of statistical indicators is accomplished through the literature analysis and relevant analysis based on the theoretical framework. Finally, through the relevant literature research, we classify the components and indicators of each sub-system, construct the framework of the coordinated development indicator system of the disaster area, and further explore the methods of the indicator assignment and result measurement.

The coordinated development of a disaster area is a conceptual framework that encompasses multiple elements. The relationships among these elements within the complex system of the disaster area are intricate. The subsystems of this complex system exhibit characteristics of continuity and complex interdependence. Consequently, the coordination and development of each subsystem contribute to the overall improvement of the entire system [37,40,41]. The social subsystem includes aspects such as residents' lives, urban and rural development, infrastructure, and public services. The degree of development within this subsystem largely reflects how well the people-centered approach to post-disaster recovery and reconstruction is being implemented [38]. The economic subsystem includes elements such as the economic level and industrial structure. The level of development within this subsystem reflects the sustainability of progress in disaster-affected areas. Additionally, improving the economic level serves as a significant driving force for the overall development of these areas. The ecological subsystem includes elements like resource utilization and environmental protection. The level of development within the ecological subsystem indicates the environmental foundation available for the development of disaster-affected areas. A healthy ecological environment supplies the necessary resources for the growth and recovery of these areas (Figure 2). Based on the above analyses, the weights of the indicators were determined separately, and, then, the degree of development of each system, the degree of coordination, and the Coordinated Development Index were studied separately, to have a comprehensive understanding of the level of coordinated development of the disaster area.

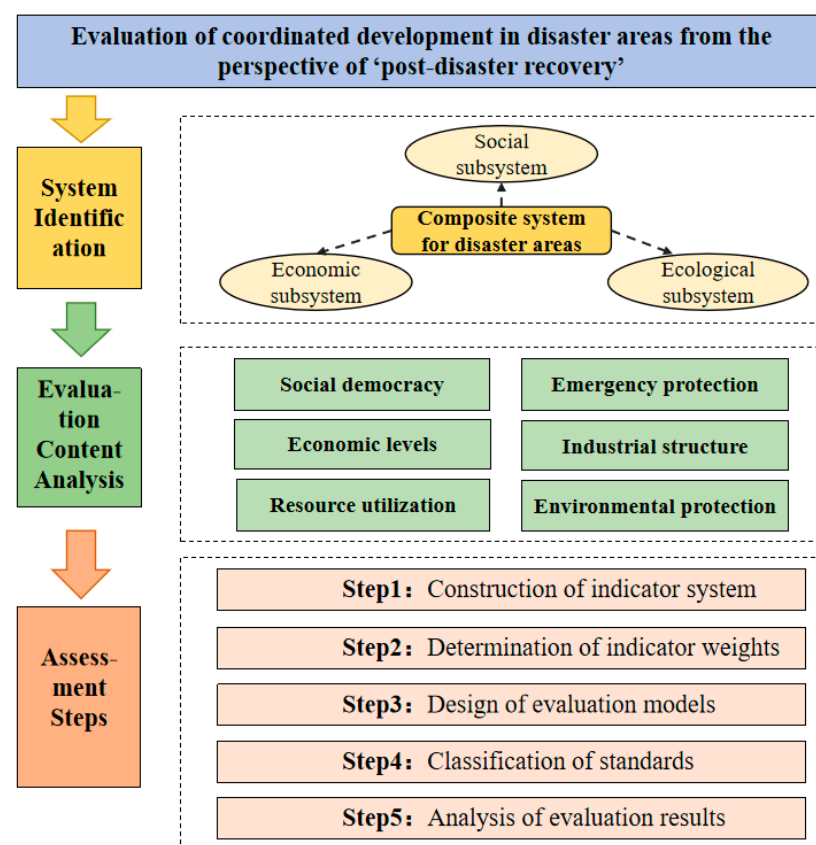


**Figure 2.** Evaluation framework for coordinated development of complex systems in disaster areas.

### 3.2. The Selection of Indicators

The selection of evaluation indicators in this paper is primarily based on two approaches. First, it draws on the planning policies of the Chinese government for post-disaster recovery and reconstruction to choose relevant indicators. Second, it conducts a

vulnerability analysis of the affected areas to identify the vulnerability factors of the disaster zones, which then guides the selection of evaluation indicators. After the 2008 Wenchuan Earthquake, cities such as Mianyang, Deyang, and Guangyuan developed regional development plans based on the goals of “basic recovery within three years, development and revitalization within five years, and comprehensive well-being within ten years”. The period of “development and revitalization within five years”, from 2011 to 2015, also coincided with the implementation years of China’s 12th Five-Year Plan for National Economic and Social Development. In this plan, both Sichuan Province and local governments in the cities emphasized the development and revitalization of disaster areas [42,43]. In addition, the disaster areas formulated a series of supporting policies aimed at achieving development revitalization and a well-off society. This study selected evaluation indicators by analyzing the various regional development policies and aligning them with relevant content [44,45]. Vulnerability analysis is an essential approach to identifying and assessing a system’s susceptibility and adaptive capacity when faced with external pressures or internal changes. This paper treats the disaster areas as typical complex systems of vulnerability and conducts an analysis of their vulnerability. It breaks down the coordinated development goals for the disaster areas from a top-down perspective. Based on the three subsystems of society, economy, and ecology, it carries out a vulnerability analysis to identify vulnerability factors and formulates evaluation indicators accordingly [46–48].

### 1. Analysis of Social System Vulnerability

Earthquakes cause a significant number of casualties and property damage and also pose notable challenges to the existing urbanization rate and future social development of cities. In the social subsystem, we focus on social democracy and emergency protection, selecting indicators such as the urban registered unemployment rate, urbanization rate, and per capita disposable income of urban residents as evaluation metrics for the social system.

### 2. Analysis of Economic System Vulnerability

Earthquakes lead to the collapse of numerous buildings, roads, bridges, and severe damage to urban infrastructure, negatively impacting the local economy and causing substantial losses to urban land resources. Land, as a crucial support for socio-economic development, its effective planning, and utilization post-disaster can be indirectly reflected by assessing the economic development status. Therefore, we focus on an economic level and industrial structure, selecting indicators such as GDP per capita and arable land per capita as evaluation metrics for the economic system.

### 3. Analysis of Ecological System Vulnerability

Earthquakes can cause land subsidence, landslides, and collapses, severely damaging and polluting the soil. Additionally, secondary disasters like mudslides and landslides triggered by earthquakes can severely affect local forests, wetlands, and other ecosystems. Thus, we focus on resource utilization and environmental protection, selecting indicators such as the forest coverage rate and energy-saving and environmental protection expenditure as evaluation metrics for the ecological system.

Ultimately, combining the indicators obtained from the above two methods and considering data availability and accuracy, we construct an indicator system using theoretical analysis, expert consultation, and frequency statistics. Subsequently, we employ correlation analysis to eliminate functionally redundant indicators, resulting in the final evaluation indicator system (Table 1).

**Table 1.** Evaluation indicators and weights for the coordinated development of Mianyang, Deyang, and Guangyuan disaster areas.

| Subsystem Layer                                 | Element Layer                                                              | Indicator Layer                                                             | Mianyang             | Deyang                                      | Guangyuan |
|-------------------------------------------------|----------------------------------------------------------------------------|-----------------------------------------------------------------------------|----------------------|---------------------------------------------|-----------|
| Social Subsystem                                | Social Well-being                                                          | Natural Population Growth Rate (‰)                                          | 0.1163               | 0.1165                                      | 0.1262    |
|                                                 |                                                                            | Urban Registered Unemployment Rate (%)                                      | 0.1091               | 0.1175                                      | 0.1303    |
|                                                 |                                                                            | Urbanization Rate (%)                                                       | 0.1280               | 0.1297                                      | 0.1234    |
|                                                 |                                                                            | Per Capita Disposable Income of Urban Residents (Yuan)                      | 0.1279               | 0.1290                                      | 0.1215    |
|                                                 |                                                                            | Per Capita Disposable Income of Rural Residents (Yuan)                      | 0.1253               | 0.1269                                      | 0.1198    |
|                                                 | Emergency Support                                                          | Road Density (km/100 km <sub>2</sub> )                                      | 0.1436               | 0.1286                                      | 0.1381    |
|                                                 |                                                                            | Total Insurance Premium Income (Billion Yuan)                               | 0.1224               | 0.1272                                      | 0.1223    |
|                                                 |                                                                            | Number of Health Institution Beds per Million People (Beds)                 | 0.1275               | 0.1244                                      | 0.1184    |
| Economic Subsystem                              | Economic Level                                                             | GDP per Capita (Yuan)                                                       | 0.1450               | 0.1467                                      | 0.1394    |
|                                                 |                                                                            | Total Import and Export Value (10,000 USD)                                  | 0.1353               | 0.1394                                      | 0.1360    |
|                                                 |                                                                            | General Public Budget Revenue (Billion Yuan)                                | 0.1535               | 0.1536                                      | 0.1453    |
|                                                 |                                                                            | Per Capita Retail Sales of Consumer Goods (Yuan)                            | 0.1469               | 0.1499                                      | 0.1394    |
|                                                 | Industrial Structure                                                       | The Proportion of Tertiary Industry Value Added to GDP (%)                  | 0.1312               | 0.1348                                      | 0.1328    |
|                                                 |                                                                            | The Proportion of Employment in the Tertiary Sector to Total Employment (%) | 0.1440               | 0.1289                                      | 0.1463    |
|                                                 |                                                                            | The Proportion of Primary Industry Value Added to GDP (%)                   | 0.1440               | 0.1467                                      | 0.1608    |
|                                                 |                                                                            | Ecological Subsystem                                                        | Resource Utilization | Per Capita Arable Land Area (Square Meters) | 0.1083    |
| Per Capita Water Resource Volume (Cubic Meters) | 0.1440                                                                     |                                                                             |                      | 0.1280                                      | 0.1406    |
| Forest Coverage Rate (%)                        | 0.1428                                                                     |                                                                             |                      | 0.1490                                      | 0.1572    |
| Environmental Protection                        | Energy Conservation and Environmental Protection Expenditure (10,000 Yuan) |                                                                             | 0.1329               | 0.1309                                      | 0.1409    |
|                                                 | Urban Domestic Wastewater Treatment Rate (%)                               |                                                                             | 0.1602               | 0.1488                                      | 0.1557    |
|                                                 | Industrial Solid Waste Recycling Rate (%)                                  |                                                                             | 0.1592               | 0.1537                                      | 0.1596    |
|                                                 | The Proportion of Days with Air Quality at or Better Than Grade II (%)     |                                                                             | 0.1526               | 0.1723                                      | 0.1398    |

### 3.3. Determination of Indicator Weights

This study integrates the evaluation content with a database and employs the entropy value method alongside the mean square deviation method to assign weights to the evaluation indexes comprehensively. This approach aims to ensure that the results remain as objective as possible, in contrast to subjective assignment methods [49,50]. The entropy weight method primarily utilizes information entropy to calculate the weight of each indicator based on the degree of variation among them. This approach allows for the adjustment of indicator weights, resulting in more objective evaluation outcomes with greater precision. However, since the entropy weight method only adjusts the information transfer difference between groups of indicator sequences, it is too sensitive to abnormal data, which may lead to the impracticality of the comprehensive weights [51]. To avoid this unreasonable phenomenon, this paper chooses the mean square deviation decision-making method, which is also based on data variation and has a clear concept and simple calculation, for weighting adjustment [52,53]. In addition, in the actual calculation, it is found that the entropy weighting method determines the weight of each indicator with a small degree of differentiation, while the mean square deviation method has a large degree of differentiation. Li Xiaoqian et al. believe that, when the differentiation degree of the

various methods on the evaluation of indicator differences is not too different, you can select any assignment method for indicator assignment; when the differentiation degree of the various methods on the indicator differences is different, it is recommended to use the method with a larger degree of differentiation [54]. Therefore, this study utilizes the entropy weight method and the mean square deviation method to comprehensively determine the weights of indicators, enhancing the scientific accuracy of these weights. The specific methodological steps are detailed as follows.

### 1. Entropy Weight Method (EWM)

Assuming that the total number of evaluation indicators is set to be  $m$  and the total number of evaluation objects is  $n$ , the original data matrix is formed as  $X = (x_{ij})_{m \times n}$ , where  $x'_{ij}$  represents the standardized value of the  $j$ th criterion for the  $i$ th evaluation subject, with  $i = 1, 2, \dots, m; j = 1, 2, \dots, n$ .

Calculate the information entropy of the indicator:

$$e_j = -k \sum_{i=1}^m p_{ij} \ln p_{ij} \quad (1)$$

where  $e_j$  represents the information entropy of the  $j$ th criterion;  $k$  represents a constant, which is calculated using the formula  $k = \frac{1}{\ln m}$ ; and  $p_{ij}$  refers to the proportion of the  $i$ th evaluation subject under the  $j$ th criterion, calculated using the formula  $p_{ij} = \frac{x'_{ij}}{\sum_{j=1}^m x'_{ij}}$ .

Determine the entropy weight of the  $j$ th indicator value:

$$w_j = \frac{1 - e_j}{\sum_{j=1}^m (1 - e_j)} \quad (2)$$

where  $w_j$  represents the weight of the  $j$ th criterion.

Calculation of objective indicator weights:

$$W_1 = (w_{11}, w_{21}, \dots, w_{m1}) \quad (3)$$

where  $W_1$  is the weight vector for all criteria, and  $w_{11}, w_{21}, \dots, w_{m1}$  represent the weight values for the 1st, 2nd, ...,  $m$ th criteria, respectively.

### 2. Method of Least Squares

Calculate the mean square deviation of each indicator:

$$sse_j = \frac{1}{n} \sum_{i=1}^n (x_{ij} - \bar{x}_j)^2, j = 1, \dots, m \quad (4)$$

where  $sse_j$  represents the variance of the  $j$ th criterion.

Coefficient of the  $j$ th indicator weight:

$$W_j = \frac{sse_j}{\sum_{i=1}^m sse_j}, j = 1, \dots, m \quad (5)$$

where  $W_j$  represents the weight coefficient of the  $j$ th criterion.

Calculate the weights of the indicators:

$$W_2 = (w_{12}, w_{22}, \dots, w_{m2}) \quad (6)$$

### 3. Combined Weights of Indicators

$$W = (w_1, \dots, w_m) = \frac{W_1 + W_2}{2} \quad (7)$$

where  $W$  refers to the comprehensive weight of the indicators.

Based on the above framework for the construction of the indicator system, the source of the indicators, and the calculation of the weights, the evaluation indicator system and the

weights of the coordinated development of Mianyang, Deyang, and Guangyuan disaster areas in this study were finally obtained (Table 1).

### 3.4. Post-Disaster Coordinated Development Evaluation Model

At present, there is a wealth of research on models for regional coordination and development degrees. Scholars from different fields have constructed models suitable for their research based on the subjects of their studies. By conducting a comprehensive analysis of existing achievements, appropriate models are selected to evaluate the coordinated development of the disaster area's complex systems.

#### 1. Coordination Degree Model

The coupling coordination degree correction model uses the difference between systems to reflect the degree of disharmony within the systems. Specifically, the absolute value of the difference between the systems is divided by the arithmetic mean of the maximum values of the corresponding systems at a given time. This represents the degree of difference between the unit evaluation values of the systems. The coordination degree of the system is represented by the difference between the standard value of perfect coordination, which is 1, and the degree of disharmony [34]. Therefore, the coordination degree model in this paper is as follows:

$$r = 1 - \sum_{k,l=1}^m \frac{|s_k - s_l|}{\frac{m \times (m-1)}{2}}, k, l \in [1, m], k \neq l \quad (8)$$

where  $r$  represents the coordination degree,  $s_k$  is the score of subsystem  $k$ ,  $s_l$  is the score of subsystem  $l$ , and  $m$  is the number of subsystems (when  $m$  is taken as 2, it represents the coordination degree between two subsystems; when  $m$  is taken as 3, it represents the overall coordination degree).

#### 2. Development Degree Model

The development degree can characterize the disaster-affected areas by using interval-scale variables obtained after standardizing the underlying indicators. The scores of the subsystems obtained through the comprehensive evaluation of the underlying indicators are also on an interval scale. Based on the theory of Ebert et al., interval-scale variables should be integrated using the arithmetic mean method [55]. Therefore, the development degree model in this paper employs a weighted arithmetic mean method, which is expressed as follows:

$$s_i = \sum_{k=1}^n w_k \times x_{ik}, i = 1, 2, 3 \quad (9)$$

where  $s_i$  represents the comprehensive score of the  $i$ th subsystem,  $w_k$  is the weight of the  $k$ th indicator, and  $x_{ik}$  is the normalized value of the  $k$ th indicator within the  $i$ th subsystem after processing.

$$d = \sum_{i=1}^3 w_i^* s_i, i = 1, 2, 3 \quad (10)$$

where  $d$  stands for the development degree, and  $w_i^*$  refers to the score data of each subsystem, which has been calculated using a comprehensive weighting method that incorporates both the entropy method and the mean square deviation method.

#### 3. Coordinated Development Index Model

Based on the coordination degree and development degree models, this study further constructs a Coordinated Development Index model to comprehensively examine the sustainable development of the socio-economic-ecological complex system from two aspects. The disaster area coordinated development model fully integrates the coordination status and development level of the social, economic, and ecological subsystems. Compared to single development degree or coordination degree models, it has higher stability and

applicability and can be used to measure the coordinated development level of different regions. Therefore, the calculation method of the Coordinated Development Index model in this paper is as follows:

$$z = \sqrt{r \times d} \quad (11)$$

## 4. Results

### 4.1. Calculation of Development Degree Analysis

The post-reconstruction development of cities in the Wenchuan earthquake-affected areas is comprehensively influenced by the interplay between resource-environment and socio-economic factors. Between 2005 and 2018, all three cities exhibited significant growth trends in their development indices, albeit with subtle variations in development levels across different stages (Figure 3). (1) Prior to the earthquake, Deyang City demonstrated a robust momentum of development, leading with a development index of 0.1860 in 2005. However, post-earthquake, while Deyang continued to develop, its momentum significantly slowed down, and its development status was notably inferior to that before the disaster. By 2018, Deyang's development index had risen to 0.8162 but ranked lowest among the three cities. This phenomenon indicates that Deyang still has room for further optimization and adjustment in its planning strategies for post-disaster recovery and reconstruction, particularly in ensuring the long-term effectiveness and sustainability of its strategies. (2) Guangyuan City experienced the most remarkable change in its development index during the post-disaster recovery and reconstruction process. Starting from a relatively low base of 0.1107 in 2005, it reached 0.9296 in 2018, topping the development index rankings among the three cities. Around 2011, the city's development index growth rate declined from an initial 0.0898 to 0.0430, marking a transition from rapid growth to a more moderate stage of development. This signifies that Guangyuan promptly identified a development strategy suited to its conditions during the post-disaster recovery period and has gradually adapted to its post-disaster development planning. Its development strategy has matured, leading to notable achievements in post-disaster development. (3) In comparison, the development of Mianyang City was relatively stable. Its development index rose from 0.1491 in 2005 to 0.9254 in 2018. Around 2011, the change rate of its development index declined from 0.0641 to 0.0520, representing the smallest variation amplitude. Considering both the development index and its growth rate, it can be inferred that Mianyang maintained a high degree of stability and continuity in its post-disaster recovery, reconstruction, and revitalization strategies, embodying a strategy of steady progress.

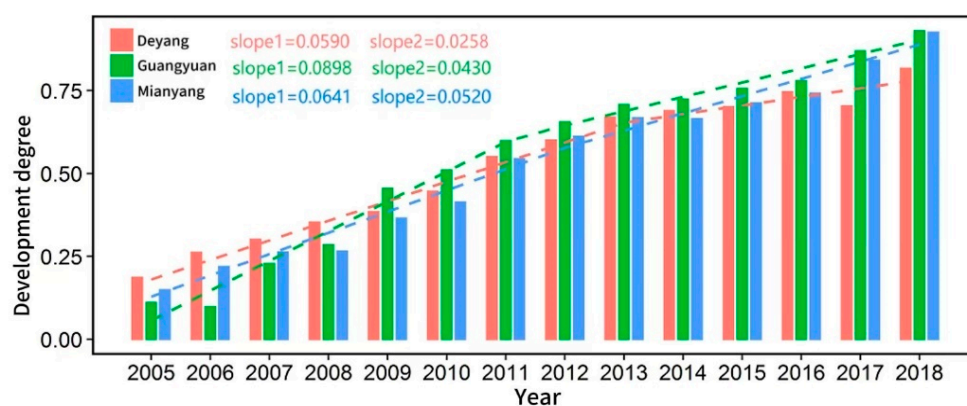


**Figure 3.** Development degree of Mianyang, Deyang, and Guangyuan cities.

### 4.2. Calculation of Coordination Degree Analysis

The coordination degree among the three cities in the Wenchuan earthquake-affected zone serves as an indicator reflecting the overall coordination level of the socio-economic-

ecological composite system in this region, exerting a notable influence on the area's future development. Within one to two years after achieving the “three-year basic recovery”, the coordination degree of all three cities began to decline (Figure 4). (1) Except for 2017 and 2018, Deyang City exhibited a significantly higher coordination degree post-disaster compared to pre-disaster levels. Taking 2005 as the base year, the coordination degree of Deyang City increased from 0.7561 to 0.7745. Around 2013, Deyang City's coordination degree started to show a marked negative growth trend, with the growth rate shifting from 0.0224 to  $-0.0485$ , indicating the most pronounced decline and aligning with the trend in development degree growth mentioned above. This underscores that the coordination degree can influence regional development to some extent. Additionally, this situation reflects that the degree of coordination among Deyang City's economic, social, and ecological systems needs further enhancement, particularly in the later stages of recovery and reconstruction, where greater emphasis should be placed on the holism and coordination of systems to achieve sustainable development. (2) Guangyuan City exhibited an overall fluctuating upward trend, with its coordination degree rising from 0.9424 in 2005 to 0.9506 in 2018 during the post-disaster reconstruction process. The coordination degree underwent a transition around 2012, changing from 0.0079 to  $-0.0072$ , with the smallest fluctuation amplitude and maintaining a high overall level. This signifies a good level of coordination among the economic, social, and ecological subsystems in this region, which also explains from another perspective why Guangyuan City's development degree surged to the top among the three cities after the transition. Subsequent efforts should focus more on enhancing the stability of coordination within the composite system in this region. (3) The coordination degree of Mianyang City demonstrated a consistent negative growth trend, shifting from 0.9272 to 0.8421. Around 2013, Mianyang City's coordination degree experienced a turning point, with its growth rate changing from  $-0.0005$  to  $-0.0179$ , consistent with the aforementioned changes in the development degree. This indicates that, during the post-disaster reconstruction process, Mianyang City should prioritize the coordination and holism of systems, intensify efforts to optimize the economic structure, improve the social environment, and enhance ecological quality, to achieve positive growth in regional coordination and sustainable regional development.

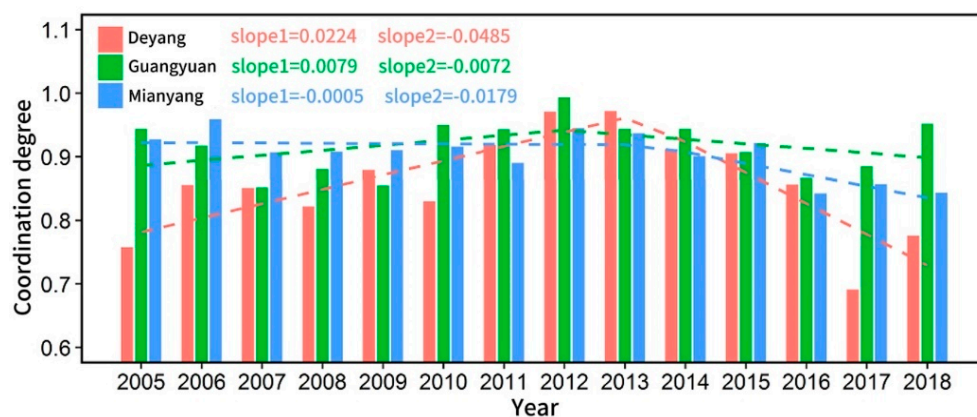


**Figure 4.** Coordination degree of Mianyang, Deyang, and Guangyuan cities.

#### 4.3. Calculation of Coordinated Development Index Analysis

The Coordinated Development Index is a key indicator that reflects the degree of coordination and development status among the social, economic, and ecological systems within a city. Since 2005, the Coordinated Development Index of the three cities in the Wenchuan earthquake-affected area (Mianyang, Deyang, and Guangyuan) has shown an upward trend, but there are still significant differences in different periods (Figure 5). (1) Deyang's Coordinated Development Index increased from 0.3750 in 2005 to 0.7951 in

2018. The growth rate of its Coordinated Development Index dropped from 0.0512 to  $-0.0092$  after 2013, beginning a negative growth trend. This shift indicates that the city is transitioning from a period of positive rapid development to a period of negative slow development. From the perspectives of both development and coordination, Deyang's significant decline in coordination after 2013 has hindered its post-disaster coordinated development level. (2) Guangyuan started from a lower base, with a Coordinated Development Index of only 0.3229 in 2005, but showed a strong development momentum in the 10 years after the disaster. By 2018, Guangyuan's Coordinated Development Index reached 0.9400, nearly tripling from 2005, with the largest increase among the three cities. Guangyuan experienced a turning point around 2011, with the growth rate of the Coordinated Development Index slowing from 0.0807 to 0.0185, suggesting that Guangyuan may have gradually reached a new balance in social, economic, and ecological aspects and has begun to enter a more stable and mature growth phase. (3) Mianyang's Coordinated Development Index steadily rose from 0.3715 in 2005 to 0.8827 in 2018. Its growth rate decreased from 0.0520 before 2012 to 0.0191 in 2018. Despite the slowdown in the growth of Mianyang's Coordinated Development Index, Mianyang maintained a more consistent development trajectory, indicating that its post-disaster recovery and development strategic planning are suitable for its future development.

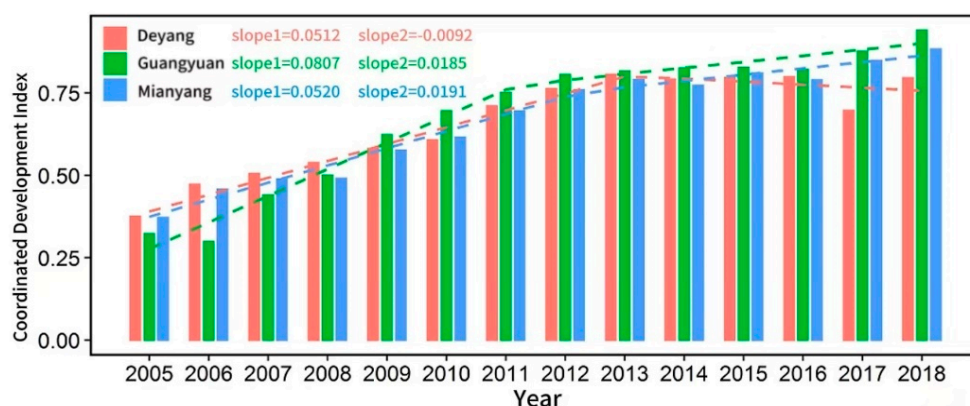


**Figure 5.** Coordinated Development Index of Mianyang, Deyang, and Guangyuan cities.

#### 4.4. Evaluation of Coordinated Development

To further evaluate the coordinated development of counties (cities, districts) within each city, data from the Sichuan County Statistical Yearbook and the Sichuan Yearbook were utilized, and four years—2008, 2011, 2015, and 2018—were selected for the evaluation of coordinated development in the disaster-affected areas. By comparing the Coordinated Development Index (CDI) of each county (city, district), it was observed that the CDI generally showed an increasing trend, but there were differences in development between the extremely severely affected areas and the severely affected areas. Between 2008 and 2018, Deyang City's level of coordinated development shifted from a mildly uncoordinated and declining type (0.3750) to an intermediate coordinated development type (0.7951). Deyang City, which includes two extremely severely affected counties (cities, districts), saw Shifang City transition from a moderately uncoordinated and declining type to an intermediate coordinated development type, and Mianzhu City moved from a moderately uncoordinated and declining type to a well-coordinated development type. Guangyuan City's level of coordinated development changed from a mildly uncoordinated and declining type (0.3229) to a high-quality coordinated development type (0.9400), with Qingchuan County, the only extremely severely affected area in Guangyuan, shifting from a severely uncoordinated and declining type to a well-coordinated development type. Mianyang City's level of coordinated development moved from a mildly uncoordinated and declining

type (0.3715) to a well-coordinated development type (0.8827), with its three extremely severely affected counties (cities, districts) showing transitions: Anzhou District from a moderately uncoordinated and declining type to a primary coordinated development type; Beichuan County from a moderately uncoordinated and declining type to an intermediate coordinated development type; and Pingwu County from a mildly uncoordinated and declining type to an intermediate coordinated development type.

In general, the Coordinated Development Index (CDI) in the extremely severely affected areas has shown a universal upward trend, with some counties (cities, districts) experiencing a decline in 2008, but then an upward trend ensued. The severely affected areas suffered less damage compared to the extremely severely affected areas, leading to differences in the assistance received during the recovery and reconstruction process. Upon comparison, it was found that the CDI in the severely affected areas, including six counties (cities, districts) in Mianyang City, four in Deyang City, and six in Guangyuan City, generally exhibited an upward trend. Among them, Jingyang District, Guanghan City, Wangcang County, and Cangxi County have all achieved a well-coordinated development status (Figure 6). The differences in post-disaster development levels among various counties and cities, such as Mianyang, Deyang, and Guangyuan, are directly related to their pre-disaster resource environments and socio-economic conditions. Additionally, these differences are influenced by the scale of financial assistance and industrial policies provided by external supporting provinces [56]. For instance, Shandong Province provided CNY 10.9 billion in support to Beichuan County in Sichuan Province, Guangdong Province provided CNY 8.2 billion to Wenchuan County, and Zhejiang Province provided CNY 7.6 billion to Qingchuan County, among others. These supporting provinces not only provided financial assistance but also aligned their policies with their industrial strengths. For example, Shandong Province invested in the construction of the Beichuan-Shandong Industrial Park, which attracted a significant number of automotive companies. Guangdong Province allocated CNY 400 million in aid to build the “Guangdong-Wenchuan Industrial Park” in Chengdu, encouraging enterprises to invest and start businesses in the disaster area, promoting the revitalization of the local industrial economy and the coordinated development of the region.

#### 4.5. Prediction and Analysis

In the process of post-disaster reconstruction, assessing the coordinated development of social, economic, and ecological systems across various regions is crucial for guiding future planning strategies. This study conducted an in-depth analysis of the coordinated development indices for Deyang, Mianyang, and Guangyuan from 2019 to 2025, based on historical data and scientific prediction methods. After conducting precision tests on the three datasets, it was confirmed that all three could pass the tests, allowing for the application of the GM(1,1) model to predict the next seven years (2019–2025). The results are shown below (Table 2).

**Table 2.** Prediction results of coordinated social economic ecological development of three cities in disaster areas from 2019 to 2025.

| City                 | Mianyang | Deyang | Guangyuan |
|----------------------|----------|--------|-----------|
| c-value              | 0.1542   | 0.2392 | 0.2228    |
| p-value              | 1        | 1      | 1         |
| 2019 predicted value | 0.9705   | 0.8822 | 1.0518    |
| 2020 predicted value | 1.0212   | 0.9165 | 1.1155    |
| 2021 predicted value | 1.0746   | 0.9521 | 1.1830    |

Table 2. Cont.

| City                 | Mianyang | Deyang | Guangyuan |
|----------------------|----------|--------|-----------|
| 2022 predicted value | 1.1308   | 0.9891 | 1.2546    |
| 2023 predicted value | 1.1899   | 1.0275 | 1.3306    |
| 2024 predicted value | 1.2521   | 1.0674 | 1.4111    |
| 2025 predicted value | 1.3176   | 1.1089 | 1.4966    |

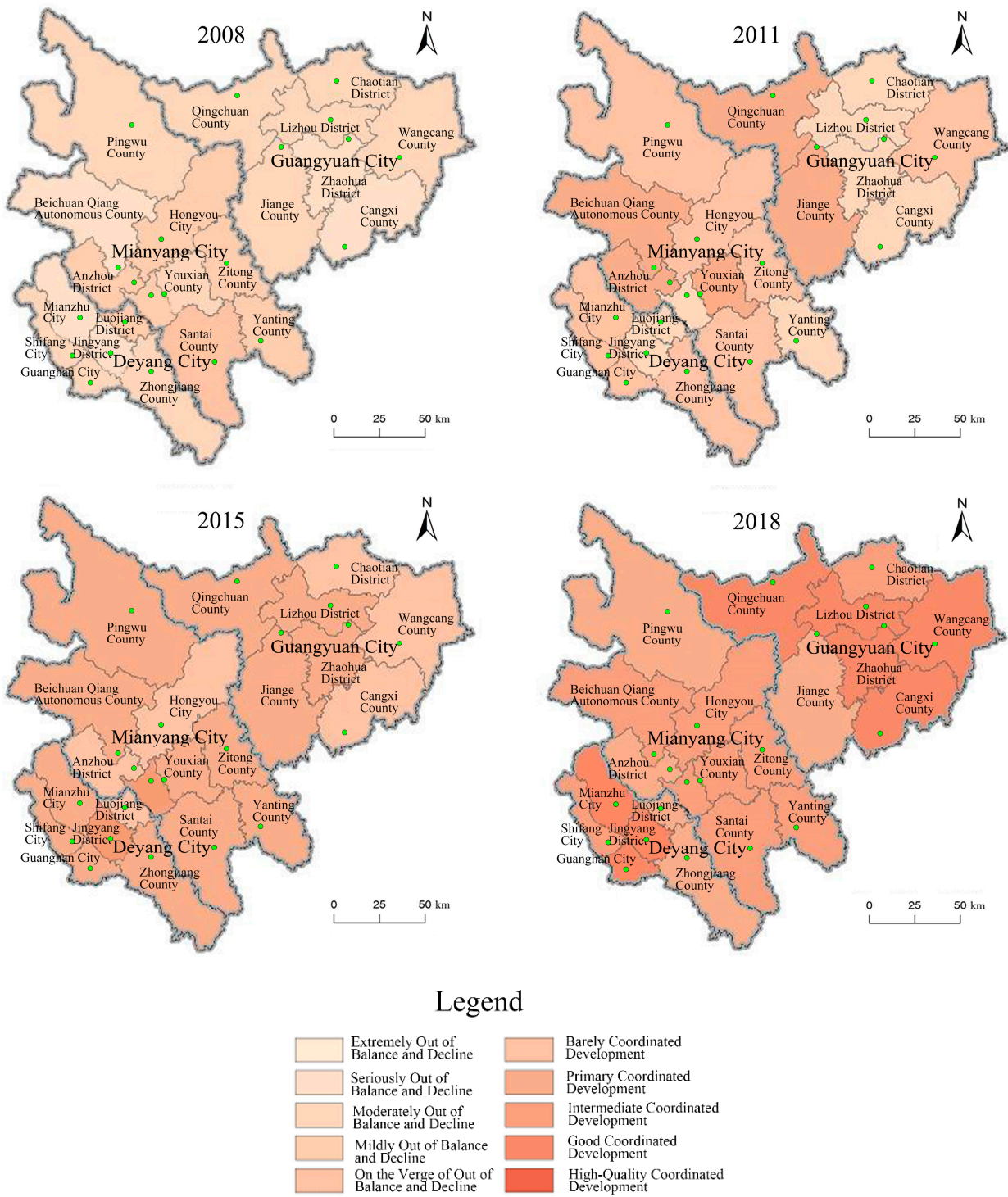


Figure 6. Changes in the Coordinated Development Index of major counties (cities, districts) in the Wenchuan earthquake-stricken area.

By utilizing the GM(1,1) model and the coordinated development data from 2005 to 2018 for Mianyang, Deyang, and Guangyuan, the predictions for 2019 to 2025 indicate that the  $c$ -values are all greater than 0 and close to 0.2, while the  $p$ -values are all 1, suggesting a high degree of reliability and applicability for the prediction model. The coordinated development indices for all three cities show a trend of increasing year by year, indicating significant progress in coordinated development during post-disaster reconstruction (Figure 7). Furthermore, despite the growth in coordinated development indices for all three cities, there are differences in growth rates and starting points. Mianyang's Coordinated Development Index grows steadily, reflecting the city's balanced development strategy during post-disaster reconstruction. Deyang starts from the lowest point and, although its growth rate is slightly slower than Mianyang's, it still demonstrates a steady upward trend, albeit with a final Coordinated Development Index lower than those of Mianyang and Guangyuan. Guangyuan stands out with its high starting point and rapid growth rate, becoming the city with the highest Coordinated Development Index among the three. Given the upward monotonic trend of the original data, the predicted values also increase annually. Since Guangyuan's index was already 0.94 in 2018, close to 1, it is normal for its predicted value in 2019 to exceed 1, and the prediction accuracy falls within an acceptable range. The prediction results suggest that Mianyang may achieve high-quality coordinated development within the next two years, Deyang will need five years, and Guangyuan only one year.

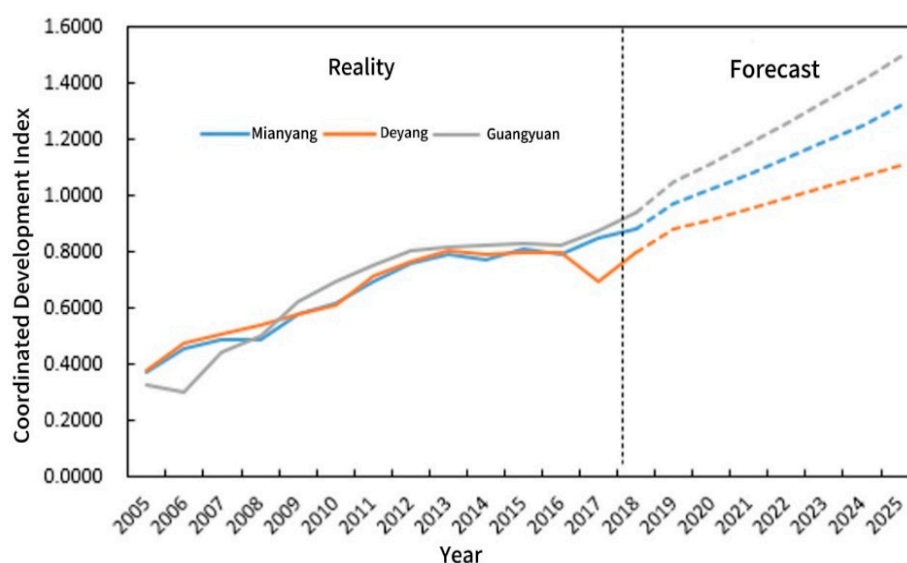


**Figure 7.** Prediction of Coordinated Development Index of composite system in typical disaster areas of Wenchuan earthquake.

## 5. Discussion

This study regards the severely affected areas of the Wenchuan Earthquake as a vulnerability complex system, constructing an index system based on a composite system consisting of social, economic, and ecological components. This research emphasizes critical aspects including social livelihood, emergency protection, economic status, industrial structure, resource utilization, and environmental stewardship. It assesses and anticipates the coordinated development of post-disaster land with a focus on ecological restoration in three representative cities: Deyang, Guangyuan, and Mianyang. By comprehensively calculating the development and coordination degrees of these cities, the conclusions below have been drawn.

### *5.1. Changes in the Degree of Development After Recovery and Reconstruction*

Based on the analysis of development degree, the overall development of the three cities after the disaster shows an upward trend. After the disaster, all three cities responded positively to the national call for post-disaster recovery and reconstruction, and they adopted recovery and reconstruction measures. They also formulated revitalization strategies according to the conditions of their respective regions. Among them, Guangyuan City has the fastest average growth rate, while Mianyang City and Deyang City rank second and third, respectively. Compared with the development level before the disaster, Guangyuan City has experienced a significant improvement after the disaster, followed closely by Mianyang City. The reasons for the rise in the development degree will be discussed below.

Guangyuan City relied on the “industry-urban integration” strategy in the post-disaster land planning to scientifically lay out industrial land and ecological protection areas. After the disaster, the city focused on restoring and rebuilding houses, infrastructure, and scenic areas. Through careful scientific planning, the city enhanced the efficiency of post-disaster land use and planning, promoting sustainable development for the region in the future. For example, Qingchuan County avoided high-risk areas of geological disasters and shifted the focus of reconstruction to ecological tourism and green agriculture. In 2018, its per capita GDP increased nearly three times compared with that in 2005. Secondly, the Chinese government issued the ‘National Wenchuan Earthquake Post-Disaster Recovery and Reconstruction General Plan’ (hereinafter referred to as the “Plan”). The ‘Plan’ pointed out that it is necessary to strengthen the reclamation of post-disaster land, repair all damaged arable land as much as possible, and adjust the land use planning and annual land use plans in the disaster areas. For example, Mianyang City optimized the layout of industrial parks through land-intensive policies and promoted the coordinated development of high-tech industries and ecological protection, which reflects the supporting role of land planning in regional resilience. Finally, as Sichuan Province is rich in ecological and tourism resources, the government carried out recovery and reconstruction of the ecological environment and tourist attractions damaged by the earthquake. The ecological economy and tourism economy were restored the fastest, which improved the overall development level of Guangyuan, Mianyang, and Deyang cities.

### *5.2. Changes in the Degree of Coordination After Recovery and Reconstruction*

By examining the results of the coordination degree analysis, it is evident that the coordination development trajectories of Deyang City and Guangyuan City show an upward trend followed by a decline, while Mianyang City experienced a continuous decline. This indicates that, during the post-disaster recovery and reconstruction phase, all three cities placed great emphasis on the coordinated development of the social, economic, and ecological subsystems, which led to a temporary increase in their coordination degree compared to the pre-disaster baseline. Additionally, the initial improvement in coordination degree in the three cities was also partly due to the improvement of environmental governance and emergency systems.

Guangyuan City implemented the “Special Plan for Ecological Restoration”, increasing its forest coverage from 42% in 2005 to 56% in 2018. Combined with soil and water conservation projects, the risk of debris flows was reduced. The negative growth in Mianyang City’s coordination degree is related to the ecological space compression during rapid urbanization. It is suggested that the city enhance its rainwater retention capacity through the construction of “sponge cities” and strictly control the development intensity in ecological red-line areas. The decline in Deyang City’s coordination degree reflects its lagging industrial transformation, such as the high proportion of energy-intensive industries, which

has increased the pressure on energy and environmental protection expenditures. This highlights the necessity for refined land functional zoning management. The three cities have adopted ecological restoration and environmental governance measures, promoting the coordinated development of the social, economic, and ecological systems from the perspectives of land planning and utilization and ecological environment protection. However, during the subsequent five-year revitalization phase, the coordination degree of the three regions exhibited a fluctuating downward trend. This suggests that the current measures may lack the necessary momentum to drive long-term and sustainable development, or they may have reached a saturation point at this stage of progress.

### *5.3. Changes in the Development Coordination Index After Recovery and Reconstruction*

The analysis of the Development Coordination Index (DCI) shows that, although the coordination levels among the three cities have fluctuated, affecting growth to some extent, all cities except Deyang have shown an overall upward trend in the DCI. Despite a slowdown in the DCI growth rates of Guangyuan and Mianyang around 2013, the overall trend still reflects an improvement in regional coordination levels after the disaster. The rise in the coordination development index (CDI) indicates that the post-disaster reconstruction strategies of the three cities have been generally effective. However, regional differences are still influenced by land resource endowments and external assistance. For example, Beichuan County used financial support from Shandong Province to build the “Beichuan-Shandong Industrial Park”, introducing low-carbon industries such as new energy vehicles to promote the coordinated development of land use efficiency and industrial upgrading. In contrast, Mianzhu City in Deyang, due to its early over-reliance on traditional industries, has higher costs for land pollution control, which limits its CDI growth rate.

Moreover, the coordination levels of Deyang, Guangyuan, and Mianyang have transitioned from mild to moderate coordination, high-quality coordinated development, and good coordination, respectively. This shows that the post-disaster recovery and reconstruction strategies formulated by the three cities generally meet regional development needs and have shifted from a rapid growth phase to a steady improvement phase. However, the three cities still need to fine-tune these plans based on current conditions, regional characteristics, and advantages. By implementing differentiated land policies, such as ecological compensation mechanisms, to balance protection and development, and strengthening cross-regional industrial cooperation, the cities can develop more targeted strategies and measures to continuously improve regional coordination levels.

### *5.4. Projected Status of Future Development After Recovery and Reconstruction*

Based on the coordination development data of Mianyang, Deyang, and Guangyuan from 2005 to 2018, a GM(1,1) model was used to predict and analyze the coordination development of these three cities from 2019 to 2025. The results show that each city has different potential and pathways in terms of coordinated development. The prediction indicates that the coordination development index of all three cities will rise in a fluctuating manner in the future. Among them, Guangyuan is expected to have the fastest growth rate in coordination development, followed by Mianyang, while Deyang is likely to have a more stable trajectory. When comparing the coordination development index in 2005 with the predicted index for 2025, it is evident that Guangyuan will experience the most significant change in coordination development, followed by Mianyang, with Deyang showing relatively smaller changes.

The prediction also suggests that Guangyuan is likely to achieve high-quality coordinated development within one year. In the future, Guangyuan could further promote the development of eco-friendly industries, such as eco-tourism, and enhance the construction

of geological disaster monitoring networks to systematically reduce disaster risks in the city. Deyang is projected to take five years to achieve high-quality coordinated development. In its future development, Deyang could prioritize the ecological transformation of industrial land. By optimizing the layout of industrial land, strictly controlling the entry of high-pollution projects, and leveraging the Chengdu-Deyang-Mianyang economic belt to optimize industrial layouts, high-energy-consuming and high-pollution enterprises could be relocated into industrial parks. This would optimize land functional zoning, limit development intensity in ecologically sensitive areas, and promote the transition to low-carbon industries. This approach will improve the efficiency of post-disaster land planning and utilization and drive the coordinated development of social, economic, and ecological systems in the post-disaster reconstruction areas. Mianyang is expected to achieve high-quality coordinated development in two years. In the future, Mianyang should enhance the resilience of emergency infrastructure while strengthening ecological restoration and the construction of green infrastructure. Additionally, all three cities need to integrate the concept of resilient cities into their “14th Five-Year Plan”, promote seismic-resistant building standards, and regularly conduct multi-department joint disaster prevention drills to systematically reduce future disaster risks.

## 6. Conclusions

This study uses the 5.12 earthquake that struck Wenchuan County, Sichuan Province, China, in 2008, as its research backdrop. It evaluates and forecasts the post-disaster recovery and reconstruction efforts in Mianyang, Deyang, and Guangyuan, which were all affected at the district and county levels. This study investigates the changes in development levels, coordination, and coordinated development in three cities after reconstruction. It also analyzes the changes in the Coordinated Development Index for the primary counties, cities, and districts in the Wenchuan earthquake disaster area. The aim is to determine whether the post-disaster reconstruction efforts have effectively enhanced the coordinated development among the social, economic, and ecological systems in these regions. Resilience is a key metric in disaster and sustainability research. The effectiveness of post-disaster recovery can be gauged by whether the affected areas not only return to their pre-disaster state but also achieve a more sustainable and coordinated trajectory of development.

Through the analysis presented in this paper, it is evident that counties and cities in Mianyang, Deyang, and Guangyuan were able to promptly implement recovery and reconstruction measures following the disaster. These cities have made significant strides in enhancing resilience through land planning and ecological restoration, yet disparities remain in the level of coordinated development among these regions post-reconstruction. For instance, Guangyuan adopted an “industry-urban integration” strategy, optimizing the layout of industrial land and ecological conservation areas, while Mianyang has promoted the coordinated development of high-tech industries and ecological protection through intensive land use policies. These initiatives have contributed to an overall increase in the Coordinated Development Index (CDI) of these areas. While the post-disaster recovery strategies in Mianyang, Deyang, and Guangyuan have generally been effective in promoting regional development, there remains room for improvement in achieving long-term resilience and sustainable transformation. Future efforts should leverage big data and follow-up surveys to further refine the evaluation system for the effectiveness of post-disaster reconstruction. It is essential to analyze the impact of these efforts on affected areas across different timescales and propose a new paradigm for scientifically advancing coordinated development post-disaster. Greater attention should be given to land planning and utilization, ecological restoration and protection, and disaster prevention and mitigation. Examples include the implementation of differentiated land policies (e.g., ecological

compensation mechanisms) and the optimization of land use efficiency through enhanced interregional industrial cooperation. These can lead to a more sustainable and coordinated development trajectory between social, economic, and ecological subsystems.

To analyze the impact of the disaster on regional development and the extent to which post-disaster reconstruction has restored regional development, this work will help to determine whether the previous post-disaster reconstruction efforts have met the expected goals and plans of the Government of China for post-disaster recovery and reconstruction. It also explores areas that can still be improved and identifies scientifically effective measures that can be taken to promote coordinated development in disaster-stricken areas. Due to limitations in data acquisition, this study selected indicators related to regional coordinated development from the three subsystems mentioned above, with a focus on economic indicators. The aim was to use changes in regional economics as a more direct measure of whether the affected areas have been effectively rebuilt and recovered post-disaster. Therefore, in the future, it will also be necessary to use big data to overcome barriers to data access, to complement and improve systems for assessing the effects of post-disaster reconstruction, and to strengthen the focus on land use planning and ecosystem restoration. In addition, in the future, we should combine the experience of post-disaster recovery and reconstruction, start from the three phases of pre-disaster, disaster and post-disaster, and develop targeted enhancement strategies for disaster prevention and mitigation measures in different regions. This will improve the coordinated development of the city's social, economic and ecological systems, enhance the region's resistance and resilience to uncertain natural disasters, and build a new model for scientific disaster prevention and mitigation and for promoting coordinated post-disaster development.

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